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ФАКУЛТЕТ ЗА ДИЗАЈН И ТЕХНОЛОГИИ НА МЕБЕЛ И ЕНТЕРИЕР ВО СКОПЈЕ

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CONTENTS

DRYING OF HARDWOOD TIMBER – SCIENCE AND INDUSTRY
(*Keynote lecture)*

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ABSTRACT

Despite the worldwide production of softwood timber being considerably greater, the importance of hardwood timber remains undiminished, especially when it comes to high-value wood products. The demand for high-quality dried hardwood timber has been experiencing continuous growth over the past decades and it predominately relies on timber dried in conventional kilns. While numerous improvements in kiln equipment have been implemented over the last decades, conventional drying of hardwoods remains a very slow process, mainly based on empirical knowledge. This paper provides an overview of the current situation related to hardwood drying in Europe and offers a discussion on potential research directions and overall industry situation by bringing into focus drying schedules and energy aspects of hardwood timber drying process. Present growth of research and technology should be accompanied by education, that is to say that the emphasis should be put on sharing and transferring knowledge to practitioners.

Key words: conventional drying, hardwoods, drying schedules, energy consumption

1. INTRODUCTION

The wood sector – a cornerstone of world's bio economy – has a long history of providing for the needs of a growing population. Annual global industrial roundwood (pulpwood, sawlogs, veneer logs and other industrial roundwood) production has now reached almost 2 billion cubic meters – the highest value in the history (FAOSTAT-Forestry database). However, due to the population growth, the global per capita wood supply has fallen during the last 50 years from 0.40 to 0.25 cubic meters (fuelwood excluded). Wood value-chain, although the best solution for climate change, is at the same time directly affected by increasable, but ultimately limited, wood supply and changing consumer demands and demographics. Stress to find more efficient and optimal ways to use wood is evident and that is where drying, the oldest operation in wood processing, plays a vital part. Drying quality, drying time and energy consumption are three parameters that should be in the focus when considering improvements in wood drying.

Drying, in general, represents a significant fraction of the industrial energy use. Energy consumption is especially important in wood drying because it is a process that consumes the most energy (70% or more) in the entire timber industry chain of production (Milić et al. 2014). At the same time, conventional kilns, type most frequently used around the world, consume around 50% more energy than it is required to evaporate the water (Elustondo and Oliveira 2009). These are the reasons for wood drying being the most energy-intensive industrial process, even more intensive than in other industries such as textile or paper production (Kudra 2004). Wood is the most environmentally friendly material on the planet, but drying – due to its relatively high energy consumption and long drying times – can easily cast doubt on how environmentally responsible is the use of wood (Milota 2010).

It is generally accepted that the drying of hardwood is more difficult and causes more problems than the drying of softwood timber (Welling 2009). This is due to a more complicated and diverse anatomical structure, generally higher density and often higher extractive content. It should be added that the products made of hardwood usually demand higher drying quality as compared to softwood products (that are primarily used in construction as structural wood).

2. HARDWOOD DRYING – CURRENT STATE IN EUROPE

The European forest-based sector provides around 8% of the Europe's total manufacturing added value and creates almost 4 million jobs. Despite having only 5% of the total world forest area, forest-based sector in Europe produces almost 30% of all high-value wood products on the global level (Wegener 2016). Although European production of sawn softwood (more than 100 million m^3) is considerably higher than that of sawn hardwood (ca. 13 million m^3), the importance of hardwood drying remains high throughout the whole sector.

Mayor drying technologies

Conventional technology still holds the leading position within the range of drying methods applied at an industrial scale, especially for hardwood. Over 95% of timber for industrial use is dried in conventional kilns (Cividini 2001). Conventional kiln is the common name for the closed chamber in which heated, humidity-controlled air is rapidly circulated over the surface of the wood being dried. Excess moisture is exhausted through vents. In recent years, especially in the Southeast Europe, there is a renewed popularity of the so-called dehumidification kilns. These kilns are a sub-type of the conventional ones, main difference being the relative humidity regulation (more on this in the *Energy aspects* chapter). The next type of kilns, commonly used to dry especially thick hardwood timber, are the vacuum kilns. Different vacuum drying technologies are used in regard to heat transfer (Espinoza and Bond 2016): conductive heating vacuum (hot plates vacuum drying), convective heating vacuum (cyclic vacuum, superheated steam vacuum) and dielectric vacuum (radio frequency or microwaves are used).

2.1 CONVENTIONAL KILN-DRYING

Conventional kiln design is continuously improved in terms of materials used, fan design, humidification system, etc. Adaptive control systems with user-friendly touch screen operation and more accurate measuring and adjusting equipment, more effective climate control, air flow adjustment, etc. are other current developments (Campean 2010). Most of these improvements have come directly from industrial experience. Optimisation of energy consumption is one of the most important aspects of equipment improvement. Rise in the energy pricing (both heat and electrical) has led the European kiln manufacturers to implement heat recovery system that reduces heat energy consumption, and – even earlier – variable fan speed control (frequency converters) that reduces electrical energy consumption. In Europe, conventional kilns for hardwood drying usually have EMC sensors with cellulose wafer instead of previously used psychrometers. Recently some manufacturers started relying more on the use of wireless EMC sensors or wireless capacitive humidity sensors for determination of air humidity in the kiln (Fig. 1).

This is an evolving manufacturing trend, and can also be observed with wireless moisture meters with tipped electrode pairs. Wireless measuring gives more freedom during loading of the kiln and promises fewer sensor defects.

Despite these technology improvements, conventional drying of hardwood timber is still very time consuming. This applies particularly on impermeable and refractory wood species such as oak (conventional drying takes more than 3 months for 50mm oak timber). However, only low-investment ideas on improvements of conventional drying can reach industrial application because the process has to stay relatively inexpensive. At the moment, this prevents the use of microwaves, X-rays or NIR in the conventional kilns for measuring the moisture content of wood. Up-scaling some concepts is another problem, considering that one batch of hardwood timber can be more expensive than the kiln itself. One of the potential improvements is the so-called oscillation drying – a form of conventional drying in which air parameters in the kiln (temperature/EMC) oscillate in comparison to the previously set scheduled parameters in predetermined time intervals (Milić et al. 2013). Drying in oscillation climates results in an enhanced mechano-sorptive creep which leads to a decrease of internal stresses of the boards. This concept has been successfully applied in a number of wood industry companies in this part of Europe, but further research and modelling are needed to improve an easy-to-use drying concept. In general, the modelling work in the future will probably focus on moisture-induced stress, sorption hysteresis, environmental impact, discolouration (Salin 2010). As customers increasingly favour lighter colours in high value-added products, discolouration (stain) in hardwoods, but also wood colour in general, is becoming more important and such market trends will to some degree dictate the direction of research in the industry as well.

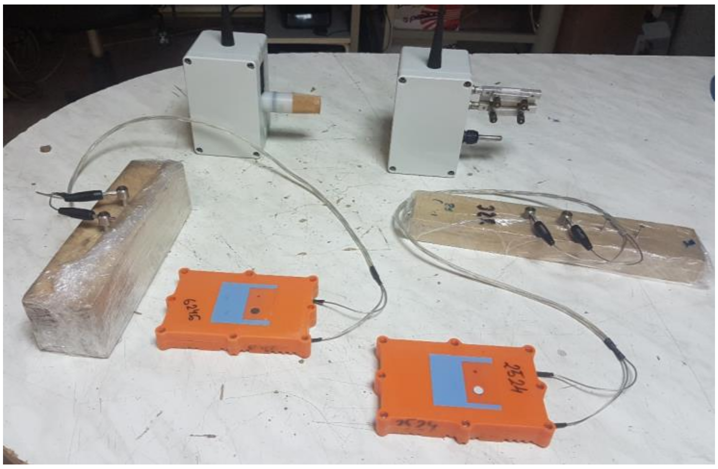

Figure 1. *Testing of wireless sensors in Nigos-elektronik (kiln manufacturer): upper left – capacitive humidity sensor, upper right – EMC sensor, down – moisture meters*

Some of the innovations in conventional drying and processes related to it in the European market (that were not present in the previous decades) are related to practices of artificial drying of fuelwood (material for pellet production, but also firewood). When it comes to the industrial wood, drying of hardwood lamellas which are used for top-layer of flooring should be mentioned. Usually, they are sawn from raw material and dried in conventional or dehumidification kilns. The main species utilised are oak and ash, with common thickness 4-6mm. Oak lamellas can be easily dried in 5 days, which – together with lack of high-quality oak wood – makes flooring companies increase the demand for this product.

Related to oak timber, some producers are discontinuing the practice of air drying and deciding on strategies where raw material is directly introduced into the kilns. One of the reasons is that air drying slows down the turnover of money, but it can also be ascribed to the issue of suitable locations that can provide good conditions for air drying of oak timber being scarce. Wood companies that maintain air drying often invest in sheds, mobile fans, even insulated walls... Drying quality of oak timber is becoming more important than ever, that is to say that the equipment that can enable better results is becoming more and more important.

From Southeast Europe, but also from other „beech regions“, a lot of beech timber is exported to China (China is by far the world’s largest importer, accounting for a whopping 50% of the total sawn hardwood imports at a global level). Usually, this timber is kiln dried to a moisture content of 12-13%. There is an interesting change in consumer demand concerning beech. The so-called „white” beech (the light coloured, unsteamed beech timber) was high in demand up until about 10 years ago. A lot of research work had been invested in the appropriate drying schedule (low temperature and high air velocity are necessary) but in recent years there has been practically no demand for white beech and almost all beech timber is light-steamed before drying. However, steamed beech is much more susceptible to problems with mould during air drying process (particularly during spring months).

Considering that there is a rising trend in exploiting and kiln drying less frequently used hardwood species in Europe (such as aspen, lime, Turkey oak...) it falls to kiln manufacturers and kiln operators in practice to create new drying schedules for this kind of timber.

Drying schedules

In conventional kilns hardwood timber is usually dried according to MC based drying schedules. These schedules are species and thickness dependent and differ for each kiln manufacturer. Joint characteristic is that they are usually “milder” (particularly related to temperature) compared to the schedules developed decades ago, that can be found in the literature (e.g. schedules developed by the Forest Products Laboratory (USA) or British kiln-drying schedules). These schedules, especially for oak, were developed for high-quality wood – lower quality timber was rarely kiln dried 50 years ago. Today, the quality of wood is often not as good as in the past and lower quality classes of timber are also kiln dried. Finally, nowadays the market demands drying quality much higher than ever before.

Having said this, it should be noted that kiln manufacturer’s schedules are very conservative, which is understandable for they aim to avoid possibility and responsibility for the eventual low drying quality. For most hardwoods, the initial drying temperature is between 30 and 40°C and during final stages it goes up to 60°C. For oak timber (but also some other species when light colour is demanded) initial temperature is even below 30°C which is often impossible to maintain in summer months. This results in problems related to EMC adjustments in order to compensate for overheating. In general, at least in Southeast Europe, in more than 90% of companies kiln producer’s drying schedules are not optimised by users which results in longer drying times and often more defects.

It should be emphasised that even with the implementation of fully automatic drying process control, the ultimate result still entirely depends on the kiln operator. Operator is the one responsible for choosing boards for planting MC probes, deciding if the MC probes will be set on ½ of thickness (more cautious approach) or 1/3 of thickness (riskier approach) etc. Finally, it is the operator’s choice which MC probes will be active during drying and that is often a deciding factor that can transform the very same drying schedule from mild to severe or vice versa (Fig. 2). If the process is run according to the maximum MC value, the climate in the kiln will be much milder than if the average MC value is taken into account.

MC (%)	Temp. (°C)	EMC (%)
45	37	15.5
40	37	14.8
35	37	14.1
30	39	13.4
27	42	11.3
24	47	9.1

MC probes	MC (%)
1	24
2	35
3	29
4	20
5	26
6	32
7	28
8	22
Maximum	35
Average	27

Figure 2. *The influence of MC probes selection on the climate in the kiln*

Energy aspects of conventional drying

It had already been said that – due to high energy consumption – drying can change the shade of green of wood products, casting a shadow over their fundamentally ecological nature. However, a broader picture will show that this energy is only a fraction of what is usually produced from wood residues in the sawmill. Latest research (Popadić et al. 2019) shows that drying beech timber obtained from one log uses only 10%-30% of the heat energy obtained by burning wood residues from the same log (coarse residues, sawdust and bark). Even though these results show beyond a doubt that this process is more than sustainable, energy efficiency in drying is an essential aspect in obtaining wood products that can outsell competitors on the market.

The structure of energy consumption (heat and electrical energy ratio) is different when it comes to hardwood drying in comparison to softwood drying. This is due to the fact that softwood drying process is short (high production rate of low-value products) and hardwood drying process usually takes much longer (low production rate of higher-value products). Research results demonstrate that with softwood drying heat energy cost is much higher than electrical energy cost, and within a few years accumulated sum of energy costs easily surpasses the price of the kiln itself and the boiler (Milota 2010). For drying of high-density hardwoods (oak, beech, ash) ratio of electrical energy cost is greater due to much longer drying time. In Europe, and especially in Southeast Europe where energy prices are still low, when it comes to hardwood drying the overall cost of energy still remains small in relation to the investment cost. However, looking at the costs per cubic meter of dried wood, hardwood drying energy costs are high (in comparison to softwood). This is the reason why almost all new conventional kilns have heat exchangers (heat recovery system), despite the fact that research and manufacturer data show variable conclusions pertinent to the energy saving possibilities of this system (5-25%). As fuel prices continue to grow, looking for additional ways to reduce drying costs is becoming more and more important.

Dehumidification kilns, as a sub-type of conventional technology, have energy efficiency that appears to be a step forward. Although they represent an old concept, new improvements of equipment and construction materials brought about a renewed interest for this type of kiln in recent years. Nowadays they are capable of reaching temperatures up to 60°C, which is adequate for most hardwoods even during the final phases of drying. With modern compressors about 0.3 kWh of electrical energy is needed to remove a kilogram of water, making them overall more economical than conventional kilns. Recent measurings (unpublished data) showed that drying of 50mm thick beech timber in dehumidification kiln consumed ca. 250 kWh/m3 of energy, which is much lower than in conventional kiln (usually over 400 kWh/m3). In addition, they do not need a boiler and that makes them a good solution for small businesses that don’t produce enough wood residues for burning. However, due to the intensive growth of pellet production in Southeast Europe and resulting growth of wood residue prices, these kilns are also being implemented by big manufacturers which then deal with their surplus of wood residue by either selling or processing wood residues into pellet. Naturally, market share of dehumidification kilns is much smaller than that of conventional ones due to availability of wood residues in wood processing companies, but also due to maintenance costs. In the future, carbon footprint of such kilns should be thoroughly evaluated (fossil CO2 associated with electricity and refrigerant).

Finally, when considering energy consumption, the trend of using more and more cogeneration plants in wood industry should not be overlooked. Cogeneration plants and kilns are closely linked (as they provide heat energy for drying), therefore a new kilns investment cycle can be expected in the near future.

3. CONCLUSION

Numerical simulation and modelling are powerful tools able to synthesise present knowledge, but wood drying research is still impossible without heavy investment of time, manpower and funds. This is only part of the reason why there were no new sensational wood drying technologies but only innovations based on the existing knowledge during the past few decades. It looks as though the scholars are more knowledgeable and interested in the equipment and kilns themselves than in the material that they process – paradoxically, the material in question being in use since the dawn of human history. There is still a need to better understand the mechanical and rheological behaviour of wood during drying – while the moisture content and temperature of the wood change with time. This is a complex phenomenon, it involves anisotropy, elasticity, viscoelasticity, mechanosorption, thermo and hygro-activation, variability of wood... Be that as it may, it is apparent that substantial foundation knowledge of fundamental traits of wood is a prerequisite for enabling further improvements of the drying process.

The three major aspects of successful drying process – time, cost and quality – influence each other in a complex manner, but it is usually necessary to find some kind of compromise. Within the drying costs, energy costs will continue to be an important research field. However, for hardwood timber, high drying quality will remain the main aim, more important than drying time and energy consumption.

It seems that, along with improvements of drying software and controls, fundamental and practical knowledge of users (kiln operators) is heading in the opposite direction. Even the existing knowledge about wood drying has not been fully applied in practise. This (rising) gap between industrial practices and academia needs to be bridged (training, technical brochures). It is imperative that key concepts of drying are interpreted correctly by kiln operators and adapted to real conditions of the timber and the kiln. In other words, drying practitioners must be able to understand, imagine, implement and improve their knowledge and scholars must be open and able to receive their feedback.

The fact that even with the hi-tech equipment we are still not able to (fully) understand wood behaviour during drying, even with tests in controlled laboratory conditions, can be frustrating. On the other hand, the day when we know and can predict everything regarding wood drying is the day wood drying stops being an art. In my humble opinion that would mark a beginning of a tedious future – so for better or worse, we are nowhere near that.

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BIO-BASED ECONOMY CASE STUDIES AT UNIVERSITY OF SOPRON

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ABSTRACT

Forest based sector plays a significant and inseparable role, through the transition and implementation of 'bioeconomy', 'bio-based economy', 'circular economy' concepts and strategies. This paper aims to report few bio-based economy case studies conducted at the University of Sorpon, and is divided in three parts. The first part describes the investigation efforts on the utilization of bark residues as a raw material for the manufacturing of thermal insulations panels. The second part is focused on the delignification of agricultural residues through an alkaline-hydrodynamic cavitation and examines their exploitation in paper and bioenergy production. Finally, the third part presents studies related to the fabrication of nanocellulose films and composites for various purposes.

Key words: resource efficiency, bio-based insulation, hydrodynamic cavitation, nanocellulose

1. INTRODUCTION

Forests and other wooded lands cover over 40% of the EU's land area, with a great biodiversity. The forest-based industries in Europe provides society with a wide variety of products and services and include**:** (i) the wood working industries, (ii) pulp and paper industries and (iii) multi-product integrated bio-refineries. The most significant sub-sector is the woodworking sector [sawmilling, planning and wood impregnation (12%), furniture (41%)] and other woodworking industries (47%) which had a turnover of €129 billion in 2015, employed more than one million people in around 170,000 small and medium-entersized companies. Additionally, 120,000 companies were active in the furniture domain. The second largest sub-sector i.e. the pulp and paper industry, was comprising of around 700 enterprises with an estimated turnover of € 81 billion in 2016, by employing about 175,000 people (Forest-based Sector Technology Platform, 2019).

The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles (EC, 2018a). Several EU policies and initiatives have an impact on the bio-based economy. The EU Bioeconomy strategy (Figure 1) and as part of it, forest-based roadmap directions targeted in a bio-based society is built on various pillars, covering numerous approaches and areas such as: sustainable forest management and forest protection; ensuring food security; social, economic and environmental considerations; mitigating and adapting to climate change; investments in research, innovation and skills; education and training; reinforced policy interaction and stakeholder engagement; enhancement of markets and strengthening European competitiveness; rural development, creation of jobs and economic growth; resource efficiency and reduced dependence on non-renewable resources; sustainable production and consumption of forest products; testing, standardization and certification (EC, 2013; EC, 2018a; Pelli, Haapala, Pykäläinen, 2017).

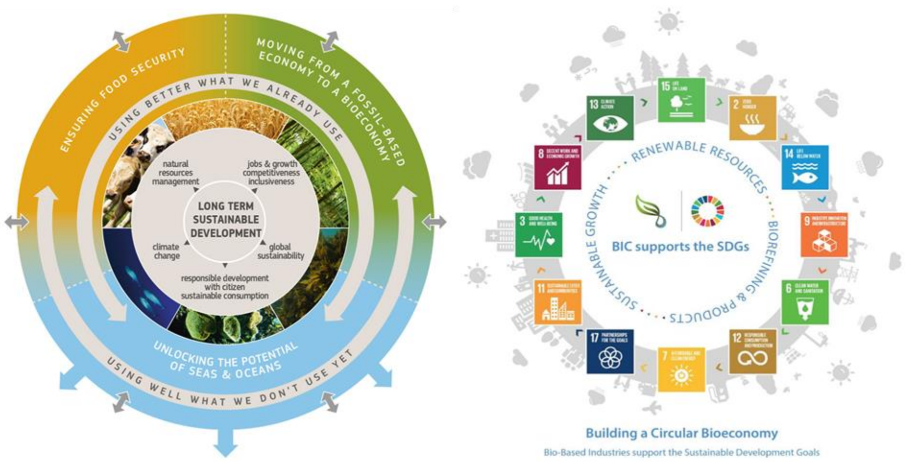

Figure 1. *Bioeconomy strategy graph (EC, 2018a) and biobased UN sustainable development goals (Biobased Industries Consortium, 2018)*

During the past few decades, the concepts of sustainability, bioeconomy, biobased economy, circular economy, green economy have appeared as frameworks for the visions and strategic orientations of the forest-bases industries (Hurmekoski et al., 2019; Pelli, Haapala, Pykäläinen, 2017). For instance, Näyhä (2019) in his study performed by interviews and surveys with Finnish forest-based companied concluded that bioeconomy was usually thought as a response to climate challenge by bio-based, renewable material while circular economy was characterized by ideas such resource efficiency, closed loops, recycling. Additionally, neither of them could be considered as inherent sustainable or green economy approached concepts. Likewise, according to Näyhä many other studies connect the three Rs of ‘Reduction, Reuse and Recycle’ to circular economy. Moreover, Bugge, Hansen and Klitkou (2016) identified three visions for a bioeconomy: biotechnology, bio-resource and bio-ecology. Staffas, Gustavsson, McCormick, 2013 report that the term BE is most often used by those who define the concept as biotechnology, life science and related technologies and applications, whereas the term BBE is based on the use of biomass resources rather than fossil-based products and systems.

In line with the studies mentioned above it can be deduced that the principles such as sustainability, bioeconomy and circularity should deep down at the heart of a successful European bioeconomy. Even it seems that i) that these concepts are used interchangeably and diversly comprehended by different actors’ and stakeholders’ sight and ii) these are overlapped and strongly interlinked to each other, still there are also descriptive differences among them. Furthermore, there are miscellaneous strategies according to the natural policies and legislation, geographical characteristics, economic growth and development and market opportunities, but all of them are identified by common characteristics. Therefore, it is obvious the existence of several and quite different explanations describing bioeconomy, bio-based economy and circular economy concepts (Figure 2). However, these concepts are well defined in other studies and is not purpose of this work (D’Amato et al., 2017; Nattras et al., 2016; Staffas, Gustavsson, McCormick, 2013).

In a relatively recent report from the EU (EC, 2011), are given the following definitions regarding to bio-based and bioeconomy concepts: ‘…a bio-based economy integrates the full range of natural and renewable biological resources, land and sea resources, biodiversity and biological materials (plant, animal and microbial), through to the processing and the consumption of these bio-resources. The bioeconomy encompasses the agriculture, forestry, fisheries, food and biotechnology sectors, as well as a wide range of industrial sectors, ranging from the production of energy and chemicals to building and transport…’. Mubareka et al. (2016) describe another similar definition related to bio-based economy as stated in one of EC publications, and determine it as one using ‘…production paradigms that rely on biological processes and, as with natural ecosystems, use natural inputs, expend minimum amounts of energy and do not produce waste as all materials discarded by one process are inputs for another process and are reused in the ecosystem.’

The EU’s wood-based industries cover a range of forestry downstream activities, including the traditional woodworking industries, furniture and building construction industries, pulp and paper manufacturing and cellulose based applications and especially multi-product biomass innovative, value-added products such as biorefineries. A key factor in the transition to a bio-based economy is the growth of biorefinery systems. Biorefineries in a general perspective include as examples the production of bio-textiles, bio-chemicals, bio-lubricants, bio-surfactants, bio-pharmaceuticals, bio-adhesives, bio-plastics, 3D printing and flexible electronics etc. products, as well the bio-technology (enzymes etc.) and bioenergy (biofuels, biogas, heat and/or electricity) (Scarlat et al., 2015).

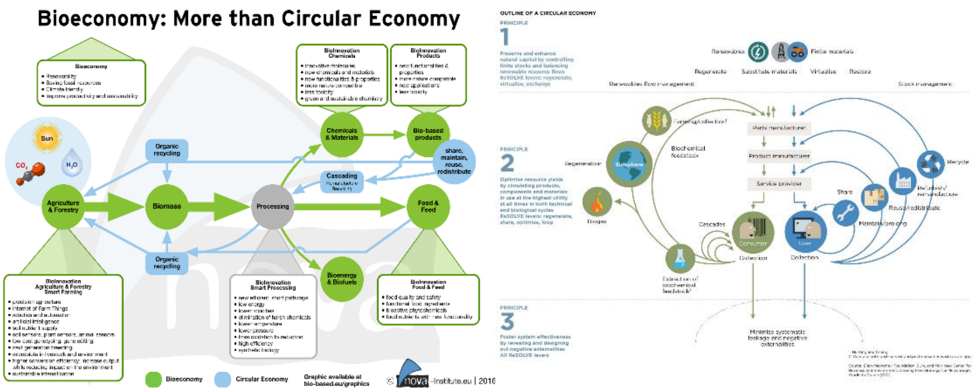

Figure 2. *Bioeconomy and circular economy concepts (nova-institute.eu; ellenmacarthurfoundation.org)*

The scope of this review is to present a brief summary of the near past and ongoing research and further to describe a few experimental case studies, implemented from the Innovation Center and Macromolecules Materials and Technology research groups, based on the Simonyi Károly Faculty of Engineering, Wood Sciences and Applied Arts at the University of Sopron.

2. BARK UTILIZATION AS INSULATION PANELS

The circular economy is an economic system in which ‘the valuable products, materials and resources is maintained in the economy for as long as possible, or by enabling the circular economy actions plans with the processing of side-streams, residues and wastes into new value chain products. This can be achieved for instance by minimizing and/or recovering the generation of agricultural and forestry biomass waste and residues, and simultaneously maximizing their resource efficiency, recycling and reuse, i.e. ‘circularity’. Key innovations in the wood working sector among others include the cascading use of wood industries residues (e.g. small diameter roundwood, sawdust and chips, thinnings, bark, tree tops and branches) as feedstocks in the manufacture of wood pulps and biorefineries, wooden packaging, or wood based panels such as thermal, acoustic and vibration insulation boards (EC, 2018a; EC, 2018b).

Each year, a huge amount in million tons of bark remains as a residual woody biomass in sawmills and wood-based industries. During 1960s, Martin investigated the bark thermal properties of three pines and seven hardwood specimens, and he was shown that bark specimens indicated lower thermal conductivity values compared to similar density wood specimens. Lately, Kain et al. (2013, 2018) have been investigating the utilization of usually low-density spruce and larch bark particleboards as thermal insulation panels. Likewise, Pásztory, Mohácsiné, Börcsök (2017) investigated the effect of black locust size particles (fine fraction: 1-8mm; medium fraction: 8-13 mm; and coarse fractions: 13-45 mm) on the thermal conductivity values of 20 mm thickness and 300 kg m^{-3} density particleboards (Figure 3a). As shown by the results, the bark particles sizes had no significant effect on the mean thermal conductivity values (~ 0.065 W/m·K) of the black locust panels and was found to be in consistence with other relevant studies.

One of the main obstacles on the fabrication of bark particleboards, is the weak mechanical properties observed on the manufactured end products of wood-based panels or composites. A potential solution to overcome this issue, could be their reinforcement with synthetic polymer fibres such as glass fibres. Therefore, the objective of a research conducted in our laboratory facilities was to examine the mechanical strength reinforcement of three commercial fibreglass types (GFRP) overlaid on both surface of bark-based boards, and their potential usage as insulation panels in building construction (Figure 3b).

Figure 3. *Black locust bark panels (a) and overlaid GFRP panels (b)*

The mean modulus of rupture (MOR) values of the control panels was calculated to be 0.54 MPa, while the mean MOR of fibreglass mesh 2.54 MPa, the mean MOR of fibreglass mat 2.82 MPa and the mean MOR of fibreglass woven fabric 4.45 MPa, which represent a percentage raise of 370%, 422% and 724%, respectively. The measured thermal conductivity mean values were ranging from 0.067 to 0.074 W/m·K.

3. HYDRODYNAMIC CAVITATION AS A DELIGNIFICATION METHOD

Alkaline assisted hydrodynamic cavitation has been testified to be an effective process for the delignification and enhancement of enzymatic digestibility of grass agricultural residues biomass for converting it into biofuels such as bioethanol or biogas. Cavitation is the process of the generation, growth and violent collapse of million vapor micro-bubbles within a few microseconds in the bulk of a liquid. This collapse is strong enough to generate high temperature and pressure conditions and induce chemical and physical transformations in the material. Cavitation can be produced by passage of ultrasonic waves through a liquid medium (acoustic cavitation) or by pressure variation in a flowing liquid which can be caused by constriction through a channel such as venturi tube, orifice plate or rotor-stator assembly (Baxi and Pandit, 2012; Hilares et al., 2016; Patil et al., 2016).

Part of current research conducted in our groups, deals with the delignification of agro-waste such as wheat straw (Badve et al., 2014) or *Miscanthus x giganteus* stalks and other agricultural residues, through the combination of an alkaline-hydrodynamic cavitation approach for the production of papermaking pulps (Figure 4).

Figure 4. *Hydrodynamic cavitation device and agro-waste paper handsheets*

It was clearly shown from Badve et al. (2014) that as cavitation parameters, i.e. treatment time and rotation speed was increased, tensile index of the wheat origin paper handsheets was linearly increased. Furthermore, as the wheat to 0.3 M KOH aqueous suspension consistency ratio was increased from 5% to 7% the tensile index was increased by 50%. This effect can be attributed to the enhance of surface velocities generation, i.e. the growth of cavitation intensity and the formation of more reactive hydroxyl radicals (OH·) as the cavitation conditions (rotation speed and time) was increased, which in turn resulted to a raise on the overall delignification rate. Chemical composition analysis of hydrodynamic cavitation treated miscanthus pulps exhibited lower lignin and hemicellulose contents and raised percentage of α-cellulose compared to raw (untreated) miscanthus as cited by the literature (Rodrigues, Jackson, Montross, 2016; Vanderghem et al., 2012). More specifically, lignin content was found to be 15.90% (dry basis weight) and holocellulose content 77.28% - comprised of 60.75% α-cellulose and 15.90% hemicelluloses content - at 7% miscanthus to suspension consistency and 20 min cavitation time at a rotation speed of 2,500 rpm.

4. CELLULOSE BASED STUDIES

The significance and importance of cellulose and cellulose derived materials is depicted by the numerous publications and ongoing research projects due to their environmental, chemical, physical, barrier and mechanical properties. These can be used in heterogeneous shapes and forms as reinforcement fillers, films, aerogels, hydrogels, filaments, hybrid nanocomposites in various fields including biomedicine and cosmetics, electronic/smart material devices, food packaging industries, in pulp and paper industry and even automotive and aerospace industry (Nechyporchuk, Belgacem, Bras, 2016; Sabo et al. 2016).

Poly(lactic) acid (PLA) is a commonly used biodegradable, bioplastic which is used extensively in the packaging industry. However, one of its bottlenecks is its unsuitability for storing liquid products due to its high water vapor and gas permeability. Halász, Hosakun and Csóka (2015) achieved to reduce the water vapor transmission rate of PLA bottles and films, and to extend their shelf-life time by almost 1/3, through a chitosan (CH)-cellulose nanocrystals (CNCs) nanocoating applied by a self-assembly, electrostatic layer-by-layer (LbL) deposition method. The four times bilayer impregnating CH-CNCs coating was found to be more efficient compared to eight times CH-CNCs LbL technique, as it illustrated in Figure 5.

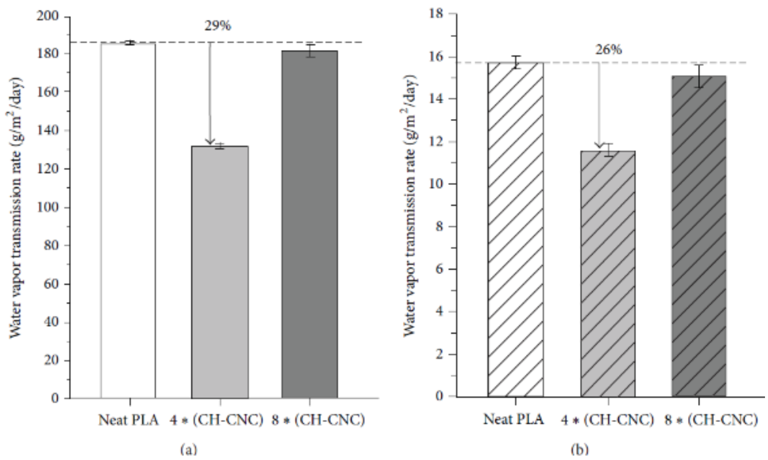

Figure 5. *Water vapor transmission rate of neat and CH-CNCs nanocoated poly(lactic) acid films (a) and bottles (b) through a LbL method*

Khatri et al. (2014) functionalized bleached pine pulp fibres with previously saccharide (glucose, sucrose, starch and alginic acid) modified ZnO nanoparticles and then tested the suitability of the produced handsheets on the detection of blood types, besides their antibacterial and antifungal resistance (Figure 6). Bradford reagent was used as a media to quantify the degree of blood antibodies immobilization with the ZnO modified cellulose sheets. Results have shown that, especially the alginic acid ZnO impregnated handsheets, could successfully differentiate the retention degree of blood antibodies and identify the blood type at a percentage rate of about 95%.

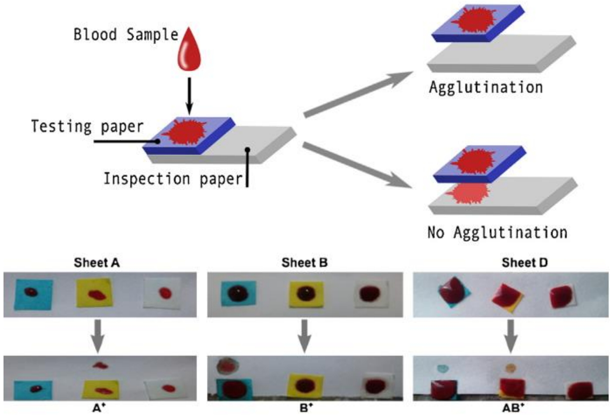

Figure 6. *Schematic illustration and images of blood type detection tests with alginic acid ZnO impregnated pulp handsheets*

In one of our previous studies, it was shown that sonication with an ultrasound horn is an efficient method of producing smooth, thin and relatively transparent BC films by a simple solvent casting method (Tsalagkas et al., 2016), which potentially could be used as substrates in smart applications such as piezoelectric energy harvesting or electric devices. Based on this study, Hosakun et al. (2018) assessed the potential of BC blend films incorporated with silk fibroin (SF), polyvinyl alcohol (PVA) and silver nanoparticles (Ag) as flexible organic light emitting diode (OLED) substrates (Figure 7). For this purpose, the co-authors examined the viscoelastic and electrical properties of the obtained films by performing complex conductivity and DMA analysis tests, under the influence of photoelectric effect (light) and above the glass transition temperature (T_g). According to their findings, the most favorable films was the BF-SF-PVA-Ag since both PVA and Ag displayed synergistic effect on the final performance of the investigated films.

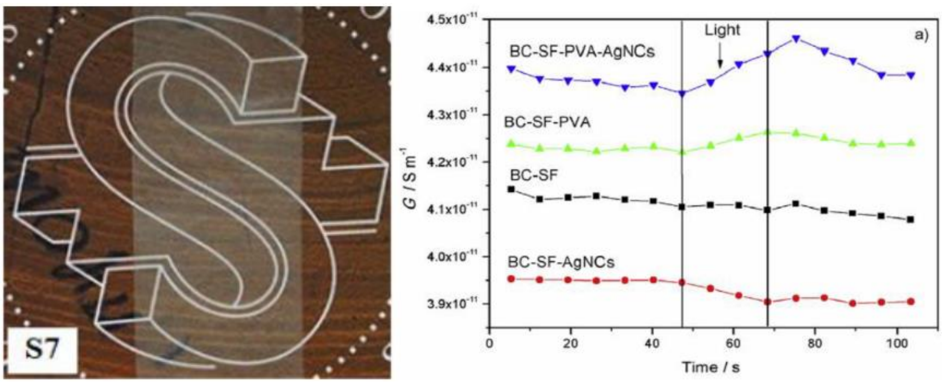

Figure 7. *BC-SF-PVA-Ag films (left) and specific conductance (G) measurement of the overall films at 22 kHz as a function of time performed on an Agilent 4284 A (right)*

5. CONCLUSIONS

This review has provided a short outline of the recent published and unpublished investigations carried out on the bio-based focused research fulfilled from our groups. In this paper we attempted to summarize their methodology, main results and outcomes prompt by our studies.

The transition from a fossil-based industrialization and dramatic climate change to a sustainable, low carbon and environmental impact, resource efficient, profitable and competitive economy with innovative, value added, bio-based products is a major challenge and still demands a lot of research and emergence of new technologies. The European Commission, through its continuous research funding opportunities, and strategic orientation policies, has already set the foundation for the accomplishment of a green, circular economy based Europe by 2050. For the successful completion of this long-term targets, and in compliance with the recent results and developments as accomplished through the Horizon 2020 projects, forest-based sector had an important share. And will continue to play a crucial part in the forthcoming framework programme Horizon Europe in line with the targets presented in the 'Vision 2040 of the European forest-based sector' and 'The forest fibre industry 2050 Roadmap to a low-carbon bio-economy' publications as issued by the Forest-based Sector Technology Platform (FTP) and Confederation of European Paper Industries (CEPI) organizations, respectively.

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ANALYSIS AND ESTIMATION OF THE PROFITABILITY OF FOREST CERTIFICATION OF WOOD PROCESSING FACILITIES IN EXPERIMENTAL FORESTRY ENTERPRISES - YUNDOLA AND BARZIA

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ABSTRACT

Forest certification plays an important role in helping and guaranteeing sustainable forest management. The interest in certification has increased in recent years. As of November 2017, the FSC-certified forestry holdings are 72, some of which are included in group certificates of the respective state-owned enterprises in whose territory they are located. The certified forest area in Bulgaria in November 2017 is 1 315 594 ha. Issues related to forest certification and sustainable woodworking management in the country are becoming increasingly important.

The main objective of the study is to analyze and evaluate the profitability of woodworking capacities in introducing the FSC Certificate for Sustainable Management of wood processing facilities in Experimental forestry enterprises - Yundola and Barzia These two enterprises are considered as model forestry enterprises, located in forest areas with high-grade coniferous and broad-leaved forests. The profitability of the wood processing plants of these enterprises over the last 5 years has been investigated and the impact of their forthcoming certification on their effectiveness has been studied.

The results obtained can be used as a guide in deciding on FSC FM / CoC certification for logging and tracking the production of woodworking enterprises in the country.

Key words: sustainable management, forest industry, forest certification, economic analysis JEL:Q01,Q23

1. INTRODUCTION

Forests are a valuable renewable natural resource, fulfilling a multitude of functions, mainly considered in economic, social and environmental aspects. From all natural resources in Bulgaria, forests represent the highest share and paramount importance. They offer habitats for animals and plants and play an important role in mitigating climate change, the basis being the water zones, reducing soil erosion and carrying many other environmental services. The societal benefits of forests, including human health, recreation and tourism, are essential but often underestimate. Bulgarian forests make a significant contribution to rural development and for many regions they are the only source of financial income. Forest biomass is currently the most important source of renewable energy for the country. Forests also provide a wide range of other products, such as cork, resins, fungi, nuts, game and fruit. To deliver these benefits in a balanced way it is necessary to ensure sustainable forest management.

For the purposes of this paper we use the definition for sustainable forest management, developed by Forest Europe in 1993 and subsequently adopted by the Food and Agriculture Organization (FAO) of the United Nations: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems."

Forest certification is a voluntary instrument, which uses a set of standards to evaluate and validate the practices of forest management. It ensures and promotes economically viable forest management, in compliance with social standards, while protecting the environment. Forest certification is a direct economic instrument to ensure the sustainable use and management of forest resources.

In Bulgaria the forest territories are around 37% of the country's territory. Approximately 67 % of them are broadleaved forests. Bulgaria is the third richest in biodiversity country in Europe. There are 3 National parks, 11 Nature parks and more than 700 protected areas in the country.

Forest certification system aims to ensure and promote economically viable forest management, in compliance with social standards, while protecting the environment. Forest certification is a direct economic instrument to ensure the sustainable use and management of forest resources.

The certification verifies that the management of forest territories is carried out in an open manner, balancing environmental, economic and social benefits.

In Bulgaria there are two forest certification systems offered on the market – FSC and PEFC. Currently FSC is the preferred one and with more than 150 users. PEFC is still not very well known and spread as there are only few companies certified according to it for chain of custody.

FSC shares the EU Commission's broad goals of setting up a better global timber trade and governance system. It promotes sustainable forest management, improves forest governance and supports sustainable consumption.

Certification bodies award forest management (FM) certification to those forest managers or owners whose practices meet FSC Principles and Criteria. As it is shown on the figure below FM certification rose from 1,084 certificates in 2012 to 1,462 certificates in 2017. This is a significant 35 per cent rise over five years.

Figure 1. *Evolution of FSC FM certificates, 2012–2017*

There are 19 forest management enterprises, which have received the FSC forest management certificate in Bulgaria. There are 807 833, 80 ha of certified forest territories which represent 19% of the total forest territory of the country. On fig. 5 is shown how the FSC certified territories are growing during the years. The first two certificates were awarded in 2006. As it could be seen on the graphic there is a tendency of growing interest to the certificate over the past few years. At least another three forest management enterprises are under certification procedures.

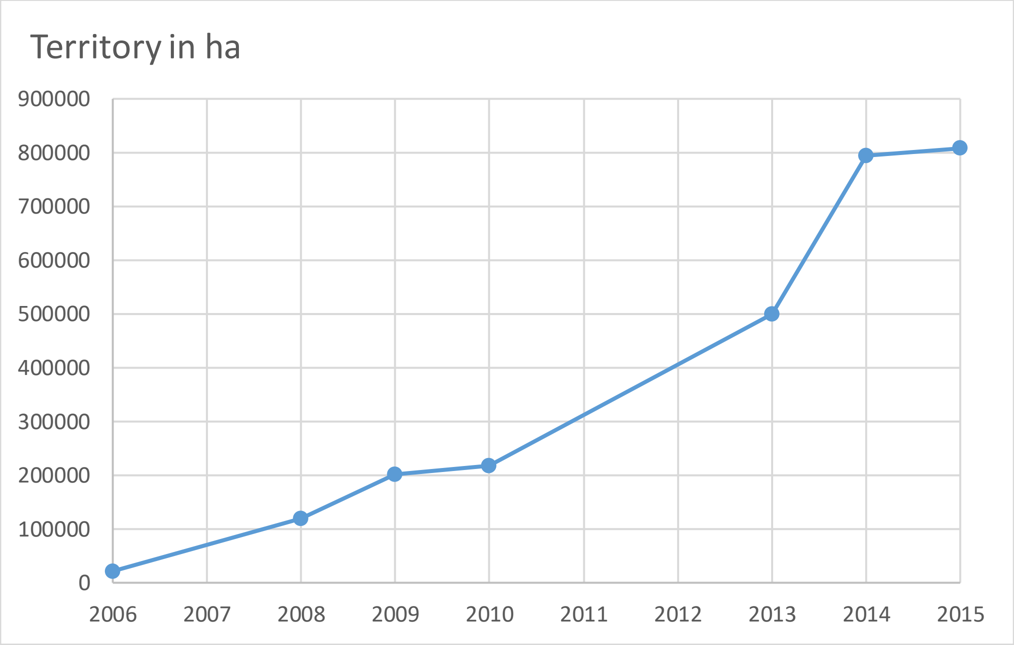

Figure 2. *Changes of FSC certified forest territories*

On fig. 3 is shown the distribution of FSC territories according to ownership. Most of the forest management enterprises are state owned forest territories - 98 %. There is only one certified municipality. The private sector is represented only with one company, which owns relatively small territory of forest plantation. In this respect the forest certification is considered as a state policy in Bulgaria at the moment.

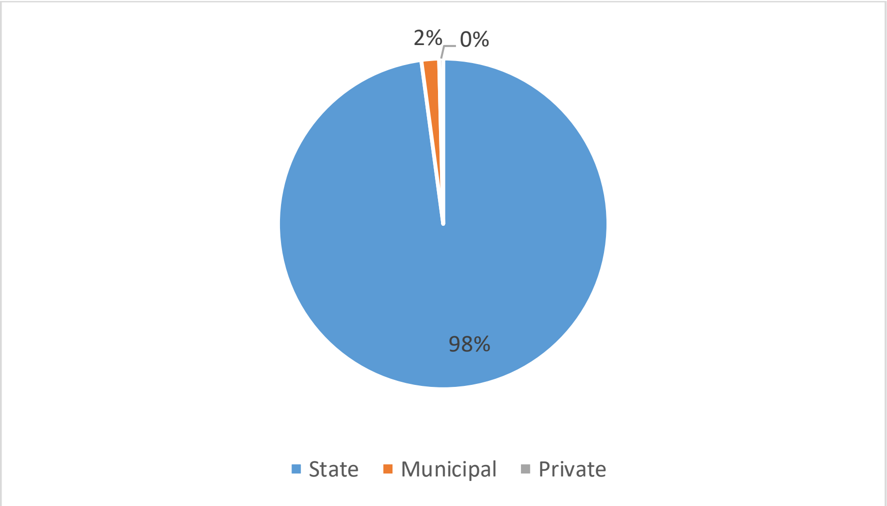

Figure 3. *Distribution of FSC certified forest territories according to ownership*

Certification is one of the fastest-growing "soft political mechanisms" that can be used to support the movement of the forest sector along the lines of sustainable development principles.

Forest certification is a partnership between environmentalists who are concerned about forest quality and biodiversity maintenance and forestry professionals who want to find ways to increase the market for environmentally friendly forest products.

An independent forest management certificate saves buyers or investors the inconvenience of confirming that their products come from well-managed forests. The certificate provides a seal of confidence on the market.

The IAG values the need for rapid and adequate introduction of forest certification in Bulgaria. As a government institution directly involved with the management and management of forests in Bulgaria, it creates all the necessary conditions for starting and implementing this process.

The Forestry Act of March 2011 has developed a special section (III) – “Forest Certification”.

The main objective of the study is to analyze and evaluate the profitability of introducing the FSC certificate for sustainable forest management. In this respect a case study analysis is carried out at Yundola and Petrohan, which are Training forest enterprises at the University of Forestry - Sofia.

These two forest enterprises and adjacent state forest and hunting forest enterprises are considered in this case as model forest areas, including certified and subject to certification forest enterprises and typical forest areas with coniferous and deciduous forests.

The following research objectives were fulfilled in order to achieve the stated goal:

1. Analysis and estimation of the profitability of the implementation of the FSC certificate for sustainable forest management in Yundola Training forests.
2. Analysis and estimation of the profitability of the implementation of the FSC certificate for sustainable forest management in the Petrohan Training forests.
3. Study and analysis of the demand for sustainable forest management products.

2. MATERIAL AND METHODS

According to the adopted classification scheme of the forest habitat types, the territory of the Yundola training forests falls entirely in the Thracian forest-growing area. Although the territory of the forest enterprise is situated on two subregions (Rila and Western Rhodopes), the natural vegetation is mainly of coniferous species - pine, spruce and fir in different proportions. Significant differences exist in the vertical distribution of plantations.

The nearest forest enterprises to Yundola training forests, which have similar characteristics and are already FSC certified, are Borovo and Dospat state forest enterprises.

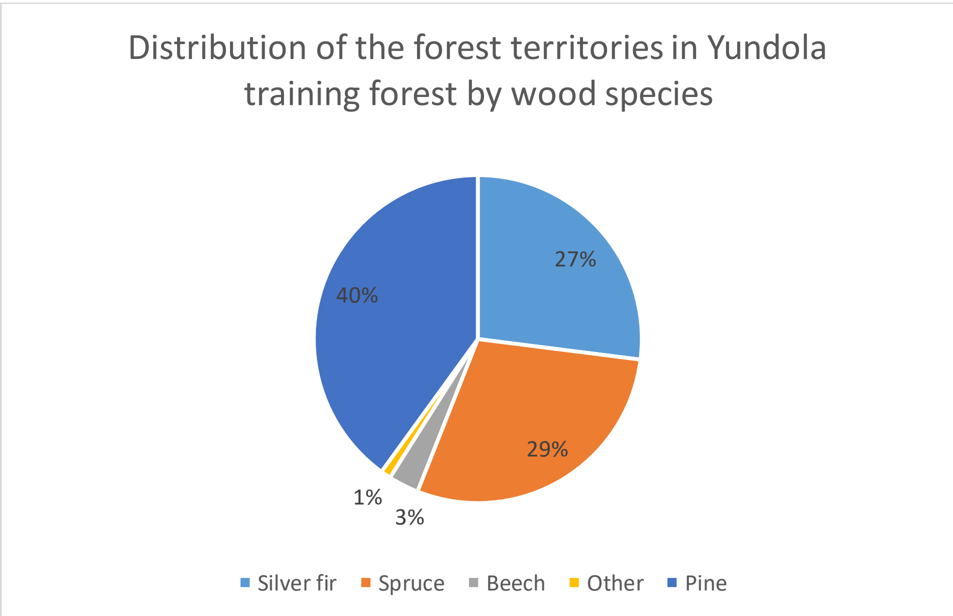

Figure 4. *Distribution of the forest territories in Yundola training forest by wood species*

In Dospat forest enterprise the main wood species are pine with nearly 70% and spruce – 23%. Similar is the situation in Borovo forest enterprise where the main wood species is pine. It is commonly spred, with the exception of the lowest parts of the unit, forming pure and mixed plantations.

The total wood-producing area of Dospat forest enterprice is 20,500.6 ha, which is 96% of its total area. The non-productive forest area is 840.6 ha or 4.0% of the total area.

The total area of the forest enterprise Borovo is 15 046.8 ha, 14 530.6 ha (96.6%) is afforested, wood-producing area and 496.7 ha (3.2%) is non-productive.

The state forest areas in all three forest enterprises account for over 85% of the total forest area, with the highest share in Borovo State Forestry, which accounts for 96.4% of its forest area.

Everywhere in the area under consideration dominate coniferous forests, most of which are state-owned.

The average age of the plantings is around 60 years. The total average gain of 1 ha is over 4.5 m3. The average stock of 1 ha is over 300 m3, the average yield is III (2.9) and the average fullness is 0.77. State-owned forest areas, on their part, facilitate security, enforcement and compliance with the FSC standard principles.

The difficult mountainous relief limits the development of the forest infrastructure, which contributes to the preservation of compact, intact forest massifs and is a prerequisite for the diversity of plant and animal species, as well as for their preservation.

The variety of soil conditions as well as the climate of the region contribute to the formation of high-productive forests, as well as to forests with a high degree of biodiversity.

The authors have obtained the following results for the training forest enterprise Yundola, based on the official financial data collected from the unit for 2016:

- Profitability of logging:
  - Profitability based on cost - 71.55%
  - Profitability based on revenue - 41.71%
- Profitability of woodworking:
  - Profitability based on cost - 35.36%
  - Profitability based on revenue - 26.12%

The above rusults show that the profitability of the forestry activity is high and on a cost basis is between 64% and 71% and for the woodworking works is between 35% and 88%. Profitability on a revenue basis is naturally a bit lower, but it is still at relatively high levels above 39% for timber and 26% for woodworking.

The nearest forest enterprise to Petrohan training forests, which has similar characteristics and is already FSC certified, is Vitinya state forest enterprise.

The territory of the Petrohan training forests covers a wide range of altitudes (from 301 to 1900 m above sea level) and falls into two zones with five subspecies (according to the forestry zoning of the country).

No significant change in the ratio of tree species is expected. In the future, the basic wood species will be preserved - beech, which fully corresponds to the potential opportunities of the formed habitats and well performing its water and protective functions.

The main wood species in Vitinya forest enterprise is the beech as well which accounts for 62%, followed by the sessile oak – 15.72%.

In Bulgaria, beech forests have an important economic importance for the forestry sector, providing around ¼ of the total annual timber yield. Their environmental role and their contribution to providing drinking water for the population is enormous. Over 60% of the area of beech forests falls into the water catchment areas of the country. A significant part of them is included in the protected area system and more than ¾ are part of the Natura 2000 ecological network.

Areas with a predominance of beech forests are a desirable place for recreation and different types of tourism, there is a rich wildlife and enormous biodiversity. The beech forests are a source of significant non-wood products - healing plants, mushrooms, fruits, fodder.

The certification of the forest unit helps for the strictly monitoring of the proper and rational distribution of tree species by habitat types that will increase forest productivity by up to 3,800 cubic meters per year.

The territory of the Vitinya forest enterprise is part of three different municipalities and has about 50% forest area of economic significance. This implies the hiring of local residents, which in turn helps to reduce unemployment in the area and improve its overall economic situation.

The authors have obtained the following results for the training forest enterprise Petrohan, based on the official financial data collected from the unit for 2016::

- Profitability of logging:
  - Profitability based on cost - 185%
  - Profitability based on revenue - 65%
- Profitability of woodworking:
  - Profitability based on cost - 9.8%

- Profitability based on revenue - 8.9%

These results suggest that the cost-based profitability is between 71% and 185% for the logging activity, but unlike the Yundola Training forests, at the woodworking works is too low, between 2.5% and 9.8%. Profitability on a revenue basis is naturally lower, but it is still at a very high level above 71% in the timber industry, while the woodworking is too low under 9%.

The authors have carried out a marketing research to determine the demand of certified wood. The research was part of a scientific project funded by Forestry University, Sofia. Two regions were selected in which the two forest enterprises owned by the Forestry University operate – Pazardzhik and Montana regions. The main aim of the research was to help the forest enterprises to successfully position their products and support a decision making regarding FSC certification.

The selected regions are important forest regions for the country. The major findings from this research could be used by any forest enterprise.

The research is made by interviews with woodworking companies from the selected regions, which were essential timber buyers. The interviews were carried out with the help of questionnaire.

The purpose was to determine the fllowing:

- FSC recognition
- FSC certified wood consumption
- Interest in buying certified timber
- Willingness to pay the price

Altogether were made 15 interviews. The results from the two regions differ significantly. The main reason is in the different characteristics of the companies operating there.

In the region of Pazardzhik operate numerous micro to small enterprises. Their main market is Turkey where the quality requirements are relevantly low. The main species used in this region are conifers as spruce, fir and pine. The interest in timber coming from sustainably managed forests is low and it was very difficult to find companies willing to participate in the research.

In the region of Montana operate less but bigger enterprises. The main species used is beech and seldom conifers and populus. Most of the companies export into EU. A clear interest towards FSC certified timber is defined.

On fig. 5 is shown how companies recognize the FSC brand.

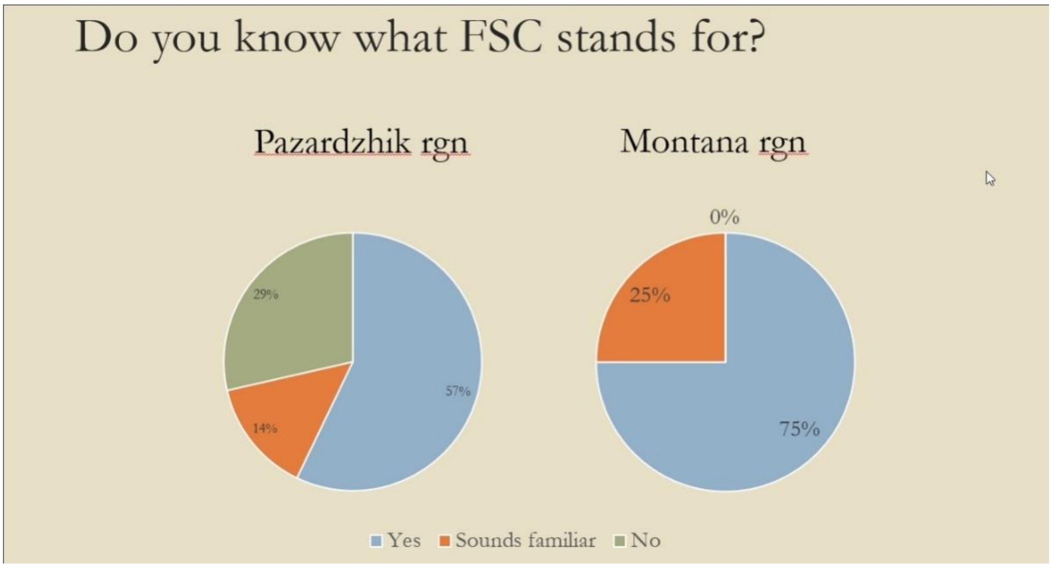

Figure 5. *FSC brand recognition in the studied regions*

A little more than 30% of the studied companies are certified to FSC CoC and are already buying certified timber.

On fig. 6 is shown the willingness of the studied companies in buying certified timber.

Figure 6. *Willingness to buy FSC certified wood*

In the region of Pazardzhik there is still lack of recognition of FSC brand and low interest in FSC certificate showed by big part of the companies, which are numerous. At the same time over 70% of the studied enterprises declared willingness to buy certified wood. Most of them are not ready to pay price which differ significantly to the current prices.

The main reason for the low interest in FSC certified wood in this region is the fact that the major part of the companies work for the Turkish market where the certificate is not required. In the future is expected this situation to change and the companies realize that.

In the region of Montana there is a clear interest in the certified timber. A major part of the woodworking companies are exporting to EU where a certificate is required.

Overall around 75% of the studied enterprises are showing willingness to buy certified timber, most of them on the condition that the price does not change significantly.

The main marketing advantage of the forest enterprises adopting the FSC FM certificate will be the use the FSC brand to distinguish their products, which will give them a competitive advantage and will help them in case of market shrinkages. Furthermore they would enter new markets where there is a demand of products from sustainably managed forests and not enough supply.

3. CONCLUSION

Currently FSC is the preferred forest certification system in Bulgaria. FSC shares the EU Commission's broad goals of setting up a better global timber trade and governance system. It promotes sustainable forest management, improves forest governance and supports sustainable consumption.

Market access is the key direct financial benefit of certification. It is closely linked to the recent phenomenon of market globalization. A research made by the authors shows that only 47% of Bulgarian certified forest management enterprises recognize this benefit.

An official survey of FSC shows that the percentage increase in CoC certificates in Bulgaria for the last two years is 49% and worldwide only in Ukraine we could see a higher increase. This suggests that the demand of certified timber will increase in the country.

The authors have carried out a marketing research among woodworking companies in two important forest regions in the country. The results show that the recognition and the interest in FSC certificate in the two regions differ significantly. The main reason is in the different characteristics of the companies operating there. In the one, where there are working numerous small companies processing conifers and operating on the Turkish and domestic market nearly 30% of the examined enterprises do not even recognize the FSC brand.

The main reason for the low interest in FSC certified wood in this region is the fact that the major part of the companies work for markets where the certificate is not required. In the future this situation is expected to change.

In the other studied region Montana, there is a clear interest in the certified timber. A major part of the woodworking companies are exporting to EU where a certificate is required.

The research show that overall around 75% of the studied enterprises are showing willingness to buy certified timber, the majority on the condition that the price does not change significantly.

The main marketing advantages to the forest enterprises adopting the FSC FM certificate is the use of the FSC brand for distinguishing their products and the possibility to enter new markets.

The results obtained from the marketing survey show that there is still no awareness and lack of interest in the FSC certificate from the large number of small woodworking companies, which are numerous in the area of Yundola training in forests. However, the survey shows that 72% of the surveyed companies will purchase certified timber from nearby forestry. Most require that the price of the certified tree does not differ significantly from the non-certified. These companies work with the raw material offered by the nearby forestry companies.The main reason for the lower interest in the FSC certificate is due to the fact that the companies in the region are mainly manufacturing their domestic products and export to Turkey, where the certificate is not required. However, in the future, this can be expected to change and this fact is recognized by some of the companies.

In the region of the Experimental Forest enterprise Petrohan, the village of Barzia, Berkovitsa Municipality and Montana region has a marked interest in certified wood. Most of the woodworking enterprises in the area work for the Western European market, where a certificate is required and a large number of them are certified for production tracking. The raw materials that are searched mainly coincide with those produced by the timber exploration.The study and comparative analysis of other forest enterprises with similar characteristics and location as the surveyed shows the following:

• Certified forest enterprises are right to evaluate their decision and are pleased with the results.

• The price of certified wood does not differ significantly from that of the uncertified.

• The main advantages of certification are the preservation of market positions and a competitive advantage as well as a better reputation and relations with the local population.

• In the future, an increase in the demand for certified timber in the region of Yundola and Petrohan may be expected. Training forests can benefit from this by going through the certification process.

The following marketing conclusions can be made to implement a successful marketing strategy for the implementation of certified wood:

• With regard to the product, certification will distinguish the timber offered by the forest enterprises and give it a competitive advantage over that offered by uncertified forest enterprises.

• In terms of distribution - the main market will remain the woodworking and furniture companies located in the region. Certification, however, will allow entry into nearby markets, where there is demand and reduced supply of certified wood.

• In terms of price - market conditions require certified wood to be offered at a price close to that of the uncertified.

• With regard to the communication mix - certification will improve community ties by creating a positive reputation on the *forest enterprises* and improving communication with the local population.

The final results of the analyzes and the quantitative estimates of the incomes with the introduction of a certified Sustainable Forest Management System show that the profitability of the forestry activity in both forest enterprises is high and on a cost basis is between 64% and 71% for the Yundola Training forests, and for the woodworking works is between 35% and 88%. Profitability on a revenue basis is naturally a bit lower, but it is still at relatively high levels above 39% for timber and 26% for woodworking.

For Petrohan, the cost-based profitability is between 71% and 185% for the logging activity, but unlike the Yundola Training forests, at the woodworking works is too low, between 2.5% and 9.8%. Profitability on a revenue basis is naturally lower, but it is still at a very high level above 71% in the timber industry, while to the woodworking is too low under 9%.

The above gives us reason to offer forest managers in FSC forest certification decisions to take into account the profitability of the two main activities: sustainable forest management (logging) and woodworking and the results obtained should be used to search for suitable alternatives before to take the final decisions.

Acknowledgements
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BONDING OF WOOD AND OTHER MATERIALS

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ABSTRACT

The objective of the research presented in the paper was to determine the suitability of epoxy and polyurethane adhesives for bonding of wood and steel together. The quality of the adhesive bond was evaluated by a shear strength test which followed after each of the pretreatment procedures: exposure to the standard climate - relative air humidity 65 % and temperature 20 °C (20/65); exposure to water - 1 day soaking; and - 2 days soaking. The results showed that the studied polyurethane adhesive can be suitable for non-structural bonding of steel and wood in dry conditions, whereas they are not suitable for more demanding application in humid conditions. Epoxy adhesive bonds between wood and steel exhibited higher shear strength than polyurethane for all pretreatment procedures.

Key words: adhesive bonding, epoxy, polyurethane, steel, wood

1. INTRODUCTION

Wood bonding is very complex technological process, which involves many factors that determine how successfully an adhesive bond will perform in practical applications. The better these factors are understood and controlled, the fewer bonding problems will be encountered. In general, any adhesive bonding comprises preparation of the surface to provide the best interaction of the adhesive with the substrate; application and distribution of the adhesive to form a contact on a molecular level between the adhesive and substrate surface; and setting of the adhesive, which involves the solidification and/or curing of the adhesive (Vick, 1999).

Process of adhesive bond formation typically involves five steps starting with flow and transfer of adhesive, following with penetration and wetting, and finishing with solidification into rigid structure. The flow of adhesive involves the spreading of the liquid adhesive along the external surface. The assembly of the wood elements leads to transfer of the liquid adhesive to the adjacent wood surface. Penetration then occurs because of capillary forces within the cell lumens and bulk flow due to applied pressure. Wetting follows or accompanies penetration. Wetting not only applies at the external wood surface, but also aids in the movement of the liquid adhesive along the walls of the cell lumens. Finally, solidification of the adhesive occurs, which in the case of thermosetting adhesives, signifies chemical reaction of the adhesive into a rigid polymer (Marra, 1992).

Any bonding of wood with the adhesive (solid wood or wood-based composites) involves some type of spreading the adhesive over the wood surface (spraying, coating, blending, etc.). Regardless of method, the purpose in spreading adhesive is to distribute an adequate amount of adhesive of uniform thickness over the bonding area, so that under pressure, the adhesive will flow into a uniformly thin layer. After the adhesive application, certain open and closed assembly times are used depending on the specific bonding process. During the assembly time, some spontaneous wetting and penetration may occur into the spread surface. Also, some thickening and skinning over of the adhesive may take place. Thus, long open times can cause the adhesive to dry out on the surface resulting in poor bonding because flow is needed for successful bonding (Frihart, 2005).

Flow, which is a first motion during the adhesive bond formation, occurs after adhesive application and promotes further when the opposing two wood surfaces are brought together. The adhesive moves laterally in the plane of the surface, flowing into irregularities and forming a film. This motion is the easiest to perform because it involves only coarse movement of the adhesive as mass flow (Marra, 1992).

Transfer of an adhesive plays important role in cases when the adhesive is applied only to one bonding surface. In such as cases, transfer of the adhesive to the opposite surface may occur simultaneously with flow, but in some instances flow will occur without transfer. Therefore, transfer is achieved with slightly more difficulty than flow and as a consequence is more easily inhibited. The adhesive must have an extra degree of mobility, beyond that needed for flow alone. This characteristic of the adhesives may be visualised as “tack” (Marra, 1992).

Penetration brings the adhesive into the coarse capillary structure of wood and into checks and ruptures created in processing. Penetration can also involve the movement of adhesive into the cell wall. Because of the small openings into which the adhesive must move, a still higher degree of mobility is necessary for penetration of the adhesive to take place. Penetration of adhesive into the porous network of wood cells is believed to have a strong influence on bond strength. Damaged wood cells may be reinforced by the adhesive, and stresses may be more effectively distributed within a larger interphase region (Marra, 1992). Adhesive penetration into wood depends on many features connected with properties of adhesives, wood and the bonding process (Šernek, Resnik, Kamke, 1999).

Wetting is a molecular action, which follows or accompanies penetration. The amount of wetting that occurs depends on the molecular nature of the adhesive; the quality of the wood surface; the molecular mobility in the adhesive; the pressure (and temperature) on the adhesive; and the time available before hardening of the adhesive arrests mobility (Marra, 1992). Wettability depends also on the wood characteristics: wood species and composition, extractives present in wood, wood anatomy, wood surface sections, wood seasoning, moisture content, temperature, etc. (Šernek, 2002).

The final adhesive motion is solidification, which stops all motions and consummates the bond-forming actions that have preceded. Basic mechanisms for hardening of adhesives are loss of solvent or liquid carrier; loss of heat; chemical reaction or combinations of these. The hardening or curing of thermosetting adhesives, which are most often used in production of wood-based panels, is usually carried out in a hot-press at a defined pressure and temperature, and for a defined period of time. Curing involves conversion of a liquid adhesive through gelation and vitrification to fully cured adhesive.

A proper adhesive bonding is a crucial part for bonding of solid wood together or for the wood-based composites manufacture, which leads to an adequate bond strength and long-term performance of the bonded products.

When bonding of wood to other materials, such as metals, glass and polymers, the process of bonding encounters many additional challenges (Saražin, Šernek, 2017; Saražin, Šernek, 2018; Šernek, Vovk, 2015). Wood is natural material, whereas many of materials are synthetic. The nature of surfaces of these materials is much different than surface of wood. Many of these substrates are nonpolar and non-porous, whereas wood is more polar like and porous. Wood surface is usually hydrophilic, whereas polymers are typically hydrophobic. Wood is hygroscopic and sensitive (dimensional stability) to moisture changes in the environment. On the other hand, metals are more sensitive to temperature changes (coefficient of thermal expansion). According to all these differences among wood and other materials, special adhesives and procedures have to be used for successful bonding.

The objective of this study was to select suitable adhesive for bonding wood and steel for use in structural applications in dry or wet environmental conditions.

2. MATERIALS AND METHODS

Specimen preparations

Wooden lamellas were prepared from spruce wood (*Picea abies*), which was preconditioned to 12 % moisture content. Dimensions of spruce lamellas were 200 mm x 50 mm x 16 mm. Before bonding the wood was cleaned and activated with sand paper. Grain orientation was never tangential to the bonding surface.

Two different types of 230 mm long and 50 mm wide steel plates were used. Both types were prior bonding cleaned with sanding mesh and wiped with degreaser (propan-2-ol). First ones were 5 mm thick steel plates with black patina (B) left on. Second ones were 3 mm thick galvanized steel plates (G).

Each test piece was made of two steel plates and one wooden lamellae as shown on the Figure 1. Dimensions of tested adhesive surface was 50 mm x 50 mm. On the other side of the test piece was another adhesive bond, which was providing symmetry of the specimens. Second bond was twice of a size as the first one (100 mm x 50 mm).

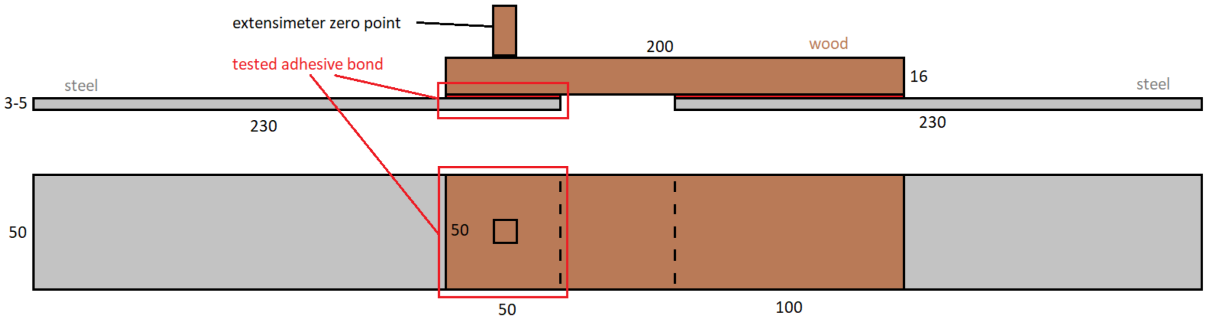

***Figure 1.** Scheme of the bonded specimen*

One epoxy and one polyurethane adhesives with different bonding parameters were used. ERGO 7420 is a two-component epoxy construction adhesive (Ep) made by Kisling company (Technical…ERGO, 2019). 0,3 mm adhesive line was defined with teflon spacers. Specimens bonded with epoxy adhesive were left to cure at least for three days. COSMO PU 190.110 is a one-component polyurethane construction adhesive (Pu) made by Weiss company (Technical…COSMO, 2019). 1 N/mm^2 of pressure was provided for two hours on specimens bonded with polyurethane adhesive.

After this, specimens were left to achieve the final strength for 7 days. All together, we had four different sample preparations:

- Epoxy adhesive on galvanized steel (EpG),
- Epoxy adhesive on black patina (EpB),
- Polyurethane adhesive on galvanized steel (PuG) and
- Polyurethane adhesive on black patina (PuB).

Exposures

Each of the sample preparations had at least 3 test specimens, which were exposed to one of the following climate conditions prior testing:

- Standard climate (20/65) refers to conditioning samples at room temperature of 20 °C and 65 % relative air humidity.
- One day (1 day) exposures in water refers to 24 hours soaking of specimens in water of 20 °C after being cured to full strength at standard climate.
- Two days (2 days) exposures in water refers to 48 hours soaking of specimens in water of 20 °C after being cured to full strength at standard climate.

Testing

Testing of shear strength of adhesive bond was carried out on Zwick Roel Z100 tensile testing machine directly after chosen exposure. The ends of the test pieces were clamped in the jaws of the testing machine and loaded until rupture. 1 mm/min constant-rate-of-traverse was used. The maximum applied force before rupture was measured with the accuracy of ± 1 N. The deformation of the tested bond was measured with the extensometer of ± 1 µm accuracy as shown on the Figure 2.

Extensometer measured the difference of distance (deformation) between the wooden part of the sample and the steel plate. The shear strength results were expressed as a mean value and a standard deviation in N/mm^2. The deformation results were expressed as a mean value in mm.

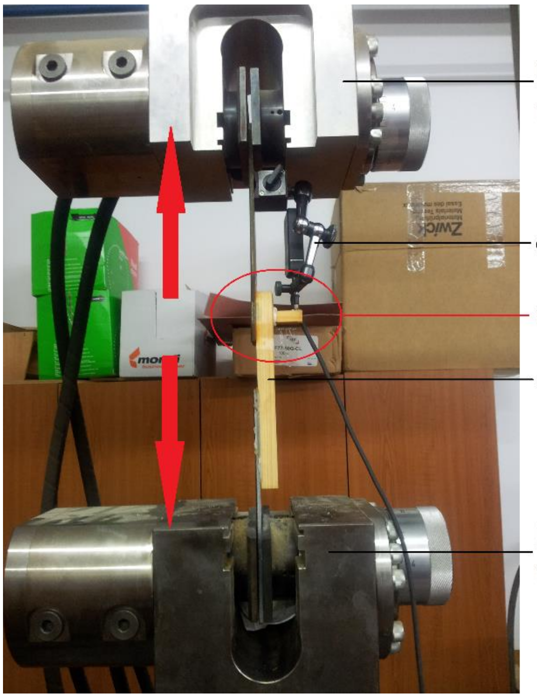

Figure 2. *Testing of the bonded specimen and placement of the extensometer*

3. RESULTS AND DISCUSSION

Results of tests carried after standard climate exposure (20/65) are shown in Table 1. No significant differences were found between different steel treatments (galvanized and black patina). However, there were bigger differences between different adhesive systems (epoxy and polyurethane), where epoxy adhesive performed better results.

Table 1. Shear strength and deformation of adhesive bonds after exposure to standard climate 20/65

Specimen preparation	Average shear strength (N/mm^2)	Standard deviation (N/mm^2)	Average deformation at break point (mm)
PuG	**4,9**	0,8	0,62
PuB	**4,9**	0,5	0,75
EpG	**6,4**	0,6	0,96
EpB	**6,2**	1,1	0,67

Because of this, exposures in water were performed only for polyurethane adhesive on galvanized steel (PuG) and epoxy adhesive on black patina (EpB). Water exposures significantly decrease the shear strengths of both adhesive systems, what can be seen on Figure 3. The loss was higher at sample pieces bonded with polyurethane adhesive. Some examples of the broken samples are shown in Figure 4. Desired wood failure was more likely noticed on samples bonded with epoxy adhesive. So the advantage of epoxy bonding system was superior after water exposures.

The measured deformations were lower after longer water exposures than ones at the standard climate, what can be prescribed to lower shear strength of the bond.

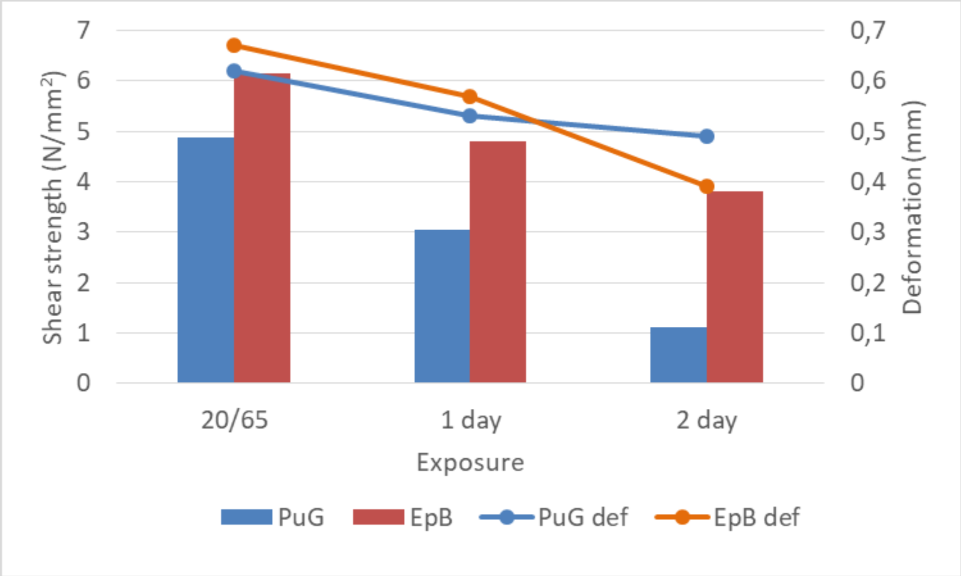

Figure 3. *Impact of the different exposures on the adhesive bond performance between wood and steel*

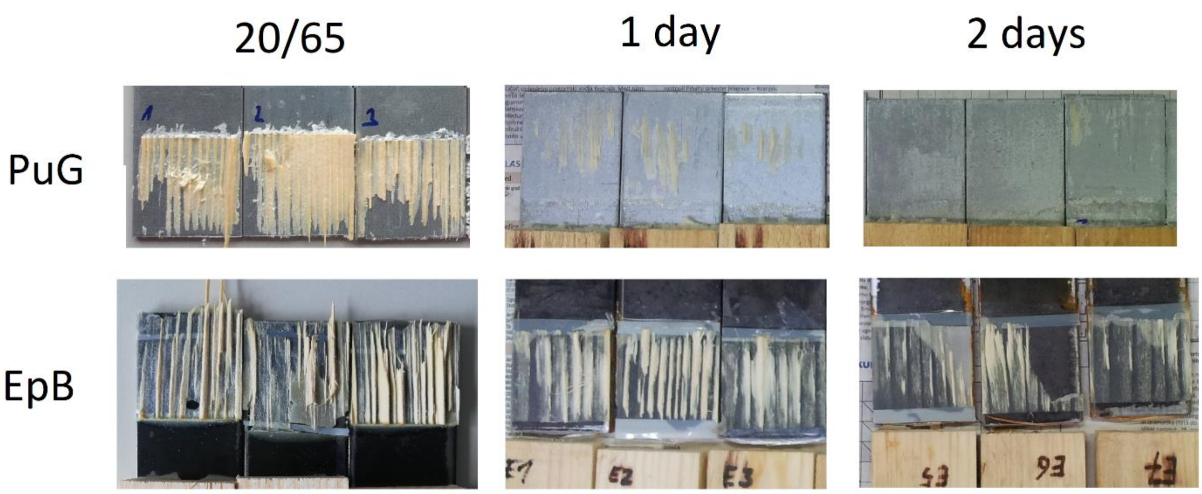

Figure 4. *Impact of the exposure to moisture and water (1 day or 2 days) on the adhesive bond failure*

4. CONCLUSIONS

It can be concluded that for dry environment conditions, both (epoxy and polyurethane) adhesive systems can be (with some limitations) used for bonding of wood and steel. In the environments with higher moisture content or exposure to water, the use of more expensive epoxy adhesive is more suitable and justified.

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RESISTANCE OF WOODEN LACQERED SURFACE TO SCRATCHING

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ABSTRACT

In this study the resistance of lacquered wood surfaces to scratching was analyzed. The samples for varnishing were previously prepared by second level and third level of grinding. Further, the samples were surface treated with unadventurous 2K polyurethane coating and modified 2K alkyd urethane coating. The aim of this study is to determine which of the used coatings will give a better resistance to scratching. The test results shows that surfaces treated with modified 2K alkyd urethane coating give greater resistance to scratching compared to the surfaces treated with unadventurous 2K polyurethane coating.

Key words: surface, resistance, scratching, grinding, 2K polyurethane coating, 2K alkyd urethane coating

1. INTRODUCTION

The basic functions of the corresponding surface treatment are: protection of surfaces against mechanical and chemical influences, decorative surface processing and increasing of the utility of the products (material and conceptual values).

Depending on the place of application, coatings are divided for internal use (interior), for example household furniture, flooring, paneling, etc. and for external use (exterior) in wooden windows, wooden walls, wooden fences, etc. Different requirements are placed before coatings for internal and external use requires of different procedures for application. The focus lies in the industrial procedures for wood processing and wooden materials.

Compared with metal tree is a "living" material. Therefore must the various technologies that are available to carefully choose the most appropriate surface treatment, in order to achieve perfect varnishing. Regarding the important influence of the following parameters:

- Type of wood species
- Presence of the extractive substances in the wood
- Type of binder - glue (PVAc, UF resin or FF)
- Deviation in moisture content of wood, especially in solid wood
- Grinding of wood: kind of material for grinding, distribution of the size of grains as well as longitudinal and / or transverse grinding
- Conditions of temperature and humidity of the air in the cabin for varnishing or in the process of drying,
- Parameters of the coating, such as viscosity, temperature, amount of alluvium, conditions of application and drying, Jaić, M., Palija, T., (2010).

For surface treatment of wood must be applied appropriate systems varnishing which can provide important insulation properties of the substrate side by the extractive materials, good wetting ability of the pores of the wood and spillage of the applied coating, a slight increase in roughness of the wood,

good elasticity of the film, thus preventing the occurrence of cracks and good mechanical properties, especially resistance to abrasion (wear) in parquets and wood paneling.
It’s important for all coatings to underscore the structure, texture and color of the wood after surface processing. Further, there are opportunities to achieve different effects as natural (nature) processing in the transparent coatings, color processing / lazur surface and fully covered (painted) laquered surface.

2. MATERIAL AND METHODS

2.1. Material Pad

As a foundation for the examination is taken lumber from spruce (Picea abies Karst.) and from oak (Quercus robur L.).

The spruce as a material can be easily processing, painted, colored, lacquered and polished, dries quickly, and as such has a wide use. This indicates that spruce is among the many distinguished wood species. The white color of the wood, small knots, proper anatomy, evenly broad rings, low mass, high elasticity and easy processing, contributes to this kind of wood to be widely used, Георгиевски, Ж., (2003).

The spruce has the following chemical composition: 19-29% lignin, carbohydrate 67.90 to 75.70%, which cost 41.0 to 57.80% cellulose, 8.09 to 13.30% pentozan and 1.10 to 1.40% acetyl group. The acidity of the water extract was 4.0-5.3 pH, Jevtić, P, (2005).

This wood belongs to the oak tree ring-porous species with broad and well visible rings on all three sections. Trachea of the early wood zone form a closed ring porous. Zones of late wood is more compact and darker colored. Glare is the larger radial surfaces, Ugrenović, A., (1950).

The oak is from heavy hard to medium hard, stable to pressure and blow and with medium elasticity. This type of oak is used as a first-class technical wood for the construction, joinery, carpentry, furniture, veneers, parquet, floors, etc.

The oak has the following chemical composition: 41% cellulose, pentozan 19%, 29% lignin, ash 0.22%. To tannin substances found in the tree are 13% in the wood and 9% in the bark, Пејоски, Б. (1966).

Planed timber is dried and conditioned. The average moisture content was 7.76% for spruce and 9.24% for oak. Planed timber is first flattened to' have lower based side. Then is formed thickness of 15 mm.

The dimensions of the samples of spruce and oak are 200 x 100 x 15 mm.

2.2 Preparation of surfaces by grinding

Achieving quality surface treatment of objects and elements of wood is related to good surface preparation and application of quality systems and appropriate protection coatings. Key operation for each surface preparation before applying the coating is grinding the surface of the wood. Grinding is especially important even after applying of all the layers of coatings until to applying of the latest-finishing layer of coating.

Grinding was done with wide-band grinding machine with paper number $N^0$80. Then a partially acceded to grinding for each system of preparation of surface grinding (I and II system), which are processed as follows:

- I system: second level of grinding - numbering $N^0$120 + $N^0$150.
- II system: third level of grinding - numbering $N^0$120 + $N^0$150 + $N^0$200.

Technical features of wide-band grinding machine:

- Manufactured: CASOLIN, Italian
- Type of element of pressure: crunches beam
- Speed of grinding: 17m / s
- Speed of movement accessory: 20 m / min.

2.3 Preparation and application of the coatings

Systems protection coating that is applied to wood surfaces, in accordance with its purpose, must meet a series of requirements reads, referring to the good mechanical, thermal and chemical resistance as well as resistance to hold the action of weathering, UV radiation and so on., and also to meet the read range decorative and aesthetic conditions depending on their application.

In the technology of surface treatment there are many types of coatings with different chemical and physical characteristics. Within the application of the protection coatings system, were used 2K polyurethane and 2K alkyd-urethane coatings.

The work was carried out tests on the resistance of scratching of coatings depending on the system of care. The survey refers to the exploitation of wood elements in the interior.

2.3.1. Preparation and application of 2K polyurethane coating

For processing of the sample's surface is used basic and final (gloss) 2K polyurethane coating. The basic and final coating is prepared by mixing the components "A" and "B" immediately before application, in terms of mixing 2:1. Applying of the coating is done with an air spraying. For all samples is used the same amount of coating 180 g/m^2, with deviation ± 5%. The conditions of application of the coating are given in Table 2.3.1.

After drying the underlying layers, and before application of the final coating is performed manually intermediate grinding with paper numbering N^0 240.

Table 1. *Conditions of applying 2K polyurethane coating*

Parameters	Value
Mode of spraying	Air spraying
Pressure of spraying	3,0 bar
Diameter of nozzle	1,2 mm
Distance of nozzle from the sample	250 mm
Temperature of coating	20 ^{o}C
Viscosity of coating	20 s (F4/20 ^{o}C)
Temperature of the air in the room	21 ^{o}C
Relative humidity of the air	60%
Amount of alluvium	180 g/m^2 ± 5%

2.3.2. Preparation and application of 2K alkyd - urethane coating

Processing of surface of the samples is performed with basic 2K polyurethane and final 2K alkyd-urethane coating.

Basic and final coating is prepared by mixing the components "A" and "B", just before use, in terms of mixing 2:1 and 1:1.

Applying the coating is done with an air spraying. For all samples the same amount of coating is used, which was 170 g/m^2, with deviation ± 5%. The conditions of application of the coating are given in Table 2.3.2.

After drying the underlying layers, and before application of the coating, is performed manually intermediate sanding with sand paper with numbering N^0 240.

2.4 Determination of resistance to scratching

Property of scratching resistance is determined according to the standard EN ISO 1518. The procedure consists in controlling and setting the needle for scratching on rehearsal, positioning weight the initial load of the carrier and moving examined under the needle plate that performs scratching on the coating. Occurred scratch observe with the naked eye or a magnifying glass and determine whether the damage reaches the ground. The result of the test is to determine whether the coating film already meets some predetermined minimum parameters for a given mass, or whether the film coating passes the test or not to run. The test ends when the same type of "satisfactory / unsatisfactory".

Table 2. *Conditions applying 2K alkyd-urethane coating*

Parameters	Value
Mode of spraying	Air spraying
Pressure of spraying	3,0 bar
Diameter of nozzle	1,2 mm
Distance of nozzle from the sample	250 mm
Temperature of coating	20 ^{o}C
Viscosity of coating	22 s (F4/20 ^{o}C)
Temperature of the air in the room	21 ^{o}C
Relative humidity of the air	60%
Amount of alluvium	170 g/m^2 ± 5%

Figure 1. *Test Instruments*
for resistance of scratching

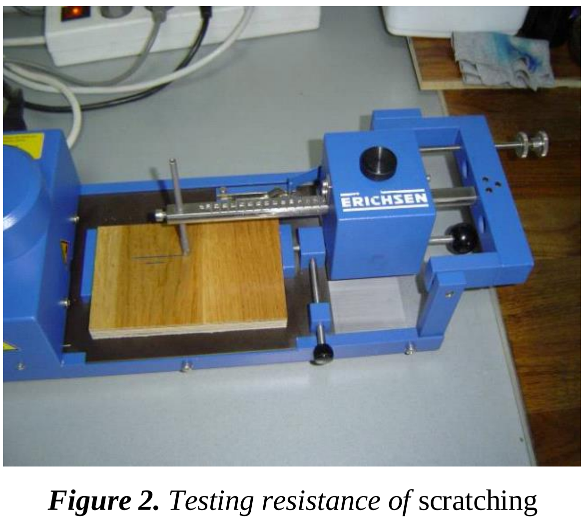

Figure 2. *Testing resistance of* scratching

3. RESULTS AND DISCUSSION

The results of the examination of the resistance of the coating film of scratching are shown in Table 3.1 and Graphical images 3.1 and 3.2.

Table 3. *Results of testing the resistance of the coating film* scratching

Nr	Wood base/ grinding system	Resistance to scratching (N)	Rating	Nr	Wood base/ grinding system	Resistance to scratching (N)	Rating
Basic polyurethane coating 2x + Final polyurethane coating 1x							
1.	Spruce / I	11	Satisfactory	5.	Oak / I	11	Satisfactory
2.	Spruce / II	15	Satisfactory	6.	Oak / II	14	Satisfactory
Basic polyurethane coating 2x + Final alkyd-urethane coating 1x							
3.	Spruce / I	15	Satisfactory	7.	Oak / I	15	Satisfactory
4.	Spruce / II	> 20	Satisfactory	8.	Oak / II	20	Satisfactory

From the values showed in the Table 3.1, it can be concluded that the greater resistance of scratching has final 2K alkyd-urethane coating when the surface is performed by the second system of grinding, for both types of wood. Lower values of resistance of scratching are measured with final 2K polyurethane coating when preparing the surface is performed by first grinding system for both types of wood.

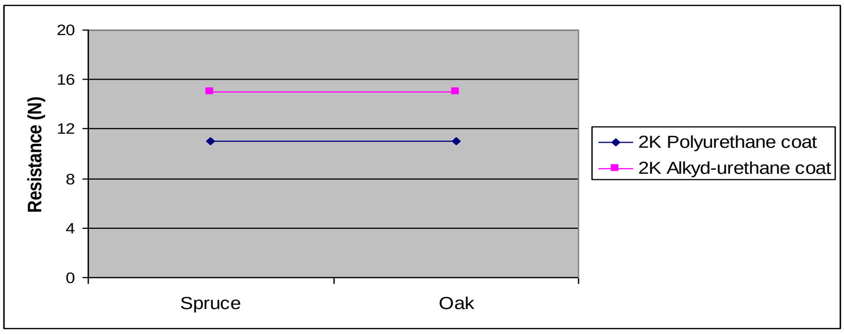

Figure 3. *Resistance of* scratching *of film coating - preparation of surface for grinding system I*

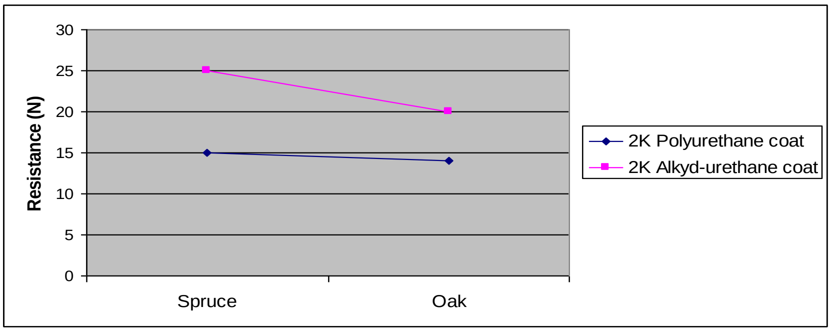

Figure 4. *Resistance of* scratching *of film coating - preparation of surface for grinding system II*

The magnitude of the resistance of the coating film of scratching has influence the way of preparing the surface by grinding. The results of the survey shows that more resistant film coating of scratching is achieved in the second system of grinding (grinding of third level). Regarding to the type of finishing coat applied, greater resistance to scratching the film coating is achieved on the final 2K alkyd - urethane coating, while less resistance of scratching the film coating is the final 2K polyurethane coating. The wood species has a minor impact on the value of the resistance of the coating film of scratching, although it can be concluded that something better values are reached the surface of spruce.

Overall, the results of the examination of the resistance of the coating film of scratching show that resistance in all cases is satisfactory.

The paper Jevtić, P, (2005) performed tests on the resistance of the coating film on the surface of scratching processed with 2K polyurethane coating, oil and wax. In terms of the types of coatings applied is achieved the best resistance surfaces processed with 2K polyurethane coating.

4. CONCLUSION

The applied two systems of protection in these trials provided good protection to the surfaces of the wood. Their influence on the quality of surface treatment of wood is expressed through resistance of scratching of the film coating. In this regard, more is efeceted 2K alkyd -urethane system which achieved higher values of resistance of scratching.

The results of the survey indicate to 2K alkyd-urethane coating systems have higher quality compared to conventional polyurethane coatings that are used for wood surface protection. Modified coating systems (2K alkyd-urethane) providing higher quality of protection of the final interior products from spruce and oak.

Good resistance of scratching, along with others quality attributes gives to modified coating systems the recognizable features in the surface treatment of wood. These coatings form films that delivers excellent durability, adhesion and resilience that contributes to their wide application in the field of surface wood protection.

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EFFECT OF POST-HEAT TREATMENT ON THE THERMAL CONDUCTIVITY VALUES OF LOW-DENSITY BOARDS MADE FROM LIME BARK PARTICLES

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ABSTRACT

Buildings in total, are reported to consume 40% of the EU's total energy demand and produce about 35% of greenhouse emissions, through their heating and cooling systems. Therefore, effective thermal insulation materials are crucial on minimizing building energy consumption and internal greenhouse gases. Research on thermal insulation panels made of biomass resources, also referred as 'bio-insulation' panels has been increasing rapidly due to their availability as renewable, low cost and eco-friendly materials.

Each year, a significant amount in million tons of bark generated during wood processing is produced globally, remains as a residual woody biomass. In addition, heat treatment affects the chemical, physical and mechanical properties of wood and mainly influences its mass, water uptake and dimensional stability. In this study, the effect of heat-treated bark particleboards on the thermal conductivity values were investigated. Particleboard samples with a target density of 350 kg m^{-3} were heat post-treated at three levels of time (15 h, 25 h and 35 h) at a heating temperature of 180 °C.

Considering all heat-treating periods, generally by increasing heat treatment time the thermal conductivity and density of bark particleboards were reduced. The measured average density was decreased by 12.7%, 16.3% and 16.1%, while the average thermal conductivity by 8.4%, 10.9% and 14.0% after 15, 25, and 35 h, respectively.

Key words: bio-based, insulation panels, thermal modification, *Tilia* L

1. INTRODUCTION

According to European Union, building sector is responsible of consuming the 40% of the total energy in Europe. Therefore, building sector becomes one of the most severe energy consumers besides industry and transportation, influencing the greenhouse gas emissions and climate change. On the other hand, emerging trends in the era of low environmental impact, enhance the significance of manufacturing thermal insulation panels made from renewable, bio-based, lignocellulosic sources obtained from agricultural and forest residues (Liu et al, 2017).

Wood and wood-based products in general, presents low thermal conductivity compared to other building materials, such as steel or concrete (Vay et al, 2015) and could potentially replace the existing oil-based insulation panels. One of the most common measurements expressing the thermal properties of insulations panels, consist specific heat, thermal diffusivity and thermal conductivity. Moreover, the thermal conductivity of wood-based panels, especially particleboards and fiberboards are considerably lower than dry solid wood of similar densities (TenWolde, McNatt, Krahn, 1988). Thermal conductivity is influenced by several factors and increases with rising temperature, moisture content and density (Sonderegger and Niemz, 2009).

Wood is a natural, renewable material characterized by positive and negative properties, such as its dimensional instability and hygroscopicity. Besides wood intrinsic hygroscopic characteristics, in addition to the stresses imposed to the mattress of particles during hot pressing, wood panels result to swell more than wood when come in contact with humidity (Del Menezzi and Tomaselli, 2006). Thermal modification is a well-known process to reduce equilibrium moisture content and renders wood less hygroscopic, mainly due to the chemical modification of wood cell wall components occurring during heat treatment, thus improving their durability. The application of heat to modify wood characteristics consists of heat treated wood at temperatures ranging from 180 to 260 °C for periods of time that can vary from few minutes up to several hours. As an example, ThermoWood which is one of the most commonly used heat treatment methods uses temperatures ranging from 180 °C up to 215 °C in ambient air at normal atmospheric pressures with water vapor moisturizing. In such a way, it is possible to improve specific wood panel physical properties such as dimensional stability (thickness swelling), and biological resistance against fungi. However, in contrast mechanical properties, wettability and bonding strength of wood panels become poorer, while their brittleness is enhanced, depending on the type and conditions of heat treatment (Ayrilmis and Winandy, 2009; Gaff, Kačík, Gašparík, 2019).

Specifically, there are several heat treatment strategies applied in wood based panels which can be classified into three different means of applications: pre-treatment, post treatment and production technology (Boonstra et al, 2006; Carvalho et al, 2015; Mendes et al, 2013; Xiangquan et al, 1997). Even though, there are numerous papers investigating the effect of heat treatment conditions (temperature and time) on the physical and mechanical properties of various wood and wood-based panels (Unsal et al, 2009) or other studies mentioned previously, to our knowledge there are only a few assessing the influence of heat on their thermal conductivity.

Pásztory, Horváth and Börcsök (2017) examined the changes in thermal conductivity values of Pannónia poplar (*Populus x euramericana cv. Pannònia)* an artificial hybrid and spruce (*Picea abies*). In the case of poplar, the thermal conductivity was decreased by 16.9, 24.0, 29.1% after 15, 25 and 35 h of treatment. In the case of spruce, the thermal conductivity was decreased by 7.4, 14.1 and 22.0%, respectively under the same time conditions. Kol and Sefil (2011) studied the thermal conductivity of ThermoWood treated fir (*Abies bornmülleriana Mattf*.) and oriental beech (*Fagus orientalis L.*) wood. Depending on heat treatment temperatures (ranging from 170 °C up to 212 °C for 2 h) the thermal conductivity was reduced in a higher extent to beech wood than fir, from 2% to 16%. Korkut et al. (2013) found that the thermal conductivity on tangential direction and radial direction of 1.5 and 2.5 h of heat-treated wild cherry wood (*Cerasus avium L.)* at 212 °C decreased with 22.21%, 19.76% and 29.43%, 29.67%, respectively.

Sekino and Yamaguchi (2010) investigated the thermal conductivity of Douglas fir (*Pseudotsuga menziesii*) and Japanese cedar (*Cryptomeria japonica*) wood shavings particles used an insulation panels with different densities, carbonized at 300 °C, 400 °C, 500 °C, 600 °C and 700 °C. The most favorable conditions, by obtaining the lowest thermal conductivity and good panel formability, were achieved at a combination of 250 kg/m^3 density and 400 °C. Olarescu, Campean and Coşereanu (2015) examined the thermal conductivity of wood panels obtained heat-treated strips from spruce (*Picea abies*) and lime (*Tilia cordata*) wood, showing that the heat treated panels displayed 13% and 6% lower thermal conductivity values in case of spruce and lime, respectively compared to untreated wood strips. The spruce wood strips were heat-treated at 200 °C for 10 h, while the lime wood strips for 3 h at identical temperature, until the strips reached a threshold mass loss of 5%. Considering all these studies, it is indicated that thermal conductivity values of all heat-treated samples, are gradually and variously decreasing depending on the heat treatment conditions, wood species and type of adhesive compared with untreated wood and wood-based panels.

The thermal degradation of wood polymers is accompanied by a weight loss, which generally increases with higher temperature and time heat treatment conditions. Paul, Ohlmeyer, Leithoff (2007) investigated the influence of temperature on weight loss of heat pre-treated strands used as raw materials for OSB panels manufacturing. According to their findings, the influence of temperature was superior to time.

This type of weight loss is expected to influence the density of the heat-treated panels, and consequently their thermal conductivity values. Xiangquan et al. (1997) reported that post-treatment was an effective way of producing dimensionally stable particleboards from fast-growing poplar wood bonded with phenol formaldehyde. Furthermore, H’ng, Lee and Lum (2012) examined the effect of heat post-treatment with mild temperatures (100, 150 and 180 °C) on the dimensional stability made of rubberwood particleboards. Since, urea formaldehyde resins are less heat resistant compared to phenol formaldehyde or isocyanate type resins, it was chosen to use 180 °C as a heating temperature to conduct these experiments. Preliminary tests, in our laboratory, on bark panels made from heat-pretreated particles at 180 °C for 1, 2 and 3 h, displayed not significantly changes on the thermal conductivity behavior of similar density particleboards, compared to untreated particleboards. In this context, the intention of this work was to determine the influence of heat post-treatment duration, under extreme time durations, i.e. 15 h, 25 h and 35 h in already manufactured low density particleboards produced with lime bark, on their thermal conductivity performance. Further, it was attempted to correlate the experimental data about the influence of weight loss with density and thermal conductivity.

2. MATERIALS AND METHODS

2.1. Particleboard production

Lime bark (*Tilia cordata* and *Tilia platyphyllos*) particles without separation of inner- and outer-bark peeled off from lime trunks in Sopron, Hungary was used as raw material for panel production. The bark was chopped into particles using a hammer mill equipped with an 8-mm screening holes. The gathered bark particles were fractionated (3 PRO Fritsch Analysette), particles ranging from 0.5 mm to 8 mm were collected for the manufacturing of bark-based panels. Bark particles were dried until a final moisture content of 6-9% was reached. An 8% urea formaldehyde (UF) adhesive stirred with a 3% aqueous solution of ammonium sulfate $(NH_4)_2SO_4$ as hardener, was used for the production of single-layer bark particleboards. The glued bark particles mixtures were manually layered and formed in a wooden frame into a mat. Thereafter, the frame was removed, and the mats were pre-pressed by hand to compact the materials without heat transfer. Two Teflon (polytetrafluoroethylene, PTFE) sheets were used on both surfaces of the mat to prevent the produced boards from sticking onto the metal plates during hot pressing process. Bars of 20 mm thickness were inserted between the metal plates before pressing to maintain a uniform thickness for all boards.

Bark panels with a size of 500 mm × 500 mm, a nominal thickness of 20 mm and a target density of 350 kg/m^3 were produced using a laboratory hot press (Siempelkamp). The pressing time was 18 second per millimeter, and the temperature of the plates was 180 °C. All the panels were kept at 20 °C and 62 % relative humidity, until equilibrium moisture content (EMC) was achieved, prior to experimental measurements.

2.2 Post manufacturing heat treatment

After reaching constant mass inside the acclimatization room, the bark panels were thermally post-treated into a chamber room. According to the heating schedule the panels were heated up from room temperature to 90°C in five hours, from 90 °C to 130 °C in another 5 hours, and the top (180 °C) temperature was achieved two in hours. Three different treatment times were used with a duration of 15, 25 and 35 hours, respectively. These treatment durations reflect the effective treatment time at the target temperature of 180 °C. After the heat post-treatment the panels were cooled down prior to thermal conductivity measurements under standard conditions (20 °C and 62% RH).

2.3. Thermal conductivity measurements

Thermal conductivity of the panel was measured by a hot-plate method using heat flow apparatus. The thermal conductivity was calculated at steady state conditions by measuring the heat flux (Equation 1), as described by Fourier's law, according to the following equation:

$$\lambda = \frac{d \cdot \phi_q}{\Delta T} \qquad (1)$$

where:
λ: the thermal conductivity (W/m·K),
Φ_q: the heat flux (W/m2),
ΔT: the temperature difference across the specimen (K)
d: the thickness of the specimen (m).

The temperature of the hot plate was 15°C and of the cold plate was 5°C. The bulk density (ρ) of the boards have been calculated from ten samples originated from the panels. The tested boards were sandwiched between the hot and cold plate, at the center of both plates within the measuring area, at room temperature. The temperature difference between the hot and a cold plate was set to 10° C and the mean temperature was 10° C.

3. RESULTS AND DISCUSSION

3.1 Panel formability

After thermal modification treatment of the consolidated panels, panels formability of each duration was estimated from its appearance (Figure 1), following to the criteria suggested by Sekino and and Yamaguchi (2010): a. no distinct deformation and easy handling with one hand; b. no distinct deformation but required handling with both hands; c. partial damage and d. unacceptable due to large cracks. Most of the panels could be group in b and c categories, even though there were few panels belonging to group d. As expected, the color appearance of bark particles became darker due to heat treatment.

Figure 1 *Panel appearance and formability after 15 h, 25 h and 35 h heat treatment*

3.2 Thermal conductivity and density

Table 1 presents the mean weight loss (WL), density (ρ) and thermal conductivity (λ) values of the lime bark particleboards, after 15 h, 25 h and 35 h, respectively. By comparing the results, it can be observed that all the panels underwent heat treatment displayed lower thermal conductivity and density values compared to the untreated panels.

Table 1. *Mean values of weight loss, density and thermal conductivity as a function of heat duration*

Time (h)	W.L. (%)	ρ (kg/m^3)		λ (W/m·K)	
		Untreated	Heat-treated	Untreated	Heat-treated
15	-13.25	359.65 (± 5.61)	314.09 (± 3.25)	0.063	0.057
25	-16.25	350.24 (± 6.13)	293.32 (± 7.96)	0.064	0.057
35	-16.17	350.34 (± 15.26)	293.68 (± 9.49)	0.062	0.054

At 180 °C and 15 h effective treatment time the apparent density was reduced by 12.66% and proportionally the thermal conductivity by 8.4%. By increasing the heating time, the density and thermal conductivity values were reduced by 16.26% and 10.9%, respectively. However, after 35 h the density percentage decrease was almost stable at 16.14% and thermal conductivity was further slightly decreased by 14.0% compared to the untreated particleboards. A possible explanation could be the further thermal decomposition of bark and UF chemical components, as well as the changes in porosity and air voids inside the panels. The thermal conductivity changes as a function of density variations prior and after heat treatment, are illustrated in Figure 2.

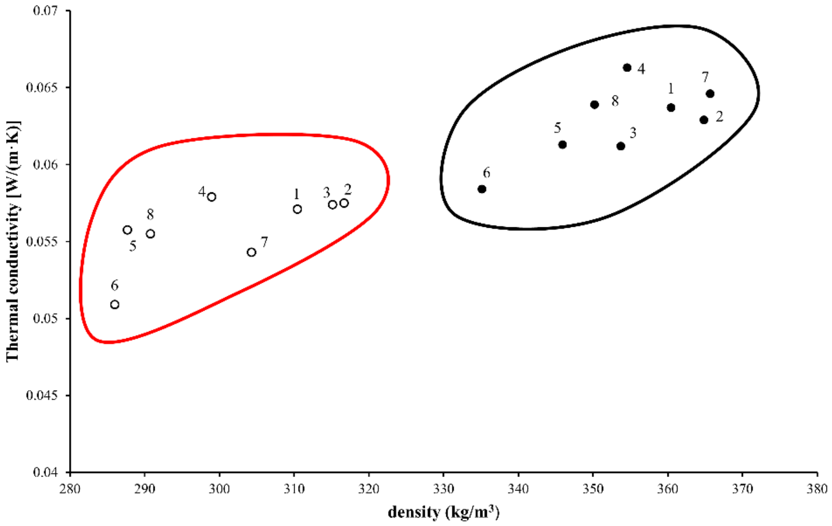

Figure 2. *Thermal conductivity as a function of density, prior (full circles - ●) and after (outlined circle - ○) at overall effective heat treatment times*

Paul, Ohlmeyer and Leithoff (2007) investigated the effect of temperature (180 °C, 200 °C, 220 °C, 240 °C) and time (30, 60 and 90 minutes) on the weight loss, equilibrium moisture content and resistance against fungal decay of heat pre-treated OSB strands. Samples constituted of pre-treated wood strands at temperature 180 °C displayed only minor weight loss up to 0.5% even after 50 minutes. In the meantime, the weight losses of wood strands at the temperature of 220 °C was 2% and 6.5% after 15 and 80 minutes. Further the co-authors concluded that i) the longer duration of heat treatment at lower temperature does not counterbalance the degree of decomposition, while ii) elongated treatment times led to a specific, nearly constant level of weight loss for each temperature. Likewise, outcomes could be determined from this study, also on the post-heat treated bark particleboards.

4. CONCLUSIONS

From the findings of this study, the following conclusions could be summarized as indicated below:

1. The weight loss and density decrease percentage became almost constant after 25 h of thermal treatment at 180 °C.
2. The thermal conductivity value was reduced only by 8.4%, even after 15 h of heat at this specified temperature.
3. As expected, long, heat treatment durations had a negative impact on the panel formability and mechanical properties. Deterioration was found to be significant, therefore higher temperatures and shorted periods of heat, should be employed. The application of other types of adhesives, rather than UF resin, would be more preferable.

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THE SURFACE PROPERTIES OF OSB PAINTED USING ELECTROSTATIC POWDER COATING PROCESS

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ABSTRACT

Use of electrostatic powder coating technology for wood-based panels has increased in last decade. In this study, oriented strandboards (OSB/2 and OSB/3 grades) were coated by powder coatings using electrostatic corona spray gun. Epoxy/polyester coatings which was suitable for indoor applications were applied to the surface of OSBs at three different curing temperatures, 120 °C for 15 min, 140 °C for 10 min, and 160 °C for 10 min using corona gun. Surface properties of the OSB specimens, roughness, wettability, scratch resistance and film thickness were determined. The abrasion resistance and scratch resistance of the coated OSB specimens improved with increasing curing temperature from 120 to 160 °C. The best surface quality was obtained from the OSB/3 specimens cured in the infrared oven having 160 for 10 min while the lowest surface quality was found in the OSB/2 specimens cured in the infrared oven having 120 °C for 15 min. The wettability of the coated OSB specimens decreased with increasing curing time.

Key words: Electrostatic powder coating, oriented strandboard, surface quality, wood

1. INTRODUCTION

Oriented strandboard (OSB) is one of the most common structural wood-based panels used in construction industry, competing with plywood panels. Use of OSB is increasing as exterior and interior wall siding furniture substrate, and home decoration. In addition to construction industry, furniture industry have recently interested in OSB material as substrate for indoor and outdoor furniture due to its significant advantages such as low price and low density, high mechanical properties and good dimensional stability (Hiziroglu, 2009).

Solvent-based paints such as alkyd or oil based paints emit considerable high organic solvents, which have a sharp odor and poisonous effect for humans in buildings, in particular for unventilated spaces (Piper, 1965). The volatile organic compounds (VOCs) released from solvent-based paints are harmful to human health. For this reason, there is an increasing global interest in electrostatic powder coating technology for wood-based panels due to its significant advantages such as one lower environmental impact, lower VOCs, low cost, design flexibility, tough and durable, chemical and moisture resistance, seamless finish, and cut/drill without damage. It also has advantages in design freedom, as the powder particles will reach any place, so it covers objects in nearly any shape. The main difference between powder coating and conventional liquid paint is that powder coating does not require a solvent to keep the binder and filler parts in a liquid form (Okadaa et al., 1998, Schmidt et al., 2013). Since there is no carrier fluid give off, the coating process releases significantly lower VOCs. The efficiency of this technique can be enhanced to 95 wt% material usage by collecting the powder. The most used thermosetting powders are epoxy, polyester, polyurethane, acrylic, and hybrid composition.

The application of powder coatings is different from the traditional wet coatings. The powder coatings are applied on the material surface using electrostatics. Its application is carried out by electrostatic spray application on the surface of substrate. The charged particles adhere to the substrate until heated and cured into a smooth or textured coating. The samples are immediately put in the oven for final curing so that the chemical cross-linking is formed. To make the coating stick, the powder is cured in an oven, creating a skin. Until recently, powder coating was almost only used on metal, as this material is easy to make electrostatic and can handle high temperatures. When a thermoset powder is exposed to elevated temperature, it begins to melt, flows out, and then chemically reacts to form a higher molecular weight polymer in a network-like structure. This cure process, called crosslinking, requires a certain temperature for a certain length of time in order to reach full cure and establish the full film properties for which the material was designed. The most common way of applying the powder coating to metal objects or furniture elements of wood-based panels is to spray the powder using an electrostatic gun or corona gun. The gun imparts a negative electric charge to the powder, which is then sprayed towards the grounded object by mechanical or compressed air spraying and then accelerated toward the workpiece by the powerful electrostatic charge.

Contrary to natural woods, sanded OSB panels have a homogeneous surfaces and sufficient moisture content to provide conductivity of the powder coatings. Based on previous studies, there is no any study on the surface properties of OSB painted by electrostatic powder coating technology. Polyester-epoxy powder coatings are used in the experiments, which were widely used for a variety of indoor applications (Wuzella et al., 2011; Wuzella et al., 2014). The OSB specimens coated with powder coatings can be alternative to melamine paper faced MDF or particleboard for indoor furniture having high mechanical properties, especially for low deflection rate for bookcase shelves and countertops. The curing step is critical for the powder coatings. In this study, surface quality of the OSB/2 and OSB/3 panels coated with electrostatic powder coatings by corona gun was studied.

2. MATERIALS AND METHOD

2.1. OSB panels

Two types (OSB/2 and OSB/3) of commercial OSB panels produced by Kronospan factory located in Kastamonu city, Turkey, were purchased from the local market. Technical specifications of the OSB/2 and OSB/3 are given EN 300 standard. The OSB panels were produced from a mixture of pine and aspen strands.The size of the OSB panels were 125 mm x 240 mm. The thickness of the OSB/2 and OSB/3 panels were 11 mm and 10 mm, respectively. Prior to powder coating process, the OSB panels were cut to the samples with dimensions of 500 mm x 500 mm using planar saw. Top and bottom sides of the OSB samples were sanded with 60 grit sand paper in a sanding machine to obtain smooth surface before the paint application. A total of 12 test samples, three replicates for each group (three treatments: 120 °C, 140 °C, and 160 °C, and one control), were obtained from the OSB/2 and OSB/3 panels. The test samples were conditioned to constant mass at a temperature of 20 °C and a relative humidity of 65%. The air-dry density values of the OSB/2 and OSB/3 were 0.593 g/cm^3 and 0.643 g/cm^3, respectively.

2.2. Powder coatings

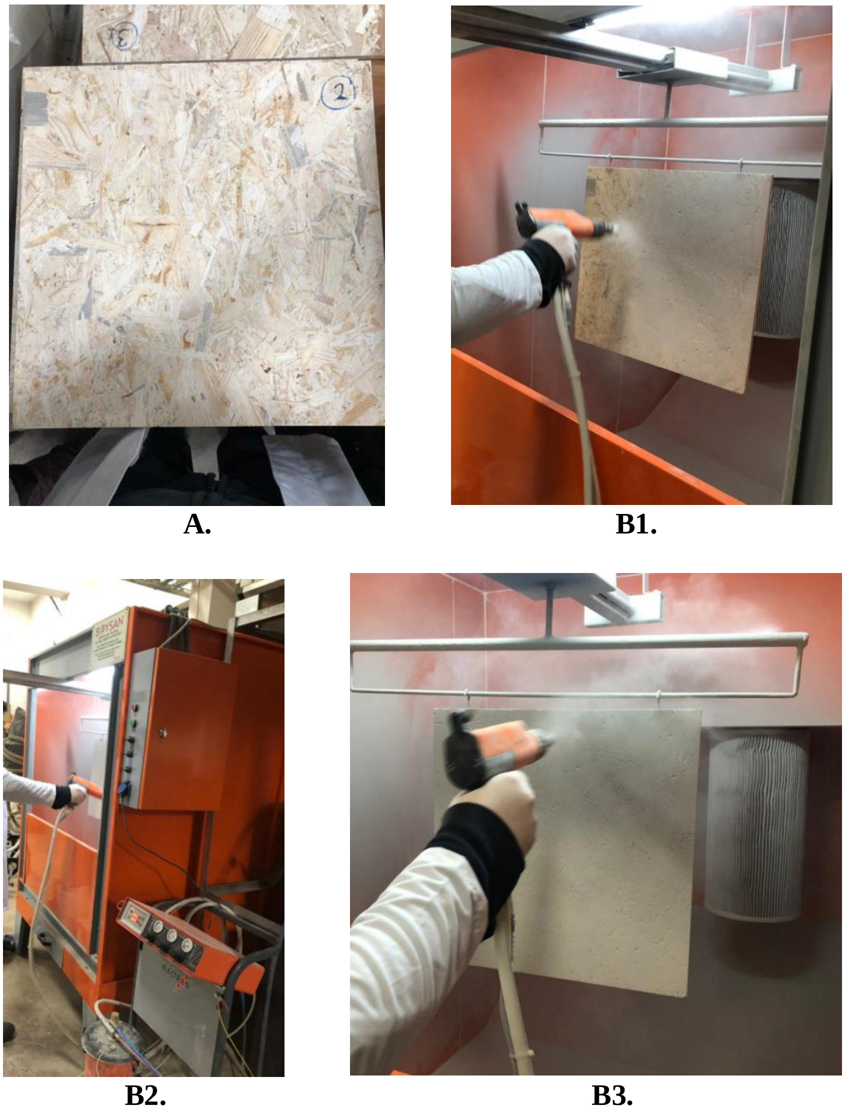
The electrosatic powder coatings (code: RAL 9016) for interior application were supplied by a commercial powder coatings company in Istanbul, Turkey. The technical properties of the powder coating (epoxy/polyester hybrid: 1/1) are given in Table 1.

2.3. Application of powder coatings on the OSB surface

The test samples were preheated in an oven for 5 min. The application of the powder coating on the sanded OSB surfaces was applied by corona spray gun, which was the most common way of applying the powder coating to material surface. The gun imparted a negative electric charge to the powder, which was then sprayed towards OSB samples by compressed air spraying and then accelerated toward the workpiece by the powerful electrostatic charge. The powder paint application on the each sample surface with dimensions of 500 mm x 500 mm was completed in 2 min. The OSB specimens were conditioned at 6 °C for 25 min to allow dew forming on the surface of the OSB, which enhanced surface conductive enough to attract the powder coating. The power of the electrostatic corona gun was 50 kV and air-velocity was 80 microamper. Powder coatings were applied electrostatically by charging the powder particles at the tip of the corona spray gun.

Table 1. *Technical properties of powder coatings (epoxy/polyester:1/1; code: RAL 9016)*

Test	Unit	Standard	Value
Physical tests			
Gloss	(60°)	EN ISO 2813	5-95
Impact ressitance	kg.cm	ISO 6272	80-100
Flexibility	mm	EN ISO 1520	7-8
Buchholz indentation test	-	EN ISO 2815	90-100
Cross-cut	Gt	EN ISO 2409	0
Density	g/cm^3	ISO 8130-3	1.30-1.70
Flow property	-	ISO 8130-5	120-175
Chemical tests			
Corrosion test (salt test)	hour	ISO 7253	1000+
UV	Delta E	300 W 48 h	< 2.80
Resistance to temperature	Delta E	200 °C-120 min	< 2.80



A. **B1.**

B2. **B3.**

Figure 1. *A: OSB panels. B1, B2, B3:Application of powder coatings on the OSB panels using the corona spray gun.*

2.4. Determination of film thickness

Film thickness is one of the important index of coating performance and appearance. As wood and wood-based panels have a complex structure, values of film thickness measurement have a different variance. The layer thicknesses of the coatings of the OSB specimens were measured with PosiTector. This equipment is a non-destructive method and it measure the layer thickness of between 20 and 300 µ.

2.5. Determination of wettability

The wettability behaviour of the 3D printed specimens was carried out using the contact angle instrument of KSV-101 (Finland). The images of the the 5-µL distilled water droplet were taken by digital video camera at 1 s intervals up to 15 s. The contact angle values were calculated by the image analysis software of KSV-101 instrument. Five specimens were used for each treatment. A total of 10 measurements for each treatment, two measurements for each specimens, at different points were taken from the specimens.

2.6. Determination of abrasion resistance and scratch resistance

The tests were conducted by fixing the sample to the rotating table. The sample was pressed on the table by abrasive wheels and additional weights, and was subsequently subjected to rotation. The rotation causes abrasive friction between the wheels and the sample surface. The number of cycles needed to completely wear out the film is the measure of the abrasion resistance. the number of cycles needed to completely wear out the film is the measure of the abrasion resistance. The intensity of wear-out was measured using a special transparent plate, divided by radial lines into 4 quadrants and 16 sectors. The scratch resistance was measured with universal motorised scratch tester (Model: Elcometer 3025). The abrasion resistance and scratch resistance of the specimens were determined according to EN 438-2:2016+A1:2018 standard. Three specimens were used for each treatment.

3. RESULTS AND DISCUSSION

The contact angle values of the OSB specimens at different intervals (1s, 5 s, and 10 s) are given in Table 2. For example, the lowest contact angle for 5 s (57.8°) was found in the OSB/2 specimens treated at 120 °C for 15 min in the infrared oven while the highest contact angle (69.4) for 5 s was found in the OSB/3 specimens coated at 160 °C for 10 min. The contact angle values coated OSB/3 specimens were found to highger than those of the OSB/2 specimens. The increase in the curing temperature decreased the wettability of the coated OSB specimens. This can be explained by the fact fact cross-linking mechanism. The result shows the mechanical properties such as hardness, flexibility, the appearance of the film surface and the chemical resistance of the cured film affected by the degree of cross-linking during the curing process.

Table 2. *The contact angle values of the coated OSB specimens*

OSB type	Infrared oven conditions		Contact angle (°)		
	Curing temperature (°C)	Curing time (min)	1 s	5 s	10 s
OSB/2	120	15	59.7	58.8	56.2
OSB/2	140	10	62.2	61.4	59.1
OSB/2	160	10	65.74	64.4	61.6
OSB/3	120	15	62.8	61.0	60.2
OSB/3	140	10	66.4	64.1	63.4
OSB/3	160	10	70.7	68.4	67.3

The dry film thickness of the coated OSB specimens changed from 146.1 to 150.6. The abrasion resistance and scratch resistance of the coated OSB specimens are given in Table 3. The best surface quality was obtained from the OSB/3 specimens cured in the infrared oven having 160 °C for 10 min while the lowest surface quality was found in the OSB/2 specimens cured in the infrared oven having 120 °C for 10 min. The results showed that increasing curing temperature improved the abrasion resistance and scratch resistance of the OSB panels. For example, the abrasion resistance and scratch resistance of the OSB/2 specimens. In a previous study Akkuş (2018) found that the scratch resistance of the particleboard coated with epoxy/polyester powder coatings was 2.83 N.

Table 3. *Abrasion and scratch resistance of coated OSB panels depending on the curing tempeature*

OSB type	Infrared oven conditions		Film thickness (µ)	Abrasion resistance (Rev.)	Scratch resistance (N)
	Curing temperature (°C)	Curing time (min)			
OSB/2	120	15	150.6	185	1.95
OSB/2	140	10	147.3	215	2.02
OSB/2	160	10	146.1	220	2.21
OSB/3	120	15	149.5	195	2.16
OSB/3	140	10	146.0	241	2.32
OSB/3	160	10	148.8	258	2.45

4. CONCLUSIONS

This study investigated some surface properties of OSB panels coated with electrostatic powder coatings (epoxy/polyester:1/1) using different temperatures in the infrared oven. The results showed that the surface quality of the OSB panels increased with increasing curing temperature. The abrasion resistance and scratch resistance of the specimens considerably improved with increasing curing temperature while the wettability of the OSB specimens decreased. The surface performance of the OSB/3 specimens were found better than OSB/2 specimens.

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IMPACT OF THE LOADING RATE ON MOR AND MOE OF THE PARTICLEBOARD USING A STANDARD BENDING TEST

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ABSTRACT

According to the European Standard EN 310:1993 for the determination of the MOE and MOR of wood-based panels, it is necessary to select the loading rate on test samples, so that the maximum load is reached within 60 ± 30s (30-90s). During the test the sample often breaks after only a few seconds, therefore, far below the required lower time boundary. The results obtained for these samples should be discarded, otherwise the resulting values for the MOR and the MOE will be biased.

This paper is focused on the impact of the loading rate on the MOR and MOE of the particleboard in a standard bending test. The test was carried out in two ways: (i) using the maximum load that can be obtained on the test device, and (ii) by applying a much lower load, for which the sample failure occurs at the prescribed time interval. In either case, the given time for achieving the maximum load was the same, which resulted in significant differences in loading rates. The obtained results for the MOR and MOE were compared. Differences in the values obtained in the two applied loading rates indicate a potential error that can be made in determining the MOR and MOE if the requirement on the time prescribed to reach the maximum force is not fulfilled.

Key words: particleboard, bending test, MOE, MOR, maximum load

1. INTRODUCTION

In the calculation of elements of particleboard in wooden structures maximum dimensions of the structural elements should be defined either according to the sizes of the allowed deflections (stiffness criterion) or permissible strength (strength criterion). The most critical values for the construction are mostly the modulus of elasticity in the bending test (MOE) and bending strenght (modulus of rupture – MOR). The MOE and MOR values of a wood based panels depend on the following: (a) the type of particle or strand, its structure (the ratio of layers), the size of particles (Suzuki, and Takeda, 2000), the particles direction (Sumardi, Kojima, Suzuki, 2008), the degree of anisotropy (Lekhnitskii, 1984 Ashkenazi, 1978; Ambartsumyan, 1970; Timoshenko and Woinowsky-Krieger, 1959); (b) density and vertical profile of density (Kelly, 1977; Kollmann and Cote, 1984; Xu, 1999; Chen, Du, Wellwood, 2010; Barbuta, Barbuta, Blanchet, Cloutier, 2012); and (c) the amount and type of adhesive (Hraszky i Kral, 2009). In addition, the MOE and MOR of a wood based panel are influenced by the factors related to the test method: the position of the sample in relation to the longitudinal axis of the panel (Jin and Dai, 2010); the number and position of the deflectometer and the calculation method (Souza et al., 2014; Tsen and ESEN, Hüseyin YÖRÜR Jumaat, 2012); the form of specimens (beam, panel) (Thomas, 2001; Thomas, 2002; Thomas, 2003), etc. The values of the MOE and the MOR are also influenced by the ambient temperature (Zhou et al., 2012), the size and duration of compression in the process of panel manufacturing (Yapici, Essen, Yorur 2013 Warmbier, Wilczyński, Danecki, 2014), the temperature in the panel production process and the percentage of the adhesive used (Maragha, tables, Madanipoor, 2018), load duration, loading rate and load size (Gerhards, 1977; McNatt, 1975; Forest Products Laboratory, 1999; Rowell, 2005; Jacques et al., 2014; Kulman et al., 2017). The research of the rate of loading has revealed that with the reduction of the loading rate the MOE and MOR decrease under the impact of static load.

The testing of the MOE and MOR of particleboard samples according to the European standard EN 310 (1994) was carried out so that the selected loading rate produces a force on the sample causing a fracture of the sample over a time interval of 60 ± 30 seconds. The incorrectly selected loading rate causes breakage of the sample, only after a few seconds and before the prescribed lower time limit.
Therefore, the purpose of this study is to determine the differences in the MOE and MOR sizes at different loading rates as well as the significance of those differences.

2. MATERIAL AND METHODS

The samples for the MOE and MOR testing were cut out of three commercial particleboards with a melamine foil of a nominal thickness of 18 mm exposed to the changing atmospheric influences of the temperature and humidity at the warehouse. Before cutting, the boards were stored in a room with a uniform temperature and humidity (22 ± 2^{0}C and 47 ± 3%) for a period of 10 days. A total of 94 samples were cut out of the boards with dimensions 18 x 50 x 410 mm, out of which 46 in the direction parallel to the forming line (||) and 49 in the direction perpendicular to the longer side of the board (⊥), 10 samples of 18 x 50 x 50 mm dimensions (4 for moisture content measurement and 6 for density measurement) according to the cutting pattern scheme (Figure 1). Before the determination of the MOE and MOR the cut samples were kept in the same area where the boards were stored prior to cutting for a period of seven days.

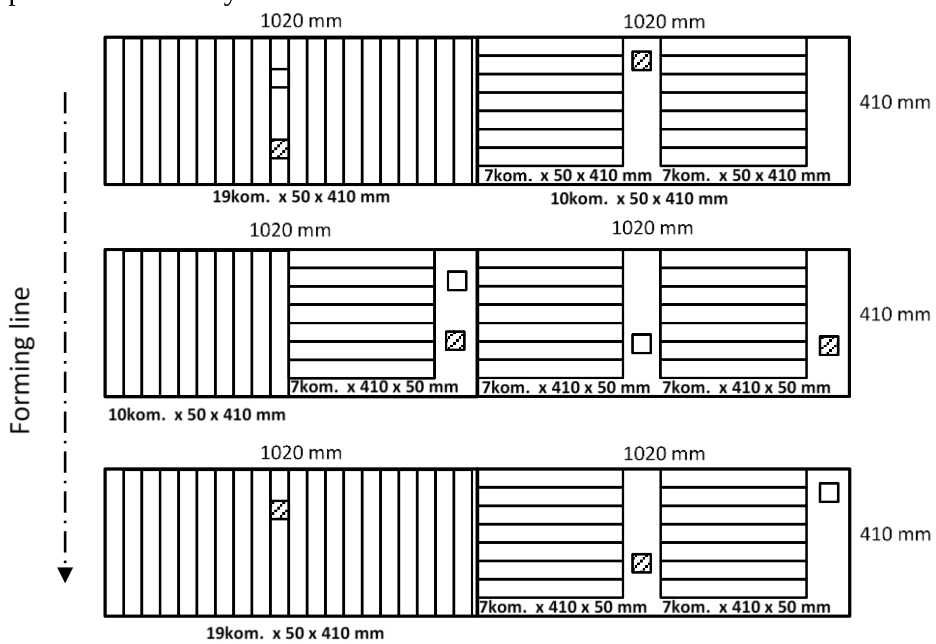

Figure 1. *Cutting pattern (☐ – test pieces for determination of moisture content, ▨ – test pieces for determination of density)*

The MOE and MOR testing was performed on a hydraulic machine for testing type WT-4 mechanical properties in the Laboratory for Wood Properties at the University of Belgrade - Faculty of Forestry.

The aim of the experiment was to compare the experimental results for the MOE and MOR in two cases. The first one, in which the loading rate is selected so that the breakage occurs in less than 30s and the other one, in accordance with standard EN 310, i.e. with the fracture of the sample occuring within the prescribed interval of 60 ± 30 seconds. In accordance with those requirements, different loading rates were tested at the beginning of the experiment and two of them were selected: (i) 4000/120 (33.33) N/s and (ii) 650/120 (5.41) N/s. (4000 N force is the maximum force that can be produced by the test machine).

Thus, a total of four groups of samples were formed: for the parallel and perpendicular directions, one group of samples for each, and within each of these groups, two groups for the loading rates of 33.33 and 5.41 N/s. Before the tests, all sample dimensions were measured and the samples were weighed. The testing of moisture content and density of the particleboard was performed according to EN 322 and EN 323.

3. RESULTS AND ANALYSIS

The measured moisture content of the samples according to EN 322 was 6.39 ± 0.61%. The measured density of the particleboard according to EN 323 was 667 ± 3.7%.

The number of samples included in the analysis is shown in Table 1 for both cutting directions and for both loading rates. The number of these samples is lower compared to the initial number of samples due to trial testing and elimination of samples in groups with a loading rate of 5.41 N/s that were broken beyond the prescribed interval. Table 1 also shows the mean value and standard deviation of density, the minimum and maximum values of the fracture force, as well as the minimum and maximum values of deflection during fracture for each group of the samples.

Table 1. *Basic Statistical indicators for density, fracture force, deflection and time to failure of the samples cut in the parallel and perpendicular directions at the loading rates of 33.33 N/s and 5.41 N/s*

Cutting direction	Loading rate (N/s)	Number of samples	Density (kg/m^3)		Fracture force (N)		Deflection (mm)		Time to failure (s)	
			Mean	St. dev.	Min	Max	Min	Max	Min	Max
ǁ	33.33	20	676	9.63	339	441	5.71	7.69	12	16
	5.41	17	668	15.03	309	426	5.08	7.51	57	90
⊥	33.33	21	667	7.22	296	398	5.47	8.55	11	17
	5.41	22	673	14.48	267	375	4.39	7.85	50	88

It is well known that the increase in board density leads to an increase in the modulus of elasticity and bending strength (Kollmann and Cote, 1984). For these reasons, the density of the individual samples used for the MOE and MOR testing was also determined in this paper. For each of the cutting directions, the density variation between the groups of samples broken at the loading rates of 33.33 and 5.41 N/s was tested using the Single Factor ANOVA . The density variation was also checked between all samples cut in the parallel and perpendicular directions.

It was found that the significance threshold was $\alpha = 0.05$, and for the same cutting direction the differences in the density between the groups of samples studied at different loading rates were not statistically significant. In addition, the variations in density between the groups of samples cut in the parallel and perpendicular directions were not statistically significant (Table 2). Therefore, the density variations can be considered to not significantly affect the MOE and MOR.

Table 2. *One-Way ANOVA to determine the significance of differences between the density of sample groups of the same direction that were broken at the selected loading rates and between the densities of all samples cut in one and the other cutting direction*

Cutting direction	F	P-value	F crit
ǁ	3.884	0.057	4.121
⊥	3.277	0.078	4.078
Between the directions	0.561	0.456	3.963

Table 1 shows that the samples exposed to the higher loading rate broke at a higher fracture force with higher deflections and much faster than the samples that were exposed to a lower loading rate. Therefore, and based on the known expressions for calculating the MOE and MOR (EN 310), at the higher loading rate of 33.33 N/s the MOE and MOR values will be higher than at the loading rate of 5.41 N/s.

Table 3 shows the basic descriptive statistics (mean, standard deviation, coefficient of variation, Cv and skewness coefficient, Cs) and the MOE and MOR for the sample groups with a loading rate of 33.33 N/s and 5.41 N/s for the parallel and perpendicular cutting directions. The last two columns show the differences between the mean values of the MOE and MOR for groups of samples that are loaded with different loading rates. Hereinafter, the modulus of elasticity for the parallel and perpendicular directions will be shown as $MOE_{\parallel}$ and $MOE_{\perp}$ and the modulus of rupture as $MOR_{\parallel}$ and $MOR_{\perp}$.

It is evident that the mean values of the MOE and MOR for the loading rate of 5.41 N/s are lower than the mean values for the loading rate of 33.33 N/s. The standard deviations show the approximate values for the same direction as well as the coefficients of variation.

Table 3. *Mean value, standard deviation, coefficients of variation and skewness coefficient* $MOE_{\parallel}$ *and* $MOE_{\perp}$,$MOR_{\parallel}$ *and* $MOR_{\perp}$,*for the loading rates of 33.33 N/s and 5.41 N/s*

Cutting direction	Loading rate (N/s)	MOE (MPa)				MOR (MPa)				Difference between the mean values (MPa)	
		Mean	St. dev.	Cv	Cs	Mean	St. dev.	Cv	Cs	MOE	MOR
‖	33.33	3163	115.6	0.037	-0.50	13.04	0.97	0.074	-0.03	95 (3.1 %)	0.66 (5.3 %)
	5.41	3068	101.3	0.033	0.48	12.39	1.27	0.103	0.28		
⊥	33.33	2678	196.0	0.073	0.67	11.50	0.93	0.081	0.17	167 (6.6 %)	0.45 (4.1 %)
	5.41	2511	219.6	0.087	-0.29	11.05	0.94	0.085	-0.43		

Figure 2 shows the results for the MOE and MOR and the time to failure for all the samples from the four groups examined. Figure 2 on the left shows the $MOE_{\parallel}$ and $MOE_{\perp}$ and Figure 2 on the right the $MOR_{\parallel}$ and $MOR_{\perp}$ for both loading rates. The x-axis represents time to failure and the time to failure prescribed by the standard EN 310 (60 ± 30 s) is shown in grey in the diagram. The samples exposed to the higher loading rate (33.33 N/s) broke after a much shorter time than the one prescribed by the standard, and also during a short time interval from 11 to 17s for both cutting directions. The samples in which the loading rate was lower (5.41 N/s) were broken in the interval prescribed by standard EN 310, in a much longer interval than the previous group, i.e. from 50 to 90s for both cutting directions, (see and Table 1).

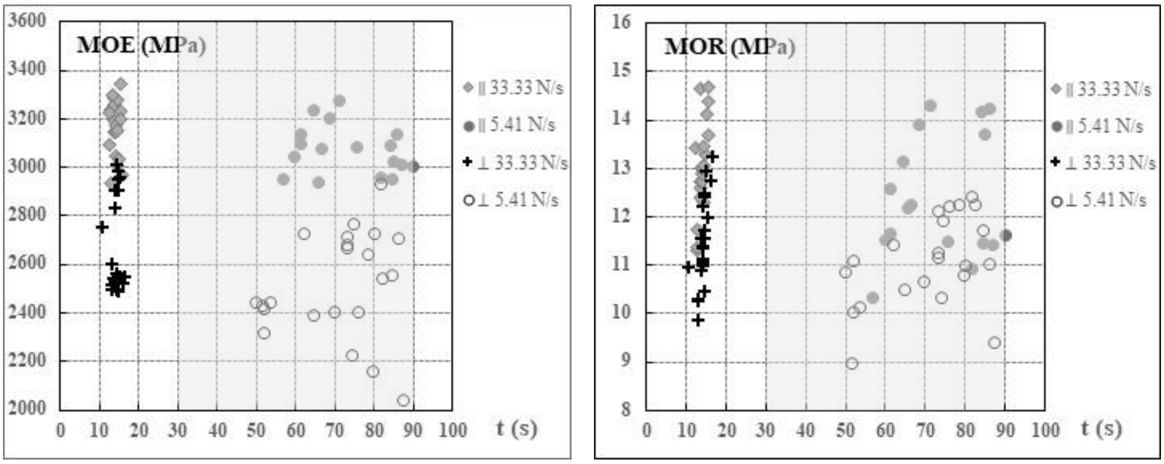

Figure 2. *The* $MOE_{\parallel}$ *and* $MOE_{\perp}$, *and* $MOR_{\parallel}$ *and* $MOR_{\perp}$ *and the time to failure for the four groups of samples at the loading rates of 33.33 N/s and 5:41 N/s*

In order to get a better insight into the distribution of the MOE and MOR results within the tested groups of samples, and in order to visually compare the results between the groups, Figure 3 shows a Box - Whisker plot for the MOE and MOR. The Box - Whisker plot for $MOE_{\parallel}$ and $MOE_{\perp}$ is shown in Figure 3 on the left, and for $MOR_{\parallel}$ and $MOR_{\perp}$ in Figure 3 on the right. The diagrams also show the points representing the mean values of the MOE and MOR from Table 3. From Figure 3 it can be seen

that for the loading rate of 5.41 N/s, the mean values of the MOE and MOR, as well as the values for the median, the minimum and the maximum values, are lower than for the loading rate of 33.33 N/s. In addition, the range of the percentile from 25 to 75 is lower for both the MOE and MOR for all sample groups that were exposed to the loading rate of 5:41 N/s, except for MOR$_{\parallel}$.
Figure 3 also shows a visible pronounced asymmetry of results for the MOE at the loading rate of 33.33 N/s. The median is considerably below the mean value, i.e. for most of the samples in this group, the measured MOE is lower than the mean value for the group. (In Table 3 it can be seen that a series of MOE$_{\perp}$ has the highest asymmetry coefficient, Cs = 0.67.)

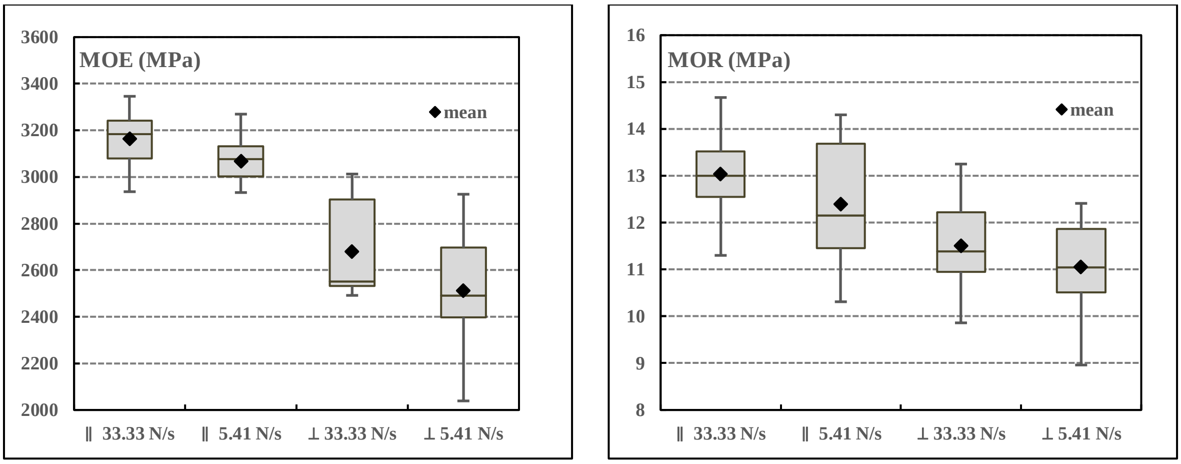

Figure 3. *The Box-Whisker plot of the MOE$_{\parallel}$ and MOE$_{\perp}$ and the MOR$_{\parallel}$ and MOR$_{\perp}$,for the loading rates of 33.33 N/s and 5.41 N/s*

As expected, the mean values of MOE$_{\perp}$ and MOR$_{\perp}$ are lower than the mean values of MOE$_{\parallel}$ and MOR$_{\parallel}$ as a result of non-homogeneous structure and anisotropy of particleboards. These differences are greater than the differences obtained for different loading rates (see also Table 3).
The single-factor ANOVA was applied to determine the statistical significance of the differences between the MOE and MOR obtained by the experiment at the lower and higher loading rate. The results are shown in Table 4. ANOVA showed that the differences between the mean values of the MOE within the same direction at the loading rates of 33.33 N / s and 5.41 N/s are statistically significant (although the percentage is small: 3.1% for the parallel direction and 6.6% Table 3), while for the MOR - there are no significant differences (the percentage differences are 5.3% for the parallel direction and 4.1% for the perpendicular direction).

Table 4. *The results of the ANOVA test of the significance of differences for the MOE and MOR between the groups of samples exposed to the loading rates of 33.33 N/s and 5.41 N/s (significant differences are highlighted)*

Cutting direction	Loading rate (N/s)	MOE(MPa)			MOR(MPa)		
		F	p	F crit	F	p	F crit
‖	33.33	**6.934**	**0.013**	**4.121**	3.148	0.085	4.121
	5.41						
⊥	33.33	**6.886**	**0.012**	**4.079**	2.449	0.125	4.079
	5.41						

The mean values for density (671 kg/m^3) and for the MOE (2855 kg/m^3) obtained in this experiment are similar to the properties that can be found in the literature. According to [10] the density of a particleboard is from 600 to 800 kg/m^3 and the MOE is from 2760 to 4140 MPa. However, the mean value of the MOR (11.99 MPa) is below the lower limit known in the literature [10]: 15.17 to 24.13 MPa.

4. CONCLUSION

This experiment has shown that, there is a difference between the mean values of the MOE and MOR for both cutting directions depending on the loading rate. A higher loading rate causes higher values of the MOE and MOR.

The differences between the mean values of the MOE at the loading rates of 33.33 N/s and 5.41 N/s are 3.1% for the parallel direction and 6.6% for the perpendicular direction. As far as the MOR is concerned, the differences between the mean values at the loading rates of 33.33 N/s and 5.41 N/s are 5.3% for the parallel direction and 4.1% for the perpendicular direction.

The results of the ANOVA test of statistical significance of these differences are not consistent. More precisely, statistically significant differences were obtained for the MOE, and they were not found for the MOR, although both mechanical characteristics were expected to be expressly dependant on the rate of loading.

The deviation from the expected results was probably caused by the different distribution of experimental results per groups due to a relatively small number of samples. More precisely, pronounced variability and asymmetry were found in the group of samples for the MOE testing cut out in the perpendicular direction examined at the loading rates of 33.33 N/s and 5.41 N/s, as well as for the MOR testing group of samples cut in the parallel direction that were tested at the loading rate of 5.41 N/s.

In addition to that, the expressions for the MOE and MOR calculation are valid only for the field of elasticity, while at higher levels of load above the elastic limit, plastic deformations are inevitable especially in the vicinity of the point of fracture.

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RESEARCH ON THE PROPERTIES OF LIGHT BOARDS FROM LIGNO-CELLULOSE MATERIALS AND CEMENT

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ABSTRACT

The aim of this research is production in laboratory conditions of light weight boards from different types of lingo-cellulosic materials and Portland cement as inorganic binder. Wood particles from recycled coniferous wood (white pine) and recycled deciduous wood species are used as lingo-cellulosic materials, as well as particles from grape vine rods, flax and hemp. Gel made from aluminum sulphate and sodium silicate solution (water glass) is used for mineralization of the particles.

Boards with thickness of 50 mm and dimensions of 400×400 mm are made in laboratory conditions. Test specimens for determination of the most important physical and mechanical properties are made from the boards. Some test specimens are used for determination of the coefficients of sound absorption and thermal conductivity.

The results from the research shows that light-weight boards from lingo-cellulosic materials and cement with density bellow 0,630 g/cm^3 can be classified as structural-insulation materials. Insulation properties and strength properties of investigated boards shows that they meet the requirements for application in construction as a material for components of wall panels, permanent formwork, roof panels, partition walls etc.

The obtained light-weight boards made of ligno-cellulosic materials and cement are a good option for sustainable material management, with a view to protecting, preserving and improving the quality of the environment, protecting human health, ensuring prudent, efficient and rational utilization of natural resources.

Key words: light wood-cement boards, recycled wood, lingo-cellulosic residues, mineral binding agents, utilisation of natural resources

1. INTRODUCTION

In recent decades, as a promising construction material, many countries in the world have produced wood-mineral boards. They proved to be inexpensive and effective material in terms of quality properties, which is successfully used in the construction of dwellings in rural and suburban areas, and also in construction of tourism buildings and commercial construction. Their basic composition includes the following components: mineral cement agent (cement, gypsum, magnesite, alkali-slag bonding agent, etc.), lingo-cellulosic residues filler (recycled chipped wood or woody stems of annual and perennial crops, etc.), mineralizer ($CaCl_2$, $Ca(OH)_2$, $Al_2(SO_4)_3$, water glass, etc.) and water. According to density and application, they are classified into three classes: lightweight (low-density board), with a density of 0,350 to 0,650 g/cm^3; medium heavy (medium density board), with a density of 0,650 to 1000 to g/cm^3, for insulation and structural application, and heavy (high density board), with a density of 1,000 to 1,400 g/cm^3, for structural application.

Special interest for quick application in practice are lightweight boards made of different types of ligno-cellulosic materials and cement, due to their advantages over other building materials, which are used in construction. The technological process for the production of these boards is comparatively easier to implement, especially that it does not require large investments for technological equipment and construction site. The raw material for the ligno-cellulosic filler is cheap and widely available - mainly recycled wood and agricultural lingo-cellulosic materials are used. The boards are characterized by good sound and thermal insulation properties, good bio and fire resistance and easy processing. In practice, lightweight panels of lingo-cellulosic materials and cement have found a wide application such as permanent formwork, partition walls, acoustic ceilings and underlayment in roofs, constituent elements, walls, panels etc. All of this predetermines the reasons for the rapid development of the production of this kind of boards in different parts of the world. Unfortunately, it should be noted that despite the positive results of long-term researches in Bulgaria and Macedonia (University of Forestry - Sofia and Faculty of design and technologies of furniture and interior - Skopje), this production has not yet found a practical realization.

The issue of using recycled wood raw material or replacing it with agricultural lingo-cellulosic residues is important and up-to-date, especially in view of the adopted Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.
Improving the efficiency of resource use and ensuring that waste is valued as a resource can contribute to reducing the Union’s dependence on the import of raw materials and facilitate the transition to more sustainable material management and to a circular economy model. That transition should contribute to the smart, sustainable and inclusive growth goals set out in the Europe 2020 strategy and create important opportunities for local economies and stakeholders, while helping to increase synergies between the circular economy and energy, climate, agriculture, industry and research policies as well as bringing benefits to the environment in terms of greenhouse gas emission savings and to the economy.

Waste management in the Union should be improved and transformed into sustainable material management, with a view to protecting, preserving and improving the quality of the environment, protecting human health, ensuring prudent, efficient and rational utilization of natural resources.

2. MATERIALS AND METHODS

Laboratory lightweight panels of various types of lingo-cellulosic materials and cement were made in the Laboratory for pressing at the Department of mechanical wood technology, University of Forestry in Sofia. The following raw materials were used:

- lime Portland cement CEM II/B-L 32.5R in accordance with BDS EN 197-1:2011;
- wood particles from recycled conifers (white pine) and recycled hard deciduous wood (beech);
- particles from chipped vine rods;
- hemp and flax residues;
- aluminum sulphate $Al_2(SO_4)_3$ in accordance with BDS 1841:1978;
- water glass (sodium silicate solution) in accordance with BDS 2284:1974.

From the aluminum sulphate and the water glass, a particle mineralization gel is prepared, which has a density of 1100 g/cm^3.

Lingo-cellulosic particles from different types of raw material are first processed in a laboratory mixer with the prepared mineralization gel, at the ratio of the gel to the wood particles, expressed in weight units, of an average 12:100, and in the components of the mineralization gel, respectively the ratio of the aluminum sulphate to the water glass is 1,4:1.

The mixing of the processed (with a mineralizing gel) lingo-cellulosic filler with cement was carried out in a laboratory mixer at a weight ratio of the cement to the filler of an average of 160:100. From the prepared moist mixture, with the use of forming frames mounted on a metal base (sheet), particleboard mats are formed for different types of boards, which are subjected to vibration for several minutes. By cold pressing at a pressure of approximately 3 MPa over a period of 24 hours, calibration of the formed mats was achieved up to the predetermined thickness of the boards. The semi-finished boards are released from the frames after 24 hours and together with the tin sheets are placed on the shelves in order to continuously lie off for 28 days, i.e. to complete hydration of the cement.

The finished boards, with a thickness of 50 mm and a format of 400 × 400 mm, are cut on test specimens for the determination of the physical and mechanical properties, as follows: density, on test specimens 100×100×50 mm; moisture content, on test specimens 50×50×50 mm; water absorption and thickness swelling for 24 hours, on test specimens 100×100×50 mm; bending strength, on test specimens 400×50×50 mm and compressive strength, on test specimens 50×50×50 mm. The coefficients of sound absorption and thermal conductivity are determined on single test specimens.

3. RESULTS FROM THE EXPERIMENTAL RESEARCH

Results from the conducted researches on physical and mechanical properties of laboratory-scale light weight boards from lingo-cellulosic materials and cement are shown in Table 1 and Figure 1.

Table1. *Average statistical values of physical and mechanical properties of light-weight boards made from lingo-cellulosic materials and cement*

No.	Board type according to the ligno-cellulosic filler	Properties				
		Density, g/cm^3	Water absorption, %	Thickness swelling, %	Bending strength, N/mm^2	Compressive strength, N/mm^2
1.	Recycled coniferous tree – white pine	0,420	102	2,2	0,62	0,58
		0,550	90	2,4	0,87	1,19
		0,570	72	3,1	1,22	1,75
2.	Recycled hardwood deciduous – beech	0,620	77	3,0	1,02	1,34
3.	Vine rods	0,630	68	2,5	1,09	1,38
4.	Hemp residuals	0,450	86	2,6	0,98	1,43
5.	Flax residuals	0,510	74	2,9	1,05	1,56

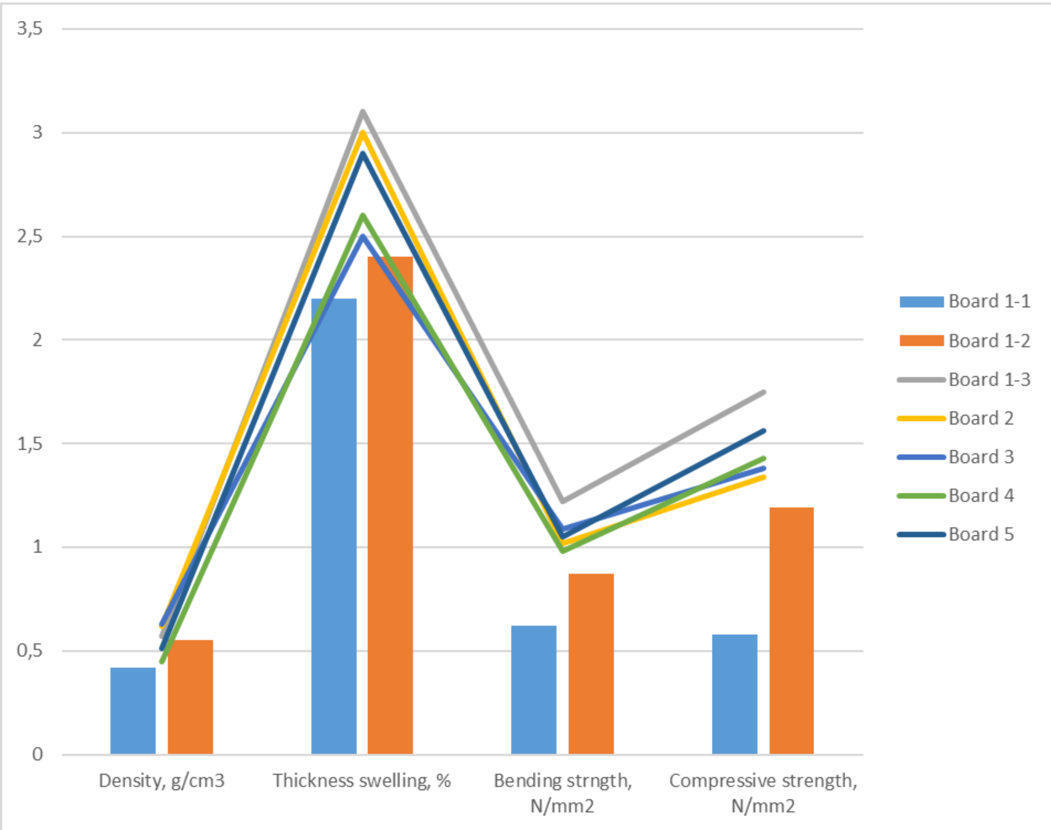

Figure 1. *Physico-mechanical indicators of light weight boards from ligno-cellulosic materials and cement*

The data presented in Tab. 1 and Fig. 1 shows that the density of the tested light boards from ligno-cellulosic materials and cement is in the limits of 0,420 to 0,630 g/cm^3, i.e. the lower density of the raw material (white pine, hemp and flax residuals) corresponds with the lower density of the boards. The increment of the density of the board made from the same raw material (in this case white pine) leads to significant increment of the strength properties.

The thickness swelling of the boards is comparably lower – from 2,2 to 3,1 %, while the water absorption is significant – from 68 to 102 %, which is due to the porous structure of the boards.
The moisture content of the tested boards is in the limits of 8,2 to 10,9 %.

The obtained values of the coefficients of thermal conductivity and sound absorption at frequency of 500 Hz for the boards made from coniferous wood raw material with density of 0,545 g/cm^3 are 0,12 W/(mK) and 0,49, respectively. On the basis of these values it can be concluded that these boards are characterized by very good insulation properties.

The results from the conducted research in order to optimize the composition of the light-weight wood-cement boards are given in Table 2.

Table 2. *Physical and mechanical properties of wood-cement boards from white pine with different composition*

Light weight wood-cement boards with different ratio of the components	Density, g/cm^3	Bending strength, N/mm^2	Compressive strength, N/mm^2
1. Ratio cement : wood			
C:W=120:100	0,410	0,33	0,28
C:W=200:100	0,620	1,46	2,09
2. Ratio mineralizator : wood			
M:W=8:100	0,550	0,64	0,91
M:W=16:100	0,540	0,93	1,27

As can be seen from the results given in Table. 2 and taking into account the data from Table. 1 and Fig.1 for light weight wood-cement boards from pine wood with a density of 0,550 g/cm^3 (C:W=160:100 and M:W=12:100), it can be concluded that the increase in the amount of cement and the mineralizer leads to an increase in the strength characteristics of the boards. It is necessary to note that it leads simultaneously to the weakening of the economic indicators of the finished production. Therefore, as compromise optimal values of these ratios should be taken C:W=160:100 and M:W=120:100.

4. CONCLUSION

Based on the results of the conducted laboratory researches for defining the physical and mechanical parameters of the light-weight boards of various ligno-cellulosic materials and cement, the following important conclusions and recommendations can be made:

1. 1. The obtained light-weight boards made of ligno-cellulosic materials and cement are of a density below 0,630 g/cm^3 and belong to the group of insulation-structural building materials;
2. 2. The insulating properties and strength characteristics of the tested boards meet the requirements for use in the construction as a material for component elements of wall panels for single-family dwellings and light constructions, permanent formwork, underlay panels in roof constructions, partition walls, etc.;
3. 3. From a technical and economic point of view, a compromise optimum composition of light-weight wood-cement boards is defined at the following weight proportions: cement: wood =160:100 and mineralizer: wood=12:100;
4. 4. The obtained light-weight boards made of ligno-cellulosic materials and cement are a good option for sustainable material management, with a view to protecting, preserving and improving the quality of the environment, protecting human health, ensuring prudent, efficient and rational utilization of natural resources.

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COMPARATIVE CHARACTERISTICS OF EXPLOITATION PROPERTIES OF MDF MANUFACTURED WITH PARTICIPATION OF NON-WOOD LIGNOCELLULOSIC RAW MATERIALS

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ABSTRACT

The shortage of wood raw material and the considerable amounts of agricultural waste and residues are one of the main environmental challenges today, which justify the relevance of studying the possibilities for utilization of non-wood lignocellulosic raw materials in the production of wood-based composites.

This article presents the study on the impact of including different non-wood lignocellulosic raw materials in the composition of MDF on their exploitation properties. Three types of non-wood lignocellulosic raw materials – maize stalks, industrial hemp stalks and thin bamboo stalks, were used for the purpose of the study. The materials were refined in laboratory conditions using defibrator disc mill. The panels were manufactured by using industrial wood-fibre mass and variation of non-wood raw materials from 10 to 40%. The main exploitation properties of MDF were determined and analysis on the possibilities of including the studied lignocellulosic raw materials in the composition of the panels was made.

Key words: MDF, maize stalks, industrial hemp stalks, bamboo stalks, exploitation properties

1. INTRODUCTION

The increasing shortage of wood raw material and growing consumption of wood-based panels (FAO) justify the relevance of studying the possibilities for utilization of non-wood annual and perennial lignocellulosic raw materials, representing agricultural waste and residues, in the production of woo-based composites.

A significant number of studies have been focused on the utilization of lignocellulosic residues in the composition of particleboards. There are different studies about the possibilities for utilization of cotton stems (Mihailova, J. et al. 2006), raspberry stems (Todorov, T. et al. 2007), wheat stalks (Wang, D. et al. 2002) in the composition of particleboard, as well as comparative analyses of using different lignocellulosic raw materials (Mihailova, J. et al. 2008). Other studies have been conducted on the possibilities for using these raw materials in the production of wood-cement panels (Mihailova, J. 2008), as well as on the suitability of particleboard manufactured with lignocellulosic raw materials for general, not load-bearing applications (Mihailova, J et.al. 2007).

The number of studies regarding the use of lignocellulosic raw materials in the production of MDF panels is significantly lower compared to particleboard manufacturing (Eroğlu H. et al. 2000; Gencer A, et al. 2001; Akgul, M et al. 2010; Mihailova, J et al. 2018a; Mihailova, J et al. 2018b). It should be noted that the global production of fibreboards exceeds the particleboard manufacturing. Since 2012 the MDF/HDF production has been growing by 4% annually on average and accounted for 83% of all fibreboard production in 2016 (FAO).

2. MATERIALS AND METHODS

The wood-fibre mass, used for the production of MDF, was obtained in the factory conditions of Welde Bulgaria AD – Troyan, according to the Asplund method. The wood-fibre mass had the following composition: beech and Turkey oak (60%), poplar (20%), and Scots pine (20%). The mass was dried in laboratory conditions to 10% moisture content.
Urea-formaldehyde resin, produced by Kastamonu Bulgaria AD, was used as a binder. The resin had an initial concentration of 58% and it was added in the wood-fibre mass at 50% concentration.
The non-wood lignocellulosic raw materials (maize, hemp and bamboo stalks) were refined on a disc mill with one rotating grinding disc, presented on Figure 1.

Figure 1. *Laboratory disc mill*

The mass produced from the different non-wood lignocellulosic raw materials was dried to the following water content: maize stalk mass – 9%; hemp stalk mass – 10%, bamboo stalk mass – 10%.
The addition of adhesive and water repellants was made using a high-speed glue blender with needle-like blades at 850 min^{-1} for 40 to 60 s. The hot pressing was performed on a laboratory press type PMC ST 100, Italy.

The pressing was carried out at 185 ± 5 ºC hot pressing temperature and pressing time of 1 min/mm. A three-stage pressing regime was applied at the specific pressure, as follows: I stage - 2,5 MPa; II stage - 1,3 MPa; III stage - 0,6 MPa. The duration of the different stages was the following: I stage - 20% of the whole pressing cycle; II stage - 30% of the pressing cycle; III stage – 50% of the pressing cycle.

The panels were manufactured with a thickness of 6 mm and a density of 850 $kg.m^{-3}$. The physical and mechanical properties of the produced MDF panels were determined in accordance with the requirements of the respective EN standards (EN 310; EN 317 and EN 323).

3. RESULTS AND ANALYSES

The summarized results for the exploitation properties of MDF panels, produced with the different non-wood lignocellulosic raw materials, are presented in Table 1.

Table 1. *Exploitation parameters of MDF panels produced at different content of non-wood lignocellulosic raw materials*

Panel No.	Non-wood raw material *Px*, %	Density *ρ*, $kg.m^{-3}$	Water absorption *A*, %	Swelling in thickness *Gt*, %	Bending strength *fm*, $N.mm^{-2}$
Maize stalk mass					
1.	10	852	68.61	16.86	37.76
2.	20	861	69.32	18.32	35.89
3.	30	848	73.52	23.77	34.49
4.	40	841	75.76	23.09	30.16
Hemp stalk mass					
5.	10	848	81.44	28.53	44.02
6.	20	854	85.78	29.53	43.99
7.	30	845	86.54	31.50	43.52
8.	40	858	89.13	32.96	42.96
Bamboo stalk mass					
9.	10	857	66.49	31.69	28.80
10.	20	863	64.87	32.74	27.77
11.	30	846	64.95	27.92	26.97
12.	40	845	63.74	27.02	24.72

The density of the obtained panels is very close to the predetermined value of 850 $kg.m^{-3}$, and varied from 841 to 863 $kg.m^{-3}$, i.e. the variation of this main exploitation and characteristic parameter of the panels was only 2.6% which justified the analysis of the influence of the different types of non-wood lignocellulosic materials on the properties of the produced MDF panels.

A comparative analysis in a graphical form of the water absorption variation of MDF panels, produced at different content of the studied non-wood lignocellulosic materials, is presented on Figure 2.

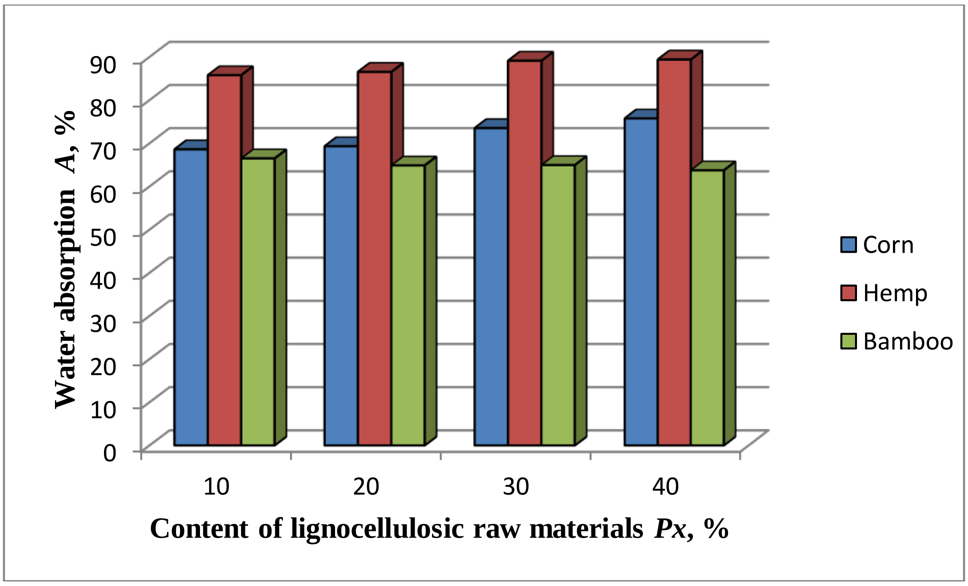

Figure 2. *Variation of water absorption of MDF panels produced at different content of non-wood lignocellulosic materials*

The water absorption of the MDF panels deteriorated (increased) with the addition of maize and hemp stalk mass, whilst the addition of bamboo stalk mass resulted in improved values of the studied parameter. The deterioration of water absorption of the panels was determined when the content of maize stalk mass and hemp stalk mass exceeded 20% and 10%, respectively.

The lowest water absorption (63.7%) was determined for MDF panels with 40% content of bamboo stalk mass. The highest values of this indicator were observed for MDF panels produced with 40% content of hemp stalk mass, where 89.1% water absorption was reported. The comparative analysis showed the best (lowest) values of water absorption at equal percentage content of non-wood lignocellulosic raw materials were determined for MDF panels produced with bamboo stalks, and the worst values were determined for the panels produced with industrial hemp stalks. The water absorption of MDF produced with maize stalks is similar to the one of MDF with bamboo stalks.

A comparative analysis in a graphical form of the swelling in thickness of MDF panels produced at different content of the studied non-wood lignocellulosic materials, is presented on Figure 3.

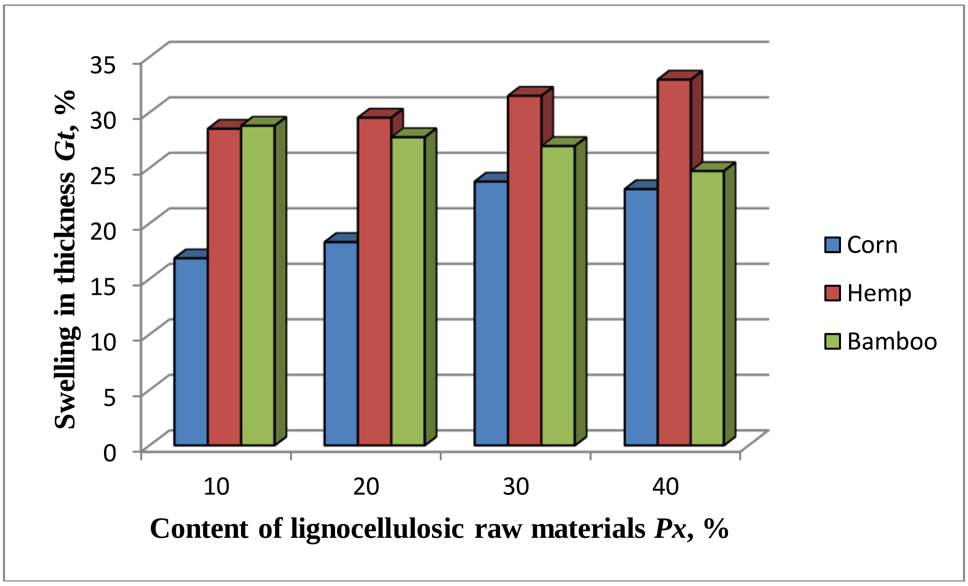

Figure 3. *Variation of swelling in thickness of MDF panels produced at different content of non-wood lignocellulosic materials*

The addition of all studied types of non-wood lignocellulosic raw materials resulted in deterioration (increase) of the swelling in thickness.

Regarding the swelling in thickness only the panels produced with 10% content of maize stalk mass met the standard requirements for application in humid environment. The panels, produced with 20% content of maize stalk mass, exceeded the standard requirement (EN 622-5) insignificantly with a variation within the statistical error. All panels produced with participation of maize stalk mass met the requirements for application in dry conditions.

The most significant deterioration of the swelling in thickness of MDF panels produced with industrial hemp stalk mass was determined when the content of non-wood lignocellulosic raw material was increased from 30 to 40%. The panels produced with industrial hemp stalks met only the requirements for use in dry conditions. The addition of bamboo stalk mass resulted in deteriorated swelling in thickness at 10% content of non-wood raw material, followed by constant levels of the values with a slight decrease.

The best values of swelling in thickness were determined for MDF panels produced with participation of maize stalks; the highest value of swelling in thickness was reported when using industrial hemp stalk mass.

A comparative analysis in a graphical form of the bending strength of MDF panels produced at different content of the studied non-wood lignocellulosic materials, is presented on Figure 4.

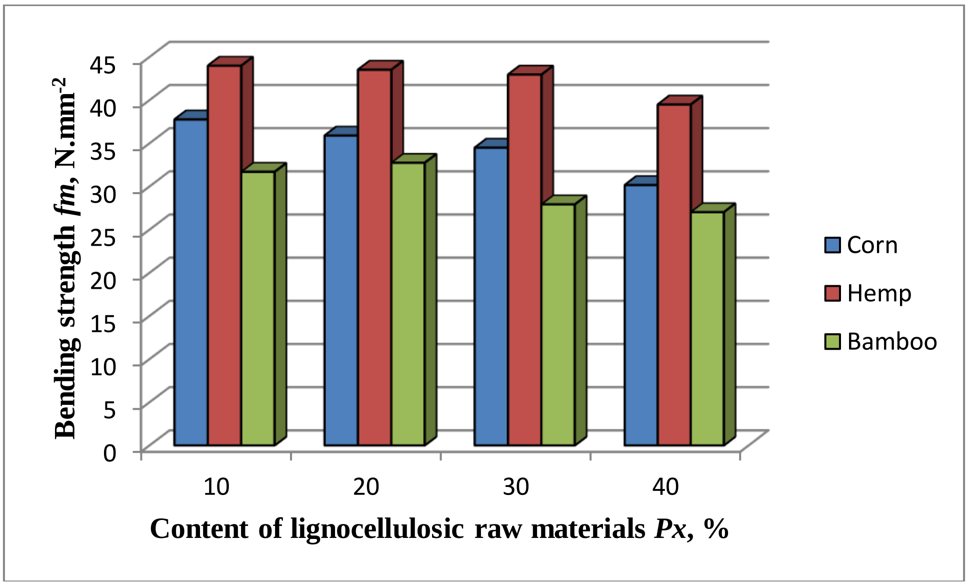

Figure 4. *Variation of bending strength of MDF panels produced at different content of non-wood lignocellulosic materials*

The highest bending strength values of the studied lignocellulosic raw materials were determined for MDF panels produced with participation of industrial hemp stalk mass, followed by the panels produced with maize stalk mass. The worst values of this indicator were determined for MDF produced with bamboo stalk mass.

Regarding the bending strength, the panels produced with maize stalk and hemp stalk mass up to 40% met the stringent requirements, i.e. for load-bearing applications in humid environment. However, it should be noted that the inclusion of more than 20% non-wood lignocellulosic mass resulted in significant decrease of the bending strength. The panels produced with up to 20% non-wood mass met the standard requirements for load-bearing applications and use in dry conditions.

4. CONCLUSIONS

As a result of the present study it was determined that, in general, the studied non-wood lignocellulosic raw materials, if not treated in advance, lower the physical and mechanical properties of the panels. However, this type of raw material can successfully be incorporated in the composition of MDF panels as a partial substitute of wood. Regarding the swelling in thickness all MDF panels produced with maize stalk mass met the standard requirements for general application and use in dry conditions. MDF panels produced with industrial hemp stalks met the standard requirements at up to 20% content of non-wood lignocellulosic raw material. With regard to the panels produced with bamboo stalk mass the content of lignocellulosic raw material should be at least 20%.

All produced MDF panels met the bending strength requirements for general application and use in dry conditions. MDF produced with a content of maize stalk stem mass up to 40% met the most stringent requirements for load-bearing applications and use in humid environment; these requirements are met also by the MDF panels produced with industrial hemp stalk mass up to 20%.

In the comparative analysis of the physical and mechanical properties of MDF produced with maize, industrial hemp and bamboo stalk mass, it was determined that maize stalks are the most suitable raw material, followed by the hemp stalks. Maize crops have a relatively larger distribution; the main disadvantage is the relatively low refining yield. Regarding the panels produced with bamboo stalk mass, a significant deterioration of panel strength properties was observed, mainly due to the chemical composition of bamboo stalks. Despite these drawbacks, the use of all three studied non-wood raw materials in the composition of MDF panels can be recommended, even without initial chemical treatment of the lignocellulosic raw materials, as a partial substitute of wood. However, the share of this type non-wood raw material should not exceed 20%.

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EN 310:1999 Wood-based panels - Determination of modulus of elasticity in bending and of bending strength

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SHAPE STABILITY OF CURVED FURNITURE PANELS MADE OF INTERNAL PRISMATIC FIBERBOARD LATHS LAMINATED WITH MDF PANELS

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ABSTRACT

Curved furniture elements are increasingly used in cabinet furniture. For making this type of construction, it is preferable to use bent lamination of wood or fixed to form by gluing composite materials. A major problem of fixed to form curvilinear composite materials is their shape stability. Significant internal stresses in the curved furniture composite materials leads to a change in shape. In this regard, the aim of the study is to determine the shape stability of agglomerate curvilinear furniture composite made of inner layer of fiberboard laths and two face layers of thin MDF. Curved agglomerate furniture composite with an internal radius of curvature (225 mm) were made. It was used three different PVA glues - „Pastelo“, „Kleiberit“ and „Apel“. Two types of laths are used – made from laminated and unlamented chipboard. Shape stability of all curved furniture elements were determined by measuring radius of curvature. Additionally, the shape stability of the samples was determined after convective heating in a drying chamber at 55° C.

Key words: curved furniture elements, shape stability, PVA glue

1. INTRODUCTION

Curved furniture elements get more frequently involved in the construction process of modern cabinet furniture. The most widespread in furniture factories are the technologies for production of one-direction curved furniture boards. According to their purpose, they are used as constructive elements in cabinet furniture – for example for arched doors, arches, front side of drawers. The production of this kind of constructive elements is based mainly on the usage of two types of technologies - glue bent lamination (fig. 1a) and kerf bending of wooden materials (fig. 1b). Lamination is the process of bending many thin parts together and holding them in the desired shape until the glue between them dries. Kerf bending is the process of cutting a number of square-grooved slots (dadoes) into a piece of material that allow it to bend. It consists of making successive parallel cuts, or kerfs, on the surface of the stock that will later become the inside surface of the curve. The kerfs remove sufficient material to allow a curve to be formed. (Gillman, R. *et al.* 2001).

Figure 1. *a - glue bent lamination; b - kerf bending*

The glue bent lamination technology has higher productivity than the kerf bending technology. Beside this, the necessity to cut numerous slots in wooden material contributes to considerable increase of the noise level of this production process. The noise from the circular saws and milling instruments in any production factory has negative effect on human health (Vitchev, P. 2013, Vitchev, P. 2015).

Depending on the structure, the kerf bending furniture panels could range from middle-layer particleboard laminated from both sides with linings as MDF, HDF, thick veneer or thin plywood. The middle layer is usually cut in the area where the bending is going to be.

In many cases, instead of cutting square-grooved slots for kerf bending, tightly arranged side-by-side prismatic laths of solid wood or particleboard are used (these laths got as result of cutting waste parts of particleboard panels). When using laths made of solid wood or particleboard for the middle layer, the preparation process prior to pressing is considerably simplified. In addition, this way provides conditions in furniture factories for utilization of waste from the cutting process (Kavalov, A., Rusanov, Hr. 2000).

As it is well-known, the main problem of the glue-curved wooden elements is their shape stability. After the detail is pressed and released from the mold, it is going to “spring back” a little bit from the stresses in the bent material. When the press form is opened after the usual glue-curing period, the stave will be perfectly flat across its width. But within 24 hours it usually resumes the cup (Osgood, J., 1985). Water absorption has negative effect on creep behavior of medium density fiberboard (MDF) composites (Kazemi N. S. *at al.* 2008). The temperature resistance of the glue compounds is another major factor influencing the shape stability of glue-curved panels. Chow examined the relation between durability and softening temperature of adhesives (Chow 1973).

Further, Steiner and Chow evaluated the low-temperature durability of many common wood adhesives including a cross-linked PVAc emulsion in a cyclic-exposure test (Steiner and Chow 1975). On the other hand, the continuous change of rheological property of polymers can be easily attained by temperature change without any chemical reactions. (Motohashi K. et. al., 1984). Generally, the availability of internal pressure in curved linear furniture aggregates brings to creeping and uncontrolled shape modification. In this relation, the purpose of this research is to determine the shape stability of agglomerate curved linear furniture details made of glued MDF and inner filling of particleboard laths.

2. MATERIAL AND METHODS

For determining the shape stability of glue-curved agglomerate furniture panels, samples were produced with internal radius of the curvature 225mm and cross section size 10x18 mm (fig. 2a). Laminated and non-laminated particleboards with 680 kg/m^3 density and 18 mm thickness have been used for producing the inner layer (made of filling laths). The particleboards were cut into laths with a cross-section 11x18 mm. For external face layer of the samples have been used one-side laminated (melamine faced) MDF with 740 kg/m^3 density and thickness of 3,2 mm. The production of each curvelinear board was based on the use of 2 pieces of one-side laminated MDF details with dimension size 650x350x3,2 mm and 36 pieces of fiberboard filling laths.

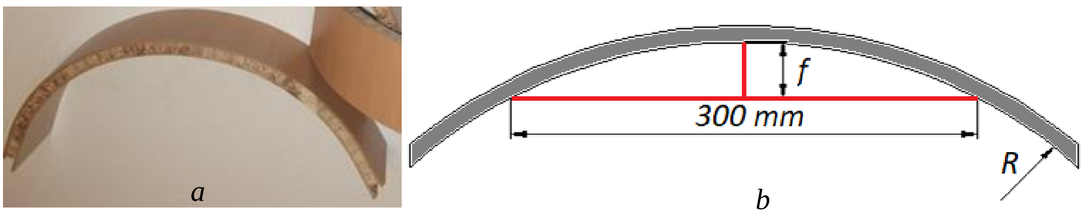

Figure 2. *a – samples; b - determination of the internal radius R of samples by measuring the perpendicular between the middle of the chord with length of 300 mm and the circuit*

The bonding of the so-prepared „sandwich-packs” is made with polyvinyl acetate glue. Polyvinyl acetate (PVAc) emulsion is a type of water-based environment-friendly adhesive. To determine the impact of the adhesive over the shape stability of the glue-curved boards, 3 types of dispersed glues have been used - „Pastelo“ (Bulgaria), „Kleiberit“ (Germany), и „Apel“ (Turkey). All of glues are PVA based with D3-class of water resistance by DIN EN 204/205. Due to the crosslinking groups in the polymers, these adhesives provide a superior moisture and heat resistance compared to non-reactive PVAc dispersions. All used adhesives were applied in a liquid state, the gluing process of samples was carried out according to adhesive manufacturer's instructions. Application of adhesive was over the non-laminated (coated) surface of the MDF boards, where used quantity was about 150 g/m^2. The readymade “sandwich-pack” is then positioned in press mold with internal radius of 225 mm, and external radius of 243 mm. The bending process of those “sandwich-packs” is performed with hydraulic pressure equipment at following technology regime: temperature at 18°C; bending pressure at 0,4 MPa; bending duration of 60 min. Samples are obtained by width cutting of the so-made glue-curved aggregates (curved furniture panels).

To determine the shape stability of glue-curved agglomerate furniture panels, the internal radius of the curvature *R* is measured 24 *h* after being taken out from the press former (mold). The following parametric formula is used to define the radius of arc-curve through three points (fig. 2b):

$$R = \frac{150^2 + f^2}{2f}, mm \qquad (1)$$

Whereas *R* is the internal radius of glue-curved panel, *mm; f* is the shortest distance (perpendicular) between the middle of chord with length of 300 mm and the circuit, *mm*.

In addition, the shape stability has been explored for glue-curved agglomerate furniture panels subject to heating impact. The thermal stability of glued wood joints is an important criterion to determine the suitability of adhesives in the field of engineered wood. For this purpose drying chamber Binder ED 400 (Germany) was used, in which the sample details were subject of convective heating for duration of *60 min* at temperature *t=55°C*. At this test, the internal radius of the sample details was measured at every *15 min*.

In order to identify the authenticity of the study, statistical data processing was performed over 6 equally made sample details. The following statistical indicators have been calculated for the study: arithmetic mean, the average quadratic deviation, standard deviation, variation coefficient and punctuality index.

3. RESULTS AND DISCUSSION

The results from the measurement of the internal radius of glue-curved agglomerate furniture panels after 24 *h* from being released (at air temperature of 20°C and 65% air humidity) are presented at fig. 3. The change of the internal radius *R* is not influenced (≈1% change) by the type of laths used for medium layer of the glue-curved furniture boards (laminated and non-laminated fiberboards). The best shape stability belongs to the sample details made with PVAc glue “Pastelo”. Depending on the used adhesive the internal radius changes in the range from 1,6% to 4,4 % after 24 hours of released stay of the samples. This proves generally the very good shape stability of the glue-curved boards with inner layer of particleboard laths, laminated both sides with MDF and PVAc adhesives.

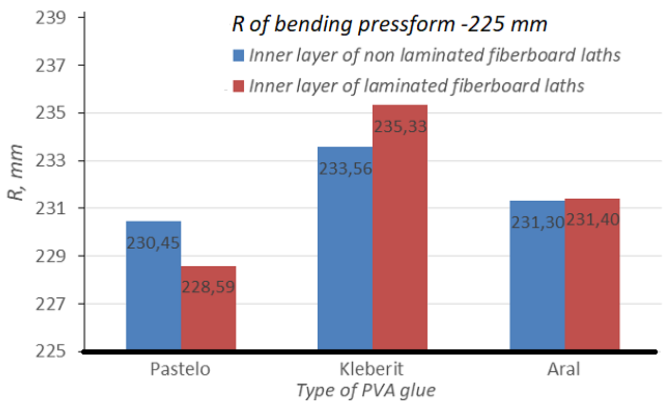

Figure 3. *Change of the internal radius of the sample details after 24hours of released stay at air temperature of 20°C and 65% of air humidity*

The results from measurement of the internal radius *R* of glue-curved agglomerate furniture panels during their convective heating in a drying chamber at *55°C* temperature are presented at figures 4 and 5. Changes in the internal radius *R* of the sample details have been detected during the period from the 5th till the 15th minute (2÷4 %). Within the period from the 15th till the 60th minute the radius of the samples curvature does not change. The type of change in the internal radius during heating is the same for the sample details made and bonded by using different brands of PVAc glues. Temperatures up to 110 °C do not reduce the strength of bonded joints under standard requirements (Sedliačik, J., Šmidriaková, M. 2012). For the stability of the adhesive compounds contributes also the high level of crosslinking of the glues from class D3. Due to the crosslinking groups in the polymers, these adhesives provide a superior moisture and heat resistance compared to non-reactive PVAc dispersions.

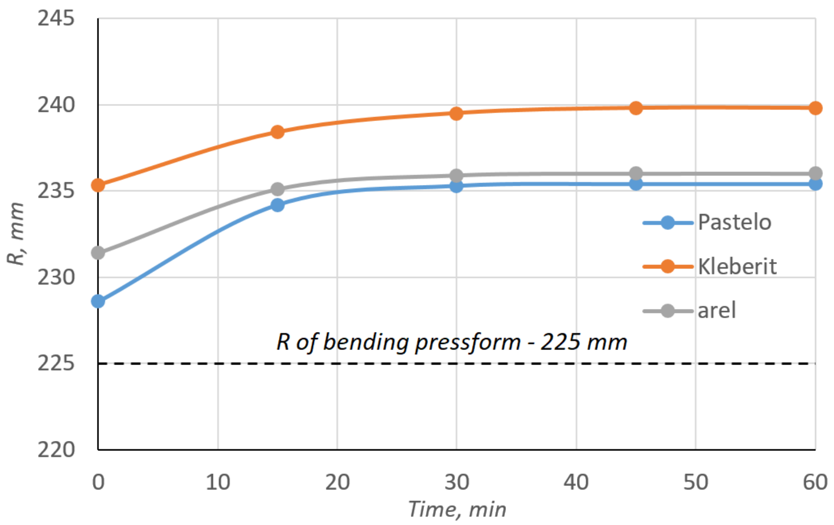

Figure 4. *Change of the internal radius of sample details with inner layer of laminated fiberboard laths during convective heating at t = 55°C.*

All that means that glue-curved agglomerate furniture panels and particularly the adhesive compounds of the used PVAc glues are resistant on temperature impacts. As a result, the shape stability of the sample details stays unchanged at prolonged impact of high operating temperatures.

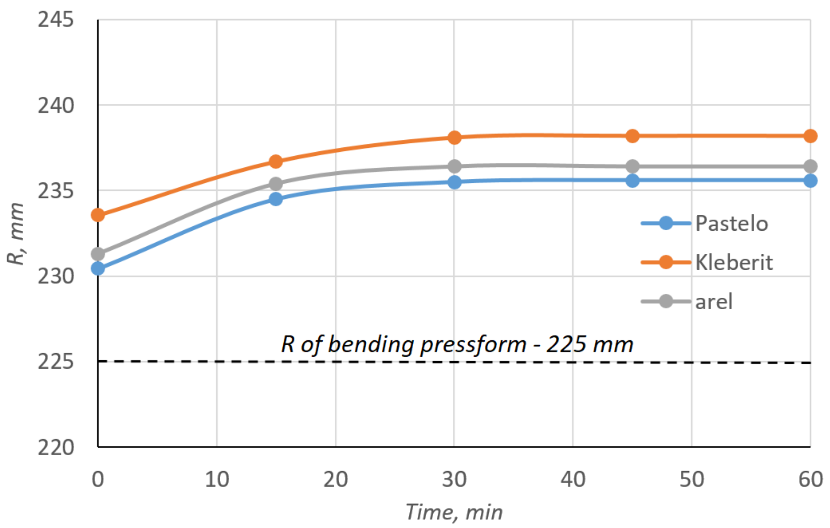

Figure 5. *Change of the internal radius of sample details with inner layer of non-laminated fiberboard laths during convective heating at t = 55°C*

This is the main reason why the change of the internal radius *R* during heating at *t = 55°C* is not influenced essentially from the type of laths (laminated and non-laminated fiberboards) used as inner layer of glue-curved boards, see figures 4 and 5.

4. CONCLUSIONS

Based on the results obtained at lab scale and under the conditions of the experiments herein, the following conclusions could be made specifically for the above-mentioned materials and PVAc adhesive glue systems:

1. For the tested glue-curved agglomerate furniture boards, the change of the internal curvature radius *R* after 24 *h* of released stay of the sample details is in the range of 5%. This shows generally very good shape stability of those panels made of inner layer of particleboard laths, laminated both sides with MDF and PVAc adhesives. The shape stability of this kind of agglomerate boards depends mainly on the used adhesive glue system.
2. The shape stability of the tested glue-curved agglomerate furniture boards is not influenced by the type of used inner layer of laths (laminated or non-laminated particleboards).
3. The glue-curved agglomerate furniture panels bonded with PVAc glues are dimensionally stable during prolonged impact (60 min) at high operating temperature (t = 55°C). Some minor change is reported (2-4 %) in the internal radius of the sample details during the first 15 minutes of heating at *t* = 55 °C.

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INFLUENCE OF FSC CoC CERTIFICATION ON PLYWOOD PRODUCING ENTERPRISE PROFITABILITY

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ABSTRACT

The aim of the researches presented in the paper is to study the influence of the certification in FSC on the market expansion and profitableness of the plywood producer in Bulgaria. Penetration of the fast improving or well developed distribution markets can provide great marginal increment of return on equity.

For studying this influence, have been analyzed the main components of the economic efficiency before and after the certification. Problems appear to the supply markets are considered in meaning of the supply chain costs in order to follow Chain of Custody requirements.

Alternatives for supplying the industrial roundwood of beech and poplar are assessed to outline the constraints in economic efficiency deriving after the FSC in the part of CoC certification.

Key words: plywood, profitability, FSC, CoC

1. INTRODUCTION

Forest certification is regarded as a set of procedures aimed at assessing the quality of forest management and timber harvesting according to specific standards (Enescu et.al., 2019). It seeks to create a set of rules and institutions for forest certification that integrate environmental, social, and economic goals (Meidinger, 2003). There are two types of certificates (i.e. Forest Stewardship Council – FSC): certificate for forest management (FM) and certifiate for Chain of Custody (CoC) (Klarić et.al., 2016). Although FSC has a clear mandate under its principles to ensure that International Lalour Organization core conventions and best ecological practices are adhered to in certified forest management units, this does not apply outside the forest (Karmann et. al., 2009). Chain of Custody system was aimed to give clarification of timber mobilization system in an industry (Dewa et.al., 2017).

In Bulgaria by 2016 almost the 19% of the all forest areas are certified in FSC (Kitchoukov et. al. 2018). Till now there is no official statistics for the enterprises in forest-based industries under CoC, but the main enterprises producing plywood are certified. Many of the managers and stakeholders are afraid and unsure about the real benefits of certification compared to costs. As stated Gilani et. al. (2017) the costs for certification could be the most important barrier for certification. The role of studies dedicated to the subject of FSC and CoC is to assess and reveal the benefits of certification translated to the “language” of entrepreneurs and local forest managers.

The problem of effects caused by the certification in FSC or CoC is rather established in the literature. The FSC itself provide quite reliable analysis. The main issues remain the perceptions of stakeholders and the benefits-costs ratio. Very often the public approached with suspicion of certification of forests or wood processing producers, and needs to be stimulated. These include in the objectives of studies devoted to the perceptions to certification. Previous research based on surveys among the forest owners and entrepreneurs in UK (Samuel, 1999) found that the principle reasons of forest owners and other supply chain participants for certification are economic. Certification would seem to have good potential as a marketing tool in the given situation (Rametsteiner, 1999). In the research about certification in Romania (Hălălişan et al. 2013) found that main benefits of FSC custody chain certification are to keep the customer and to improve the image, confirmed also by Paluš et.al.(2016). Another research revealed, that some Asian countries rated “reduce business risks” as the top FSC benefit followed by “meet corporate social responsibility goals” and “meet buyer’s requirements” of the company (Bowers et. al., .2012). Cao et.al. (2011) summarized the following main benefits of certification under FSC FM/CoC: Price premium; Product differentiation; Market access; Consumer goodwill; Environmental and social benefits; Policy incentives; Third-party assurance. Definitely the market derived benefits, or market driven (Klarić et.al., 2016) are of the most wanted and easily appreciated by the forest and wood working facilities owners.

The terms, productivity and efficiency, have been used frequently in the media over the last ten years by a variety of commentators. They are often used interchangeably, but this is unfortunate because they are not precisely the same things (Coelli et. al., 2005). Efficiency can be defined as the demand that the desired goals are achieved with the minimum use of the available resources (Martic et. al.,2009). In the far 1957 M. J. Farrell proposed that the efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions under constraints of their prices and production technology. In the current study the following elements of economic efficiency, regarding the FSC CoC certification are considered:

- The costs efficiency.
- The revenues efficiency.
- Allocative efficiency.

The allocative efficiency is well presented by the so called profitability ratios as result of total factor productivity (Coelli et. al., 2005).

The aim of the current study is to assess the economic effects of FCS and CoC certification in plywood enterprise in Bulgaria in terms of the technical efficiency of certification costs and benefits, and allocative one measured through profitability.

2. MATERIAL AND METHODS

The current study analyses the results of the implementation of FSC CoC in the supply chain and market penetration of the biggest plywood enterprise in the country. The enterprise produce plywood and hard fiberboards. In the recent years the enterprise diversified the distribution market in EU and non EU countries. Markets of the EU require certification in CoC, but these in exterior countries do not. All the features explained determine the effects of certification like difficult to highlight. By this reason in the study are implemented the following approaches:

- Data Envelopment Analysis (DEA) for overall performance of the enterprise before and after certification.
- DEA for overall performance after certification to distinguish the efficient scale of certified production.
- Deterministic assessment of the certification costs during the years the enterprise has been certified.

The classical input oriented CCR model proposed by Charnes et. al (1978) was applied in the present study. Despite the BCC model, used by Korkmaz (2011) and preferred due to the more accurate pure technical forestry efficiency estimation, it was aimed at assessing the common scale and pure factor efficiency (Martic et. al., 2009). Distinguishing the pure factor efficiency is needed to outline the problems in some of the resources involved, so we compared CCR to BCC in the manner of Kovalcik (2018). Sporcic et. al (2009) also solved the trivial DEA task of assessing the efficiency or forestry organizational units, providing the comparison of CCR and BCC. The two step procedure, comprehensively described by Cooper et al. (2007) was used in order to fill all the sufficient conditions for efficiency.

The model is used in following envelopment form (dual model):

Step 1 – estimation of efficiency

$$\min \theta \ , \qquad (1)$$

Subject to: $\sum_{i=1}^{n} \lambda_j x_{ij} - \theta x_0 \leq 0$ (2)

$\sum_{i=1}^{n} \lambda_i y_{ij} - y_0 \geq 0$ (3)

Step – 2 estimation of slacks:

$\max \sum_{i=1}^{n} s^- + \sum_{r=1}^{s} s^+$, (4)

Subject to:

$\sum_{i=1}^{n} \lambda_i x_{ij} - \theta^* x_0 = -s^-$ (5)

$\sum_{i=1}^{n} \lambda_i y_{ij} - y_0 = s^+$ (6)

Where λj are individual countries coefficients in dual form of j-th Decision Making Unit (DMU) – each DMU is one year, before or after certification. Θ is the so called efficiency scores and Θ* is the optimal efficiency, delivered by the first step. Notations s+ and s- are slacks that measure shortage of GVA (notated as y0 for the particular DMU being estimated) or surplus of resources (xij i-th type of resource of j-th country).

The main input for the analysis before and after certification are:

- Costs for raw materials – round wood of poplar, beech and other. Compared before and after the certification.
- Inventories – until DEA models allow to be used all kind of variables like input and outputs, inventories whatever they are directly indicate the problems and their reduction is a tool for improvement. DEA directly can suggest the optimal levels before and after the certification.
- Certified raw materials purchasing – directly influencing the optimality and the conditions of enterprise after the certification. Its levels can compare to the levels of the usage.

The main outputs are:

- Revenues – typical and the most indicative variable, directly presenting the state of the enterprise.
- Production of certified plywood – direct result of the certification. The bigger the share is the greater impact has certification on the enterprise improvement.

DEA models are calculated with DEA Frontier software.

In the study were used complementary models of deterministic type like profitability ratios in respect of total costs, total revenues and direct margin between produced certified plywood and costs to maintain certification. The ratios are following:

Profitability of total costs:

$$P_{TC} = \frac{PR}{TC} \quad (7)$$

Where PR is the profit of usual economic activity; TC – total costs for the period.

Profitability of total revenues:

$$P_{TR} = \frac{PR}{TR} \quad (8)$$

Where PR is the profit of usual economic activity; TR – total revenues for the period.

Profitability of certified production:

$$P_{CP} = \frac{CP - CC}{CC} \quad (9)$$

Where (CP – CC) is the margin between Certified Production (CP) and Certification Costs (CC);

3. RESULTS

The enterprise analyzed had great improvement until the 2016. Markets had gone up and the profitability had been sufficient for the purpose of stakeholders. After, markets outside the EU went down (Turkey for example) the overall state went down. On the figure 1 are shown the costs and revenues of usual activities.

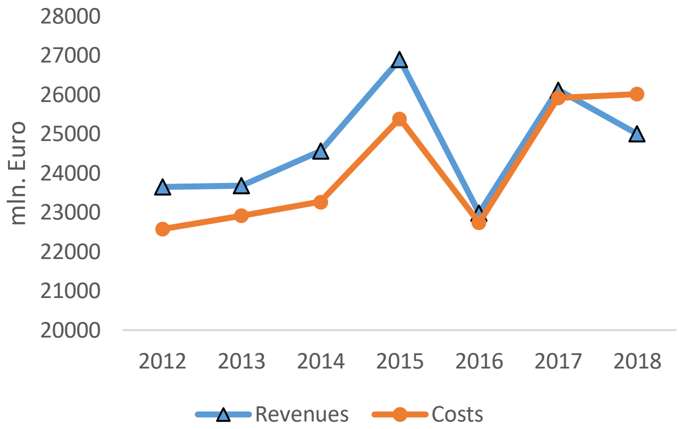

Figure 1. *Total costs and total revenues of analyzed enterprise*

The economic activity has definitely gone up after 2016, but the efficiency broke down. In fact, this is not the result of the markets that require certification. So, in the study, it is assumed that positive effects can be seen in two directions - in pushing improvement and profitability in good economic conditions and in pulling the enterprise out of the crisis.
Economic efficiencies are presented in table 1.

Table 1. *Estimated efficiencies of the analyzed inputs of production*

Year	Efficiency of inventories and material costs	Efficiency of certified raw materials, inventories and material costs	Efficiency of certified raw materials and certification costs
2012	0,89		
2013	0,94		
2014	0,94	1,00	0,06
2015	1,00	1,00	0,41
2016	0,82	0,85	0,87
2017	0,95	0,99	0,60
2018	0,93	1,00	1,00

Results in table 1 showed that the most vulnerable output is the certified production. Costs for maintaining the certificate, which on annual base the enterprise pay to auditing institution and the higher supply costs for certified raw materials put under pressure the volume of certified production. *Efficiency of certified raw materials and certification costs* includes as output only the certified production, which means that the ratio of produced plywood to supplied round poplar wood should be as greater as possible. The only efficient year in the *Efficiency of inventories and material costs* is 2015, with the best economic conditions. The effects of crisis appeared after find some reduce in the *Efficiency of certified raw materials, inventories and material costs*. The appearance of the certified production and materials place some stability and pushes the efficiency upward. The *Efficiency of certified raw materials and certification costs* revealed the power of certification in times of the crisis.

Despite the costs, higher requirements and difficulties it gains the advantage in compare to the failure of the overall system.

The main causes of the problems are presented in Table 2, in terms of the so called slacks in DEA.

Table 2. *Estimated slacks of the analyzed efficiencies*

Year	Efficiency of inventories and material costs	Efficiency of certified raw materials, inventories and material costs		Efficiency of certified raw materials and certification costs	
	Inventories	**Certified raw materials**	**Inventories**	**Certified raw materials**	**Post - cert Cost**
2012	2 062,13				
2013	1 549,36				
2014	1 349,13	0,00	-	0,00	127,26
2015	-	-	-	3 247,92	-
2016	5 803,76	741,31	3 593,63	6 897,28	0,00
2017	6 051,70	219,20	2 545,57	0,00	38,52
2018	5 828,60	0,00	-	0,00	-

Results in table 2 presented that the main problems are inventories in any level and type of efficiency. During the years from 2016 – 2017 the enterprise couldn't adapt to the changing external environment. It remains to maintain the inventories of all type and to purchase certified wood. In 2018 adaptation was done and the quantities of purchased certified poplar got into the efficient barriers. Certification costs are an issue in the beginning of certification and beginning of crisis. The problem of certified raw materials in terms only of certified production appear due to expectations in times of economic boom. But since the average share of certified production is no more than 15% the elasticity of reaction is higher than any other materials purchased.
Supplementary ratios of profitability are presented in table 3

Table 3. *Estimated profitability ratios of the analyzed efficiencies*

Year	Overall		Certified production margin
Base	**Costs**	**Revenues**	**Costs**
2012	4,8%	4,6%	
2013	3,4%	3,3%	
2014	5,6%	5,3%	-75,5%
2015	6,0%	5,6%	-30,5%
2016	1,1%	1,0%	48,6%
2017	0,8%	0,8%	130,5%
2018	-3,8%	-4,0%	287,3%

The ratios presented above reveal, that the bad conditions did not influenced the profitability of certification, and certified production. Certified production had constantly improving ability to return the investments in the pre certification costs, i.e. certification itself. The low (negative) ratios for 2018, compared to these of certified production reveal the constantly expanding role of that plywood to the abilities of surviving.

4. DISCUSSION

The research has shown that certification is useful and creates sustainability, but not at the beginning. Then the certification costs and the expensive adjustment of the plywood production processes have created risks for the enterprise under investigation. DEA models revealed a high sensitivity of certified production performance to the expectations of managers for the external environment. Under no circumstances should the cost of maintaining the standard be underestimated.

Plywood production is costly, with a huge scale, and these costs can suddenly be a very big problem when a crisis occurs. As the results of the study have shown, certified production is a stable system that has a positive effect on efficiency. It should be noted that this is an effect of CoC certified only when distributive markets call for such certification. Otherwise, the effects that certified production will have on efficiency will appear throughout the whole certification period.

The results showed a very interesting feature of certified plywood production. It follows its own path of development and reaction to the environment. The constantly growing profitability that has been established shows this. The results point to the hypothesis that large scale production and markets requiring CoC can achieve greater sustainability than if the enterprises sell only on markets that do not require such certification.

Certainly FSC certification is subject to constraints and one of them has been shown in the present study. This is the need for a cost-effective production scale that allows enterprise to survive for a one to three year low profitability period. If so the enterprise would gain a tool for sustainability. Furthermore the competitive advantage is still remaining its actuality until non certified plywood products exist on markets.

5. CONCLUSIONS

The present study revealed that certification itself does not jeopardize the profitability of production if the sufficient scale exists. Certified of production is developing steadily and predictably. Enterprises should search and diversify their production on markets with high requirements to the round wood suppliers. Certification can be threat only if scale is small or markets do not care of the producer morale. Nowadays the great competition in plywood producers and the invasion of Asian plywood of dubious quality place the requirement for establishing competitive advantage. Certification of FSC – CoC is definitely one. There are no doubt that the producers especially bigger ones are obligatory to get certified. The only issue is the scale and capabilities to overcome costs pressure. This places the need for alternative ways for gaining the sufficient scale to be find.

Acknowledgements
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PHYSICAL PROPERTIES OF PLYWOOD DURING PROLONGED WATER EXPOSURE

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ABSTRACT

The aim of this research is to study the physical properties of experimental plywood bonded with alcohol-soluble phenol-formaldehyde resin during prolonged water exposure. On the basis of the obtained data for the changes of the physical properties of plywood after exposure to prolonged water treatment of 192 days, water resistance of experimental plywood is evaluated. Tests for the thickness swelling, volume swelling and water absorption are made after immersion in water for prolonged period in controlled laboratory conditions. The measuring of thickness, length, width and mass of plywood test specimens for determination of these properties is made after immersion in water for the period of 1 day (24 hours) to 192 days (4608 hours).

Plywood model in this experiment was made from peeled beech veneers bonded with pure alcohol-soluble phenol-formaldehyde resin.

The results from the research showed that the plywood model is characterized by uniform density; it is dimensionally stable during and after prolonged water exposure, without any deformations of the shape of the test specimens. The changes of the values of thickness and volume swelling, as well as the values of water absorption in the analyzed period are proportional to change of the duration of the period of water exposure.

According to the obtained data from the tests of these properties the plywood model meets the requirements for load-bearing plywood for use in construction.

Key words: plywood, alcohol-soluble phenol-formaldehyde resin, physical properties, water resistance, prolonged water treatment, thickness swelling, water absorption, dimensional stability

1. INTRODUCTION

The world deficit of quality wood raw material is a motive to make researches in the area of structural wood-based panels in order to produce stable panels that will meet the exploitation requirements in modern construction. Because of its characteristics, plywood panels are most durable wood-based panels for constructional needs. These panels are considerate as constructional material with highest performance, so its application as structural or non-structural materials in wooden buildings construction is on a significant level. Plywood panels have high strength to weight ratio, decreased anisotropy compare to solid wood, as well as possibility to receive and distribute loads. Because of these characteristics, plywood panels are used in many applications in construction of wooden buildings, such as flooring, siding, roofing, shear walls etc.

High dimensional stability and consistency of plywood panels under water impact is a basic prerequisite for their use in construction in humid conditions. As a result of this, the researches in the field of wood-based panels are directed to finding methods and technical-technological solutions for production of panels with high physical properties. These properties are important and they have impact on other properties, so during determination of the plywood quality a special attention is paid on them.

Plywood properties, especially its consistency on prolonged water exposure depend on the resin used for veneer bonding. The research presented in this paper comprises a laboratory production of water-resistant beech plywood bonded with alcohol-soluble phenol-formaldehyde resin. Tests of the physical properties of this plywood model were made in order to determinate the consistency on prolonged water exposure.

2. EXPERIMENTAL METHODS

For the realization of the research experimental eleven-layered plywood was made from beech peeled veneers with thickness of 1,5 and 1,85 mm (Figure 1). The veneers with thickness of 1,5 mm runs parallel to the longitudinal axis of the panel, while the veneers with thickness of 1,85 mm runs perpendicular to this axis. The orientation of adjacent layers in plywood structure is at right angle, which means that the grain direction of the surface layers is parallel to the length of the panel. The central layer of plywood structure represents a veneer sheet with thickness of 1,85 mm, oriented perpendicular to the face grain of the panel. The moisture content of the veneers used in plywood was 9,77 %.

Alcohol-soluble phenol-formaldehyde resin (RFE-2) was used as plywood binder which is a product of company “Fenoplast 99” OOD, Ruse, Republic of Bulgaria. Ethyl alcohol was used as resin solvent without adding filler and modifier. The binder with concentration of 51% was applied in quantity of 180 g/m^2.

The composition of veneers with applied binder was put in a hot press using the following parameters: specific pressure of 1,8 kg/cm^2, temperature of hot plates 155ºC and pressing time of 30 min.

After pressing process was completed, plywood is cooled to the ambient temperature of 20ºC into the press for 30 minutes under reduced pressure. Cooling of plywood panel into the press is made by cooling the hot plates with circulating cold water into the plates. The plywood cooling was done in order to obtain flat panel and to reduce the warping and deformation of the pressed panel.

The experimental plywood had a density of 828,35 kg/m^3, dimensions of 1180×910×15,61 mm and moisture content of 8,86 %.

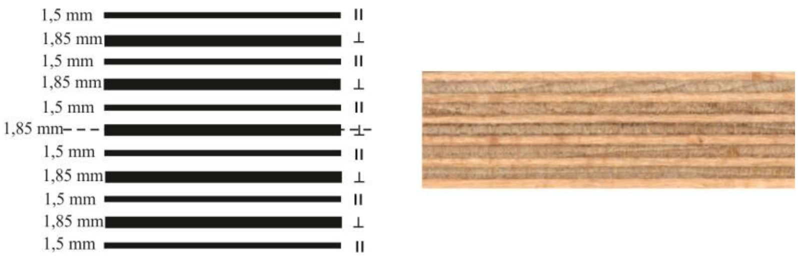

Figure 1. *Pattern and cross-section of plywood structure*

On the basis of the obtained data for the changes of the physical properties of plywood after exposure to prolonged water treatment of 192 days, water resistance of experimental plywood is evaluated. Tests for the thickness swelling and water absorption are made after immersion in water for prolonged period in controlled laboratory conditions. The measuring of thickness, length, width and mass of plywood test specimens for determination of these properties is made after immersion in water for the period of 1 day (24 hours) to 192 days (4608 hours). Control measurings were done in intervals of: 1 day, 2, 3, 4, 6, 8, 12, 16, 24, 32, 42, 52, 72, 92, 132, 152 and 192 days.

The test specimens with standard dimensions of 100×100 mm for research and analysis are made according to the national standard for wood-based panels MKS D.C8.100. The thickness swelling and water absorption of plywood are tested according to the national standard MKS D.C8.104.

The obtained data were statistically analyzed. One way ANOVA was used to determinate the significance of the effect of the duration of the water treatment on the values of the tested physical properties. Tukey’s test was applied to evaluate the statistical significance between the mean values of the properties at different duration of the immersion in water.

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The obtained results from the tests of physical properties of the experimental plywood are shown in tables 1, 2, 3, 4, 5, 6 and on figures 2, 3 and 4.

The analysis of the obtained results for tested physical ptoperties of plywood showed a tendency of increasing of the mean arithmetical values by the increasing of the duration of the treatment of the test specimens. Increasing of the values of all tested properties is intense in the initial period of treatment whereupon the maximal value is achieved in the final control measuring.

Table 1. *Statistical values for relative water absorption of experimental plywood*

Duration of water treatment [days]	***N***	***Mean (%)***	***Std. Deviation (%)***	***Std. Error (%)***	***95% Confidence Interval for Mean (%)***		***Min (%)***	***Max (%)***
					Lower Bound	***Upper Bound***		
1	5	20,47	1,18	0,53	19,01	21,93	19,22	21,99
2	5	26,73	1,06	0,47	25,42	28,04	25,46	28,10
3	5	30,84	1,03	0,46	29,56	32,12	29,73	32,04
4	5	33,64	1,07	0,48	32,31	34,97	32,38	34,78
6	5	37,01	1,25	0,56	35,46	38,57	35,57	38,61
8	5	38,88	1,23	0,55	37,35	40,41	37,48	40,49
12	5	40,51	1,23	0,55	38,98	42,04	39,17	41,98
16	5	42,02	1,36	0,61	40,32	43,71	40,48	43,27
24	5	43,24	1,40	0,63	41,50	44,98	41,64	44,29
32	5	45,29	1,51	0,67	43,42	47,16	43,44	46,66
42	5	47,14	1,55	0,69	45,21	49,07	45,24	48,55
52	5	48,70	1,57	0,70	46,74	50,65	46,75	50,20
72	5	51,09	1,62	0,72	49,08	53,10	49,03	52,62
92	5	52,79	1,65	0,74	50,74	54,84	50,70	54,41
132	5	54,04	1,74	0,78	51,88	56,21	51,85	55,82
152	5	55,93	1,88	0,84	53,59	58,27	53,60	57,90
192	5	57,26	1,98	0,89	54,80	59,73	54,76	59,35

The analysis of the obtained results for the relative water absorption of experimental plywood (Table 1, Table 2, Fig. 2) showed increasing of the mean arithmetical values of this property by prolongation of the duration of the water treatment. These values are within the limits of 20,47 % after immersion in water for 1 day to 57,26 % at the end of the water treatment of 192 days. The increasing of relative water absorption has highest intensity in the initial period of water treatment (period of 1 to 2 days). The increment of the mean value of relative water absorption in this initial period of immersion is 30,57%. Further increasing of the relative water absorption has lower intensity, so in the period from 48 to 72 hours (from the second to the third day) the increment in the mean value of this property is twice as low as the increment in the mean value of relative water absorption for the period of 24 up to 48 hours.

The ANOVA: ($F(16;68) = 260,838$; $p<<0,001$) indicated that there is statistically significant difference in the mean values of relative water absorption between different duration of the water treatment. The post-hoc Tukey’s test showed that after immersion period of 6 days up to 192 days (the end of the water treatment) the differences in the mean values of the relative water absorption between two successive measuring are not statistically significant. In this period there is a further increasing of the relative water absorption, but with lower intensity. The increment of the mean value of the relative water absorption between two successive measuring in the period between 6 days and 192 days does not exceed 5,06%.

If we compare the value of the relative water absorption after 6 days immersion in water and the value of the same property at the end of the water treatment (192 days) there is statistically significant difference, where the value after 192 days is higher for 54,72% compare to the value of the relative water absorption after 6 days of immersion.

Table 2. *Increment of the mean value of relative water absorption between two* successive measuring - *ΔUr*

Period for which the increment is calculated	***ΔUr [%]***
1→2d	30,57
2→3d	15,39
3→4d	9,08
4→6d	10,01
6→8d	5,06
8→12d	4,18
12→16d	3,72
16→24d	2,91
24→32d	4,74
32→42d	4,08
42→52d	3,30
52→72d	4,92
72→92d	3,32
92→112d	2,38
112→152d	3,50
152→192d	2,37

**d-days*

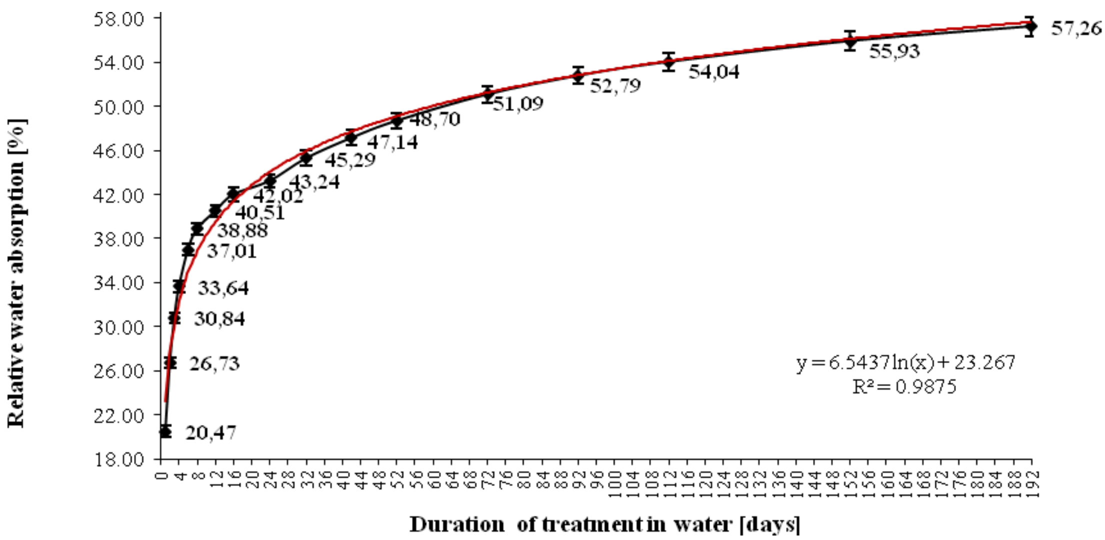

Figure 2. *Increase of the mean arithmetical values of relative water absorption for period of 1 to 192 days*

The analysis of the obtained test results for the relative thickness swelling of experimental plywood (Table 3, Table 4, Fig. 3) showed increasing of the mean arithmetical value of this property by prolongation of the duration of the water treatment. The mean arithmetical value of this property is within the limits of 7,18 % for the immersion period of 1 day to 10,84 % at the end of the water treatment of 192 days.

The increasing of relative thickness swelling has highest intensity in the initial period of water treatment (period of 1 to 2 days). The increment of the mean value of relative thickness swelling in this initial period of immersion is 15,67%. The further increasing of the relative thickness swelling is with lower intensity, so in the period from 48 to 72 hours (from the second to the third day) the increment in the mean value of this property is more than twice as low as the increment in the mean value of relative thickness swelling for the period of 24 up to 48 hours.

The ANOVA: ($F(16;68) = 57,033$; $p<<0,001$) indicated that there is statistically significant difference in the mean values of relative thickness swelling between different duration of the water treatment. The post-hoc Tukey's test showed that after immersion period of 2 days up to 192 days (the end of the water treatment) the differences in the mean values of the relative thickness swelling between two successive measuring are not statistically significant. In this period there is a further increasing of the relative thickness swelling, but with lower intensity. The increment of the mean value of the relative thickness swelling between two successive measurments in the period between 2 days and 6 days does not exceed 6,33%, in the period between 6 and 24 days does not exceed 2,63% and in the period between 24 and 192 days does not exceed 0,82%. In the last period of treatment between the last two measurments (152 to 192 days) there is no difference at all between the mean values of the relative thickness swelling.

Such data obtained from the last measurements at the end of treatment in water of 192 days indicate that the low water absorption at the end of the treatment can not cause major changes in the thickness swelling of the experimental plywood. To see if there is a further increase in thickness, it is necessary to continue the treatment in water until a full saturation of the plywood with water is achieved.

Table 3. *Statistical values for relative thickness swelling of experimental plywood*

Duration of water treatment [days]	*N*	*Mean (%)*	*Std. Deviation (%)*	*Std. Error (%)*	*95% Confidence Interval for Mean (%)*		*Min (%)*	*Max (%)*
					Lower Bound	*Upper Bound*		
1	5	7,18	0,28	0,12	6,84	7,52	6,82	7,47
2	5	8,30	0,31	0,14	7,92	8,68	7,86	8,62
3	5	8,83	0,36	0,16	8,38	9,28	8,24	9,16
4	5	9,29	0,35	0,16	8,85	9,73	8,74	9,60
6	5	9,81	0,36	0,16	9,37	10,25	9,27	10,14
8	5	10,07	0,27	0,12	9,74	10,40	9,70	10,36
12	5	10,21	0,24	0,11	9,91	10,50	9,96	10,53
16	5	10,38	0,30	0,14	10,00	10,75	10,10	10,83
24	5	10,51	0,32	0,14	10,11	10,90	10,19	10,94
32	5	10,59	0,30	0,13	10,22	10,95	10,27	10,99
42	5	10,67	0,33	0,15	10,27	11,08	10,35	11,10
52	5	10,70	0,31	0,14	10,32	11,08	10,42	11,11
72	5	10,77	0,33	0,15	10,36	11,18	10,47	11,19
92	5	10,81	0,32	0,14	10,42	11,21	10,51	11,24
132	5	10,83	0,31	0,14	10,45	11,21	10,55	11,25
152	5	10,84	0,31	0,14	10,45	11,23	10,55	11,27
192	5	10,84	0,31	0,14	10,45	11,23	10,55	11,27

Table 4. *Increment of the mean value of relative thickness swelling between two successive measuring - ΔBdr*

Period for which the increment is calculated	*ΔBdr [%]*
1→2d	15,67
2→3d	6,33
3→4d	5,20
4→6d	5,60
6→8d	2,63
8→12d	1,35
12→16d	1,66
16→24d	1,26
24→32d	0,78
32→42d	0,82
42→52d	0,24
52→72d	0,67
72→92d	0,40
92→112d	0,14
112→152d	0,07
152→192d	0,00

**d-days*

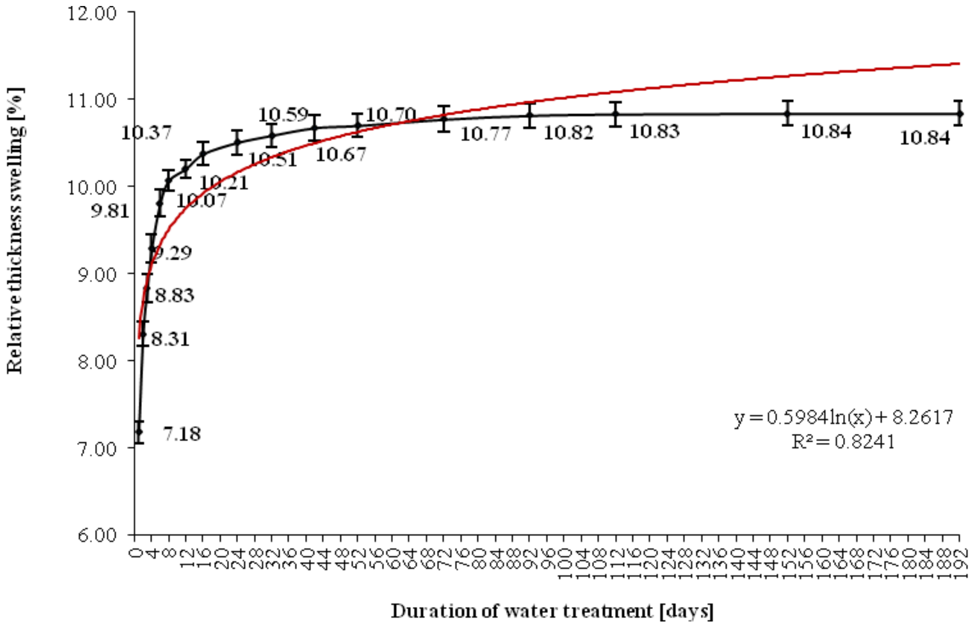

Figure 3. *Increase of the mean arithmetical values of relative thickness swelling for period of 1 to 192 days*

The national standard MKS D.C5.032 for wood-based panels for use in construction defines 12 % as a limit for relative thickness swelling for immersion period of 24 hours. According to the tests results the experimental plywood meets the requirements of this standard. After full water treatment in the period of 192 days the experimental plywood does not exceed the value of 12 %. This shows that the plywood model is dimensionally stable to water impact, which is one of the prerequisite for plywood application in high humidity conditions and for structural use in construction.

Table 5. *Statistical values for relative volume swelling of experimental plywood*

Duration of water treatment [days]	***N***	***Mean (%)***	***Std. Deviation (%)***	***Std. Error (%)***	***95% Confidence Interval for Mean (%)***		***Min (%)***	***Max (%)***
					Lower Bound	***Upper Bound***		
1	5	7,49	0,28	0,13	7,14	7,83	7,12	7,81
2	5	8,62	0,32	0,15	8,22	9,03	8,16	8,99
3	5	9,17	0,37	0,16	8,72	9,62	8,59	9,54
4	5	9,64	0,35	0,16	9,20	10,08	9,12	9,98
6	5	10,17	0,37	0,16	9,71	10,62	9,65	10,52
8	5	10,44	0,28	0,13	10,09	10,79	10,11	10,77
12	5	10,58	0,25	0,11	10,27	10,90	10,33	10,94
16	5	10,76	0,33	0,15	10,34	11,17	10,50	11,26
24	5	10,90	0,34	0,15	10,47	11,33	10,60	11,37
32	5	10,98	0,32	0,14	10,58	11,38	10,69	11,43
42	5	11,08	0,34	0,15	10,65	11,50	10,78	11,53
52	5	11,11	0,31	0,14	10,72	11,50	10,86	11,54
72	5	11,19	0,34	0,15	10,77	11,60	10,91	11,63
92	5	11,26	0,32	0,14	10,87	11,65	10,95	11,68
132	5	11,28	0,31	0,14	10,90	11,66	10,99	11,70
152	5	11,29	0,31	0,14	10,90	11,67	10,99	11,72
192	5	11,29	0,31	0,14	10,90	11,67	10,99	11,72

The analysis of the obtained test results for the relative volume swelling of experimental plywood (Tables 5 and 6, Fig. 4) showed increasing of the mean arithmetical values of this property by prolongation of the duration of the water treatment. The mean arithmetical value of this property is within the limits of 7,49 % for the immersion period of 1 day to 11,29 % at the end of the water treatment of 192 days. The ANOVA: ($F(16;68) = 57,644$; $p<<0,001$) indicated that there is statistically significant difference in the mean values of relative volume swelling between different duration of the water treatment. Highest intensity of increasing of relative volume swelling is achieved in the initial period of water treatment (period of 1 to 2 days) in which period the increasing of the value of this property is 15,09 %. After immersion period of 2 days up to 192 days (the end of the water treatment) the differences in the mean values of the relative volume swelling between two successive measuring are not statistically significant. In this period there is a further increasing of the relative volume swelling, but with lower intensity. The increment of the mean value of the relative volume swelling between two successive measurings in the period between 2 days and 6 days does not exceed 6,38%, in the period between 6 and 24 days does not exceed 2,65% and in the period between 24 and 192 days does not exceed 0,91%. In the last period of treatment between the last two measurings (152 to 192 days) there is no difference at all between the mean values of the relative volume swelling.

The increasing of the relative volume swelling is very similar to the increasing of the relative thickness swelling. This is due to the fact that the volume swelling of plywood is primary a result of the swelling in thickness. The changes of the dimensions of the plywood in length and width direction are minor and these changes do not have a big impact on volume swelling of plywood. The biggest changes in length and width dimensions of the plywood panel occur after initial period of 1 day of immersion in water. After this period of immersion there are almost no changes in these dimensions of the panel.

***Table 6.** Increment of the mean values of relative volume swelling between two successive measuring - ΔBvr*

Period for which the increment is calculated	***ΔBvr [%]***
1→2d	15,09
2→3d	6,38
3→4d	5,13
4→6d	5,50
6→8d	2,65
8→12d	1,34
12→16d	1,70
16→24d	1,30
24→32d	0,73
32→42d	0,91
42→52d	0,27
52→72d	0,72
72→92d	0,63
92→112d	0,18
112→152d	0,09
152→192d	0,00

**d-days*

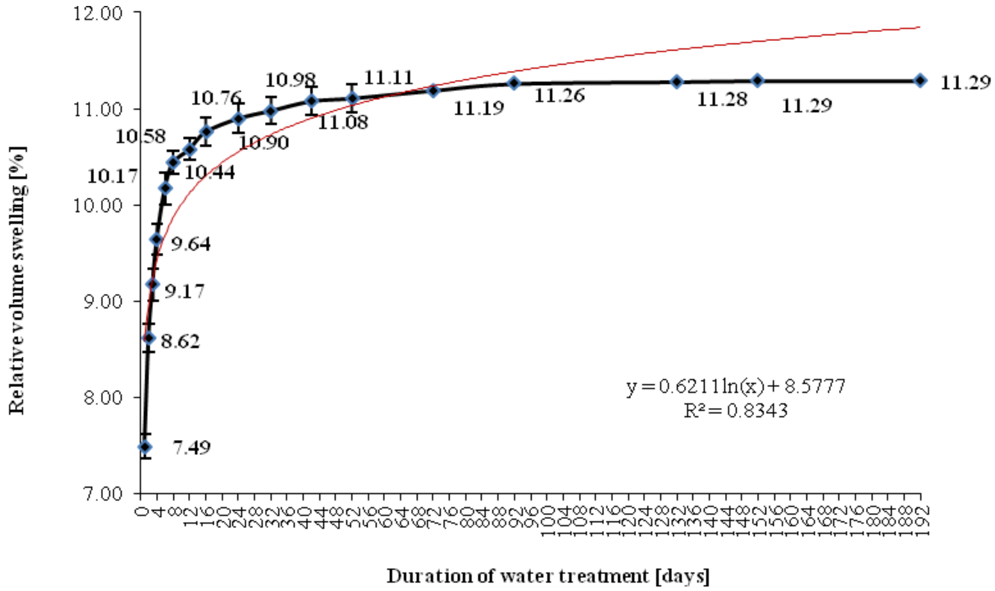

***Figure 4.** Increase of the mean arithmetical values of relative volume swelling for period of 1 to 192 days*

The obtained results for relative water absorption, relative thickness swelling and relative volume swelling correspond with the results of similar researches known in listed literature. Iliev (2007) for immersion period of 1 to 3 days gives the values of 32,82 to 42,92 % for relative water absorption and 6,94 to 7,54 % for relative thickness swelling for seven-layer beech plywood overlaid with phenol-formaldehyde foil. Iliev *et al*. (2008) for the same period of water treatment gives the values of 31,97 to 41,16 % for relative water absorption and 6,88 to 7,15 % for relative thickness swelling of nine-layer beech plywood overlaid with phenol-formaldehyde foil. Jakomovska Popovska (2011) for water treatment of nine-layer beech plywood in the period of 1 day to 3 days gives the values within the limits of 32,43 to 44,34% for relative water absorption and 9,95 to 11,06 % for relative thickness swelling.

Aziri (2012) gives the value of 33,26 % for relative water absorption and 6,85 % for relative thickness swelling of nine-layered beech plywood after immersion in water for 1 day and 65,66 % and 8,68 % after immersion in water for 52 days. Aziri *et al.* (2013) gives the values of 26,76 to 53,27 % for relative water absorption, from 5,31 to 8,00 % for relative thickness swelling and from 6,24 to 9,50% for relative volume swelling of seven-layered beech plywood overlaid with phenol-formaldehyde foil for immersion period of 1 to 52 days.

From the analysis of the results from the research of the physical properties of plywood during prolonged water exposure a general statement can be made, according to which there is a tendency of increasing of the mean arithmetical values of all tested properties by the increasing of the duration of the water treatment of the test specimens. Increasing of the values of all tested properties is intense in the initial period of treatment whereupon the maximal value is achieved in the final measuring.
The visual analysis of plywood test specimens after completed water treatment of immersion for 192 days showed that there were no deformations, delaminating and warping of the plywood test specimens (Fig. 5). The stability of the form and the structure of the plywood panel after prolonged water exposure show that high-quality plywood is made durable for application in high humidity conditions.

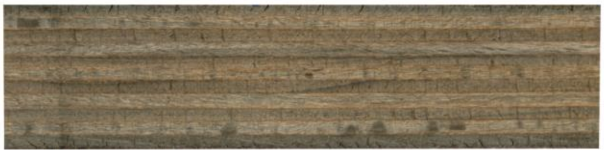

Figure 5. *Test specimen of plywood after immersion in water for period of 192 days*

4. CONCLUSIONS

On the basis of the realized research it can be concluded that the experimental plywood represents a stable material with a density that exceeds the requirements of the national standard for structural plywood for use in construction. The plywood model is dimensionally stable during and after prolonged water treatment, without any deformations of the shape of the test specimens.
From the obtained test results for water absorption, thickness swelling and volume swelling of the plywood model it can be concluded that the experimental plywood model is resistant to water impact, which is one of the requirements for plywood application in high humidity conditions in construction. Plywood water resistance can be additionally improved by overlaying the panel with phenol-formaldehyde resin impregnated paper.

According to the tests results of the physical properties the experimental plywood meets the requirements of the national standard and can be used as load-bearing panel in construction. After full water treatment in the period of 192 days the plywood model does not exceed the limitation value of 12% for thickness swelling defined by the standard. The analysis of the research results showed that after analyzed period of treatment of 192 days the maximum value of the water absorption is not achieved and the values still have increasing tendency. The maximum value of this property can be defined only by continuing the experiment in the period of time over 192 days.

The results from the research can help in selection of materials and defining the technological parameters for production of dimensionally stable water-resistant plywood durable for application in high humidity conditions.

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USE OF NATURAL FIBER REINFORCED BIO-PLASTIC FILAMENTS FOR 3D PRINTERS AS ALTERNATIVE TO PETROLEUM-BASED PLASTIC FILAMENTS

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ABSTRACT

Use of natural fibers in thermoplastic filaments for 3D printers has recently increased due to its significant advantages such as environmentally friendly and cheaper as compared to the synthetic fibers and fossil sources. Natural fibers, in particular for wood fibers or flour, are the most abundant environmental friendly bio materials for thermoplastics due to their low cost, low density, high modulus, non-toxic, easy supply, recycling and abrasion properties. Cellulose is non-allergic, tolerating high temperatures, and is an excellent electric insulator material, which can be processed with many 3D-printing methods. As the natural fibers are incorporated into the thermoplastics, the price of filaments for 3D printers will decrease, which considerably increase the use of 3D printer by consumers in near future. The consumers prefer environmentally friendly filaments for their 3D materials. Petroleum plastics such as acrylonitrile butadiene styrene (ABS), polyethylene, and polypropylene are harmful to the ecosystem and environment, although their good processing properties and relatively cheap price than bioplastics. However, due to increasing shortage in fossil fuels, the price of petroleum plastics is getting increasing. For this reason, use of bio plastics such as polylactic acid (PLA), Poli-β-hidroksibutirat (PHB), and thermoplastic starch in the thermoplastic filament production for 3D printers have rapidly increased. In addition, use of natural fibres help lowering the usage of petroleum based plastics and negative environmental effects. In this study, properties of the natural fibers and bioplastics are studied. In addition, the quality properties of the 3D printed products produced from natural fibers and bioplastics using 3D printers were studied.

Key words: natural fibers, bioplastics, 3D printer, wood, thermoplastics, biocomposite

1. INTRODUCTION

3D printing is an attractive technology that offers numerous new possibilities for the manufacturing of products. It enables users to create real objects based on a virtual computer model and thus opens up an almost unimaginable number of possibilities. The development of 3D printing has seen extraordinary growth over the past few years. The bio based filaments used in the production of 3D printed specimens are produced from thermoplastics and wood or other plant fibres. Additive manufacturing (AM) technologies, also known as 3D printing, includes different technologies which have in common manufacturing of a part by depositing material layer-by-layer Conner et al., 2014).

3D printing is classified as an additive manufacturing (AM) process, where the material is added in layers, allowing users to create a real product directly from a 3D computer model. Such a technology is the opposite of conventional subtractive processes, such as CNC milling, where the product is the result of the removal of material; formative processes (casting or forging), where a mould is usually required; and joining processes, such as welding and bonding. There are several types of 3D printing process, but all of them are based on producing an object layer by layer. In this way, users can create complex shapes that are not otherwise possible by forming and moulding. The variety of materials (different plastics, metals and composites) offers the possibility to produce a wide range of products. However, 3D printing is best suited for the production of prototypes, small series, and unique products for the market. The development of 3D printing has seen extraordinary growth over the past few years. For example: the technology of photopolymers that consolidate with UV light has seen many improvements, 3D printing technology in several colours is now possible, and laser-sintering technologies that enable the production of finished products for toolmaking, medicine and prosthetics are well established. There are also possibilities to use 3D printing in the construction industry, with the printing of concrete forms. Typical shapes of bioplastics and natural fibers are given in Figure 1.

A. **B.** **C.**

Figure 1. *A: Bioplastic (Polylactic acid). B: Wood fibers. C: Wood flour*

Typical filament extruder and resulting filaments from natural fibers and bioplastics are given in Fgures 2 and 3, respectively.

Figure 2. *Wood/polymer filament extruder*

Figure 3. *Wood/PLA filament for 3D printing*

Main advantages of 3D printing are possibility to produce complex products without special tools or moulds etc., for producing prototypes of low-volume customized products or unique one piece products and efficiently using the raw material, leading to low or zero waste (Wimmer et al., 2015). Materials for 3D printing range from polymers (polyamide, acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyvinyl alcohol (PVA) to even ceramic, gypsum, metals (stainless steel, gold and silver, titanium) to even concrete for 3D printing in the construction industry (Henke and Treml, 2013).

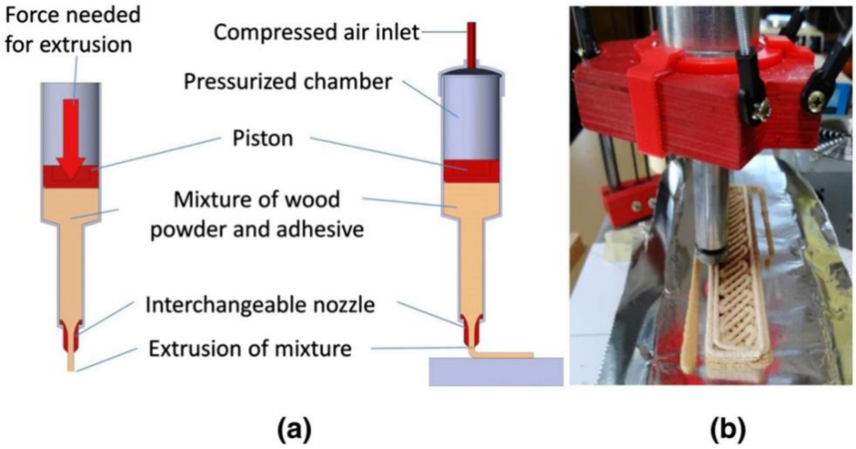
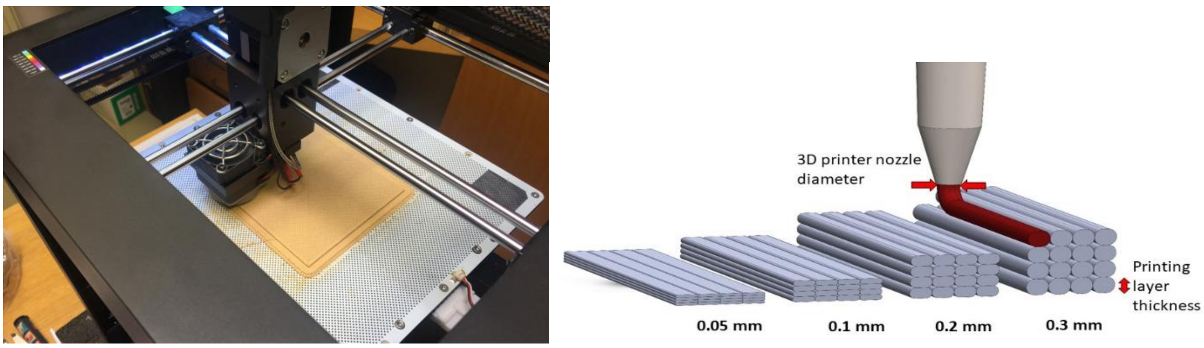


Figure 4. *a) Test setup for measuring the extrusion force by means of a universal testing machine (left) and the test set-up for 3D printing with a pressurized chamber (right), b) 3D printing with a mixture of wood powder and adhesive*



A. **B.**

Figure 5. *A: Printing of wood/PLA specimen using 3D printer. B: Different printing layer thickness*

Two of the factors that limit the expansion of 3D printers are the price and the ecological effects of the materials. In high-performance printers for professional use, the printing material is supplied by the manufacturer of the printer, for example, UV-curing resin materials for laser sintering (mostly with an unrevealed composition and patent restrictions) have a high price, because they are adapted to their machine's settings. Cheaper 3D printers use less expensive polymers; however, most of the materials are of synthetic origin, which means a potential for introducing harmful materials into the environment. However, with the development of new materials and lower prices for 3D technologies, 3D printing could expand into the area of manufacturing unique end-products or small batches of special products. There are a number of possibilities for lowering the price and the health-associated hazards for printing materials. One of them is the use of natural materials such as wood and resins.
The thermoplastic filaments used in the 3D printers, such as ABS, polyethylene, and polypropylene, are mostly produced from petroleum-based fossil fuels. However, these plastics are harmful to environment, humans, and aquatic animals. For this reason, many countries have focused on the production of filaments based on the bio plastics such as polylactic acid (PLA), polyhydroxybutyrate

(PHB), and thermoplastic starch. Although the petroleum plastics are cheaper and easily available as compared to the bioplastics, their use is decreasing due to significant advantages of bioplastics such as easy-supply, recycling, renewability, low-abrasion to machine tools, biodegradability and easy compostability after disposal (Ayrilmis et al. 2019a). Furthermore, natural fibers such as wood, flax, hemp, and jute are environmentally friendly lignocellulosic sources and used as reinforcing filler for thermoplastic composites. The moisture of wood powder should be less than 1% before compounding in the extruder because steam generation cause to micro bubbles and voids in the material

2. BIOPLASTICS

Bio-plastics are a form of plastics derived from plant sources such as sweet potatoes, soya bean oil, sugarcane, hemp oil, and corn starch. These polymers are naturally degraded by the action of microorganisms such as bacteria, fungi and algae (Reddy et al., 2013). The problems of conventional plastics are, taking decades to degrade in nature and are produced by non-renewable sources like petroleum, coal and natural gas. Environmental, economic, and safety challenges have provoked many scientists to partially substitute petrochemical-based polymers with biodegradable one’s i.e. (Reddy et al., 2013). The common types of bio-plastics are based on cellulose, starch, poly lactic acid (PLA), poly-3- hydroxybutyrate (PHB). The classification of biodegradable polymers are given in Figure 6.

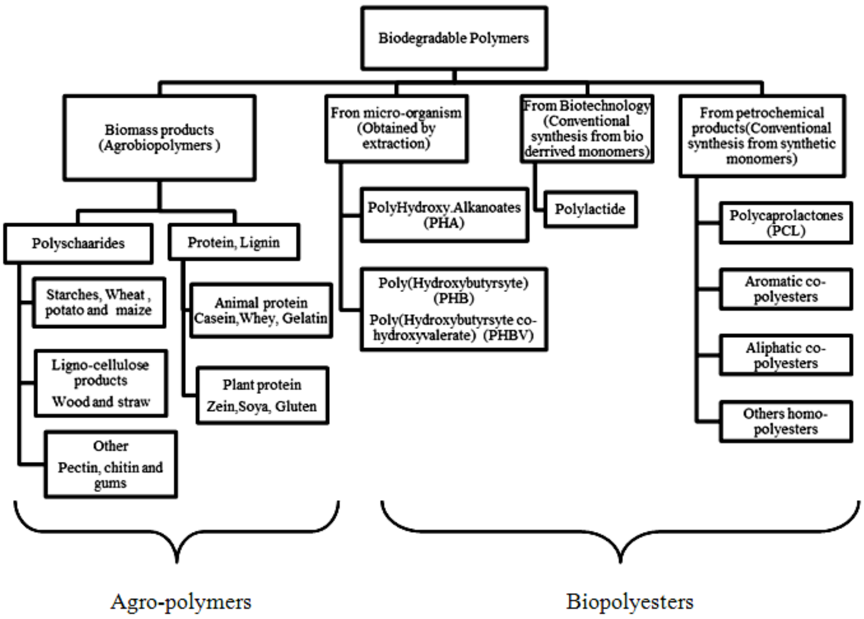


Figure 6. *The classification of biodegradable polymers*

3. NATURAL FIBERS

There are six basic types of plant-fibers. They are classified as follows: bast fibers (jute, flax, hemp, ramie and kenaf), leaf fibers (abaca, sisal and pineapple), seed fibers (coir, cotton and kapok), core fibers (kenaf, hemp and jute), grass and reed fibers (wheat, corn and rice) and all other types (wood and roots). Of these fibers, jute, ramie, flax, and sisal are the most commonly used fibers for polymer composites (Ayrilmis et al., 2016).

3.1. Chemical and mechanical composition of plant-fibers

The chemical composition of plant-fibers varies depending upon the type of fiber, climate condition, age and the digestion process. Component mean values of some plant-fibers are shown in Table 1 (Ashori, 2006). The properties of each constituent contribute to the overall properties of the fiber. Primarily, fibers contain cellulose, hemicellulose, lignin, and extractives in various amounts and chemical compositions. Cellulose is the essential component of all plant-fibers. The molecular structure of cellulose is responsible for its supramolecular structure and this, in turn, determines many of its chemical and physical properties (Ayrilmis et al., 2016). The performance of natural-fiber/thermoplastic composites depends on several factors, including fibers chemical composition, cell dimensions, microfibrillar angle, defects, structure, physical properties, and mechanical properties, and also the interaction of a fiber with the polymer (Balaji et al., 2014-2015). In order to expand the use of natural fibers for the filaments used in 3D printers and improved their performance, it is essential to know the fiber characteristics.

Table 1. *Comparison of physical and chemical properties of plant-fibers with those of wood raw materials (Ashori, 2006)*

Properties	Kenaf	Straw	Bagasse	Bamboo	Eucalyptus	Birch	Spruce
Physical:							
Fiber length, mm	1.3†	1.3	1.7	2.3	1.0	1.9	3.6
Fiber width, µm	27†	12.9	20	14.4	18	25	35
Felting factor‡	49†	102	85	161	51	58	101
Chemical: Ψ							
Holocellulose, %	76.5	78.1	77.8	76.6§	74§	81§	71§
Hemicellulose, %	32.6	24.1	27.9	19.5§	18§	40§	27§
Lignin, %	16.2	18.4	20.8	23.4§	26§	19§	29§

† Dimensions for whole stem kenaf from bast and core in the ratio of 35% and 65%, respectively.
‡ The ratio of fiber length to fiber width.
Ψ Expressed on dry matter.
§ Extractive free basis.

Cellulose is a linear chain of ringed glucose molecules and has a flat ribbon-like conformation. The repeat unit is comprised of two anhydroglucose rings. Within these cellulose fibrils there are regions where the cellulose chains are arranged in a highly ordered (crystalline) structure, and regions that are disordered (amorphous-like). The structure and distribution of these crystalline and amorphous domains within cellulose fibrils have yet to be rectified. However, it is these crystalline regions contained within the cellulose microfibrils that are extracted, resulting in cellulose nanocrystals (CNCs) (Ayrilmis et al., 2016). Lignin is a complex hydrocarbon polymer with both aliphatic and aromatic constituents. Its mechanical properties are lower than those of cellulose. Lignin acts as the plastic matrix that, in combination with hemicellulose, binds fibers together and provides woody material with its structural rigidity and resistance to moisture and microbial attack (Ayrilmis et al., 2016). The mechanical properties of fibers as compared to conventional polymers are given in Table 2 (Ashori, 2008).

Table 2. *Mechanical properties of fibers as compared to conventional polymers (Ashori, 2008)*

Fiber	Density (g/cm^3)	Elongation (%)	Tensile strength (MPa)	Young's modulus (GPa)
Fibers (Reinforcements)				
Cotton	1.5-1.6	7.0-8.0	287-800	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp	1.5	1.6	690	70
Ramie	1.5	1.2-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22.0
Coir	1.2	30.0	175	4.0-6.0
Viscose (cord)	-	11.4	593	11

Soft wood (kraft)	1.5	-	1000	40
E-glass	2.5	2.5	2000-3500	70.0
S-glass	2.5	2.8	4570	86.0
Aramid (normal)	1.4	3.3-3.7	3000-3150	63.0-67.0
Carbon (standard)	1.4	1.4-1.8	4000	230.0-240.0
Polymers (Resins/Matrices)				
ABS	1.05	10	55	2.8
Polycarbonate	1.22	100	62	2.3
Polyetherimide	0	-	105	2.8
Nylon	1.12	29	66	3.5
Polyethylene (HDPE)	0.95	30	28	1.04
Polypropylene	0.9	200	35	0.83
Polystyrene	1.05	15	35	2.76
Epoxy Resin	-	6.2	32	0.5

Wood fiber is one of the most abundant environmental friendly materials for thermoplastics due to its low cost, low density, recycling and abrasion properties. In the filament production, wood flour is used as a by-product in the manufacturing of timber and workshop, furniture, doors and windows. Cellulose is non-allergic, tolerating high temperatures, and is an excellent electric insulator material, which can be processed with many 3D-printing methods. Natural fibers are suitable to reinforce a wide variety of thermoplastics such as polypropylene, polyethylene, polystyrene, polyvinyl chloride, and polyamides. In general, natural fibers have a higher Young's modulus as compared to commodity thermoplastics thereby contributing to the higher stiffness of the composites.

When used natural fibers, its orientation is important for final product properties. In FDM technology, 3D printing wood-fibre orientation appears to follow the printing orientation of the filament, while inter filament and interlayer interactions could be considered as the weakest link of the printed material. Some specific properties of wood can also reflect in the 3D printed products such as high swelling ratio which reflects their anisotropic hygroelastic properties (Duigou et al., 2016). The idea of the research was to use rheometer to measure properties of 3D printed parts and effect of different printing settings, materials and temperature on properties of final 3D printed products.

Great interest exists in 3D printing with eco-friendly and recycled materials including wood, cellulose, natural fibres, sugars, lignin (Wimmer et al., 2015) or other natural resins and several materials that contain wood particles have appeared on the market, but not much was published on its properties and properties of parts printed from this materials. The processing technology of 3D printing is similar to the co-extruding the melt thermoplastic polymer and wood filler, but the main differences are in extruder type and its working process, the pressures during extrusion and cooling/hardening conditions after extrusion.

Wood is an organic material that is widely available in the form of wood residues. Small pieces of wood, chips and particles can be milled into smaller fractions to provide a fine wood powder, which can then be used as a filler material in 3D printing with conventional plastic materials. Wood powder can also be used for printing in combination with a variety of commercial and natural adhesives. In this way the impact of 3D-printed products on the environment can be dramatically reduced. 3D products printed with wood powder and adhesive could be used for the prototyping of complex organic shapes. Due to the low density of such products, they can be used as a container for more complex forms, to make moulds for laminated furniture, or as a support for making furniture in combination with veneers and foils. The wood flour gas significant advantages as compared to the thermoplastics is considerably cheaper than thermoplastics (200 USD per ton while 1 ton of PLA is 1200 to 2000 USD), higher modulus, environmentally friendly, non-toxic, and easy supply. The diameter of the filaments changes between 1.75 mm and 3.00 mm and are sold in spools at a cost rate of \$15–30 per pound (Tisserat et al., 2015). As the wood flour incorporated in the thermoplastics the price of material for 3D printers will decrease, which considerably increase the use of 3D printer in near future. The consumers will prefer the environmentally friendly materials for their 3D materials.

With a right combination of polymer, wood particles (size, distribution, content) and additives a wide variety of performance levels in compounds can be achieved. For example beech sawdust can act as reinforcement in the case of flexural stress and also tensile strength. Effective mixing is crucial for achieving optimal dispersion of WF and optimizes the properties of the composites (Bledzki et al., 2005). The reduction of tensile strength values in biocomposites is typical of poor interfacial bonding between the more hydrophobic PLA and the hydrophilic biocomposites, so the appropriate additives or processing techniques should be used to improve material properties (Tisserat et al., 2015).

Coupling agents have been extensively used in wood fiber and polymer composites to improve the fiber/polymer bonding and in turn to enhance the water resistance. The coupling agents improve the quality of adhesion between plastics and fibers to reduce the gaps in the interfacial region and to block the hydrophilic groups. For example, the anhydride groups in the MAPP enter into an esterification reaction with the surface hydroxyl groups of wood fibers and covalently bond to the hydroxyl groups (Fig. 7).

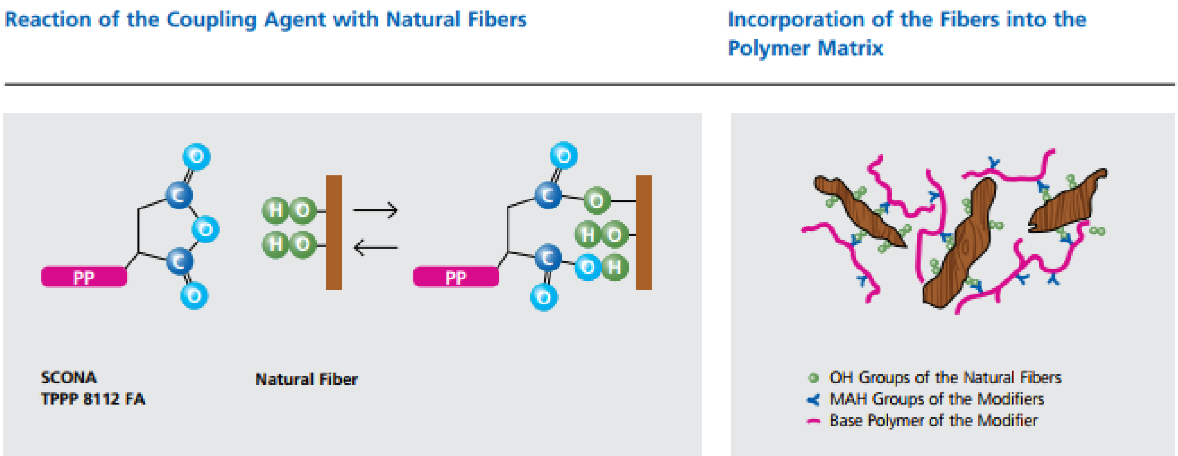


Figure 7. *Reaction of the coupling agent with natural fibers and incorporation of the fibers into the polymer matrix*

4. RECENT CASE STUDIES ON 3D PRINTED MATERIALS FROM WOOD/BIOPLASTIC FILAMENT

Ayrilmis et al (2019b) investigated the surface properties of 3D printed specimens produced from wood/PLA filaments. They reported that the amount of wood flour was gradually increased from 0 to 50 wt% (by 10 wt% increments) in the production of PLA based filaments with 1.75 mm diameter using twin screw extruder. The bar specimens were produced from the filaments using fused deposition modeling (FDM) 3D printer. The surface roughness of the specimens significantly increased with the incorporation of wood flour into the PLA filament. However, the wettability of the specimens significantly decreased with increasing wood flour content. This was mainly attributed to the higher surface free energy of PLA than the beech wood. The contact angle values of the 3D printed wood/PLA specimens having wood flour content up to 30 wt% were less than 90°, which wetting behavior of all the specimens was favorable. They concluded that the contact angle and surface roughness data of this study could be useful for the coating industry and filament producers.

Kuzman et al. (2019) investigated the viscoelastic behaviour of 3D-printed samples produced from different types and contents of wood and thermoplastics, and printing settings. The highest storage modulus, measured with a rheometer, was in the samples printed from filament B (PLA), and the smallest modulus was obtained from Filament C (co-polyester with 40% wood). The storage modulus of samples of Filament D (PLA with 35-40 % wood), Filament A (ABS), and Filament B (PLA) exhibited a slight decrease in the storage modulus as the printing layer thickness was increased. They concluded that the viscoelastic behaviour of the 3D printed neat polymer and wood/polymer parts produced at different processing parameters and conditions could be considered for filament producers for material selection and the design engineers when wood/PLA printed parts fabricated through FDM technique.

Kariz et al. (2018a) investigated the effect of wood content in 3D printing materials on the properties of 3D printed parts. Six filaments using polylactic acid (PLA) with varying loading levels of wood particles from 0% to 50% by weight were produced and used for 3D printing. The density of the filaments and 3D printed parts used in this study slightly decreased with increasing wood content. The tensile strength of the filaments increased from 55 MPa to 57 MPa with an addition of 10% wood, but decreased with higher levels of wood content to 30 MPa for filaments with 50% wood content. The surface of the parts printed from the filament without the addition of wood was smoother and the printed part had no voids within the structure. With increasing wood content the surface becomes rougher, more voids were present, and had visible clusters of wood particles (due to wood particle clustering and clogging in the printer nozzle). Higher wood content in 3D printed parts decreased the storage modulus. measured with torsional loading on a rheometer, but did not change the glass transition temperature.

Ayrilmis et al. (2019a) carried out the water absorption and mechanical properties of the 3D printed samples increased with increasing printing layer thickness from 0.05 to 0.3 mm. They reported that this could be explained by the fact that the amount of empty space in the 3D printed specimen increased with increasing layer thickness, which absorbed more water. The bending and tensile properties of the 3D printed wood/PLA composite specimens significantly improved with decreasing printing layer thickness. The increase in the layer thickness caused bigger gaps, which increased the porosity in the cross section of the specimen. Higher porosity resulted in lower mechanical properties. The results revealed that the decrement in the printing layer thickness enhanced the strength and modulus of the specimens because of more material in the same volume. The strength of printed parts depends also on printing layer thickness.

Wimmer et al. (2015) reported that bio-based filaments can be designed for a variety of product properties, showing good printability. Good type-haptic was achieved, along with good mechanical properties and low warping. A PLA-type filament, blended with 15% PHA, and filled with 15% cellulose (pulp) has delivered reproducible results.

Kariz et al. (2018b) Filaments from a mixture of wood powder and polylactic acid (PLA) polymer were made and used for 3D printing. Different wood ratios were used: 10 %, 20 %, 30 %, 40 %, and 50 %. Specimens were 3D-printed with fused deposition modelling (FDM) printer and conditioned in climates with different levels of relative moisture (RH): 33 %, 65 %, and 87 %. Moisture content, dimensional swelling, and bending properties of printed specimens were measured after conditioning. The results showed that specimens made from filaments with higher wood content had higher moisture content, larger dimensional swelling, and lower modulus of elasticity (MOE).

Aydin (2015) reviewed nine different 3D printed furniture case studies have been reviewed to find out how AM could be used for furniture production. He reported that AM provided design flexibility and so each piece of furniture could be printed distinctly.

5. CONCLUSIONS

3D printing technology having flexibility and cost-efficiency represents the opportunity for small companies to engage in new production without big investments. There is virtually zero waste. Natural fibers are renewable and offer great advantages for the filament producers. Natural fibers also can be successfully replaced with synthetic fibers as reinforcing filler in the production of thermoplastic filaments. The petroleum based thermoplastics are harmful for humans and environment. As a result, use of the natural fibers, which is environmentally friendly material, will rapidly increase in the production of thermoplastic filaments used in the 3D printers in near future.

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RECENT DEVELOPMENTS IN THE MANUFACTURE AND APPLICATION OF NATURAL FIBER REINFORCED THERMOPLASTIC COMPOSITES

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ABSTRACT

The use of lignocellulose based fillers and reinforcements in thermoplastics has been gaining acceptance in commodity plastics applications in recent years. Natural fibers generally refer to lignocellulosic materials derived from wood or agricultural materials such as kenaf, jute, hemp, flax, or other natural resources. Over the past two decades, natural fibers have received considerable attention as a substitute for synthetic fiber reinforcements in plastics. As replacements for conventional synthetic fibers like aramid and glass fibers, natural fibers are increasingly used for reinforcement in thermoplastics due to their low density, good thermal insulation and mechanical properties, reduced tool wear, unlimited availability, low price, and problem-free disposal. As a result of these advantages, natural fiber reinforced thermoplastic composites are gaining popularity in automotive and non-structural construction applications. In this study, recent developments in the manufacture and application of natural fiber reinforced thermoplastic composites were reviewed.

Key words: natural fibers, thermoplastic composites, wood, wood plastic composites

1. INTRODUCTION

Natural fiber reinforced thermoplastic composites have attracted a great deal of interest in researches and industry. In particular, global wood plastic composite (WPC) market size was valued at USD 4.06 billion in 2015 (Manuel, 2019). The WPC market is poised to grow at a CAGR of around 13.2% over the next decade to reach approximately $9.7 billion by 2025. Some of the prominent trends that the market is witnessing include rising demand for WPCs in emerging markets, increasing consumption of recyclable raw materials and recent advancement in the processing of WPC (Anonymous, 2017). European WPC market is presented in Figures 1 and 2.

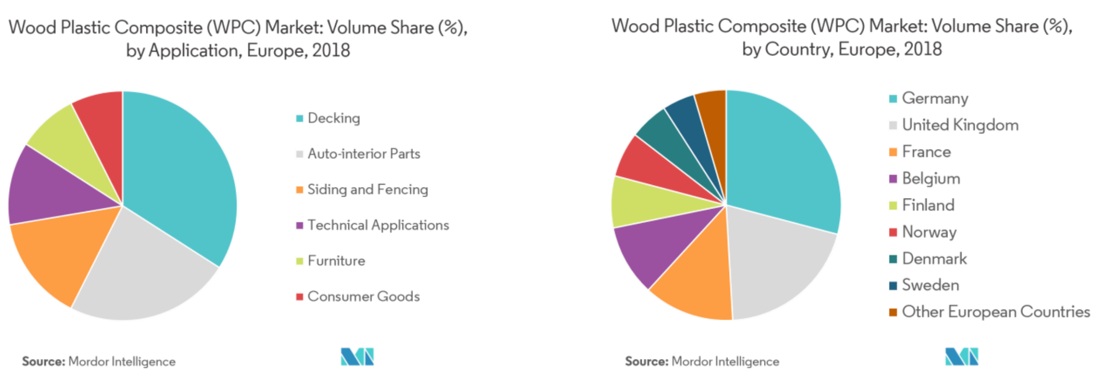


Figure 1. *WPC market: volume share by application and country (Anonymous, 2019)*

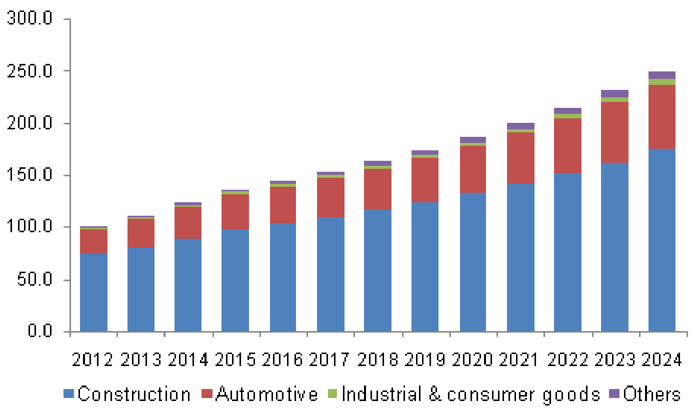
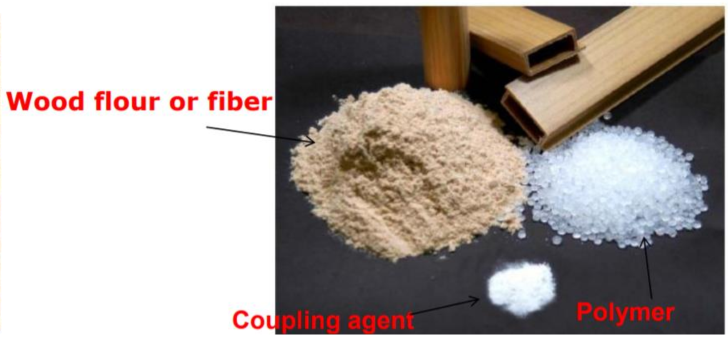


***Figure 2**. German WPC market revenue by application, 2013- 2024 ((Anonymous 2019)*

The expanding application scope in decking and fencing applications is expected to drive demand for the product in the construction industry. Growing demand for WPC as a low cost and environmentally friendly substitute to plastic and steel components in construction applications is expected to drive market growth. Decking applications dominate the global WPC market, accounting for over 80% of the total WPC demand in building and construction application. The automotive segment is expected to witness significant growth, owing to the rising demand for biobased products for manufacturing car interior parts such as seat cushions, cabin linings and backrests. Rapid growth of the automotive sector in the region, coupled with the presence of key automotive companies, such as BMW, Audi, Opel, Daimler AG and Volkswagen, is expected to boost demand for WPC market over the projected period (Anonymous, 2017).

Wood fiber is one of the most abundant environmental friendly material for thermoplastics due to its low cost, low density, recycling and abrasion properties. In WPC production, wood flour is used as a by-product in the manufacturing of timber and workshop, furniture, doors and windows. Even paper residues can be used in the production of WPC. Production residues from the manufacture of WPC as well as WPC at the end of its useful life can be recycled again, for which the products are first ground, subsequently melted again and finally processed into new products. Furthermore, agricultural wastes such as, rice husk, wheat straw, sugar bagasse are also used in the production of thermoplastic composites. (EN 15534-1, 2014). The processing temperature should be below 200 °C in order to avoid thermal decomposition of the wood. WPC compounds are presented in Figure 3.



A **B**

***Figure 3. A**: Compound (pellet) used in WPC production. B: raw materials used in WPC production*

Compared to pure plastics, WPC exhibit, amongst other differences, a higher modulus of elasticity and a higher heat resistance. Compared to solid wood, the strengths and modulus of elasticity of WPC are lower, but nonetheless comparable with OSB and MDF boards. WPC exhibit a considerably lower water absorption and swelling than solid wood and wood-based materials.

Accordingly, WPC also achieve a higher dimensional stability and durability than solid wood (Schirp, 2019). Chemical composition of common lignocellulosic fibers are given in Table 2.

Table 2. *Chemical composition of common lignocellulosic fibers (Ayrilmis and Ashori, 2015)*

Fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractives (%)	Ash content (%)	Water soluble (%)
Cotton	82.7	5.7	-	6.3	-	1.0
Jute	64.4	12	11.8	0.7	-	1.1
Flax	64.1	16.7	2.0	1.5-3.3	-	3.9
Ramie	68.6	13.1	0.6	1.9-2.2	-	5.5
Sisal	65.8	12.0	9.9	0.8-0.11	-	1.2
Oil palm EFB	65	-	19.0	-	2.0	-
Oil palm Frond	56.0	27.5	20.5	4.4	2.4	-
Abaca	56-63	20-25	7-9	3	-	1.4
Hemp	74.4	17.9	3.7	0.9-1.7	-	-
Kenaf	53.4	33.9	21.2	-	4.0	-
Coir	32-43	0.15-0.25	40-45	-	-	-
Banana	60-65	19	5-10	4.6	-	-
PALF	81.5	-	12.7	-	-	-
Sun hemp	41-48	8.3-13.0	22.7	-	-	-
Bamboo	73.9	12.5	10.2	3.2	-	-
Hardwood	31-64	25-40	14-34	0.1-7.7	<1	-
Softwood	30-60	20-30	21-37	0.2-8.5	<1	-

Based on product type the market is categorized into Polyvinylchloride (PVC), Polypropylene (PP), Polyethylene (PE) and other products (Fig. 4). Other products segment is further segmented into polystyrene and polylactide. Polyethylene accounted for more than 60% of the market in 2017 (Anonymous, 2019). PE, majorly high density polyethylene (HDPE), owing to its large strength to density ratio, strong intermolecular forces and tensile strength is preferred over any other type of thermoplastic to be used to manufacture WPCs.

Figure 4. *Polymer matrix share in global WPC market (Maida, 2017)*

2. PRODUCTION METHODS OF WOOD PLASTIC COMPOSITES (WPCs)

The predominant technologies to produce WPCs are extrusion to obtain endless profiles, hot press molding, and injection moulding and rotational molding leading to 3-dimensional forms, although commercially less important (Fig. 5). Another possibility which has only little been explored is to produce WPCs on a flat-press. The advantage of this technology is that only a relatively low pressure level is required, compared to extrusion and injection moulding. As a consequence, the naturally given wood structure is maintained, resulting in a considerably reduced material density. The productivity of the pressing technology is much higher than that of extrusion and injection moulding. Hot press molding is a simple method for producing panels with high fiber content, high dimension, different density, and lower cost in comparison with other methods (Fig. 6).

A. **B.** **C.**

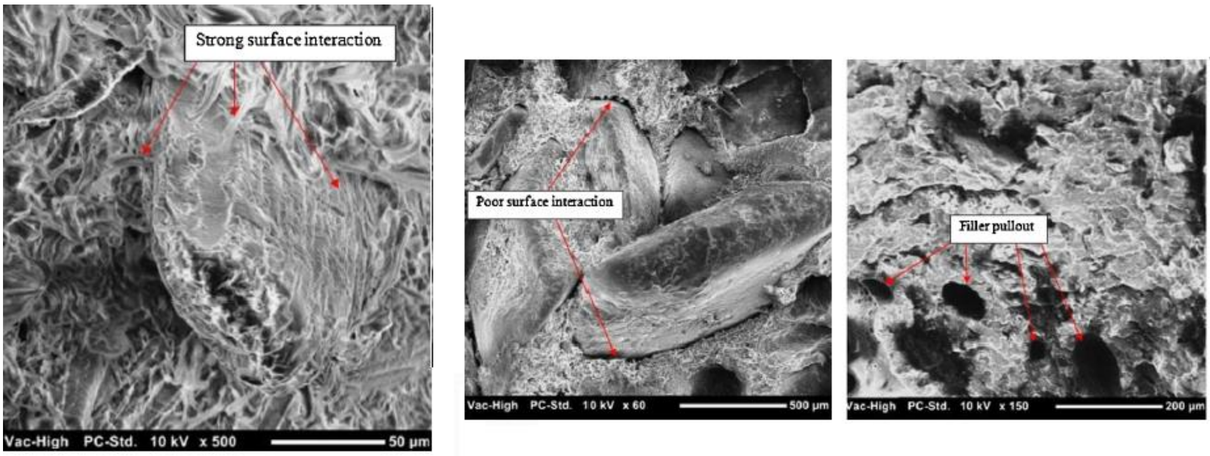
Figure 5. *Three production technique for WPCs. A: Injection molding B: Extrusion C: Hot pressing molding (Ayrilmis and Ashori 2015)*

Figure 6. *Hot press molding of automovie interior WPC parts*

Usually, wood a raw material for final consumer products possesses a number of properties that limits its application. Wood itself is composed of polymers such as lignin, cellulose, and hemicelluloses that it readily absorbs moisture, and this phenomenon alters its properties and the dimensions. Water absorption by wood can lead to bio-degradation if not protected. Thus, the WPC has a limited biological durability (Kim et al., 2008). Previous studies reported that wood-based composites such as particleboard and fiberboard prepared from durable species such as black locust and oak wood had a high biological durability, and could be used in exterior expositions (Kamdem and Sean, 1994; Reinprecht and Zubková, 2010). WPCs for exterior with and without ground contact should be adequately resistant against moisture and wood-destroying basidiomycetes. There is a commercial WPC lumber manufacture in North America, which uses western red cedar having a biological durability in the WPC formulation (Weyerhaeuser company report, 2002).

In WPCs, a polymer matrix forms the continuous phase surrounding the wood component. These matrix polymers are typically low-cost commodity polymers that flow easily when heated, allowing for considerable processing flexibility when wood is combined with them. These polymers absorb little moisture and can be effective barriers to moisture intrusion in a well-designed composite (Oksman et al. 2007). Depending on the particular application, wood composites require protection from the effects of moisture, climatic conditions, biological infestation (decay, insects, marine borers), and fire. Heat treatment has been foreseen as a technique to improve the dimensional stability and decay resistance of wood-based composites. The mechanism which improves the decay resistance is undoubtedly linked to the loss of polysaccharide in wood, and to the reduced moisture content of the cell wall. Loss of OH groups from the cell wall polymeric constituents may also affect the ability of enzymes to metabolize the substrate and/or the mode of action of low molecular weight diffusible agent.

The poor compatibility between the reinforcing material and the matrix is associated with a loss of mechanical properties of the composite. Wood and plastic are like oil and water, and do not mix well. Most polymers, especially thermoplastics, are non-polar ("hydrophobic", repelling water) substances, which are not compatible with polar ("hydrophilic"- it absorbs water) wood fibers and, therefore, poor adhesion between polymer and fiber in WPC can result (Ayrilmis and Ashori, 2015). In order to improve the affinity and adhesion between fibers and thermoplastic matrices in production, chemical "coupling" or "compatibilizing" agents have been employed. Therefore, to improve the interfacial adhesion between the polymer matrix and wood flour (WF), a chemical modification such as alkaline, acetylation, epoxide, Benzoylation, maleic anhydride grafted polypropylene or polyethylene, silan treatment or other modification of WF is an appropriate solution. The coupling agent chemically bonded with hydrophilic fiber and blended by wetting in the polymer chain. The coupling agent improves the interfacial adhesion between the filler and polymer matrix, leading to less micro-voids and fiber-polymer debondings in the interphase region. The improvement in the interfacial adhesion and stress transfer from the polymer matrix to the stiffer wood flour causes the increases in the flexural modulus and strength. The chemical reaction of the hydrophilic hydroxyl groups of the lignocellulosics and acid anhydride groups of the coupling agent, thus forming ester linkages reduce the number of free hydrophilic groups. This indicates that chemical bonding of hydroxyl groups of the wood with functional groups of the coupling agent at the interface reduces water uptake of the WPCs (Ayrilmis et al., 2013). Efficient dispersion of the filler within the polymer matrix due to the addition of the coupling agent forms more tortuous path for penetrating water, slowing down the whole process. During the preparation of the wood/polypropylene composites, the improvement of the compatibility between the hydrophilic fillers and the hydrophobic thermoplastic is very important, whether the filler is an organic fiber, because the interfacial adhesion between the filler and matrix plays an important role in determining the mechanical properties of the composites (Fig. 7).



A **B.**

Figure 7. *Effect of coupling agent on the interfacial bond of wood and polymer matrix. A: Good bonding between wood and polypropylene matrix bythe coupling agent (MAPP) . B: poor interfacial bonding without the coupling agent MAPP (Ayrilmis et al. 2013).*

Hygroscopicity of natural fibers also affect the physical and mechanical properties of WPCs. Absorbed moisture interferes with and reduces hydrogen bonding between cell wall polymers and alters the mechanical performance of the product. The natural fibers should be dried in a dryer at 100 °C for 24 h to reach 0-1% moisture content and then stored in sealed plastic bags until blending with the polymer matrix. Main mechanical properties of polypropylene/wood composites with or without coupling agent is given in Table 2.

Table 2. *Main mechanical properties of polypropylene/wood composites with or without coupling agent*

Property	Unit	PP	PP +40 wt% wood flour	PP + 40% wood flour + 3% coupling agent	PP + 40% wood fiber	PP + 40% wood fiber + 3% coupling agent
Specific gravity	-	0.90	1.05	1.05	1.03	1.03
Tensile strength	MPa	28.5	25.4	32.3	28.2	52.3
Tensile modulus	GPa	1.53	3.87	4.10	4.20	4.23
Bending strength	MPa	38.30	44.20	53.10	47.90	72.40
Bending modulus	GPa	1.19	3.03	3.08	3.25	3.22

PP: polypropylene. Coupling agent: Maleic anhydride grafted PP (MAPP).

3. MODIFICATION OF NATURAL FIBERS

Alter the cell wall macromolecules in solid wood leads to reduce dimensional stability and moisture content, and improve resistance to biological attack (Hill, 2006). Hydrothermal treatment is one of the effective thermal treatment methods (Saliman et al., 2017). The efficiency of hydrothermal treatment is highly dependent on treatment temperature and time. The modification techniques for the natural fibers are given below (Ayrilmis et al., 2015).

- Acetylation of wood has been widely used for modifying wood with acetic anhydride, which results in the esterification of accessible hydroxyl groups in the cell wall with acetyl groups. The fibers are usually immersed in glacial acetic acid for 1 h, then immersed in a mixture of acetic anhydride and a few drops of concentrated sulfuric acid for a few minutes, then filtrated, washed and dried in a ventilated oven. This is an esterification method which should stabilize the cell walls, especially in terms of humidity absorption and consequent dimensional variation.

- Alkali treatment (also called mercerization): it is usually performed on short fibers, by heating at approx. 80 °C in 10% NaOH aqueous solution for about 3–4 h, washing and drying in a ventilated oven. This process disrupts the formation of fiber clusters for obtaining smaller and better quality fibers. It should also improve fiber wetting.

- Treatment with stearic acid: the acid is added to an ethyl alcohol solution, up to 10% of the total weight of the fibers to be treated and the obtained solution is thus added drop wise on the fibers, which are then dried in an oven. It is an esterification method as well.

- Benzylation: the fibers are immersed in 10% NaOH and then stirred with benzoyl chloride for 1 h, filtrated, washed and dried, then immersed in ethanol for 1 h, rinsed and dried in an oven. This method allows for the decreasing of the hydrophilicity of the fibers.

- Toluene diisocyanate (TDI) treatment: the fibers are immersed in chloroform with a few drops of a catalyst (based on dibutyltin dilaurate) and stirred for 2 h after adding toluene-2,4-diisocyanate. Finally, the fibers are rinsed in acetone and dried in an oven.

- Peroxide treatment: the fibers are immersed in a solution of dicumyl (or benzoyl) peroxide in acetone for about half an hour, then decanted and dried. Recent studies have highlighted significant improvements in the mechanical properties.

- Anhydride treatment: it is usually carried out by utilizing maleic anhydride or maleated PP (or PE) in a toluene or xylene solution, where the fibers are immersed for impregnation and reaction with the hydroxyl groups on the fiber surface. Literature reports significant reduction of water absorption.

- Permanganate treatment: the fibers are immersed in a solution of $KMnO_4$ in acetone (typical concentrations may range between 0.005 and 0.205%) for 1 minute, then decanted and dried. Investigations have pointed out a decreased hydrophilic nature of the fibers upon performing this treatment.

- Silane treatment: the fibers are immersed in a 3:2 alcohol–water solution, containing a silane-based adhesion promoter for 2 h at pH ≈ 4, rinsed in water and oven dried. Silanes should react with the hydroxyl groups of the fibers and improve their surface quality.

- Isocyanate treatment: isocyanate group can react with the hydroxyl groups on the fiber surface, thus improving the interface adhesion with the polymer matrix. The treatment is typically performed with isocyanate compounds at intermediate temperatures (around 50 °C) for approximately 1 h.

- Plasma treatment: this recent method allows significantly modifying the fiber surface. However, chemical and morphological modification can be very heterogeneous depending on the treatment conditions, and therefore it is not easy to generalize; process control is a critical aspect, and the final surface modifications strongly depend on it. More specifically, TDI, dicumylperoxide and silane treatment seem to guarantee the best results with concern to mechanical properties, while alkali treatment and acetylation seem to give better improvements in thermal and dimensional stability.

For some applications it may be necessary to improve the fire performance. Therefore, a knowledge of the effect of fire retardants in WPCs is also critical. Polymers employed in WPC burn and drip in case of fire leading to a very risky scenario. Burning plastics may produce hazards such as the evolution of toxic gases, loss of physical integrity, and melting and dripping thereby providing other ignition sources. Thus, fire retardant agents must be employed in order to improve fire behavior. The most effective and widely used fire retardant chemicals for WPCs are ammonium polyphosphate and expandable graphite, decabromodiphenyl oxide, magnesium hydroxide, melamine polyphosphate, aluminum hydroxide, and boron compounds (zinc borate) (Ayrilmis and Ashori, 2015). Ayrilmis et al. (2012) investigated physical, mechanical, and fire properties of the flat-pressed WPCs incorporated with various fire retardants (10% by weight) at different levels of wood flour (WF) content, 40, 50, or 60 wt%. The modulus of rupture of the WPC panels containing FRs decreased with the increase in the WF content from 40 to 60 wt%. The modulus of elasticity increased with the increase in the WF content from 40 to 50 wt% and then decreased as the WF content reached 60 wt%. The WPC panels incorporated with zinc borate gave an overall best performance in both physical and mechanical properties followed by the panels treated with decabromodiphenyl oxide, magnesium hydroxide, and ammonium polyphosphate. Higher levels of the WF content resulted in significantly improved fire resistance of the WPC panels with and without FR as measured in the cone calorimeter. Of the four fire retardants tested, ammonium polyphosphate showed the most improvement over untreated ones.

Nanocellulose reinforced polymer composites

Micro/nanofibrils (nanocrystalline cellulose (NCC), nanofibrillated cellulose (NFC)) isolated from natural fibers have garnered much attention for the use in composites, coatings, resins, and film because of high specific surface areas, renewability and unique mechanical properties in the past two decades (Fig. 8). Nanocrystals are ricelike, needle-shaped and strong with diameters in the 5- to 10-nm range and lengths on the order of 100 to 200 nm, depending on the source. In contrast, nanofibrils, which tend to have roughly 5-nm diameters, as spaghetti-like because they are longer (a micrometer or more), flexible, and easily entangled (Ayrilmis and Ashori, 2015).

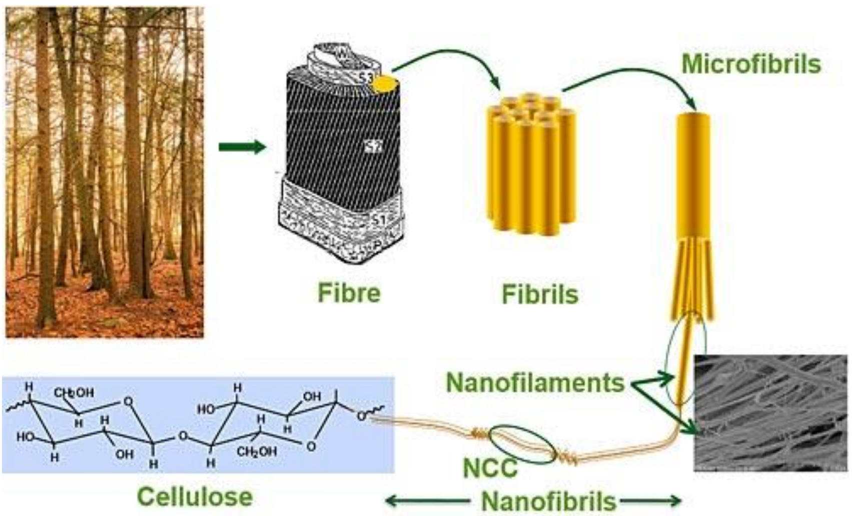


Figure 8: *Structure of wood: from tree to nanocellulose*

Nanocellulose in nanocomposites as reinforcing filler has many important properties, such as biocompatibility, biodegradability, being environmentally benign, natural abundance, light weight, potential for chemical modification, and excellent mechanical strength. However, two main drawbacks are its substantial hydrophilicity and poor compatibility with hydrophobic polymer matrices. Oksman et al. studied the production methods of cellulose nanocomposites with focus on casting, melt processing and resin impregnation. In other study, Dufresne (2017) investigated on the various processing technique of nanocellulose based polymer composites, specially, advantages and challenges of wet and melt processing of both NCC and NFC based thermoplastic composites.

4. CONCLUSIONS

This study reviewed the properties and uses of natural fibers in the thermoplastic composites. The market of the natural fiber reinforced thermoplastic composites have rapidly increased in last decade. This is due to significant advantages of natural fibers as compared to the synthetic fibers and mineral fillers, as mentioned in the text. The modification of natural fibers improve the physical, mechanical, thermal properties of the composites. In particular, nanocellulose applications in the thermoplastic composites have attracted a great deal in the researches and industry. In near future, it is believed that the use of nanocellulose in the high value added thermoplastic composites will increase as a function of decreasing price of nanocellulose. Furthermore, bioplastics will be partly replaced with petroluem plastics in the production of natural fiber reinforced thermoplastic composites used in indoor applications because it is environmentally friendly biomaterial.

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TOOL WEAR IMPACTS ON CUTTING POWER AND SURFACE QUALITY IN PERIPHERAL WOOD MILLING

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ABSTRACT

The aim of the research presented in this paper is to determine the impacts of tool wear on the cutting power and quality of the processed surface, as the selected workability criteria for different peripheral milling regimes. The test was carried out on test samples made from beechwood (*Fagus silvatica L*) planks of uniform density and moisture content and without visible wood structure flaws. The tool wear in this paper was defined using the values of flank wear width before and after peripheral milling of beech samples. The dependences of the examined criteria (cutting power and surface quality) on the level of tool wear in different processing regimes were formed. On the basis of the obtained test results, it can be concluded that tool wear undoubtedly significantly affects the cutting power and processed surface quality, which could be important for determining the cutting regime and the interval of tool replacement.

Key words: solid wood milling, tool wear, cutting power, surface quality

1. INTRODUCTION

The contact surfaces of tools in the machining process are exposed to high pressures and friction, which results in tool wear. Tool wear is one of the important factors in mechanical wood processing since it directly affects surface quality, cutting forces, cutting power and energy consumption. The speed, intensity and character of the process of wearing of cutting tools are influenced by: the material to be processed, tool material, tool geometry, the coefficient of friction, the temperature of the cutting zone, cutting speed, feed and depth of a cut, the static stiffness of the system, the dynamic behavior of the system and other technological processing conditions (Klamecki, 1979, Porankiewicz, et al., 2005, Ratnasingam, 2010, Ratnasingam et al., 2013, Nouari et al., 2003).

In general, indirect and direct methods can be used to measure tool wear (Castejón et al., 2007, Kurada and Bradley, 1997, Fadare and Oni, 2009, Danesh and Khalili, 2015). Some of the criteria for indirect tool wear measurement are: cutting power, cutting force, machined surface quality, deviation from the machining accuracy and the like. A more reliable way is to directly measure tool wear. One of the direct methods is measuring the loss of blade material due to mechanical, electro-chemical and temperature events during the cutting process. On the other hand, such measurements are highly complicated. A much simpler way is to measure the elements of wear, that is, to measure the changes in the geometry of the cutting wedge. Some researchers (Pahlitzsch and Sandvoss, 1970; McKenzie and Karpovich, 1975) found that changes in wear profile geometry are more closely related to the tool performance than to the amount of wear.

There are two main types of cutting tool wear that appear in the form of wear zones as flank wear and crater wear of the cutting wedge (Figure 1). The following cases occur depending on the technical conditions and processing regimes, i.e. depending on the dominant impact factors:

a) flank wear on the clearance surface is intense and the wear on the rake surface is poor, which means that the pressure on the clearance surface due to tensile stress relaxation is greater than the pressure of chip on the rake surface (figure 1a), the

b) crater wear of the rake surface, the wear on the clearance surface is poor, which means that the pressure of the chip on the rake surface is greater than the pressure on the clearance surface due to tensile stress relaxation (figure 1 b),
c) intense wear on both surfaces of the cutting wedge (figure 1 c)

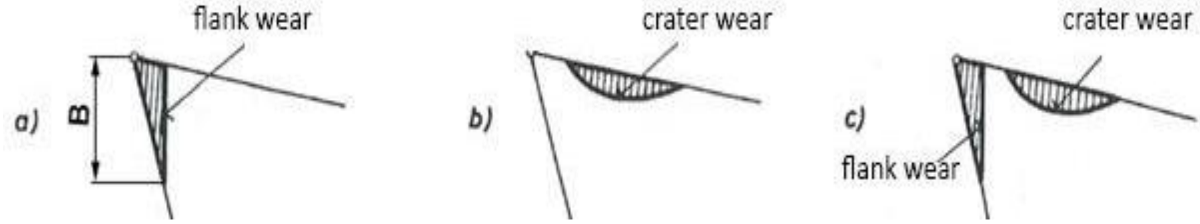

Figure 1. *Shapes and positions of the wear zones (flank and crater) on the cutting tool wedge*

The direct consequence of the tool wear is a gradual loss of its cutting ability in material processing, resulting in an increase of the cutting forces and has an adverse effect on the quality of the processed surface (Itaya and Tsuchiya, 2003). The cutting force is directly related to the energy consumption (cutting power) during processing, that is, the greater the cutting force, the higher the energy consumption value (Orlowski et al., 2013, Aguilera and Martin 2001, Kovač and Mikleš 2010, Cristovao, 2013), which in turn incurs greater costs of processing.

The surface profile and roughness of a machined part are two of the most important product quality characteristics. Surface roughness is a widespread product quality index influenced by a number of factors such as processing conditions, tool wear, tool vibration, characteristics of the tool and workpiece materials, and technological parameters of processing which significantly affect product quality (Kilic et al, 2006, Lu, 2007, Csanadi et al, 2015,). The mechanism of creating the surface profiles depends on the process of machining along with a number of other factors that are difficult to control, which makes it almost impossible to set an absolutely accurate prediction model for the achievement of the desired surface quality.

2. MATERIAL AND METHODS

A total of 10 radial beech (*Fagus silvatica L.*) wood planks were selected for testing of 150 mm in width, 30 mm in thickness and 1.100 mm in length and with no visible flaws in wood structure. From both ends of each of the planks, three test samples were produced for the laboratory testing of physical properties at the Laboratory for Wood Properties of the University of Belgrade Faculty of Forestry. Physical properties were tested in accordance with the standard for density determination (EN 323:1993) and the standard for determination of moisture content of wood-based panels (EN 322: 1993). The density and moisture of the boards were tested on a total of 60 samples of dimensions 50 x 50 x 30 mm.

The samples had been conditioned before testing in the laboratory environment conditions: relative humidity of 45 ± 5% and room temperature of 20 ± 3°C. These conditions brought samples to an equilibrium moisture content of 8 ± 1%, which is a standard recommendation for the values of moisture content for furniture in Serbian climatic conditions. The average beech samples density was 0.652 g / cm^3 in the ovendry state, or 0.673 g / cm^3 with an average moisture content of 7%. In addition, the coefficient of variation of the measurement which is less than 5% indicates that there is no significant difference in the tested properties of the samples and therefore there no significant impact of density and moisture content on the tested criteria.

After cutting the samples for determining density and moisture, for the purpose of measuring the cutting power during peripheral milling test samples were produced of dimensions 1000 x 150 x 30 mm. The machining regime was as follows: the speed was v = 38 m/s, the feed was u = 16 m/min and cutting depth was a = 4.5 mm. All experimental measurements were carried out at the Center for Woodworking Machines and Apparatus at the University of Belgrade - Faculty of Forestry. The cutting power was measured at each passing. The tests were repeated with a sharpened and blunt milling cutter. After each fifth pass, for the purpose of measurement of processed surface roughness a sample were cut out of dimensions 1000 x 30 x 10 mm. The cutting power was measured with a

universal MiniMax machine equipped with a Maggi Engineering, Vario Feed device, which has the possibility of continuously changing the feed in the 3 to 24 m/min range.
The test was conducted by using a single-piece milling cutter D = 125 mm with four hard metal blades of width b = 40 mm with a clearance angle $\alpha = 15^o$, and the rake angle $\gamma = 25^o$ and the cutting angle $\delta = 65^o$ (figure 2).

Figure 2. *A drawing and photo of the tool*

An SRD1 measuring device, which performs acquisition, analysis and processing of the obtained data, was used to measure the power. The device allows the storage of data and has the possibility of later data display (figure 3).

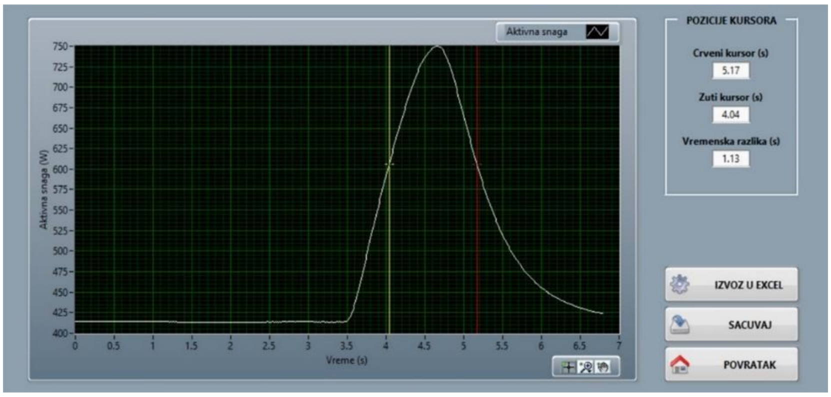

Figure 3. *The registered data interface in cutting power measurement*

The installation contains a CW-TAN wattmeter of the Circutor producer for unbalanced three-phase systems with the following characteristics: 300 V, 5 A, 230 VAC, 50 Hz with a 0.5% accuracy, with an analog 0-10 V output. The output signal is directly led to an acquisition card whose range can be adjusted (1, 2, 5 and 10 kW) depending on the power of the engine drive. The device uses the *Power Expert* software package, developed in cooperation of the Center for Woodworking Machines and Apparatus and Unolux company from Belgrade. The signals are software scaled and converted to real values with the corresponding units of measurement. The measuring device is portable and can be connected to different machines with a maximum power limit (of up to 10 KW).

The roughness of the processed sample surfaces was measured using a contact-mechanical roughness meter TIME3200 Surface Roughness Tester TR200 (figure 4a). The length of the needle movement path is determined in accordance with ISO 4288:1996, which provides for the selection of reference length and total length of observation based on the values of the basic roughness parameters. In accordance with the expected values for the roughness average (Ra) ($2 < Ra \leq 10$ μm), a reference length of 2.5 mm was selected, i.e. a total length of observation of 12.5 mm, for determining the roughness of processed surfaces on the samples. At each passing of the milling cutter, changes in the cutting power were registered, and after each fifth pass, from the test plank for measuring the cutting power a test sample was extracted for processed surface roughness measurement at eight measuring points (figure 4b).

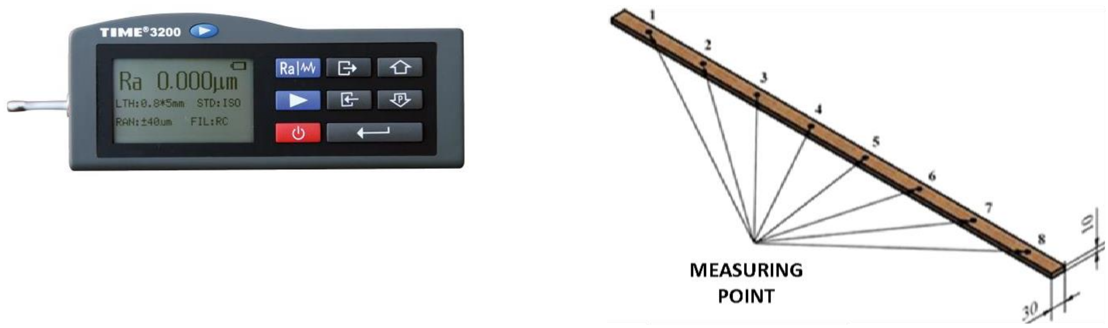

Figure 4. *TIME3200 roughness meter TIME3200 Surface Roughness Tester TR200 and surface roughness test sample*

The tool wear was measured using a Supereyes HD Digital Microscope B008 that has the ability to take photos, record, store and process data (figure 5). The camera software also has the ability to measure the length between two points, the angle between two lines and automatically calculate the values of respective radii of registered circles.

Figure 5. *Digital microscope connected to a computer and the microscope*

The parameter through which the tool wear was defined in this paper is flank wear width (*B*). The flank wear width was measured in three different blade areas (figure 6).

Figure 6. *A blade with marked zones*

The length of the first zone (I) is 2 mm, measured from the start of the blade. The length of the second zone (II), which continues after the first one is 3 mm, and the length of the central, third zone (III) is 30 mm. Ten measurements were performed in the first and second zones, five measurements at each of the two sides of the blade. Twenty measurements were performed in the third zone, which is the most active part of the cutting edge. The total number of measurements per blade was 40 and the procedure was repeated on all four blades.

3. RESULTS AND DISCUSSION

A total of 80 power measurements were performed, out of which 40 on a sharpened milling cutter and 40 on a blunted milling cutter. The measurements were divided into groups of 5 after which the test samples were taken for roughness measurement. Table 1 shows the results of cutting power measurement with sharpened and blunted milling cutters for the investigated cutting regimes.

Table 1. *The values of mean cutting power for the peripheral milling of beech wood*

Number of the group of measurement	Average cutting power values [W]	
	Sharpened milling cutter	Blunted milling cutter
1	662.64	695.69
2	715.29	669.47
3	524.34	658.16
4	526.29	653.97
5	523.66	662.81
Average	590.44	668.02

Apparently, the average cutting power values is smaller in the peripheral milling with sharpened milling cutter, compared to the average cutting power values during peripheral milling with a blunted milling cutter.

Table 2 shows roughness measurement data with sharpened and blunted milling cutters for the investigated cutting regimes. The measurements were repeated after every five passes.

Table 2. *The values of the processed surface roughness during peripheral beech wood milling*

Number of the group of measurement	Average roughness values [µm]	
	Sharpened milling cutter	Blunted milling cutter
1	5,96	6,92
2	5,98	6,76
3	5,99	6,82
4	5,86	6,96
5	5,97	6.89
Average	5.96	6.87

As expected, the average roughness values is smaller in the peripheral milling with sharpened milling cutter, compared to the average roughness values of the processed surface during peripheral milling with a blunted milling cutter

Tables 3 and 4 shows the mean flank wear widths of the sharpened and blunted milling cutter before and after the completion of the experiment with a sharpened and blunted milling cutter.

Table 3. *Average values of the flank wear width of the sharpened milling cutter before and after the experiment*

Number of blade	Flank wear width [µm]					
	Before processing			After processing		
	I	II	III	I	II	III
Z_1	24.678	24.377	24.002	28.964	67.698	108.956
Z_2	25.804	23.596	25.987	28.976	59.876	109.787
Z_3	24.384	24.672	24.673	28.754	66.532	107.658
Z_4	24.981	24.479	24.941	27.543	61.256	116.507
Z_4	24.981	24.479	24.941	27.543	61.256	116.507
Average	24.96	24.28	24.90	27.56	61.84	116.73

Table 4. *Average values of the flank wear width of the blunted milling cutter before and after the experiment*

Number of blade	Flank wear width [μm]					
	Before processing			After processing		
	I	II	III	I	II	
Z_1	74.141	129.427	147.598	76.517	159.871	411.921
Z_2	87.517	130.833	156.118	88.476	175.894	389.267
Z_3	75.377	143.668	158.685	76.612	154.146	373.667
Z_4	52.601	147.368	156.789	56.233	163.022	327.031
Average	72.41	137.82	154.80	74.46	163.32	375.47

It is evident that the flank wear width is smaller before the processing, compared to the widths after the experiment with a sharpened and blunted milling cutter

The pictures below show an example of a cutting wedge flank surface on a milling cutter blade (with an indicated flank wear width) in the case of a sharpened and blunted blade (figure 7, figure 8, figure 9 and figure 10).

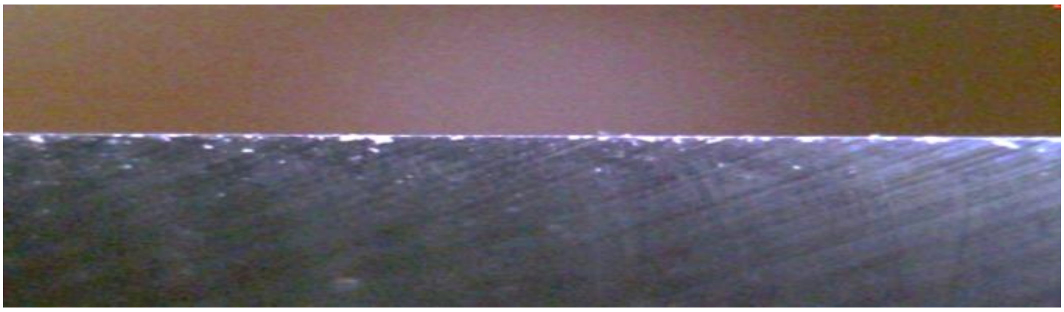

Figure 7. *A picture of a flank wear width on a newly sharpened blade*

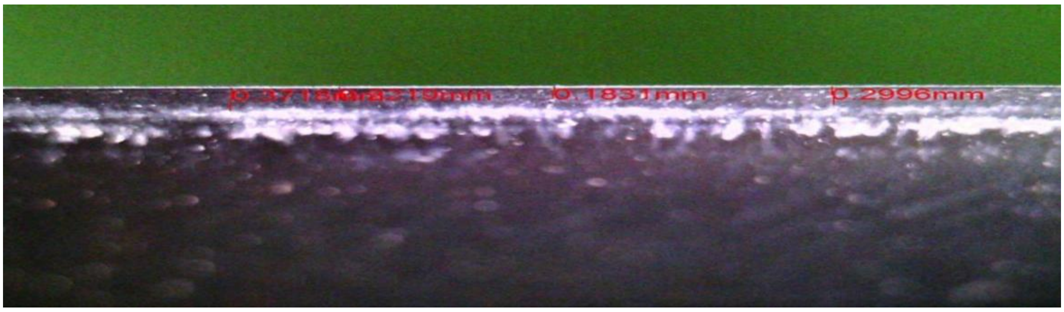

Figure 8. *A picture of a flank wear width after the experiment on a newly sharpened blade*

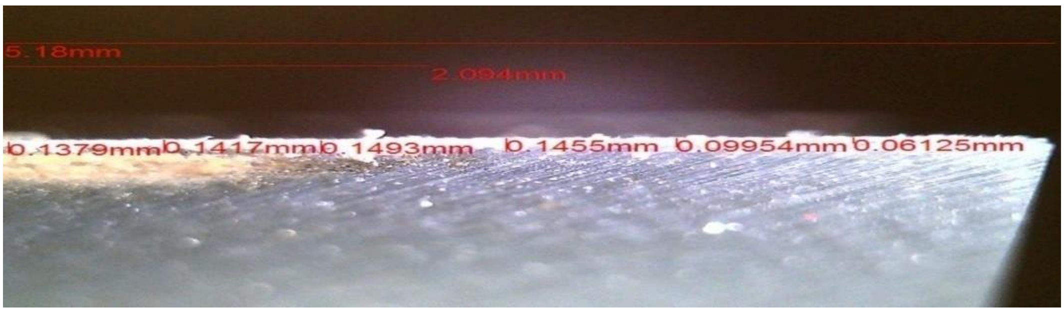

Figure 9. *A picture of the flank wear width on the blunted blade before starting the experiment*

Figure 10. *A picture of the flank wear width on the blunted blade after performing the experiment*

An electronic microscope was used to measure the radius of the blade (figure 11) at the cutting edge side in the case of a sharpened and blunted tool, which confirms previously mentioned.

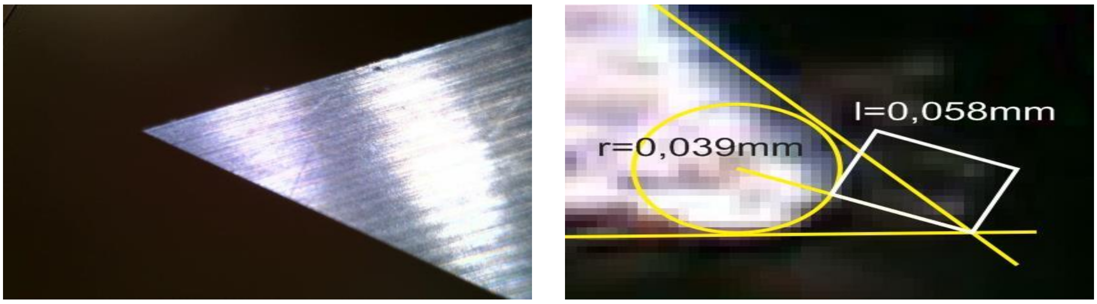

Figure 11. *Radius of the blade cutting edge*

It is evident that the flank wear width is smaller before the processing, compared to the widths after the experiment. The highest values of the flank wear width were registered in the third zone, both before and after the material processing. Since the central part of the blade (third zone) is also the most active part, it is expected to be the most burdened part, and hence also to show the highest values of the tested wear parameter. The smallest wear was recorded in the first zone, which was expected since in the process of material processing that part of the blade does not come into contact with the object of processing. The second zone located between the first and third zones is partially loaded in the material processing, so the values of the flank wear width are expected to be in the range between the first and the third zone widths. These conclusions also apply to the situation from the beginning of the experiment, when the milling cutter was sharpened and when the experiment started with an already used milling cutter.

Table 5 shows parallel data on the average measured values of cutting power, processed surface roughness and flank wear width of the milling cutter blade

Table 5. *Summary average measurement results of the cutting power, processed surface roughness and blunting zone width of the milling cutter blade*

Starting with	Average cutting power	Average roughness of the processed surface
Sharpened tool	590.44	5.96
Already used tool	668.20	6.87
Difference [%]	13.17%	15.27%

The following can be concluded from Table 5:

- Tool wear causes an increase in cutting power. In this case it amounts to 13.17%;
- Tool wear affects processed surface roughness. In this case it amounts to 15.27%;

4. CONCLUSIONS

This paper shows that the applied measurement method can effectively be used to evaluate tool life in the wood cutting process, so that it can be applied in practice to monitor tool wear along with the monitoring of cutting power, and be used as a complement to that monitoring.

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DETERMINATION OF PERFORMANCE INDICATORS AND QUALITY OF TCT KNIVES WHEN SHARPENED WIT PCD GRINDING WHEELS

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ABSTRACT

This article presents experimental results in respect of planer knives sharpening made of TCT, type K40 and K20 according to ISO grade classifications with abrasive tools from Polycrystalline Diamond (PCD). The specific consumptions of PCD abrasive was defined. The grits of PCD abrasive were with common heightened durability, anti-stick properties and organic binder. Some qualitative indices when sharpen planer knives were studied.

Key words: planer knives, cutter head, sharpening, abrasive tools, polycrystalline diamond, tungsten carbide tools

1. INTRODUCTION

An important stage in the production and use of planer knives for longitudinal milling of wood and wood-based materials is their sharpening. Planer knives that have been used and show signs of wearing off, as well as newly delivered knives have to be sharpened. Sharpening is done on the back side of the knives until the knife edge is restored. Of particular importance is the correct choice of the abrasive tool and the choice of the adequate sharpening mode [2, 3].

The aim of the present work is to perform comparative experimental tests for determination of the specific consumption of diamonds of abrasive tools with an organic binder and a combined metal / organic binder produced in Bulgaria, as well as some qualitative indicators for normal and forced sharpening of planer knives with TC edges, type K40 and K20. The planer knives are part of assembled cutter head.

2. MATERIAL AND METHOD OF WORK

Experimental research was carried out using cutter head with HM insert knives for preliminary and fine planing of solid wood and wood composed materials on four-side processing machines (fig. 1).

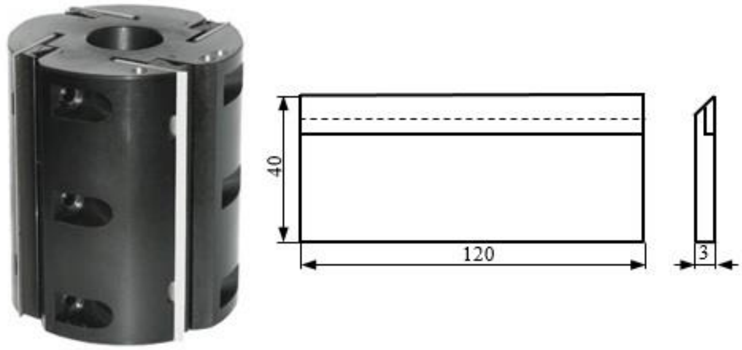


Figure 1. *Assembled cutter head with HM insert knives, type K40*

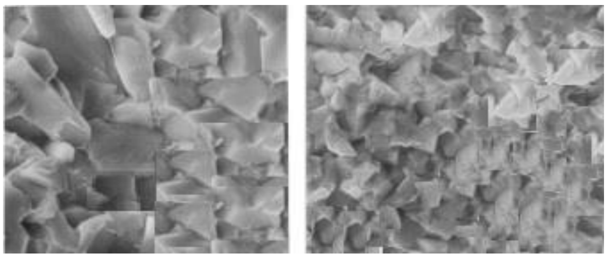
The basic parameters of the cutter head and the removable knives are given in Table 1. The planer knives are with tungsten carbide tipped edges, type K40, K20 and heat treated to hardness HRC 89.

Table 1. *Basic parameters of the cutter head and knives*

***D*, mm**	***d*, mm**	***L*, mm**	***B*, mm**	***s*, mm**	***z*, mm**	**β, ^{0}**	**Type**
123	32	120	40	3	4	45	T.C.T.

The indications in Table 1 correspond to:
D – Diameter of the cutter head;
d – Bore size;
L – Length of the knife;
B – Width of the knife;
s – Thickness of the knife;
z – Number of knives;
β – Angle of sharpening.
T.C.T. – tungsten carbide teeth.

These cutter head have designed for shapers machine, spindle moulder machine. The cutting plates consist of sintered materials composed of metal carbides and metallic binders: WC – 92% and Co – 8%) with medium grain of WC – 1,0 - 2,0 µm (fig. 2 A) and those from K20 with micro grain of WC up to 1,0 µm (fig. 2 B) [6].



A **B**

Figure 2. *Fracture of a standard tungsten carbide: A - Medium Grain 1,0-2,0 µm; B - Micro Grain up to 1,0 µm*

The abrasive PCD grinding wheel (fig. 3) has 12A2 45^0 shape (conical cup - CC) and works with its front surface (manufactured in ZAI JSC - Bulgaria).

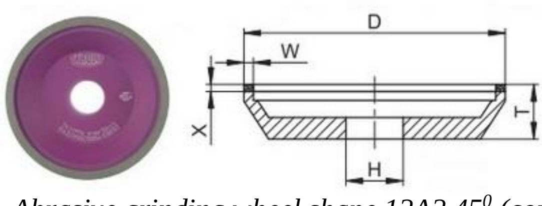


Figure 3. *Abrasive grinding wheel shape 12A2 45^0 (conical cup)*

The characteristics of the experimental abrasive wheels are given in Table 2.

Table 2. *Characteristics of the experimental wheels*

Shape and dimensions	**Abrasive type**	**Mesh Size**	**Bond Type**	**Concentration, %**
12A2 45^0 125x5x3x32	SD (Synthetic Diamond)	125/100	B8/A	100
12A2 45^0 125x5x3x32	SD (Synthetic Diamond)	125/100	BM/A	100

Experimental diamond wheels SD are made of synthetic diamond with ordinary durability.

B8/A is an organic bond based on a phenol-formaldehyde resin with added filler of barium sulphate and talc and with the addition of anti-friction agents in order to control its wear resistance, heat resistance, grit retention and lubrication.

BM/A is a metal-organic bond made of phenol-formaldehyde resin, metallic powders of copper and potassium, and zirconium dioxide to increase the bond rigidity.

The studies were performed under the following sharpening modes:
- cutting speed (V) – 18 m/s;
- longitudinal feed speed (V_l) – 1,0 m/min;
- cross feed speed (V_{dm}) – from 0,03 to 0,23 mm/double motion.

The studies were carried out according to the scheme of Table 3, with cross-feed being performed before each gradual movement of the longitudinal feed.

Table 3. *Scheme of the test carried out*

Abrasive wheel	**TCT**	**Cooling**	**Cross feed speed, mm/double motion**							
			0,03	**0,05**	**0,08**	**0,10**	**0,12**	**0,15**	**0,18**	**0,20**
SD 12A2 45^0 125x5x3x32 125/100 B8/A 100	K40	-		+		+				
	K40	+		+		+		+		+
SD 12A2 45^0 125x5x3x32 125/100 BM/A 100	K20	-		+		+				
	K20	+		+		+		+		+

Legend: + with cooling; - without cooling

Two studies were also carried out in forced sharpening with greater direct and reverse cross feed in the following modes:
- cutting speed (V) – 18 m/s;
- longitudinal feed speed (V_l) – 1,0 m/min;
- cross feed speed:

i. V_{dm}= 0,20 mm/double motion; $\overline{V}_{dm}$ = 0,15 mm – direct motion; $\overline{V}_{rm}$= 0,05 mm – reverse motion.

ii. V_{dm}= 0,23 mm/double motion; $\overline{V}_{dm}$ = 0,15 mm – direct motion; $\overline{V}_{rm}$= 0,08 mm – reverse motion.

The quality indicators of the treated surfaces are defined:

A. Grinding surface roughness (Ra):

The measurements were performed with the digital profilomer, model „Surftest SJ-210“ (Mitutoyo, Japan). The applied methodology is in accordance with BDS EN ISO 4287 and is described in details (Gochev 2005). For each knife, six measurements were made: four parallel to the cutting edge and two diagonals.

B. Micro indentations of the cutting edge

The maximum breakage deposit (H_i, µm) of the cutting edge were measured (Fig. 3). For that purpose a microscope with eyepiece-micrometer, model „Technival 2“ (Germany) was used. The measuring numbers were analogous with the index of roughness.

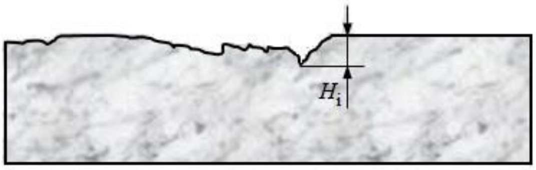


Figure 4. *Maximum breakage deposit s (H_i) of the cutting edge*

C. Width of the cutting edge (B_i):

It was measured by analogy to the micro- indentations of the cutting edge in the narrowest and the widest parts.

D. *Availability of cracks, micro cracks, burns, blue in the face and some other defects in the cutting edge area:*

These indices were located by visual observation and with the help of a magnifying lens in the process of knives sharpening or after already sharpened knives. They were also perceived as limiting conditions.

The following restrictive requirements have been imposed to the quality of sharpened TC knives:
- roughness of surfaces, R_a = 0,32-0,63 μm;
- micro indentations of the cutting edge, H_i = 18-25 μm;
- width of the cutting edge, B_i = 5-15 μm;
- is allowed in the close of knife edge: availability of burns, blue, change of the surface structure and etc.

The specific consumption of PCD (Q_s, ct/mm^3) is a basic indicator of abrasion resistance of the abrasive tool [4, 5]. It is defined as attitude of the mass of the consumed PCD (m_a, ct) to the volume of the take down material (V_m, mm^3), i.e.:

(1) $$Q_s = \frac{m_a}{V_m}$$

The relative consumption of PCD (Q_r, *ct/g*) is defined as attitude of the mass of consumed PCD to the mass of take down material (m_m, g):

(2) $$Q_r = \frac{m_a}{m_m}$$

The consumption of PCD is defined to the weight method or by measuring of the linear wearing out of the PCD layer.

The weight method is related to accurate weighing of the abrasive disk before and after carrying out a certain amount of work. A main disadvantage is the inaccuracy of weighing, result of the materials in the lubricant-cooling liquid. The weight of the removed metal layer was determined for each of the knives with the help of an electronic scale model „Sartorius“-type 610-D (Germany).

These disadvantages are largely overcome by using the linear wear measurement method of the PCD layer. This was done immediately before and after work, using a stereo microscope, over the width of the radial sections of the diamond layer.

The relative spending on PCD is the specified according to weight method:

(3) $$Q_r = \frac{W_a}{m_m}\alpha_a$$

Where W_a is the wear of the PKD layer at each test, mg;
- α_a – a coefficient that measures the bond density and concentration of PKD in the layer.

The same index determined by the linear wear method of the diamond layer in a disk operating on its face is determined by the following formula:

(4) $$Q_r = \frac{h_a.200.m_a}{X.m_m}$$

Where h_a is the wear of the wheel in the thickness of PCD layer during the tests, μm;
- X – the thickness of PCD layer before the tests, μm;

In order to obtain the volumetric specific consumption of diamond, it is necessary to multiply (Q_r) with the density of the treated material γ_m (g/cm^3), i.e. $Q_s = Q_r.\gamma_m$

The studies were carried out with the help of automatic high productivity grinding machine for flat knives, model HMS I of a firm „Vollmer” (Germany) and lubricant cooling fluid - 1~2% an aqueous solution of calcined soda (Na_2CO_3).

The studies were carried out using an automatic, high-performance sharpening machine for planer knives, model „HMS I“ of a firm „Vollmer“ (Germany) and a lubricating-cooling liquid - 1~2% aqueous solution of calcined soda (Na_2CO_3).

The knives of the cutter head were mounted on the table of the sharpening machine on the step plate (Figure 5) to ensure simultaneous sharpening [3].

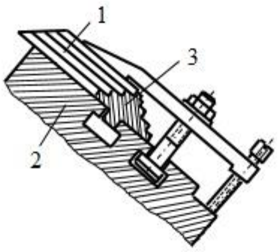


Figure 5. *Mounting of knives on the table of a sharpening machine on the step plate: 1 - knife; 2 - table; 3 – step plate*

3. RESULTS AND DISCUSSION

The results of the research were processed by the variation statistics methods with the software products QstatLab5 and Microsoft Excel. All results of the studies on the sharpening of planer knives, at different values of the cross feed are presented in graphical form (fig. 6-9) including and with forced sharpening with greater direct and reverse cross feed.

Table 4 shows a comparison of qualitative indicators for sharpening of TC planer knives BK8 and BK8M with PCD abrasive wheels with and without cooling.

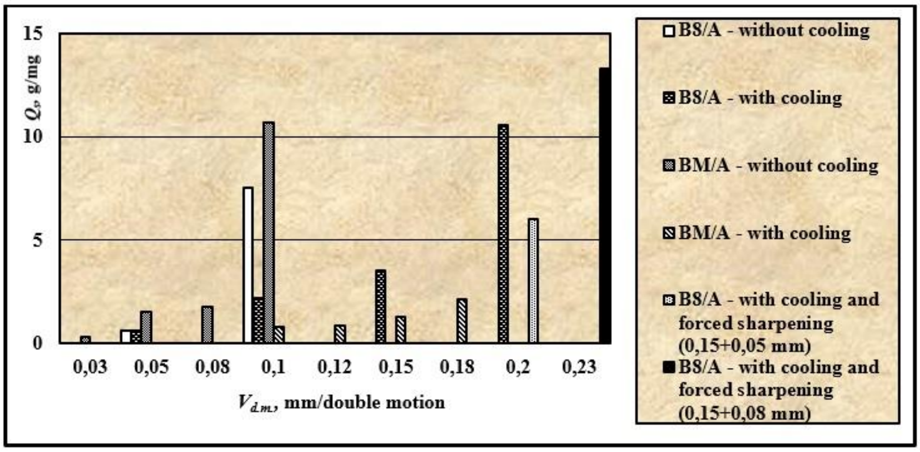


Figure 6 . *Dependence between specific consumption of PCD (Q_s) and the rate of the cross feed ($V_{дв.х.}$)*

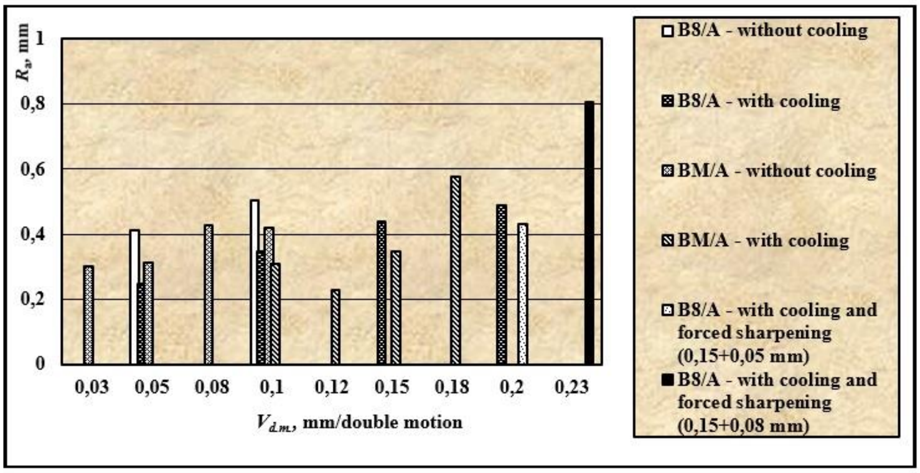


Figure 7. *Dependence between the rate of the cross feed ($V_{дв.х.}$) the roughness index (R_a)*

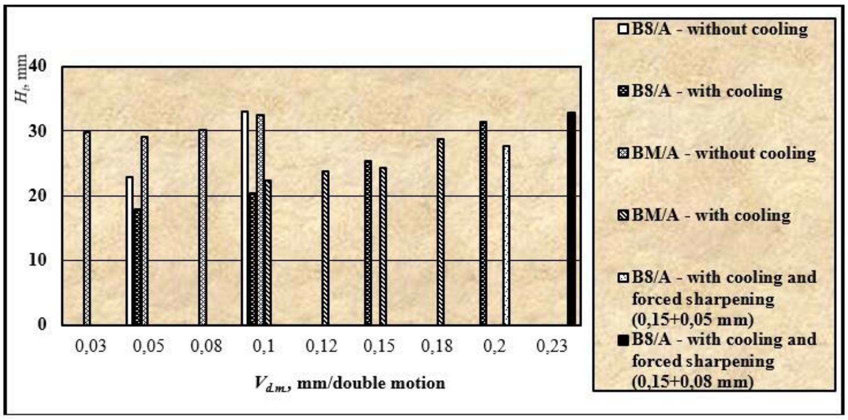


Figure 8. *Dependence between the rate of the cross feed ($V_{дв.х.}$) and H_i index*

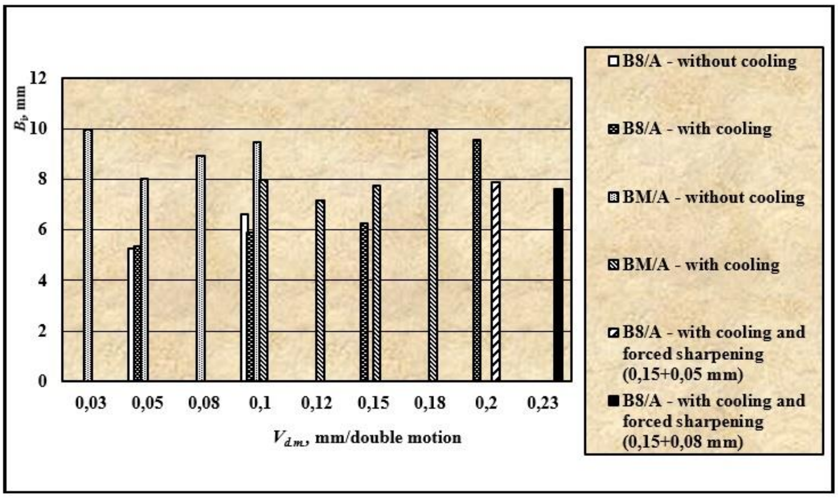


Figure 9. *Dependence between the rate of the cross feed ($V_{дв.х.}$) and the width of the cutting edge (B_i)*

Table 4. *Comparative table of qualitative Indicators for sharpening of TC planer knives with diamond abrasive wheels*

Bond	$V_{дв.х.}$, double motion	Cooling	Quality Indicators of sharpening			Existence of defects
			R_a, µm	H_i, µm	B_i, µm	
B8/A	0,05	-	0,41	22,9	5,26	
		+	0,25	17,8	5,37	
	0,10	-	0,51	33,1	6,61	burning
		+	0,35	20,4	5,89	
	0,15	+	0,44	25,4	6,25	
	0,20	+	0,49	31,3	9,56	highly cracked line
	0,20 (0,15+0,05)	+	0,43	27,6	7,91	
	0,23 (0,15+0,08)	+	0,81	32,8	7,61	lack of straight line, highly cracked line
BM/A	0,03	-	0,30	29,8	9,98	
	0,05	-	0,31	29,2	8,04	
	0,08	-	0,43	30,2	8,96	light burning
	0,10	-	0,42	32,5	9,50	burning at the end
		+	0,31	22,4	7,98	
	0,12	+	0,23	23,7	7,17	
	0,15	+	0,35	24,3	7,75	
	0,20	+	0,58	28,7	9,95	breaking at the end

It can be seen from Figures 6-9 and Table 4 that:

1. Abrasive wheel with B8/A bond without cooling at V_{dm} = 0,10 mm/double motion heated the sharpened TC knives and the specific diamond consumption is Q_s = 7,54 g/mg. This is 12 times more specific diamond consumption at V_{dm} = 0,05 mm/double motion width (Q_s = 0,64 g/mg), or that wheel can run without cooling to V_{dm} = 0,05 mm/double motion.

2. Abrasive wheel with BM/A bond without cooling at V_{dm} = 0,08-0,10 mm/double motion heated the sharpened TC knives. The specific diamond consumption increases slightly to cross feed speed V_{dm} = 0,08 mm/double motion, but at V_{dm} = 0,10 mm/double motion, the specific diamond consumption is increased 10 times (Q_s = 10,71 g/mg). It follows that an abrasive wheel with a BM/A bond can run without cooling to cross feed speed V_{dm} = 0,08 mm/double motion.

3. Abrasive wheel with B8/A bond whit cooling works well to to cross feed speed V_{dm} = 0,15 mm/double motion and specific diamond consumption Q_s = 3,59 g/mg Q_s = 3,59 g/mg – relatively high but within acceptable limits. At V_{dm} = 0,20 mm/double motion, the specific diamond consumption is increased to Q_s = 10,56 g/mg, as they are obtained edges with a highly cracked line. Therefore, an abrasive wheel with a B8/A bond with cooling can work well with cross feed speed to V_{dm} = 0,15 mm/double motion.

4. In forced sharpening with abrasive wheel with B8/A bond, with cross feed speed $V_{дв.х.}$ = 0,20 mm/double motion: $\vec{V}_{dm}$ = 0,15 mm – direct motion and $\overleftarrow{V}_{rm}$= 0,05 mm – reverse motion, performance indicators are much better than the same wheel and with direct cross feed speed $V_{дв.х.}$ = 0,20 mm/double motion. The specific diamond consumption is 40% smaller, which is significant in this large cross-feed. With cross feed speed $V_{дв.х.}$ = 0,23 mm/double motion: $\vec{V}_{dm}$ = 0,15 mm – direct motion and $\overleftarrow{V}_{rm}$= 0,08 mm – reverse motion, did not get good results because the B8/A abrasive wheel has reached its limit.

5. The abrasive wheel with BM/A bond has much better sharpening capabilities than a wheel with B8/A bond. This is confirmed by the studies, which has 2,6 times less specific diamond consumption per wheel B8/A at a cross-feed of 0,10 mm/double motion.

4. CONCLUSION

On the basis of the conducted experimental studies and the analysis made, the following conclusions can be made:

1. The diamond wheel with its bond, grain type, and sharpening mode, cooling, and type of TC knives have a steady effect on performance indicators performance indicators and sharpening quality.

2. The roughness of the polished surfaces (R_a) in all sharpening modes is within the standard range, with a general tendency to increase the cross-feed being increased and R_a. When sharpening with cooling, the roughness of the surfaces greatly improves.

3. The size of the micro-indentations of the edge (H_i) increases with increasing the cross-feed (V_{dm}). The knives cooling helps to reduce the micro-indentations of the cutting edge. In some heavier sharpening modes, high H_i values are obtained, which can be reduced by smoothing the edge without crosswise feeding the abrasive wheel.

4. In all studies, the width of the edge B_i of the TC knives is within the standard requirements.

5. It is recommended to use the following brands of diamond discs and sharpening modes:

- abrasive wheel SD (PCD) 12A2 45^0 125x5x3x32 125/100 B8/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,08-0,10 mm/double motion; without cooling;
- abrasive wheel SD (PCD) 12A2 45^0 125x5x3x32 125/100 BM/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,05 mm/double motion; without cooling;
- abrasive wheel SD (PCD) 12A2 45^0 125x5x3x32 125/100 BM/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,12-0,15 mm/double motion; with cooling.

6. It is recommended forced sharpening with B8/A abrasive wheel with cooling and with cross feed speed $V_{дв.х.}$ = 0,20 mm/double motion: $\vec{V}_{dm}$ = 0,15 mm – direct motion and $\overleftarrow{V}_{rm}$= 0,05 mm – reverse motion. The specific diamond consumption decreases by 40% less.

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INVESTIGATIONS OF THE FREE SPACE VIBRATIONS OF A WOODWORKING SHAPER, CONSIDERED AS A MECHANICAL SYSTEM WITH THREE MAIN BODIES

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ABSTRACT

Investigation of the free undamped spatial vibrations of a woodworking shaper, considered as a mechanical system with three main bodies, is the object of the proposed study. First, an original mechanic-mathematical model of a woodworking shaper developed by the authors is presented. The model considers woodworking shapers with lower placement of the spindle. In this model the woodworking shaper, the spindle and the electric motor's rotor are regarded as rigid bodies, which are connected by elastic elements with each other and with the motionless floor. The model takes into account the needed mass, inertia and elastic properties of the elements of the considered system. It includes all necessary geometric parameters of this system. After that a system of matrix differential equations is compiled and analytical solutions are derived. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a machine used in the practice. As a result of the whole study, the natural frequencies and the mode shapes of the free spatial vibrations of the studied mechanical system are obtained and illustrated.

Key words: woodworking shapers, free vibrations

1. INTRODUCTION

The tendency to significant reduction of the level of the vibrations and the noise accompanying the work of modern woodworking machines in recent years implies expanding and deepening the research of the dynamic processes in these machines (Barcík, Kvietková, Aláč, 2011; Beljo-Lučić, Goglia, 2001; Trposki et all, 2013).

Woodworking shapers are in the group of woodworking machines with high levels of vibration and noise (Vukov et all, 2016). The introduction of measures for reduction of the level of vibration and noise requires understanding the essence of phenomena which are typical for this machine and its individual elements (Kminiak, Siklienka, Šustek, 2016; Koljozov et all, 2016; Orlowski, Sandak, Tanaka, 2007). It is necessary to conduct concrete studies in which the machine can be considered as a mechanical vibrating system with known characteristics (Amirouche 2006, Angelov, Slavov, 2010, Coutinho 2001). Some recommendations, based on the results of these investigations and applicable to the design, manufacture and operation of woodworking shapers, can be made.

It is very important to put suitable vibration isolators between the machine and the floor (Veits, Kochura, Martinenko, 1971; Wittenburg 1977). The aim is to limit the distribution of machine's vibrations to the environment. Unified elastic elements with known dynamic characteristics are commonly used. The selection of vibration isolators with optimal qualities is associated with conducting a preliminary study of the vibration behavior of the machine to assess the influence of the different elasticity coefficient of the vibration isolators.

The drive electric motor is a major element of the cutting mechanism. It is one of the sources of vibrations during the work of the woodworking machines (Stevens 2007). The rotor's vibrations, generated during operation, are transmitted through its two bearing units and reach the machine's body. On the other hand, vibrations, generated by other elements of the machine, reach the rotor back through bearing units. In that way bearing units are very important for interaction of the electric motor and the machine's body.

Variable loads arise during the operation of the woodworking shaper on its working tool. They are transmitted to the spindle and by its two bearing units reach the machine's body. Vibrations, generated by other elements of the machine, reach the spindle and the cutter back through bearing units.

It is clear that the characteristics (stiffness, damping properties, etc.) of the spindle bearings and the electric motor's rotor bearings as well as of the vibro-isolators between the machine and the floor are important for the vibrations and the operation of the machine.

The idea that the woodworking shaper, its spindle and the electric motor's rotor are regarded as rigid bodies, which are connected by elastic elements with each other and with the motionless floor, derives from the written above. These elastic elements are four vibration isolators between the machine and the floor, two bearing units of the spindle and two bearing units of the electric motor's rotor.

The aim of this study is to investigate the free undamped spatial vibrations of the woodworking shaper, which is considered as a mechanical system with three main bodies. Therefore, first it is necessary to develop mechanic - mathematical model of the woodworking shaper, its spindle and the rotor of the driving electric motor. The model should take into account the characteristics of the woodworking shaper construction, the mass, inertia and elastic properties of its components as well as all needed geometric parameters of the system. A system of matrix differential equations is composed on the basis of this model and analytical solutions are presented. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a real machine. As a result of the study, the natural frequencies and the mode shapes of the studied mechanical system will be obtained and illustrated.

2. MATERIAL AND METHODS

This study examines the class of woodworking shapers with a low positioned spindle, which are often used in practice of the forestry industry (Filipov 1977, Obreshkov 1996). The analysis of their construction shows the strong influence of the spindle and the drive motor on the operation of the whole machine. Fig. 1 shows the general view of woodworking shapers. Fig. 2 shows a scheme of this type of woodworking shapers. The machine's body is marked with *1*, *2* is the drive electric motor, *3* – the belt drive, *4* – the vibration isolators between the machine and the floor, *5* – the spindle with the bearings, *6* – wood shaper's saw.

Figure 1. *General view of woodworking shaper*

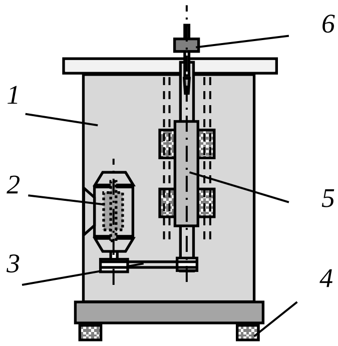

Figure 2. *Scheme of woodworking shaper*

Fig. 3 shows the spindle with its bearing units. Fig. 4 shows the spindle with fitted cutter. Fig. 5 shows the drive electric motor.

Figure 3. Spindle with bearing units

Figure 4. Spindle with fitted cutter

Figure 5. Drive electric motor

In the following discussions, the woodworking shaper, its spindle and the rotor of the driving electric motor are regarded as rigid bodies, which are connected by elastic elements with each other and with the motionless floor. These elastic elements are the four vibration isolators between the machine and the floor, the two bearing units of the spindle, and the two bearing units of the electric motor’s rotor.

A mechanical - mathematical model of wood shapers with lower spindle is built for studying its free undamped spatial vibrations. The model is shown in Fig. 6.

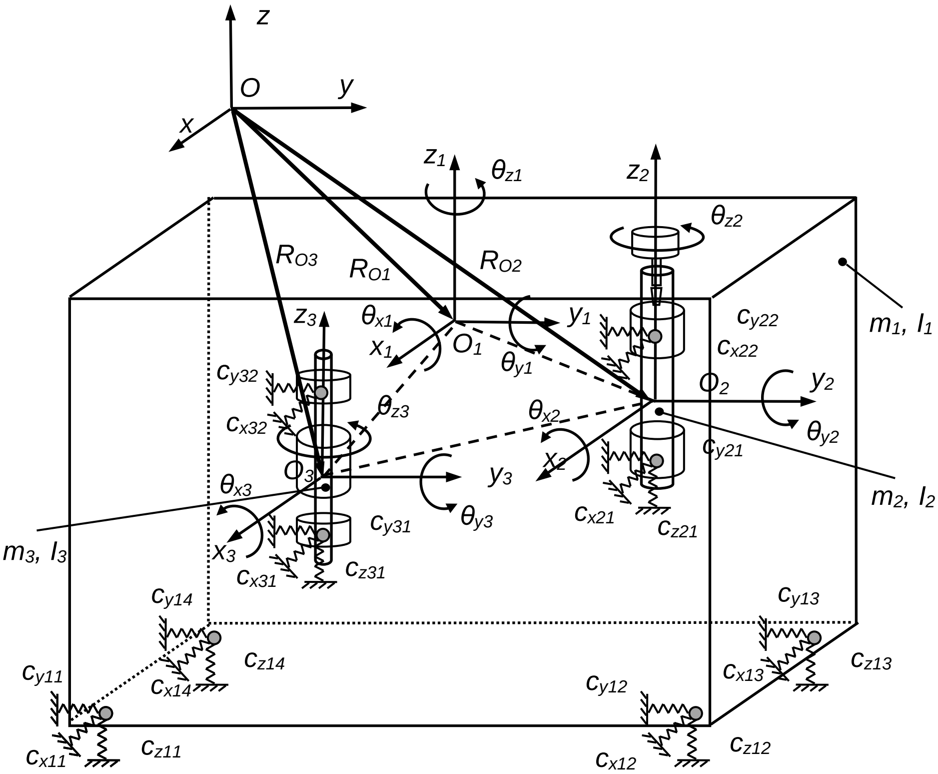

Figure 6. *Mechanic-mathematical model of the wood shaper, its spindle and motor’s*

The following symbols are used:

m_1, m_2, m_3 – mass of the woodworking shaper, the spindle and the rotor of the driving electric motor;

$\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$ – inertia moment tensors of the woodworking shaper , the spindle and the rotor of the driving electric motor;

c_{x1i}, c_{y1i}, c_{z1i} , $i = 1, 2, 3, 4$– elastic coefficients of the vibroisolators between the machine and the floor;

b_{x1i}, b_{y1i}, b_{z1i} , $i = 1, 2, 3, 4$– damping coefficients of the vibroisolators between the machine and the floor;
c_{x2i}, c_{y2i}, c_{z2i} , $i = 1, 2$– elastic coefficients between the body of the machine and the spindle;
b_{x2i}, b_{y2i}, b_{z2i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the spindle;
c_{x3i}, c_{y3i}, c_{z3i} , $i = 1, 2$– elastic coefficients between the body of the machine and the rotor of the driving electric motor;
b_{x3i}, b_{y3i}, b_{z3i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the rotor of the driving electric motor.

The three bodies of the mechanical system perform spatial vibrations - three small translations and three small rotations relative to the axes of the rectangular local coordinate systems that are fixedly connected to the bodies.

The position of the mechanical system in space is defined by the vector of the generalized coordinates (Fig. 6), which is

$$\mathrm{q} = \left[x_1\ y_1\ z_1\ \theta_{x1}\ \theta_{y1}\ \theta_{z1}\ x_2\ y_2\ z_2\ \theta_{x_2}\ \theta_{y_2}\ \theta_{z_2}\ x_3\ y_3\ z_3\ \theta_{x3}\ \theta_{y3}\ \theta_{z3}\right]^{\mathrm{T}}. \tag{1}$$

The mechanical system has 18 degrees of freedom. The building of its mechanic-mathematical model is presented below.

Matrixes of the transition

The matrixes of the transition in small vibrations from the local coordinate systems of the bodies $O_i x_i y_i z_i$ to the reference coordinate system $Oxyz$ have the form

$$\mathrm{A}_{\mathrm{i}}^{0} = \begin{bmatrix} 1 & -\theta_{zi} & \theta_{yi} & x_i \\ \theta_{zi} & 1 & -\theta_{xi} & y_i \\ -\theta_{yi} & \theta_{xi} & 1 & z_i \\ 0 & 0 & 0 & 1 \end{bmatrix}, i = 1,2,3 . \tag{2}$$

Vectors of the position of random points

The vector of the position of the center of mass of the relevant body, projected in the reference coordinate system, is determined with

$$\mathrm{R}_{\mathrm{Ci}}^{0} = \mathrm{A}_{\mathrm{i}}^{0}.\mathrm{r}_{\mathrm{Ci}} = \begin{bmatrix} l_{Cx} + x_i + l_{Cz}.\theta_{yi} - l_{Cy}.\theta_{zi} \\ l_{Cy} + y_i - l_{Cz}.\theta_{xi} + l_{Cx}.\theta_{zi} \\ l_{Cz} + z_i + l_{Cy}.\theta_{xi} - l_{Cx}.\theta_{yi} \\ 1 \end{bmatrix}, i = 1,2,3 , \tag{3}$$

where $\mathrm{r}_{\mathrm{Ci}} = \left[l_{Cx} \quad l_{Cy} \quad l_{Cz}\right]^{\mathrm{T}}$ is the vector of the position of the center of mass in the local coordinate system.

Linear velocity vectors of any points

The linear velocity vector of any point Ci of body i, projected in the reference coordinate system, is obtained by differentiating by the time of the position’s vector of the same point

$$\mathrm{V}_{\mathrm{Ci}}^{0} = \frac{d\mathrm{R}_{\mathrm{Ci}}^{0}}{dt} = \begin{bmatrix} \dot{x}_i + l_{Cz}.\dot{\theta}_{yi} - l_{Cy}.\dot{\theta}_{zi} \\ \dot{y}_i - l_{Cz}.\dot{\theta}_{xi} + l_{Cx}.\dot{\theta}_{zi} \\ \dot{z}_i + l_{Cy}.\dot{\theta}_{xi} - l_{Cx}.\dot{\theta}_{yi} \\ 0 \end{bmatrix} \qquad i = 1,2,3 . \tag{4}$$

Vectors of the angular velocities of the bodies

The vector of angular velocity of the body *i*, projected in the local coordinate system, is

$$\Omega_i^i = \begin{bmatrix} \dot{\theta}_{xi} \\ \dot{\theta}_{yi} \\ \dot{\theta}_{zi} \\ 0 \end{bmatrix} \qquad i = 1,2,3 \,. \tag{5}$$

The kinetic energy

The kinetic energy of the mechanical system is

$$E_K = \sum_{i=1}^{3} E_{Ki} \,, \tag{6}$$

where $E_{Ki} = \frac{1}{2}.\left(m_{RR}^{i}.V_{Ci}^{0\,T}.V_{Ci}^{0} + \Omega_i^{i\,T}.I_{\Theta\Theta}^{i}.\Omega_i^i \right)$,

$m_{RR}^{i} = \int_{V_i} \rho_i\,.\mathbf{I}\,.dV_i = m_i\,.\mathrm{I}$.

The elements of the matrix **M** of mass-inertial properties are defined by the expression

$$m_{i,j} = \frac{\partial^2 E_K}{\partial \dot{q}_i\,.\partial \dot{q}_j} \tag{7}$$

Potential energy

Potential energy is defined by

$$E_P = E_{PK}(q)_m + E_{PG}(q)_i \tag{8}$$

where $E_{PK}(q)_m = \sum_{m=1}^{8} \frac{1}{2}.q^T.C(q).q$,

$E_{PG}(q)_i = \sum_{i=1}^{3} - m_i.g^T.R_{Ci}^{0}$,

$C(q)$ is a matrix of elastic properties;

$g = \begin{bmatrix} 0 & 0 & g & 0 \end{bmatrix}^T$ – vector of gravitational acceleration,

m is the number of the elastic element between two bodies of the mechanical system

The elements of the matrix **C** of elastic properties are determined by the expression

$$c_{m,n} = \frac{\partial^2 E_{PK}(q)_{ij}}{\partial q_n.\partial q_m} \tag{9}$$

Differential equations

The differential equations of the free undamped spatial vibrations are derived by using the Lagrange’s method. A system of differential equations which describes the small free vibrations of the examined mechanical system is obtained.

$$M.\ddot{q} + C.q = 0 \tag{10}$$

The natural frequencies and the mode shapes of the mechanical system are obtained after solving the system equations (10)

3. RESULTS AND DISCUSION

Carrying out numerical investigations of the free undamped spatial vibrations of a woodworking shaper with lower spindle requires knowledge of the parameters of its elements. Therefore the three bodies and the whole machine are modeled with software Solid Works. These models are shown respectively in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. The mass center of the body 1 coincides with the center of the local coordinate system of the body 1 and the center of the reference coordinate system. The mass center of the body 2 coincides with the center of the local coordinate system of the body 2. The mass center of the body 3 coincides with the center of the local coordinate system of the body 3.

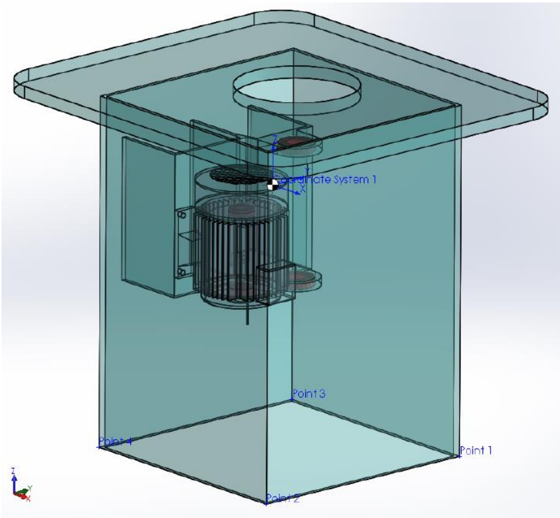

Figure 7. *Body 1*

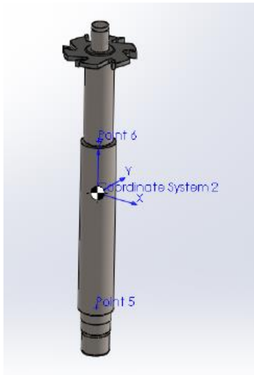

Figure 8. *Body 2*

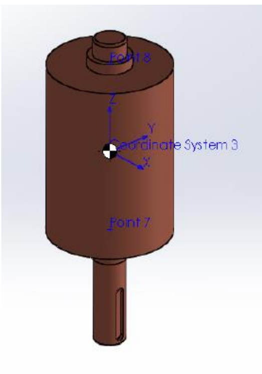

Figure 9. *Body 3*

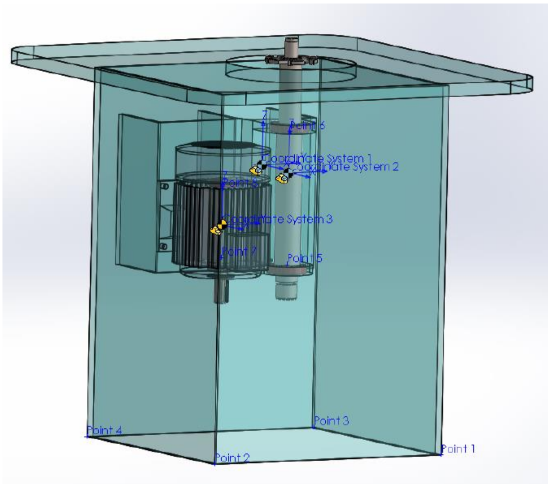

Figure 10. *Woodworking shaper*

The presented data of the machine FD-3, which is produced in ZDM – Plovdiv, is used for calculations.

Mass of the bodies: body 1 – $m_1 = 391{,}52\ kg$; body 2 – $m_2 = 11{,}123\ kg$; body 3 – $m_3 = 14{,}378\ kg$. Tensor of mass inertia moments of the body 1 to the local coordinate system of the body 1, $kg.m^2$

$$I_1 = \begin{bmatrix} 49{,}2672 & -0{,}0395 & -0{,}2525 \\ -0{,}0395 & 52{,}0000 & -0{,}4405 \\ -0{,}2525 & -0{,}4405 & 47{,}9480 \end{bmatrix}.$$

Tensor of mass inertia moments of the body 2 to the local coordinate system of the body 2, $kg.m^2$

$$I_2 = \begin{bmatrix} 0{,}2937 & 0 & 0 \\ 0 & 0{,}2937 & 0 \\ 0 & 0 & 0{,}0052 \end{bmatrix}.$$

Tensor of mass inertia moments of the body 3 to the local coordinate system of the body 3, $kg.m^2$

$$I_3 = \begin{bmatrix} 0{,}0516 & 0 & 0 \\ 0 & 0{,}0516 & 0 \\ 0 & 0 & 0{,}0206 \end{bmatrix}.$$

Coordinates of the centers of mass, m

Body №	l_{Cx}	l_{Cy}	l_{Cz}
1	0	0	0
2	0,009	0,066	–0,020
3	0,019	–0,115	–0,134

Coordinates of the supporting points of the elastic elements
Coordinates in the coordinate system of the body 1, *m*:

Point	l_{xi}, **m**	l_{yi}, **m**	l_{zi}, **m**
1	0,309	0,316	-0,654
2	0,309	-0,284	-0,654
3	-0,291	0,316	-0,654
4	-0,291	-0,284	-0,654
5	0,009	0,066	-0,234
6	0,009	0,066	0,076
7	0,019	-0,015	-0,210
8	0,019	-0,015	-0,050

Coordinates in the coordinate system of the body 2, *m*:

Point	l_{xi}, **m**	l_{yi}, **m**	l_{zi}, **m**
5	0	0	-0,214
6	0	0	0,096

Coordinates in the coordinate system of the body 3, *m*:

Point	l_{xi}, **m**	l_{yi}, **m**	l_{zi}, **m**
7	0	0	-0,076
8	0	0	0,084

Elasticity coefficients

Between Bodies	c_{xi} ,N/m	c_{yi} ,N/m	c_{zi} ,N/m
0 - 1	350000	350000	800000
1 - 2	2250000	2250000	2250000
2 - 3	2250000	2250000	2250000

Fig. 11 graphically illustrates the calculated natural frequencies [Hz] and mode shapes of free spatial vibrations of the studied mechanical system.

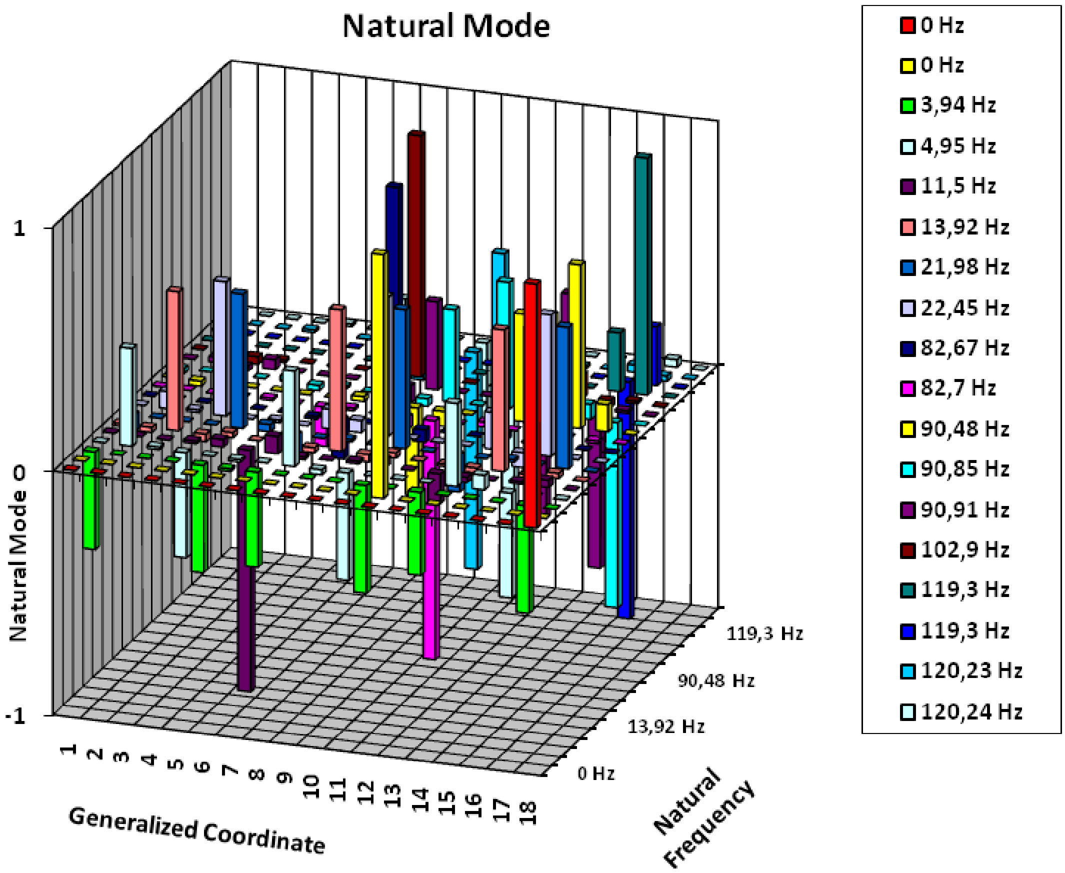

Figure 11. *Natural frequencies and mode shapes of the studied mechanical system*

Fig. 11 shows calculated natural frequencies and mode shapes of this system. Natural frequencies are 120.24 Hz; 120.23 Hz; 119.30 Hz; 119.29 Hz; 102.90 Hz; 90.91Hz; 90.85Hz; 90.48Hz; 82.70 Hz; 82.67 Hz; 22.45 Hz; 21.98 Hz; 13.92 Hz; 11.50 Hz; 4.95 Hz; 3.94 Hz ; 0 Hz; 0 Hz . These values are required for determination of the resonance zones. The knowledge of the resonance zones allows optimizing working regimes by taking measures to avoid machine operation in these areas or to pass quickly through them. The obtained and illustrated mode shapes are useful for the investigation of the vibration behavior of the machine. Analysis of the received natural frequencies and mode shapes provides an additional opportunity for the formation of reasonable recommendations for the construction of these machines.

4. CONCLUSION

This study presents original investigations of the free undamped spatial vibrations of a woodworking shaper, which is considered as a mechanical system with three main bodies. An original mechanic-mathematical model of a woodworking shaper developed by the authors is presented. The model considers woodworking shapers with lower placement of the spindle. In this model the woodworking shaper, the spindle and the electric motor's rotor are regarded as rigid bodies, which are connected by elastic elements with each other and with the motionless floor. It takes into account the characteristics in the construction of woodworking shapers. The model renders into account the needed mass, inertia and elastic properties of the elements of the considered system. It includes all necessary geometric parameters of this system. Then a compiled system of matrix differential equations is presented and analytical solutions are derived. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a machine, used in the practice. As a result of the whole study, the natural frequencies and the mode shapes of the free spatial vibrations of the studied mechanical system are obtained and illustrated.

They are necessary for determination of the resonance zones and for analyzing the vibration behavior of the machine.

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FREE DAMPED SPACE VIBRATIONS OF A WOODWORKING SHAPER, CONSIDERED AS A MECHANICAL SYSTEM WITH THREE MAIN BODIES

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ABSTRACT

Proposed study investigates the free damped spatial vibrations of a woodworking shaper, which is considered as a mechanical system with three main bodies. It presents an original mechanic-mathematical model targeted to investigations of the free damped spatial vibrations of woodworking shapers, developed by the authors. The model considers woodworking shapers with lower placement of the spindle. In this model the woodworking shaper, the spindle and the electric motor’s rotor are regarded as rigid bodies, which are connected by elastic and damping elements with each other and with the motionless floor. The model takes into account the needed mass, inertia, elastic and damping properties of the elements of the considered system. It includes all necessary geometric parameters of this system. After that a system of matrix differential equations is compiled and analytical solutions are derived. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a machine used in practice. As a result of the whole study, the free damped spatial vibrations of the studied mechanical system are obtained and illustrated.

Key words: woodworking shapers, free damped vibrations

1. INTRODUCTION

The specificity of the work of woodworking shapers implies frequent passing through transient regimes. It turns out that studying the characteristics of these regimes is especially important to ensure the proper machine’s work [Kminiak et al. 2016, Orlowski et al. 2007, Veits et al. 1971]. Consequently, a careful study of damped vibrations of this machine is required [Gochev and Vukov 2017, Gochev et al. 2017]. Investigations of these vibrations facilitate selecting of some of the woodworking shaper’s components and aid the control of its technical state [Barcík 2011, Beljo et al. 2001, Vukov et al. 2015]. This mainly concerns the vibroisolators between the machine and the floor, as well as the bearing units of the spindle and the rotor of the electric motor [Stevens 2007]. Such a study can be done numerically with the parameters of a particular woodworking shaper [Vukov et al. 2016a,b]. It is based on a previously developed mechanic-mathematical model of this machine [Amirouche 2006, Angelov and Slavov 2010, Coutinho 2001].

The proposed study considers the class of woodworking shapers with a lower spindle position, which are often used in practice of the forestry industry. The analysis of their construction shows the strong interconnection between the work of spindle with mounted tool on it, the rotor of the drive motor and the operation of the whole machine. The idea that the woodworking shaper, its spindle and the electric motor’s rotor are regarded as rigid bodies, which are connected by elastic and damping elements with each other and with the motionless floor, derives from this analysis. These elastic and damping elements are four-vibration isolators between the machine and the floor, two bearing units of the spindle and two bearing units of the electric motor’s rotor.

The aim of this study is to investigate the free damped spatial vibrations of the woodworking shaper. Therefore, first it is necessary to develop mechanic - mathematical model of the woodworking shaper, its spindle and the rotor of the driving electric motor. The model should take into account the characteristics of the woodworking shaper construction, the mass, inertia, elastic and damping properties of its components as well as all needed geometric parameters of the system. A system of matrix differential equations is composed on the basis of this model and analytical solutions are presented. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a real machine. The obtained results are illustrated graphically so as to make their analysis easier.

2. MATERIAL AND METHODS

This study examines the class of woodworking shapers with a low positioned spindle, which are often used in practice of the forestry industry [Filipov 1977, Obreshkov 1996]. The analysis of their construction shows the strong influence of the spindle and the drive motor on the operation of the whole machine. Fig. 1 shows the general view of woodworking shapers. Fig. 2 shows a scheme of this type of woodworking shapers. The machine's body is marked with *1*, *2* is the drive electric motor, *3* – the belt drive, *4* – the vibration isolators between the machine and the floor, *5* – the spindle with the bearings, *6* – wood shaper's saw.

Figure 1. *General view of woodworking shaper*

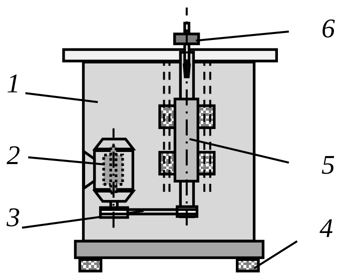


Figure 2. *Scheme of woodworking shaper*

Fig. 3 shows the spindle with its bearing units. Fig. 4 shows the spindle with fitted cutter. Fig. 5 shows the drive electric motor.

Figure 3. *Spindle with bearing units*

Figure 4. *Spindle with fitted cutter*

Figure 5. *Drive electric motor*

In the following discussions, the woodworking shaper, its spindle and the rotor of the driving electric motor are regarded as rigid bodies, which are connected by elastic and damping elements with each other and with the motionless floor. These elastic and damping elements are the four-vibration isolators between the machine and the floor, the two bearing units of the spindle, and the two bearing units of the electric motor's rotor.

A mechanical - mathematical model of wood shapers with lower spindle is built for studying its free damped spatial vibrations. The model is shown in Fig. 6.

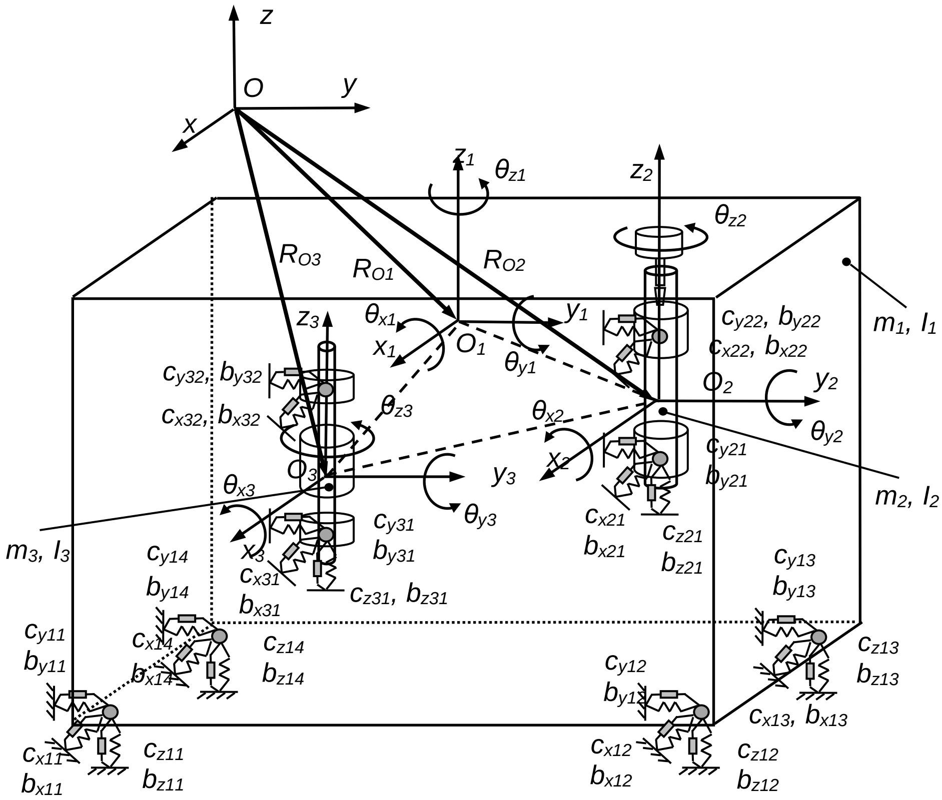


***Figure 6.** Mechanic-mathematical model of the wood shaper and its spindle*

The following symbols are used:

m_1, m_2, m_3 – mass of the woodworking shaper, the spindle and the rotor of the driving electric motor;

$\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$ – inertia moment tensors of the woodworking shaper , the spindle and the rotor of the driving electric motor;

c_{x1i}, c_{y1i}, c_{z1i} , $i = 1, 2, 3, 4$– elastic coefficients of the vibroisolators between the machine and the floor;

b_{x1i}, b_{y1i}, b_{z1i} , $i = 1, 2, 3, 4$– damping coefficients of the vibroisolators between the machine and the floor;

c_{x2i}, c_{y2i}, c_{z2i} , $i = 1, 2$– elastic coefficients between the body of the machine and the spindle;

b_{x2i}, b_{y2i}, b_{z2i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the spindle;

c_{x3i}, c_{y3i}, c_{z3i} , $i = 1, 2$– elastic coefficients between the body of the machine and the rotor of the driving electric motor;

b_{x3i}, b_{y3i}, b_{z3i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the rotor of the driving electric motor.

The three bodies of the mechanical system perform spatial vibrations - three small translations and three small rotations relative to the axes of the rectangular local coordinate systems that are fixedly connected to the bodies. It is assumed that the axes of the local coordinate systems are parallel to the axes of the reference coordinate system.

The position of the mechanical system in space is defined by the vector of the generalized coordinates, which is

$$\mathbf{q} = \left[x_1\ y_1\ z_1\ \theta_{x1}\ \theta_{y1}\ \theta_{z1}\ x_2\ y_2\ z_2\ \theta_{x_2}\ \theta_{y_2}\ \theta_{z_2}\ x_3\ y_3\ z_3\ \theta_{x3}\ \theta_{y3}\ \theta_{z3} \right]^{\mathrm{T}}. \tag{1}$$

The mechanical system has 18 degrees of freedom. The building of its mechanic-mathematical model is presented below.

The differential equations of the free damped spatial vibrations are derived by using the Lagrange's method

$$\frac{\mathrm{d}}{\mathrm{dt}}\left(\frac{\partial E_K}{\partial \dot{\mathrm{q}}}\right)-\left(\frac{\partial E_K}{\partial \mathrm{q}}\right)+\frac{\partial F_b}{\partial \dot{\mathrm{q}}}+\frac{\partial E_P}{\partial \mathrm{q}}=0\,, \tag{2}$$

where E_K and E_P are respectively the kinetic and the potential energy of the systems, and F_b is the dissipation energy or dissipative function.

The obtained system of differential equations, which describes the small free damped vibrations of the mechanical system, is

$$\mathrm{M}.\ddot{\mathrm{q}}+\mathrm{B}.\dot{\mathrm{q}}+\mathrm{C}.\mathrm{q}=0\,. \tag{3}$$

The matrix in these equations which characterizes the mass-inertial properties of the mechanical system is **M,** and the elastic properties – **C.** $\mathbf{B}(\dot{\mathbf{q}})$ is the matrix that characterizes the damping properties of this system.

$$\mathrm{M}=\left[a_{ij}\right],\quad a_{ij}=\frac{\partial^2 E_K}{\partial \dot{q}_i.\partial \dot{q}_j},\qquad \mathrm{C}=\left[c_{ij}\right],\quad c_{ij}=\frac{\partial^2 E_P}{\partial q_i.\partial q_j}.$$

The matrix $\mathrm{B}=\left[b_{m,n}\right]$ is obtained by substituting the elements of the matrix C – $c_{m,n}$, with $b_{m,n}$. Solutions of the system of the differential equations (3) are searched as.

$$q=\mathrm{V}.\,e^{pt}\,. \tag{4}$$

After differentiation of equations (4) and substituting in (3) it is obtained

$$\left(p^2.\mathbf{M}+p.\mathbf{B}+\mathbf{C}\right)\mathbf{V}=0\,. \tag{5}$$

where **V** is the matrix of natural vectors (modal matrix).

The matrix of natural vectors (modal matrix) has the form

$$\mathrm{V}=\left[\mathrm{v}_{r,j}\right]_{18\times 18}\,, \tag{6}$$

where $\mathrm{v}_\mathrm{r}=\left[v_{ri}\right],\ i=1,2,\ldots,18$ is the natural mode vector on the generalized coordinate for r-th natural frequency.

The vibrations are defined by their natural values p_r and their natural vectors $\mathbf{u}_r$, which in their general type are complex conjugate numbers

$$p_r=-\alpha_r\pm i.\beta_r\,, \tag{7}$$

$$\mathbf{u}_r=\mathbf{v}_r\pm i.\mathbf{w}_r\,, \tag{8}$$

where $\alpha_r=\sigma_r.\omega_r\,,\quad \beta_r=\omega_r\sqrt{1-\sigma_r^2}\,,$

σ_r - relative damping coefficient,

α_r - damping coefficient,

β_r - frequency of free damping vibrations,
w_r - the imaginary part of the natural vector caused by the damping of the system,
v_r , ω_r - mode shapes and natural frequencies of not damping system.

The determination of α_r and w_r from the matrix **V** and **B** makes it possible to form this matrix

$$\mathbf{K}=\left(\mathbf{V}^{T}.\mathbf{M}.\mathbf{V}\right)^{-1}.\left(\mathbf{V}^{T}.\mathbf{B}.\mathbf{V}\right)=\left[k_{ik}\right]. \tag{9}$$

The damping coefficients are $\alpha_r = 0{,}5k_{rr}$. By using the matrix **K** is formed the matrix

$$\mathrm{D}=\left[d_{ik}\right] \quad \begin{vmatrix} d_{ik}=0, \quad when\ \omega_i^2=\omega_k^2 \quad ; \\ d_{ik}=k_{ik}\dfrac{\omega_k}{\left(\omega_k^2-\omega_i^2\right)}, \quad when\ \omega_i^2\neq\omega_k^2 \end{vmatrix} \tag{10}$$

The matrix **W** of the imaginary part of the natural vectors of the damped system is determined by the formulas

$$\mathrm{W}=\mathrm{V}.\mathrm{D}, \tag{11}$$

where $\mathrm{D}=\left[d_{ik}\right]$ is matrix (10); $\mathrm{V}=\left[v_{rk}\right]$ – matrix (6).

The general solutions of the system of natural values p_r and natural vectors $\mathbf{u}_r$, are derived from the initial conditions of motion. The general solutions of the system of differential equations in matrix form, with initial conditions $t=0,\ q(0)=q_0,\ \dot{q}(0)=\dot{q}_0$, are

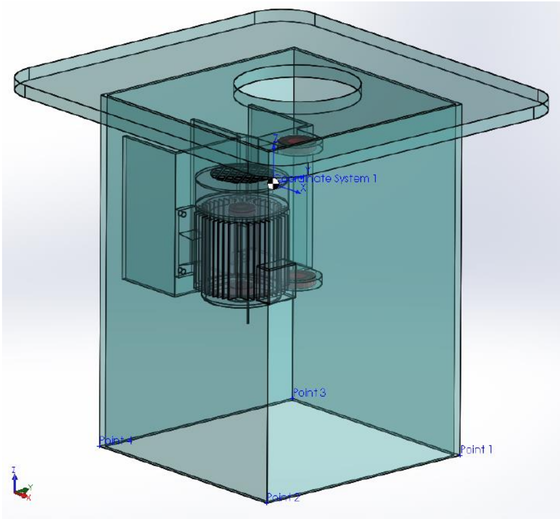
$$\begin{aligned} q(t)=&\sum_{r=1}^{18}\frac{2}{g_r^2+h_r^2}\left[\mathrm{G}_r.\mathrm{M}.\dot{q}(0)+\left(-\alpha_r.\mathrm{G}_r.\mathrm{M}+\beta_r.\mathrm{H}_r.\mathrm{M}+\mathrm{G}_r.\mathrm{B}\right).q(0)\right]e^{-\alpha_r t}.cos\beta_t\, t+ \\ &+\sum_{r=1}^{18}\frac{2}{g_r^2+h_r^2}\left[\mathrm{H}_r.\mathrm{M}.\dot{q}(0)+\left(-\alpha_r.\mathrm{H}_r.\mathrm{M}-\beta_r.\mathrm{G}_r.\mathrm{M}+\mathrm{H}_r.\mathrm{B}\right).q(0)\right]e^{-\alpha_r t}.sin\beta_r\, t. \end{aligned} \tag{12}$$

where

$$g_r=-2\alpha_r\left(\mathrm{V}_r^{T}.\mathrm{M}.\mathrm{V}_r-\mathrm{W}_r^{T}.\mathrm{M}.\mathrm{W}_r\right)-4\beta_r\mathrm{V}_r^{T}.\mathrm{M}.\mathrm{W}_r+\mathrm{V}_r^{T}.\mathrm{B}.\mathrm{V}_r-\mathrm{W}_r^{T}.\mathrm{B}.\mathrm{W}_r;$$
$$h_r=2\beta_r\left(\mathrm{V}_r^{T}.\mathrm{M}.\mathrm{V}_r-\mathrm{W}_r^{T}.\mathrm{M}.\mathrm{W}_r\right)-4\alpha_r\mathrm{V}_r^{T}.\mathrm{M}.\mathrm{W}_r+2\mathrm{V}_r^{T}.\mathrm{B}.\mathrm{W}_r;$$
$$\mathrm{G}_r=g_r\mathrm{L}_r+h_r\mathrm{R}_r; \quad \mathrm{L}_r=\mathrm{V}_r.\mathrm{V}_r^{T}-\mathrm{W}_r.\mathrm{W}_r^{T};$$
$$\mathrm{H}_r=h_r\mathrm{L}_r-g_r\mathrm{R}_r; \quad \mathrm{R}_r=\mathrm{V}_r.\mathrm{W}_r^{T}+\mathrm{W}_r.\mathrm{V}_r^{T}.$$

3. RESULTS AND DISCUSSION

Carrying out numerical investigations of the free damped spatial vibrations of a woodworking shaper requires knowledge of the parameters of its elements. Therefore the three bodies and the whole machine are modeled with software Solid Works. These models are shown respectively in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. The mass center of the body 1 coincides with the center of the local coordinate system of the body 1 and the center of the reference coordinate system. The mass center of the body 2 coincides with the center of the local coordinate system of the body 2. The mass center of the body 3 coincides with the center of the local coordinate system of the body 3.



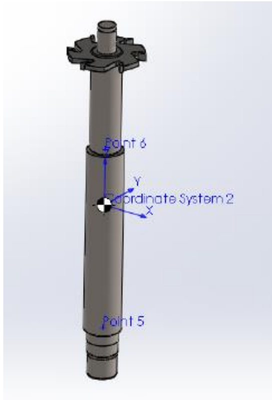
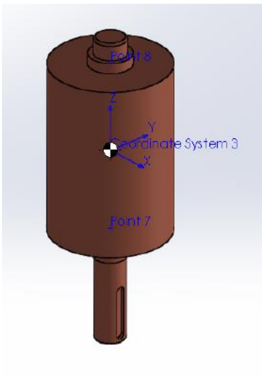


Figure 7. *Body 1* ***Figure 8.*** *Body 2*



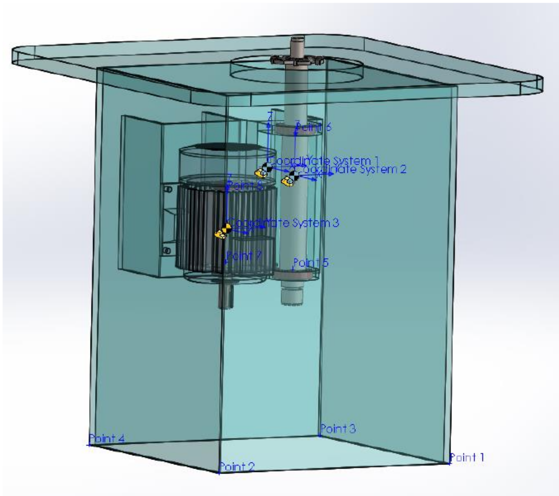


Figure 9. *Body 3* ***Figure 10.*** *Woodworking shaper*

The presented data of the machine FD-3, which is produced in ZDM – Plovdiv, is used for calculations.

Mass of the bodies: body 1 – $m_1 = 391{,}52\ kg$; body 2 – $m_2 = 11{,}123\ kg$; body 3 – $m_3 = 14{,}378\ kg$. Tensor of mass inertia moments of the body 1 to the local coordinate system of the body 1, *kg.m*^{2}

$$\mathrm{I}_1 = \begin{bmatrix} 49{,}2672 & -0{,}0395 & -0{,}2525 \\ -0{,}0395 & 52{,}0000 & -0{,}4405 \\ -0{,}2525 & -0{,}4405 & 47{,}9480 \end{bmatrix}.$$

Tensor of mass inertia moments of the body 2 to the local coordinate system of the body 2, *kg.m*^{2}

$$\mathrm{I}_2 = \begin{bmatrix} 0{,}2937 & 0 & 0 \\ 0 & 0{,}2937 & 0 \\ 0 & 0 & 0{,}0052 \end{bmatrix}.$$

Tensor of mass inertia moments of the body 3 to the local coordinate system of the body 3, *kg.m*^{2}

$$I_3 = \begin{bmatrix} 0{,}0516 & 0 & 0 \\ 0 & 0{,}0516 & 0 \\ 0 & 0 & 0{,}0206 \end{bmatrix}.$$

The coordinates of the mass centers of the bodies are shown in table 1.

Table 1. *Coordinates of the centers of mass*

Body №	l_{Cx}, m	l_{Cy}, m	l_{Cz}, m
1	0	0	0
2	0,009	0,066	–0,020
3	0,019	–0,115	–0,134

The coordinates of the supporting points of the elastic elements are shown in table 2, table 3 and table 4.

Table 2. *Coordinates in the coordinate system of the body 1*

Point	l_{xi} , m	l_{yi} , m	l_{zi} , m
1	0,309	0,316	-0,654
2	0,309	-0,284	-0,654
3	-0,291	0,316	-0,654
4	-0,291	-0,284	-0,654
5	0,009	0,066	-0,234
6	0,009	0,066	0,076
7	0,019	-0,015	-0,210
8	0,019	-0,015	-0,050

Table 3. *Coordinates in the coordinate system of the body 2*

Point	l_{xi} , m	l_{yi} , m	l_{zi} , m
5	0	0	-0,214
6	0	0	0,096

Table 4. *Coordinates in the coordinate system of the body 3*

Point	l_{xi} , m	l_{yi} , m	l_{zi} , m
7	0	0	-0,076
8	0	0	0,084

The elasticity and damping coefficients are shown in table 5 and table 6.

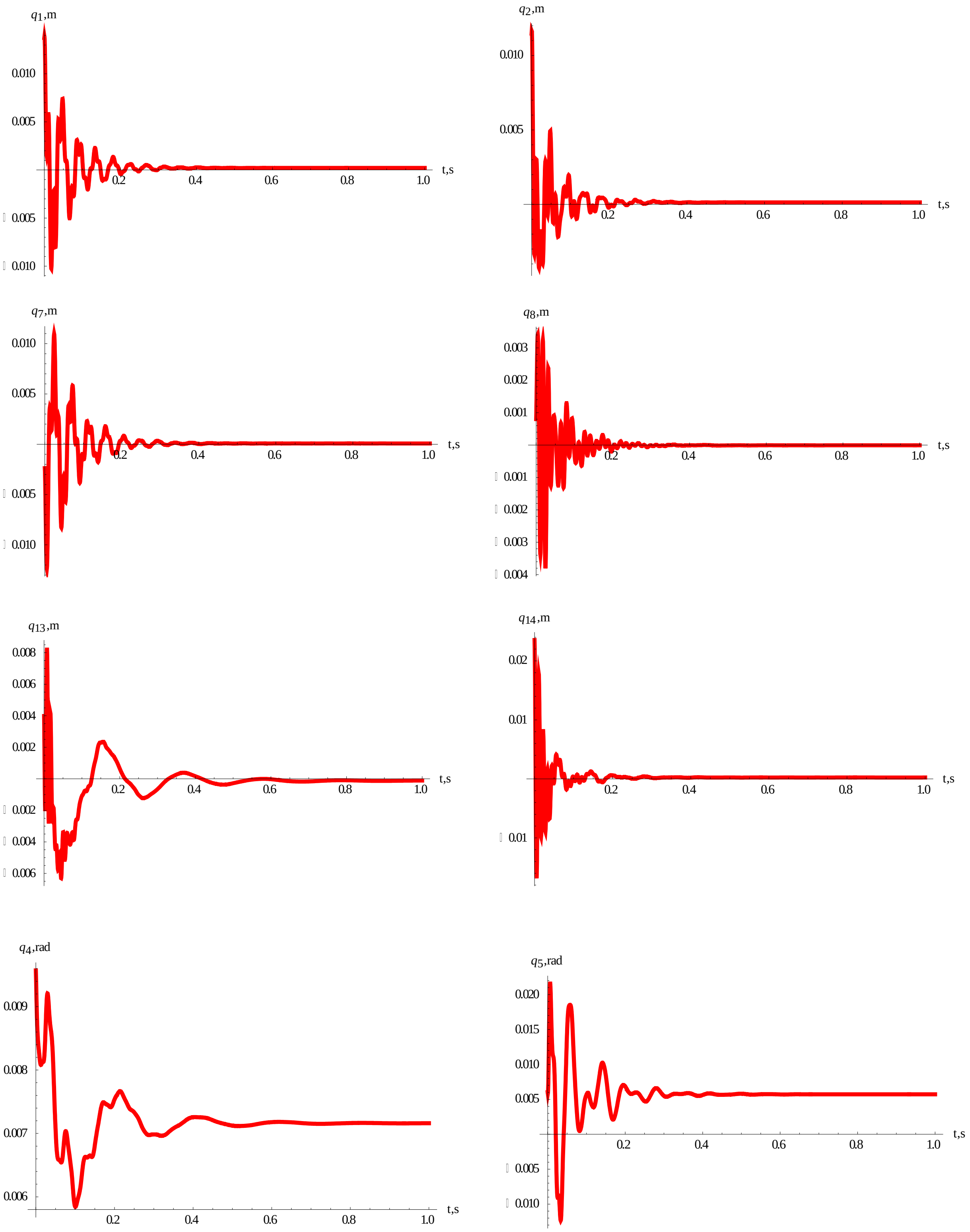
Table 5. *Elasticity coefficients*

Between Bodies	c_{xi} ,N/m	c_{yi} ,N/m	c_{zi} ,N/m
0 – 1	350000	350000	800000
1 – 2	2250000	2250000	2250000
2 – 3	2250000	2250000	2250000

Table 6. *Damping coefficients*

Between Bodies	b_{xi} ,(N.s)/m	b_{yi} ,(N.s)/m	b_{zi} ,(N.s)/m
0 – 1	980	670	470
1 – 2	980	670	470
2 – 3	980	670	470

The calculations are performed by using a software product Mathematica. The amplitudes of the free damped vibrations are calculated for the above-mentioned wood shaper. Fig. 11 graphically shows the results of the numerical investigations of the free damped vibrations. Just a few of the results are represented here due to the limited place.



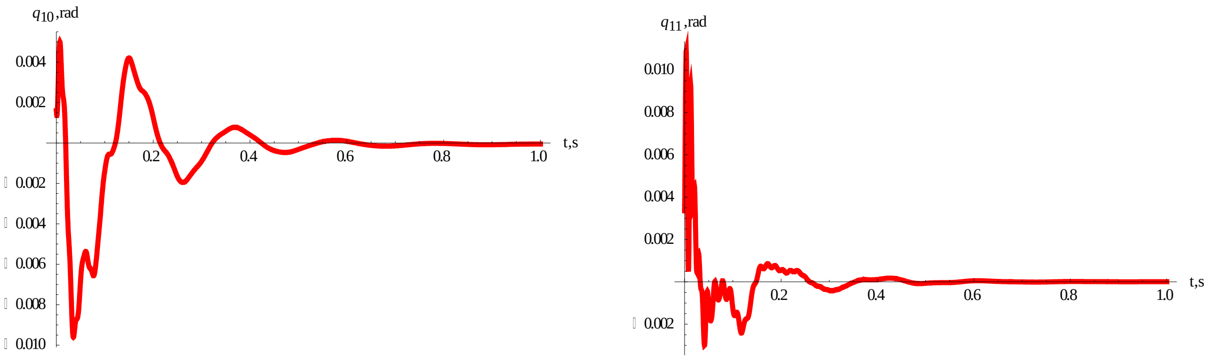


***Figure 11.** Results of the investigations*

The obtained graphs of the damped vibrations show that at the used coefficients of elasticity and damping all vibrations in the mechanical system get quiet within 1 sec. These coefficients are on a machine in optimal technical condition. The presented model allows modelling and exploration of various technical conditions of this machine and offers possibilities for the practical determination of the current technical state.

4. CONCLUSIONS

The presented study investigates free damped spatial vibrations of a woodworking shaper. The investigations are carried out on the base of an original mechanic-mathematical model of a woodworking shaper, developed by the authors. The model considers woodworking shapers with lower placement of the spindle. In this model the woodworking shaper, the spindle and the electric motor's rotor are regarded as rigid bodies, which are connected by elastic and damping elements with each other and with the motionless floor. It takes into account the characteristics in the construction of woodworking shapers. The model renders into account the needed mass, inertia, elastic and damping properties of the elements of the considered system. It includes all necessary geometric parameters of this system. Then a compiled system of matrix differential equations is presented and analytical solutions are derived. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use parameters of a machine, used in practice. As a result of the whole study, the free damped spatial vibrations of the studied mechanical system are obtained and illustrated. The results of the conducted study allow analyzing the influence of the parameters of the elastic and damping elements of the construction on the machine's work. The main goal is to increase the reliability of the machine, as well as the accuracy and quality of the wood articles' processing.

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CNC WOOD MACHINES ACCURACY AND REPEATABILITY

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ABSTRACT

Machine accuracy can be defined as a degree of coincidence between measured, calculated or specified, and supposed correct, already known or given physical size value. The repeatability presents machine capability to achieve predetermined physical size value in numerous repetitions in the same working conditions.

There are many influential factors upon wood machine accuracy and repeatability, which consequently affect final product quality. Determining these factors and finding out their values is difficult and expensive. The main goal of this paper is to establish a possibility for implementation of new, enough reliable, method for product dimension and shape control using the photography and suitable software (Digimizer for dimension and Meshroom for shape determination) in order to obtain satisfying results for wood processing. Namely, accuracy and repeatability must fit into given tolerances used for wood products, which are significantly less demanding than those in metal works.

Applying this particular measuring method, CNC wood machine users would be able to control working parameters on regular basis, improving the product quality.

Key words: CNC, accuracy, repeatability

1. INTRODUCTION

Modern wood machining technologies are in the great incline in the countries of Western Balkans in order of achieving better productivity, production quality and at last but not the least minimizing the lack of work labor. CNC machines are highly productive and flexible as well. However, many enterprises choose used machines with expired or almost expired technological life cycle. Those machines often perform inadequate production accuracy consequently raising the amount of rejects, amount of material, energy and production time, as well as the total costs. The calibration of these machines is mostly time demanding, expensive in the terms of human labor and equipment needed. In the light of previously said an idea, of possibility of simple machine accuracy measurement, appeared. The basic idea was introduction of photography and software analysis in order to determine possibility of avoiding machine measurement inaccuracies.

2. MACHINE ACCURACY AND REPEATABILITY

Machine accuracy can be defined as a degree of coincidence between measured, calculated or specified, and supposed correct, already known or given physical size value. Also, the maximum translational or rotational error between any two points in the machine's work volume (Slocum A. 1992). Machine has to produce parts of the required shape and dimensions keeping the required tolerances and to achieve the desired surface roughness. CNC machine accuracy is greater compared to the conventional machines, so they demand more precise and more sophisticated methods for working parameter evaluation.

The repeatability presents machine capability to achieve predetermined physical size value in numerous repetitions in the same working conditions. In other words, it is the error between a numbers of successive attempts to move the machine to the same position. Repeatability is often considered to be the most important parameter of a computer controlled machine (or sensor) [Slocum A. 1992].

Steper motor used on CNC machines and ball screw pitch will give accuracy. Stepper motor of 1.8 degree per step means 200 steps per revolution. Ball screw of 5 mm per revolution. divided by 200 means 0.025 mm.

Accuracy and repeatability must fit into given tolerances used for wood products, which are significantly less demanding than those in metal works.

Furniture elements are often made in batches, sometimes containing hundreds of pieces. For industrial production, it is important that the parts produced are interchangeable during assembly. This means that from the series, from a large number of pieces, each of them can be included in the product without any previous pairing or finishing. Reciprocal interchangeability is a feature of the parts of the product that they can be interconnected without prior adjustments and refinements, while ensuring the conditioned quality and functionality of the product.However, due to the imperfection of machines, tools and errors of the worker, as well as due to the material properties, the production of the final wood products must take into account that the dimensions and shapes of the machined parts will deviate to some extent from the nominal measures and the desired shapes.

The vadely type of joint that is used for conecting furniture is the hole used to joint the dowel/hole. Holes can be made on on conventional or CNC machines. The errors that occur in this process are numerous and directly affect the quality of the product. A very common problem encountered by furniture constructors is the type of fit and the tolerance class. The hole deformation and the deformation of the dowel result in a small contact surface. In order to achieve adequate rigidity and durability of the product, the constructors are forced to increase the number of dowels above the required number. Increasing the number of dowels results in longer assembly times, which directly affects longer operating times. The deformation occurs in the combination of a machine low accuracy and poorly prepared tools, while deformation of the dowel is most often caused by inadequate moisture content, so that after drying, a dowel cross sectopn deviates from the "ideal" circle. As a sum of these two errors, we obtain point contact, instead of surfaces contact between the dowel and the holes.

When making holes on numerical machines, those two problems are easier to counteract and they will depend on the shape of the tool and the processing parameters. Videly used standard for tolerating measures in the furniture industry is DIN68100. For tolerating joints recommendation is to use acuracy class TD10 and TD15. The size of the overlap should range from 0.1 to 0.2mm, (Džinčić and Palija 2017), (Džinčić et all 2017), (Džinčić, Živanić 2014). If we compare the accuracy of the stepper motor with the prescribed tolerances, we will see that the accuracy of the stepper motor is 4 to 10 times higher than the required tolerance.

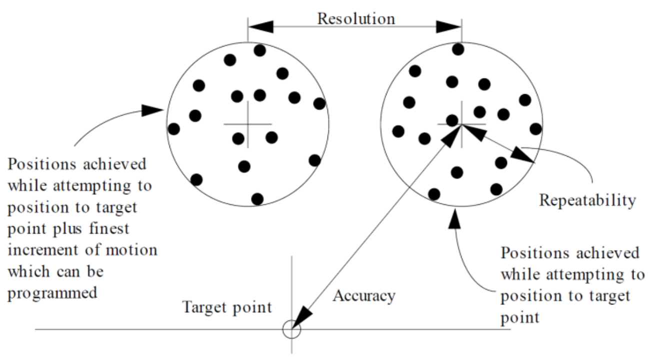

Figure 1. *Machine accuracy and repeatability (Slocum A. 1992)*

Third parameter is resolution, but it depend on machine construction and it can be defined as the smallest mechanical step the machine can make during point to point motion, and it gives a lower bound on the repeatability (Slocum A. 1992).

Machine accuracy and repeatability depends on many factors. Main factors that influence are presented on Figure 2 (Laspas T. 2014).

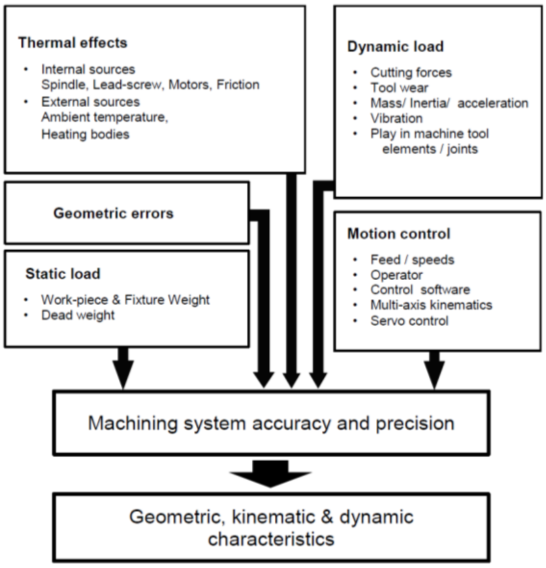

Figure 2. *Main factors that affect machine accuracy (Laspas T. 2014)*

Modern CNC machines usually have real-time monitoring technology, failure analysis and troubleshooting methods.

CNC machine commonly used following methods of diagnosis: direct method, CNC system self diagnostics, functional program testing method, Module exchange, the principle of analysis, PLC procedural law (Kuric I. et al, 2012).

3. MEASURING ACCUARCY AND REPEATABILITY

The main goal of this paper is to establish a possibility for implementation of new, enough reliable, method for product dimension and shape control using the photography and suitable software (Digimizer for dimension and Meshroom for shape determination) in order to obtain satisfying results for wood processing.

Applying this particular measuring method, CNC wood machine users would be able to control working parameters on regular basis, improving the product quality.

Dimensions measurements from the photos can obtain analysis of the CNC machines for boards (predominantly 3-axe machines). In the case of previous the bulk accuracy is not important since the tool motion is linear.

The tryout of implementation of this method was performed on side boards of wardrobe with the height of about 2000 mm, the width of 600 mm and the thickness of 18 mm. Drills and cuts were performed on BIESSE SKIPPER 100 machine equipped with displacement (move) control system (Figure 3). The photos were taken with Nikon D90 camera, with Nikkor 50 mm f 1.8 objective, places on the post as shown on Figure 4.

Figure 3. Biesse Skipper 100

Figure 4. Positioning of camera

The distance between the camera and the working piece were 4 m, ensuring the entire board is in the scope. All boards were marked and positioned along the ruler. The role of the ruler was to define the true dimensions on the photo. After photographing, all the photos were analyzed usin the Digimizer software. All the photos were rotated for 180 degrees in order to set the reference point in upper left corner.

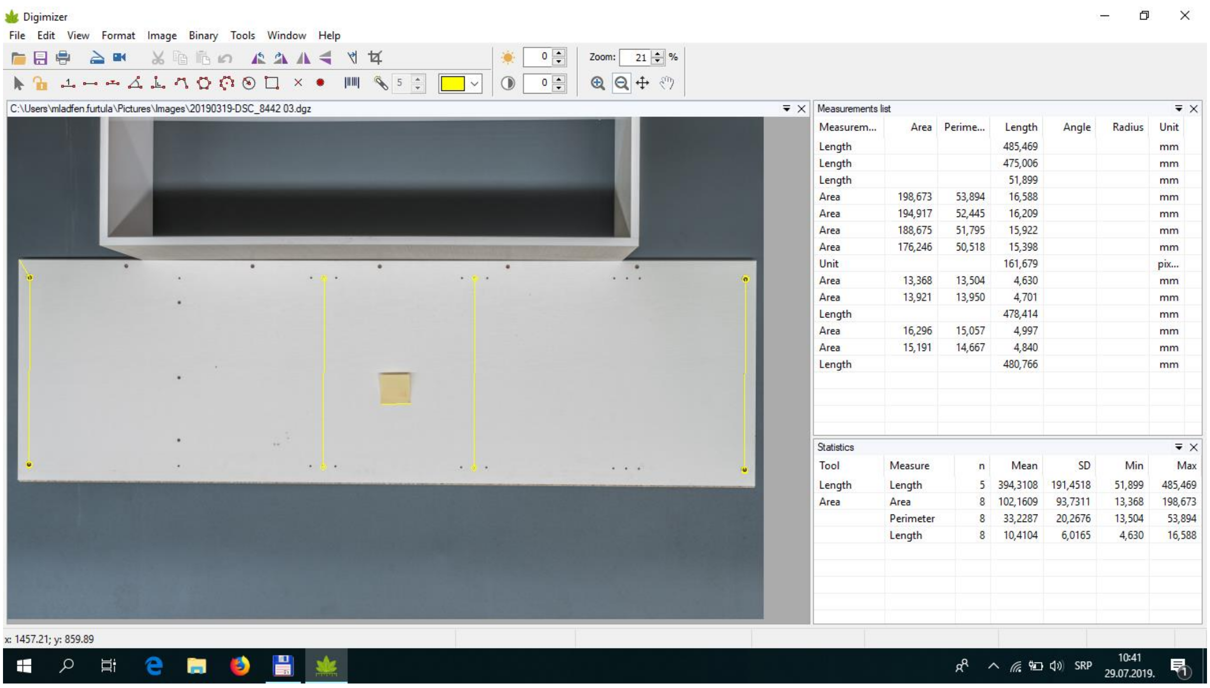

Figure 5. Analyzed picture in Digimizer

All boards were measured in the Digimizer software by measuring the distance between reference point and characteristic holes in the board corners. Along with this, the control measurements were performed in tpsDig 232 software, for the same distances.

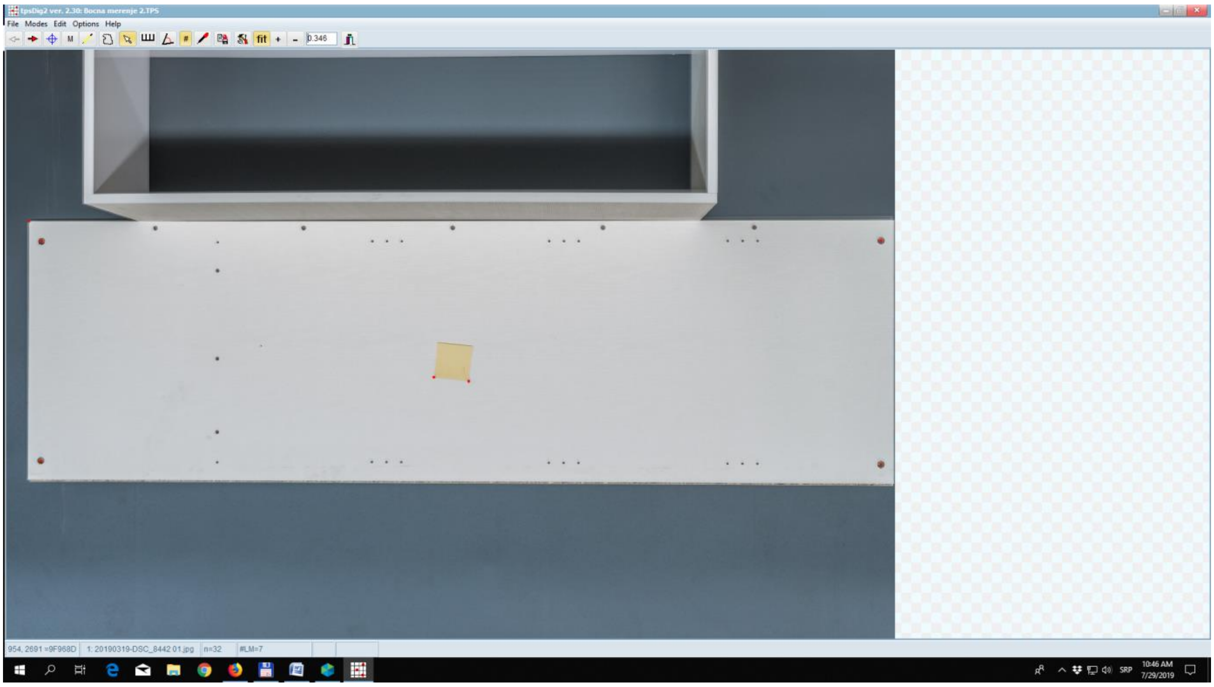

Figure 6. *Measuring with tpsDig232*

This series of measurements failed since the distance of camera was too large. Namely, the camera resolution of 12 mega pixels which presents 0,5 mm per pixel at the chosen distance. The objective applied did not distort picture so it is not wide ranged.

The shape control method is required for machines that operate with more than just 3 axes (more than 3 degrees of freedom). Acquiring 3D model is possible by applying 3D scanners, but unfortunately these are pretty expensive, especially for high precision scanners (0,1 – 0,2 mm). This is the reason why the model making was done by photogrammetry, that is taking shoots from as many possible angles and putting them all together in 3D model. There are many programs for this purpose. There are commercially available programs as well as those which are freeware. Such commercially programs are: iWitness PRO, Pix 4D, Photo Modeler, Autodesk ReCap, Reality Capture, Metashape and freeware are: COLMAP, Regard 3D, Visual SFM, Open MNG and Meshroom.

The object was photographed by mobile phone camera (Nokia 6, 16 mega pixels, f 2.0, 1µm, PDAF) from as many angles possible. Afterwards those photos were set as input data into the proper software.

Figure 7. *3D object*

Program applied was Meshroom 2019. 1.0 as well as Photo Modeler Premium (later used in Evaluation mode). Meshroom software hasn't fulfilled expectations since it failed to produce 3D model (main cause is the inappropriate computer equipment – to slow graphic cards and lack of RAM memory).

On the other hand, Photo Modeler Premium achieved to produce 3D model, but for the further analysis additional adjustments were needed, mainly camera adjustments because it worked in uncalibrated camera mode.

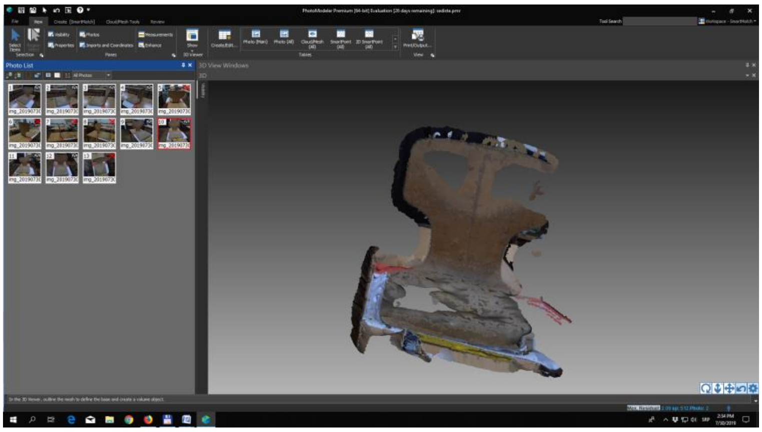

Figure 8. *Working with Photo Modeler Premium*

4. CONCLUSION

Possible procedures for determination of accuracy, precision and repeatability applying photos and photo software analysis were presented in this paper. Although the initial experiments didn't perform in expected manner, such type of approach has sufficient potential for supposed applications. It is also to be mentioned that much better results would be obtained with better computer and photo equipment and that such measurements could be ideal for fast control measurements at Universities for practical educational purposes and commercial service for CNC machine owners for calibrating accuracy and repeatability of their machines.

Future work in this area will demand precise experimental setup in the terms of proper geometry and positioning of the camera, possible signal generating in order to compare it with those from machine transducers and finally developing two channel control loop system.

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PROPERTIES OF SELECTED WOOD COATINGS APPLIED ON THM - DENSIFIED NORWAY SPRUCE (PICEA ABIES K.)

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ABSTRACT

The aim of this study was to investigate the performance of diverse wood coating systems on THM-densified spruce wood. For this purpose, Norway spruce [Picea abies K.] was thermo-hydro-mechanically densified in a closed system, under pressure and steam. Five different types of solvent- and water-based coating systems were applied. To assess the interaction of the coatings and the densified wood, following tests were carried out: exposure to UV light, water permeability and climatic variation. The color of densified wood is more stable to UV light than non-treated wood and the coating system has insignificant influence on the color change. When specimens are exposed to a short-term change of climatic variation, the total volume change is less than 5% on uncoated densified wood, neglectable if coated. In case of long-term variation, (specimens exposed until constant weight), the protection effect of the coatings is less significant. The total volume change is appr. 8%. Therefore, if coatings are partially preventing moisture and water uptake of densified wood at short term exposure, they confer limited protection at long term exposure. Moreover, there is not significant performance difference within the different kinds of coating systems.

Key words: wood, coating, densification, UV radiation, water permeability, wood modification

1. INTRODUCTION

Chemical and thermal modification has the potential to improve some less favorable properties of wood. Increasing the density of solid wood by means of compression has been applied since the middle of the last century (Stamm & Seborg R.M., 1941; Navi & Heger, 2004; Kutnar & Šernek, 2007; Sandberg, Haller, & Navi, 2013). Higher density generally results in improved mechanical properties. However, thermo-hydro- mechanical process causes changes in surface properties of the wood, like the increase of surface hydrophobicity, that might lower gluing or coating ability (Sandberg & Navi, 2007). In addition to the change of mechanical properties of the wood, aesthetic visual properties are changed. The treated wood becomes a darker color that depends on the process of modification. Furthermore, wood is an anisotropic material and it is dimensionally unstable when it encounters moisture. THM-modification reduces the equilibrium moisture content, inducing a higher resistance against wood destroying organisms and increased service life in exterior conditions might be expected. One way to protect the wood from moisture uptake, weathering, blistering, adhesion failure and degradation via microbiological attack is the surface protection with coatings. Beside the protection function, coatings have aesthetic function as well (Dawson et al. 2005). In the last few decades the use of solvent born wood coatings has been subjected to high environmental pressure. Protecting the environment and be more sustainable leads to the option for increasing the use of waterborne wood coatings.

For quantifying the efficiency of a coating to protect the wood from water and moisture, various tests have been developed (Hjort, 1996; Feist et al. 1985). In this study, the influence of the coatings on densified wood is investigated according to liquid water absorption, water vapor absorption, and

UV- light resistance. Another focus is to compare the influence of the coating system (water based, or solvent based) on densified wood.

2. MATERIAL AND METHODS

2.1 Materials

2.1.1 Densified wood

Norway spruce [Picea abies K.] from the Jura mountains (Switzerland) with a density of ca. 416 kg/m³ was used for this experiment. Samples of 73mm x 43mm x 44mm (R × T × L) were stabilized at 20°C/65% RH and densified in closed system with pressure and steam (process conditions confidential). After densification, samples were cut to the following dimensions (R × T × L): 10 mm x 24 mm x 40 mm and stabilized at 20°C/65%RH (**Ошибка! Источник ссылки не найден.**Figure 1).

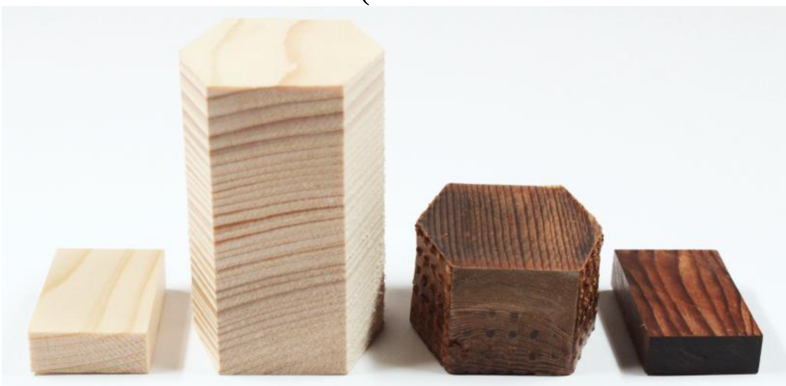


Figure 1. *Non-treated (left) and densified specimens (right)*

2.1.2 Coatings

Before coating, specimens' surface was sanded on Homag machine, first with grit size P100 and then P180. The used coating systems, and their characteristics are presented in Table 1.The coatings were prepared according to the data sheet from the manufacturer.

Densified and non - densified specimens were coated with 2 layers and intermediate sanding (grit paper P320), by hand brushing.

Three repetitions of samples have been prepared for each test and each variant (densified and non-densified wood).

Table 1. *Coating systems and their characteristics (technical datasheet)*

Label of coatings	Solvent 1	Solvent 2	Water based 1	Water based 2	Water based 3
Base	polyurethane acrylate resin	polyurethane acrylate resin	polyurethane-polyacrylate resin	polyurethane acrylate resin	polyurethane acrylate resin
Solvent	solvent based	solvent based	water based	water based	water based
Solid content [%]	23.1	26.6	30.3	30	35
Amount per surface (wet mass)	100-120g/m²	80-120g/m²	100-120g/m²	120-140g/m²	100-120g/m²
Colour	colourless	colourless	colourless	colourless	colourless
Gloss	mat	satin finish	satin finish	mat	satin finish
Mechanical resistance	good	high	good	good	very high
UV resistance	/	/	/	very high	high
Water resistance	/	/	good	good	very high
Chemical resistance	good	good	/	very high	very high

2.2 Methods
2.2.1 Color changes

This test is carried out according to the European standard EN 15187, 2006. Specimens were coated only on one side (24 mm x 40 mm). The color of the specimens was measured with a Spectrophotometer (Byk, Geretsried, Germany, Type: 6834) prior exposure to UV light. Subsequently. specimens were put in a Xenon Test chamber (Haan, Germany, Type: Q - Sun 3100), and the color was measured after 48 h, 96 h and 200 h of exposure. The specimens were measured on the same spot after each period.

The three lamps of the Xenon test chamber emitted 0.45 W/m_2 at 340 nm, temperature of the black panel and inside chamber air were 55°C and 40°C respectively., RH was set at 50%.

Color changes were calculated according to the Commission Internationale de l`Eclairage (CIE), and L*a*b* colored space system. The CIE Lab system evaluates a color on three coordinates in respect to their lightness (L) and their chromatic parameters (a – from red to green, b – from yellow to blue). The global color change ΔE is calculated according to equation 1.

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \quad (1)$$

Where:

L1 and L2 are the lightness values measured on the same wood area before and after exposure respectively,

a1 and a2 are the chromatic values in the red to green axis on the same wood area before and after exposure respectively,

b1 and b2 are the chromatic values in the yellow to blue axis on the same wood area before and after exposure respectively.

The evaluation and meaning according the ΔE values are given in Table 2.

Table 2. *Evaluation of color distances ΔE according to DIN 5033 (1966)*

ΔE value	Meaning
0.0-0.5	Almost no difference
0.5-1.0	Difference may be visible to the trained eye
1.0-2.0	Noticeable color difference
2.0-4.0	Perceived color difference
4.0-5.0	Substantial color difference that is rarely tolerated
>5	The difference is perceived as a different color

2.2.2 Water permeability test

Water permeability test is based on the standard DIN EN 927-5, 2007. Coated specimens were conditioned in climate with 20°C/65% RH and were sealed from five sides with Tosanol Seidenglanzlack (70500-002901) from Bosshard (Rümlang, Switzerland). The sealing layer was applied two times, with intermediate drying of approximately 12 h and intermediate sanding (grit paper P320). When the sealer was dry, specimens were left in 20°C/65% RH until constant weight. Subsequently, the specimens were immersed in water appr. 2 mm on the coated side for 72 h. For evaluating the impermeability of the sealer, specimens (10 mm x 24 mm x 40 mm) from non – treated wood were covered from all sides with the sealer and tested together with the treated specimens. After 72 h immersed in water, the weight of the specimens was determined.

2.2.3 Climatic variation

Specimens for this purpose were coated from all sides with coated systems described in
. Coated specimens were kept in climate room with 20°C/65% RH until constant weight. After that, specimens were put in a dry and wet climate, respectively (Figure 2 and 3). The weight and the volume were measured.

This test was performed two times:
Cycle 1 - duration between climate change was 7 days (Figure 2)
Cycle 2 - duration between climate change was until weight constancy on the specimens. (Figure 3)

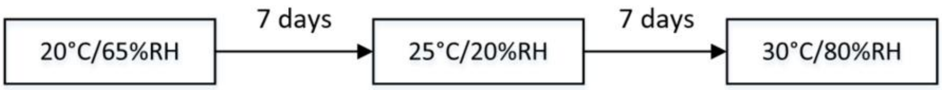


Figure 2. *Cycle1-duration of climate variation test - 7 days*

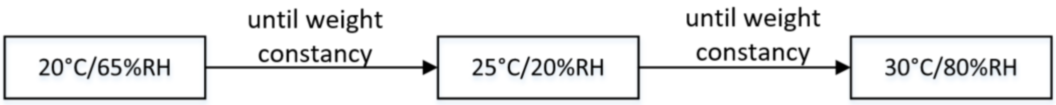


Figure 3. *Cycle 2- Duration of the climate variation test - until weight constancy*

3. RESULTS AND DISCUSSION

3.1 Color changes

Results of colour change are presented in **Ошибка! Источник ссылки не найден.**. Coated untreated wood displays the highest ΔE values from 12.6 until 18.7 after 200 h of UV radiation. Six units difference according to Table 2 is an obvious difference between the colours before and after the irradiation. The general tendency of coatings on untreated wood is to limit the global color change in this timeframe, with exception of Solvent 1. Therefore, untreated wood has the tendency to get yellow during the time (Δb = 9.75 (48h); 10.96 (96h); 11.60 (200h)). The yellowing on the wood is generated by the lignin and lignin derivates, such es quinones, quinone methides and stilbenes (Hon & Glasser, 1979). UV radiation decreased the lignin content in the wood producing vanillin and syringaldehyde (Sanderman. Wilhelm, 1961). In this case the coatings are not preventing the wood of changing the color. Densified wood has a smaller range of ΔE from 4.32 until 5.45. One-unit difference is almost not visible with naked eye (Table 2). Therefore, the two figures, show that coatings slow down the color change on not densified samples, while they accelerate the color change on densified samples. Even though the densification process itself limits the color change of samples due to UV light.

Previous studies showed that darkening of the wood surface is a result of a heat treatment as a function of treatment temperature and the kind of wood (Bekhta & Niemz, 2003). Hemicelluloses of thermally heated wood degrades and thus the lignin content on heat-treated wood increases proportionally. Thus changes in the wood lightness during heat treatment are observed mainly due to the degrading of hemicelluloses and wood colour becomes darker (Huang et al. 2012). From this test, coatings are not preventing densified wood from UV radiation. Accordingly, there is no difference in the performance between solvent based and water-based coatings on densified wood.

According to Table 2 coated densified wood has smaller change than coated untreated wood. Comparing untreated wood and densified wood, densified wood is much more stable to UV radiation. The best results for the coating are shown with Solvent 2. In Figure 5 is shown how the wood looks like after different duration of UV light exposure.

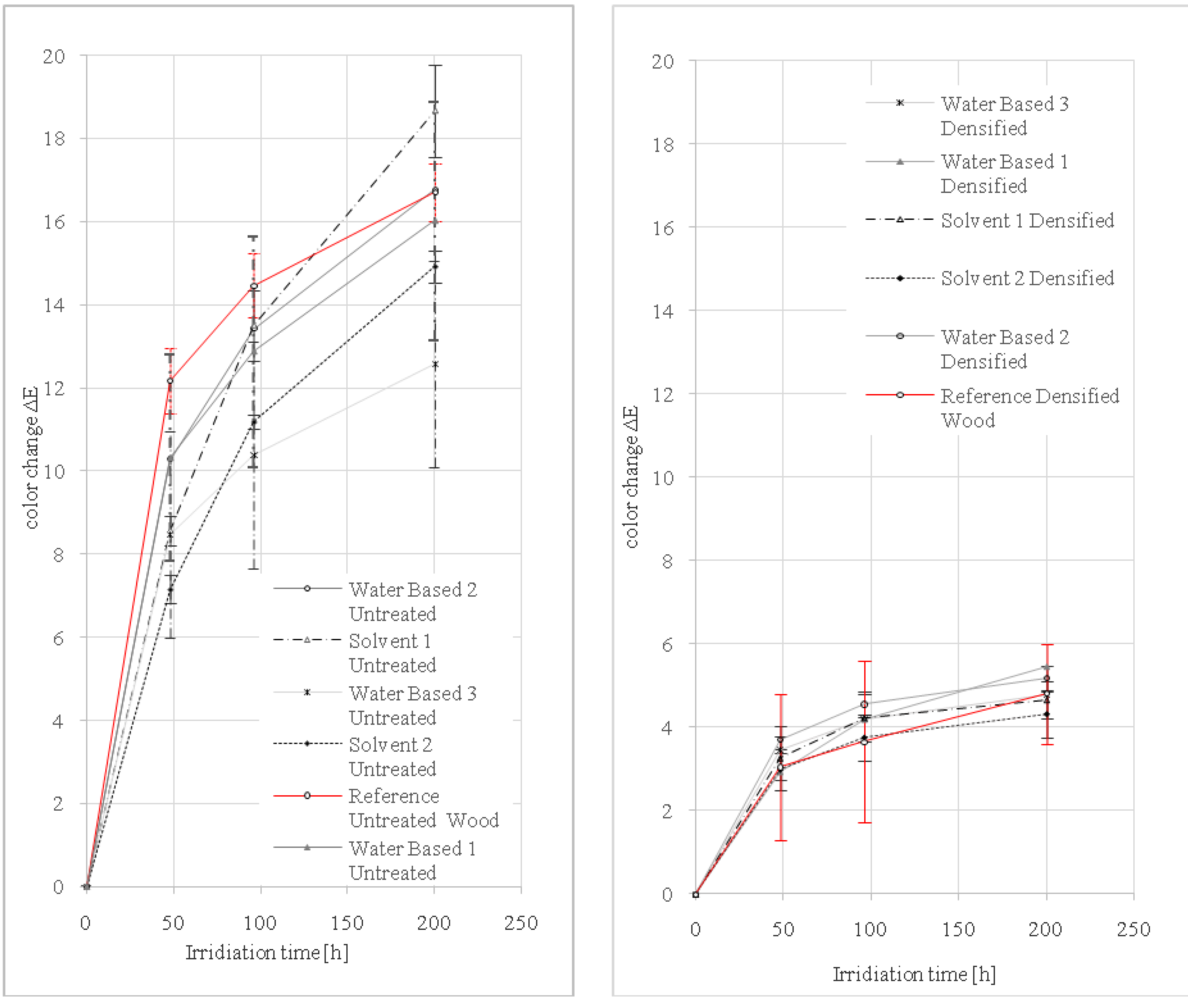


***Figure 4.** ΔE on non-treated wood (left) and densified wood (right)*

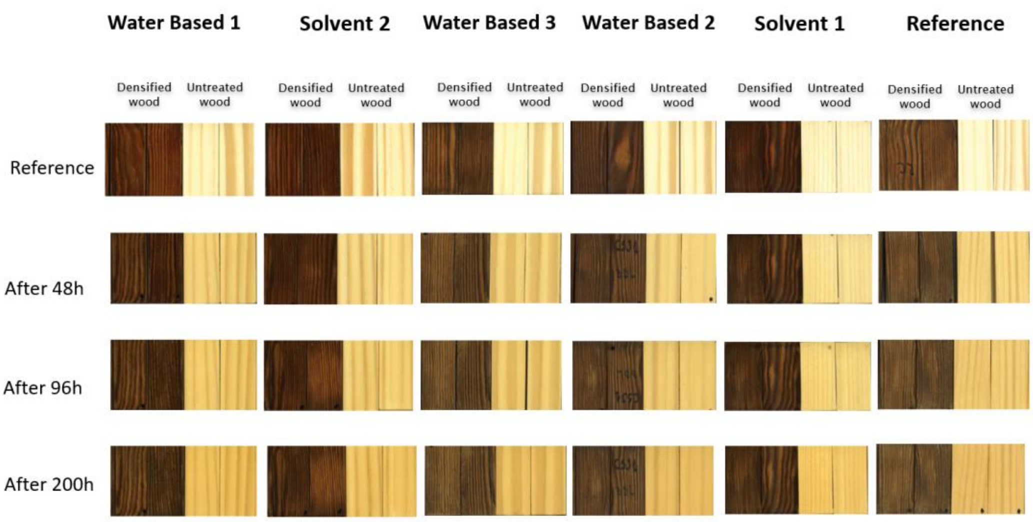


***Figure 5.** UV treatment on densified and non - densified wood with different coatings systems*

3.2 Water Permeability Test

Results from water permeability test are presented in Figure 6. The Reference densified specimens without coating display a water uptake of 443.2 g/m2 (±121.6 g/m2), while non–densified specimens have a water uptake of 718 g/m2 (±124.2 g/m2). That shows that densified wood, by the thermo – hydro mechanical process is less reactive to liquid water. The reason for that is explained by Tanahashi, et al. 1989. They discovered that steaming results in an increase in cellulose crystallinity, microfibril width and micelle width. When the water is removed from the matrix, hydrogen bonds reform between the polymers in the matrix. As the temperature decreases, the process leads the amorphous fraction to return to the glassy state where the elastic deformation of the microfibrils and the matrix is frozen. Furthermore, from the coated samples, the best results of densified wood are shown with Water based 2 (water uptake 58.9 ± 3.31g/m2) and Solvent 2 (water uptake 70.5 ± 3.4 g/m2). The Reference standard sample has 36.1 ± 4.3 g/m2 which proves that the test is valid. From these results both solvent based and water-based samples have similar permeability properties for liquid water. There is a small difference between coated densified and non- treated wood, which proves that the coatings can prevent the interaction between wood liquid water.

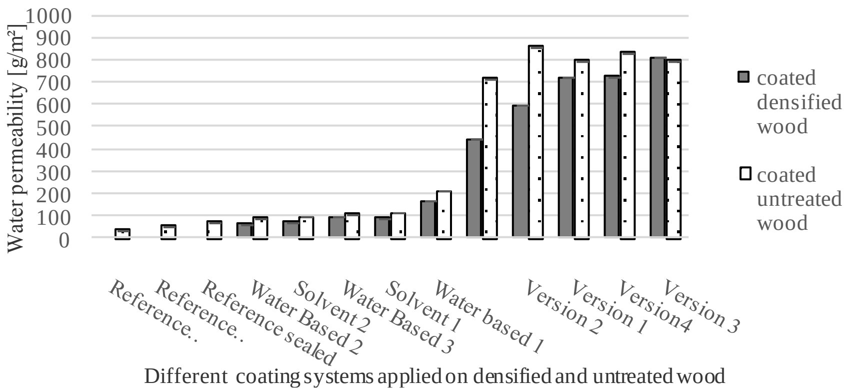


Figure 6. *Water permeablity uptake on densfied and non - densified coated specimens*

3.3 Climatic variation

To reveal the inertia of densified and coated samples to react to the environment hygroscopicity, two different exposure cycles have been designed. Cycle 1 mimics a short exposure of densified wood objects to moderate conditions for 7 days, followed by 7 days in a rather dry environment and 7 days in rather wet conditions. Cycle 2 mimics a long-term exposure, where samples have time to reach an equilibrium in the same conditions. Details on cycle 1 and 2 are given in chapter 2.2.3.

3.3.1 Climatic variation according to cycle 1

Figure 7 (left row) presents the volume change of samples at the end of each cycle step. In Figure 7A climate changes between 20°C/65% RH and 25°C/20% RH are presented. As expected a volume shrinkage has occurred for all specimens. The maximum shrinkage is observed for the Reference densified and reference non-treated wood with 2.2% (± 0.45%) and 1.84 % (±0.22%), respectively. In Figure 7B is shown the difference between 20°C/65% RH and 30°C/80%RH where swelling has occurred. In Figure 7C is presented the total volume change from the two extreme climates 25°C/20% RH and 30°C/80%RH. From the results, there is not much influence from any coating, and the difference is negligible.

This test showed that densified wood is less reactive to water vapor than untreated wood. Coatings are minimizing the interaction of the densified wood and ambient humidity. From this experiment, coatings by itself are protecting the wood from the vapor humidity. Best performance has Water Based 2. Therefore, the other coatings as Water Based 3, Solvent 2 are not very different with their performance for blocking the interaction of the wood and ambient humidity. For water vapor permeability test, there is almost no difference between solvent based and water-based coatings.

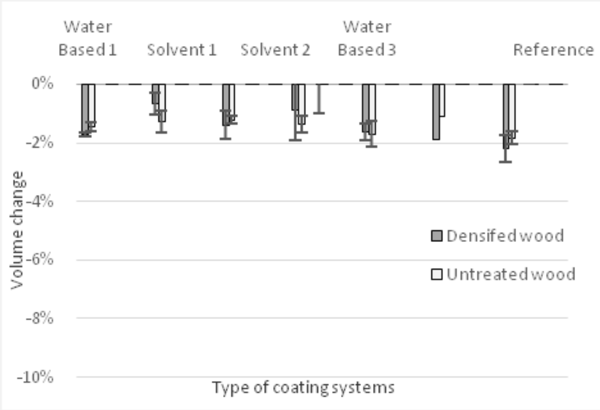
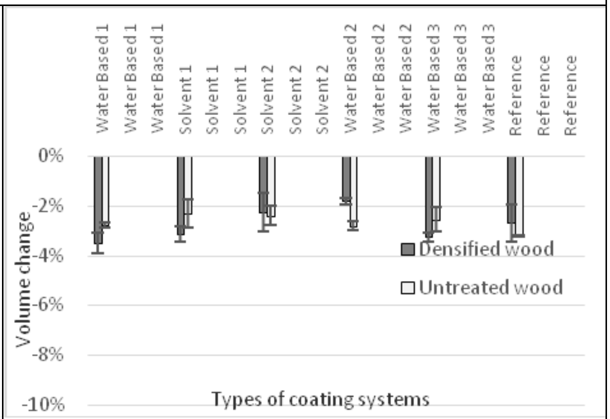
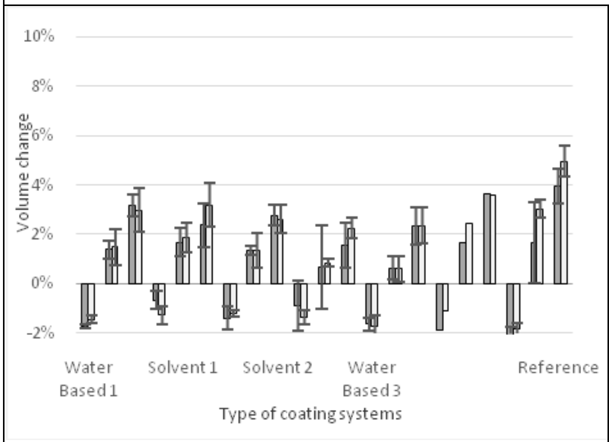
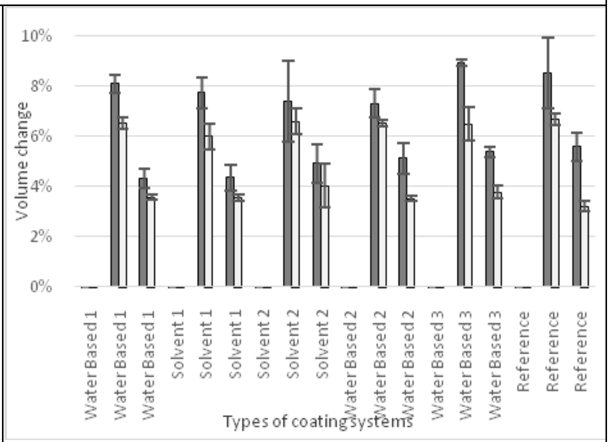
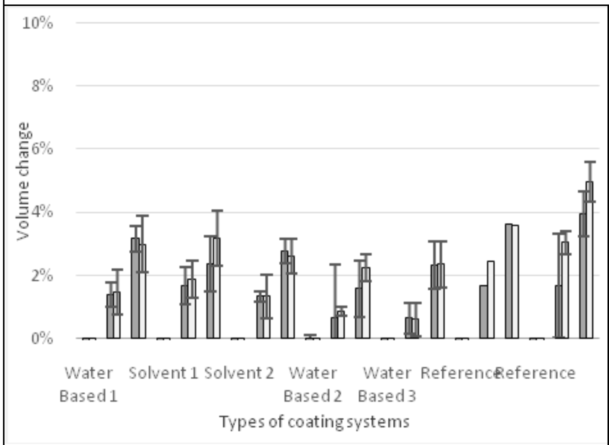
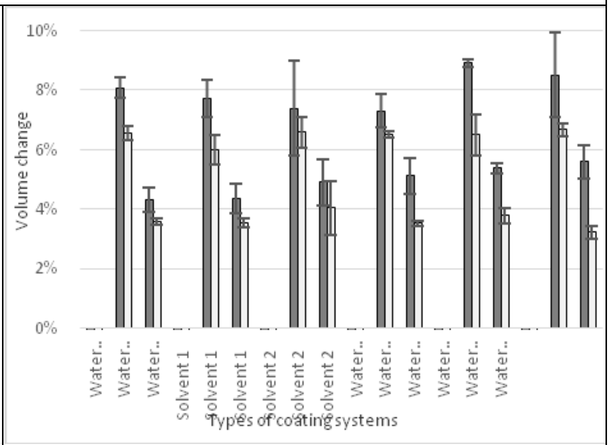
Cycle 1	Cycle 2
A: Climate: 20°C/65% RH and 25°C/20%	
	
B: Climate: 20°C/65% RH and 30°C/80 % RH	
	
C: Climate: 25°C/20% RH and 30°C/80 % RH	
	

Figure 7. *Climatic variation of different coatings systems on densified and non – densified wood according to cycle 1 (left row) and cycle 2 (right row) before changing climate with one standard deviation A) 20°C/65% RH and 25°C/20% RH B) 20°C/65% RH and 30°C/80 % RH, C) 25°C/20% RH and 30°C/80% RH*

From this experiment, in the both phases (shrinkage and swelling) densified wood has bigger values then untreated wood. The reason for that is the sensitivity of the matrix softened with moisture where partial deformation from the thermo hydro mechanical process was recovered (Tanahashi et al., 1989). The results of densified and non-densified coated wood showed that after moisture equilibrium in certain climate, coatings have very small influence. That means the coatings are not blocking the interaction of water vapor and the wood. Accordingly, there is no clear difference between the performance of solvent based and water-based coating systems according to densified and non-densified wood.

From this aspect, the coatings are lowering the speed of moisture uptake, is protecting the densified wood from liquid water for a limited period only.

4. CONCLUSION

From this study the following conclusion can be made:

Color change – densified wood is much more stable than untreated wood. The coatings almost have no influence on the color change when the densified wood is exposed to UV radiation.

Water permeability – coatings protect densified wood from interaction with liquid water for a limited period.

Dimensional changes: densification conferred to wood a certain inertia in comparison to non-treated wood (smaller swelling in short exposure, bigger swelling in long exposure). Similarly, the coatings evaluated in this work slow the swelling of densified and non-treated wood but do not completely prevent it.

There is no clear difference between the performance of water based and solvent based coatings. From this study, Solvent 2 and Water Based 2 coatings would be the best options.

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TRENDS OF NUMBER OF WOOD TECHNOLOGY STUDENTS SINCE INTRODUCTION OF THE BOLOGNA PROCESS IN UNIVERSITY TEACHING IN CROATIA

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ABSTRACT

Croatia joined the Bologna process in 2001 and has been an active participant ever since. All study programmes have been aligned with the Bologna structure in 2005, and all students graduating in Croatia from these programmes receive ECTS credits and are entitled to diploma supplements. This article presents an analysis of the number of enrolled students of various study programmes at the Faculty of Forestry in Zagreb since academic year 2005/06. The base for these analysis are data of the number of students gathered from Information System of Higher Education Institutions (ISVU) for students of various undergraduate study programmes and specially for two wood technology graduate programmes. Correspondence analysis was performed for students enrolled in undergraduate programmes. Time series data analysis was performed for three wood technology study programmes.

Key words: wood technology, students, Bologna process, correspondence analysis, trend

1. INTRODUCTION

The European Union has committed to the principle of sustainable development as its policies and actions, based on balanced economic growth, price range of stability, strengthening the internal market, research and development, innovation, education, competitive social market economy and a high level of protection and improvement of environmental quality (Lučić, 2009). University education is more than the next level in the learning process; it is a critical component of human development worldwide. It provides not only the high-level skills necessary for every labor market but also the training essential for teachers, doctors, nurses, civil servants, engineers, humanists, entrepreneurs, scientists, social scientists, and a myriad of other personnel. It is these trained individuals who develop the capacity and analytical skills that drive local economies, support civil society, teach children, lead effective governments, and make important decisions which affect entire societies (EPI, 2019).

The UNESCO Recommendation concerning the Status of Higher-Education Teaching Personnel provides the following definitions of academic freedom and institutional autonomy: Academic Freedom: Higher-education teaching personnel are entitled to the maintaining of academic freedom, that is to say, the right, without constriction by prescribed doctrine, to freedom of teaching and discussion, freedom in carrying out research and disseminating and publishing the results thereof, freedom to express freely their opinion about the institution or system in which they work, freedom from institutional censorship and freedom to participate in professional or representative academic bodies. All higher-education teaching personnel should have the right to fulfil their functions without discrimination of any kind and without fear of repression by the state or any other source. Higher-education teaching personnel can effectively do justice to this principle if the environment in which they operate is conducive, which requires a democratic atmosphere; hence the challenge for all of developing a democratic society (UNESCO, 1997).

The *Trends series* has been published by the European University Association and its predecessor organisation since the signing of the Bologna Declaration in 1999, and provide an institutional perspective on higher education policy and institutional developments in Europe. Over the years, the focus of Trends has been changing. Whereas previous reports analysed mainly how the Bologna reforms have been implemented at the European universities, Trends 2015 discussed, amongst other themes, also developments in learning and teaching (L&T). Trends 2018 research continues and further enhances this focus, and explores recent European policy developments and institutional strategies and practice on L&T (EUA, 2019).

The Bologna Declaration was a common declaration of the European education ministers singed in 1999 in Bologna, which marked the process of higher education reform known today as the Bologna Process (AZVO, 2019). Croatia joined the Bologna process in 2001 and all study programmes have been aligned with the Bologna structure in 2005. All students graduating in Croatia from these programmes receive ECTS credits (European Credit Transfer and Accumulation System) and are entitled to diploma supplements. The Croatian Qualifications Framework is a reform instrument for regulating the system of qualifications at all levels in the Republic of Croatia through qualifications standards based on learning outcomes and following the needs of the labour market, individuals and society (CROQF, 2019).

This article presents an analysis of the number of enrolled students of various study programmes at the Faculty of Forestry in Zagreb since academic year 2005/2006, and analysis of the author's teaching hours per given course in a particular academic year. The base for these analysis are data of the number of students gathered from Information System of Higher Education Institutions (ISVU, 2019) for students of various undergraduate study programmes and specially for two Wood Technology graduate programmes.

Correspondence analysis was performed for students enrolled in three undergraduate Bachelor's programmes. Time series data analysis was performed for three wood technology study programmes, one Bachelor's and two Master's programme. It is known that future projections can not predict the detail movement of analized variables, such is the number of students. They are only a rough indication of the future course, assuming that the policies won't change significanty (Hanke and Reitsch, 2001). According to Rozga and Grčić (2002), by analyzing data we got a picture of what happened in the (near) past, what is the current situation, and planned and future course of events, i.e. the movement of number of wood technology students in the near future.

Demographic changes affecting the number of students have to be taken into consideration when designing higher education policies and goals. Many countries are concerned about the decreasing number of young people and how such changes will affect higher education participation and funding (EACEA, 2018).

2. MATERIAL AND METHODS

The base for these reserch are data of the number of students gathered from Information System of Higher Education Institutions (ISVU) for students of five courses in four undergraduate study programmes (university and professional) and specially for students of two courses in two wood technology graduate programmes at the Faculty of Forestry in Zagreb since academic year 2005/2006. Also, in database are included the author's teaching hours per given course in a particular academic year. Since analysis include last 14 academic years, for the purpose of shortening the name we used mark **A05** for the academic year 2005/2006, the **A06** for the academic year 2006/2007, etc., up to **A18** for the academic year 2018/2019. Study programmes involved in this research are shawn in Table 1., and the names of courses with abbreviations for variable names are shown in legend in Table 2.

Table 1. *Legend forstudy programmes*

Name of study programme	Code	Type of study programme	Semesters	ECTS
Wood Technology	**DT**	undergraduate university	6	180
Wood Technology	**SS**	undergraduate professional	6	180
Forestry	**ŠP**	undergraduate university	6	180
Urban Forestry, Nature Conservation and Environmental Protection	**PU**	undergraduate university	6	180
Wood Technology Processes	**DP**	graduate university	4	120
Design of Wood Products	**DD**	graduate university	4	120

***Table 2.** Legend for analyzed variables*

Variable	Course	Course Code	TEHINSU	Academic years	Semester	ECTS	Lectures (hours)	Exercises (hours)	Exercises groups
M1	Mathematics	DT-1101	33556	A05-A18	1st	7	**45**	**45**	**2**
M2	Mathematics	ŠP1002	33852	A05-A17	1st	7	45	**45**	**2**
M3	Mathematics	PU1002	33780	A05-A17	1st	7	45	**45**	**2**
M4	Mathematics for Engineers	SS102	48478	A08	1st	7,5	**45**	**60**	**1**
		SS103N	163675	A13-A18					
S1	Basic Statistics	DT-2314	33636	A06-A18	3rd	4	30	**30**	**2**
S2	Applied Statistics	DP-2353	33701	A09-A18	3rd	4	30	**15**	**1**
S3	Applied Statistics	DD-2376	33725	A09-A18	3rd	4	30	**15**	**1**

Database for this reserch include the number of students involved in four Mathematical courses (M1, M2, M3, M4) and three Statistical courses (S1, S2, S3) since introduction of the Bologna process in university teaching at the Faculty of Forestry in Zagreb, as well and author's teaching hours. Author of this paper worked as *assistant* from A05, *senior assistant* from A12, and *associate professor* from A16 (as a *associate teacher for exercises* on all of courses from A05, and as a *lecturer*, with exercises, on M4 from A17 and M1 from A18). Data gathered for these analysis are shown in Table 3.

***Table 3.** Number of students and author's teaching hours according to courses*

Academic year	Number of students according to Courses							Author's teaching hours according to Courses						
	M1	**M2**	**M3**	**M4**	**S1**	**S2**	**S3**	**M1**	**M2**	**M3**	**M4**	**S1**	**S2**	**S3**
A05	78	118	51					90	90	90				
A06	83	122	49		20			90	90	90		60		
A07	115	129	74		58			90	90	90		60		
A08	81	123	75	44	40			90	90	90	60	60		
A09	115	125	70		32	11	7	90	90	90		60	15	15
A10	131	117	98		49	11	5	90	90	90		60	15	15
A11	131	112	86		47	15	8	90	90	90		60	15	15
A12	139	117	92		31	22	5	90	90	90		60	15	15
A13	143	110	90	41	35	23	6	90	90	90	60	60	15	15
A14	125	98	76	33	42	12	10	90	90	90	60	60	15	15
A15	118	103	82	12	51	20	12	90	90	90	60	60	15	15
A16	113	94	74	40	41	17	9	90	90	90	**150**	60	15	15
A17	42	87	75	41	32	13	7	90	90	90	**150**	60	15	15
A18	39			10	26	18	9	**180**			**150**	60	15	15

Explanations for missing datas in Table 3: author is't involved in teaching anymore (last row for courses M2 and M3); study program has not been enrolled (several years for M4); first generations of students not started yet (S1 started in A06, and S2, S3 in A09).

Correspondence analysis as a descriptive/exploratory technique designed to analyze simple two-way and multi-way tables containing some measure of correspondence between the rows and columns was used to explore the differency/similarity of number of students enrolled in the first year of three different Bachelor's university study programmes.

Data analysis for this paper, as well as tabular and graphical representations, were performed in Microsoft Excel and Statistics software packages.

3. RESULTS AND DISCUSSION

During the last 14 academic years author was involved in teaching of 4865 students. Minimum of 102 students is recorded in this academic year 2018/2019 (A18), and maximum of 448 students in A13. Average number of students per academic year is 348, with standard deviation of 90 students, that lead us to 95% confidence interval from 295 to 400 students per year. Coefficient of variation for number of students in academic year is 0,26.

According to number of courses in one academic year, author was involved 1 year in 3 courses (A05), 2 years in 4 courses (A06, A07), 2 years in 5 courses (A08, A18), 4 years in 6 courses (A09-A12), and 5 years in 7 courses (A13-A17). Average number of courses per academic year is 5,7 with standard deviation of 1,3 (95% confidence interval from 4,9 to 6,5). Coefficient of variation for number of courses in academic year is 0,23.

Distribution of students according to academic years and courses are shown in Figure 1. and Figure 2.

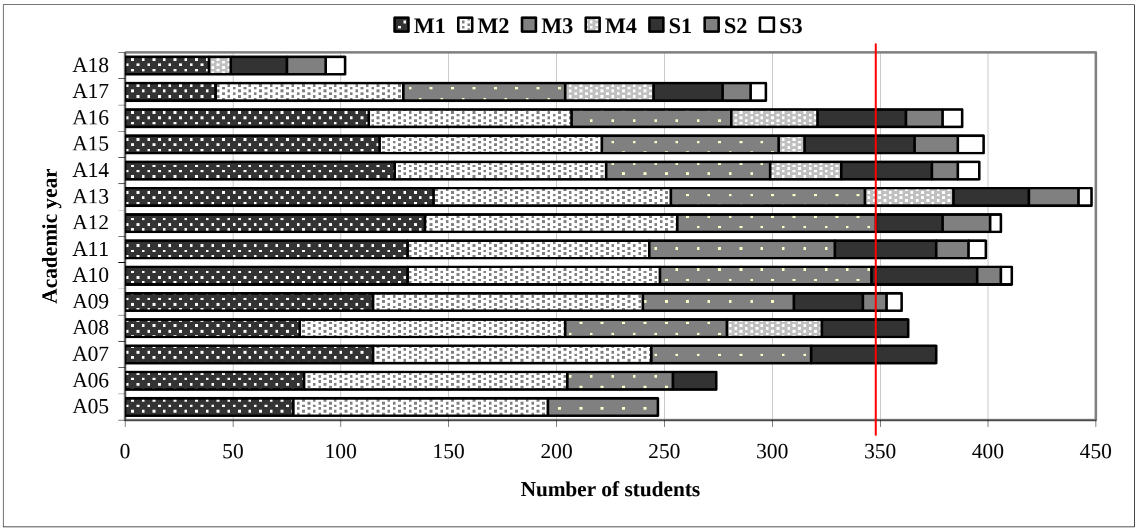

Figure 1. *Didtribution of students according to Academic years*

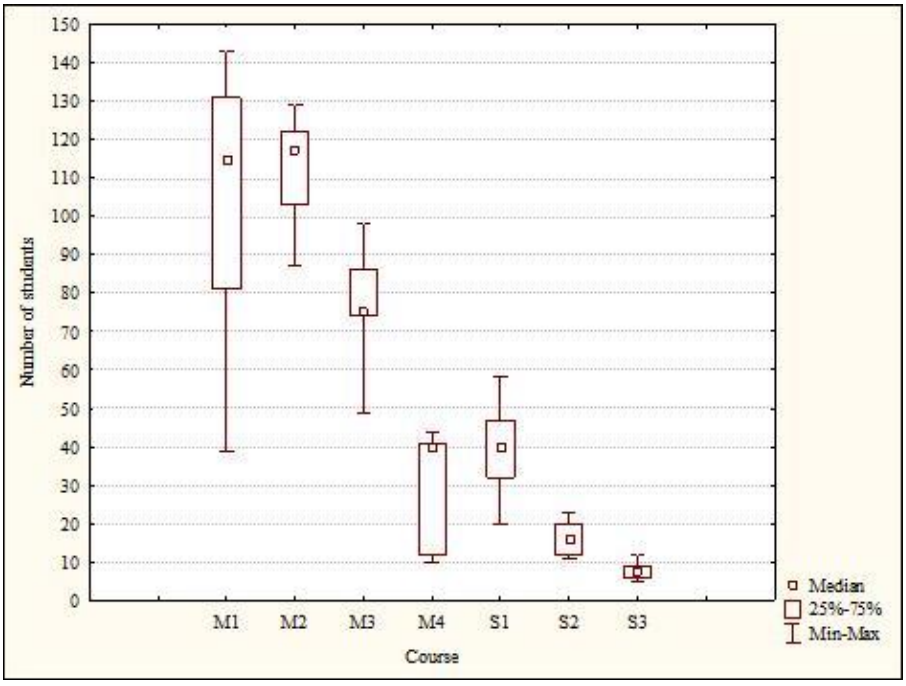

Figure 2. *Didtribution of students according to Courses*

Descriptive and inferential statistics were determined for the number of students for all of the courses included in these analysis, from the 1st year of undergraduate Bachelor's university and professional study programmes (Y1) to 2nd year of graduate Master's university programmes (Y5). The results are given in Table 4.

Table 4. *Statistics for number of students according to Courses*

Variable	Valid N	Mean	Std.Dev.	Conf.L. -95%	Conf.L. +95%	Minimum	Median	Maximum	Coef. Var.
M1	14	104	34	84	123	39	115	143	0,33
M2	13	112	13	104	120	87	117	129	0,12
M3	13	76	14	68	85	49	75	98	0,19
M4	7	32	14	18	45	10	40	44	0,46
S1	13	39	11	32	45	20	40	58	0,28
S2	10	16	4	13	19	11	16	23	0,28
S3	10	8	2	6	9	5	8	12	0,29

According to National qualifications frameworks for higher education in Croatia (Law on Scientific Activity and Higher Education, 2017), the criteria for engagement and workload of teachers and associates in teaching in undergraduate, graduate, postgraduate and specialist studies are: 150 teaching hours for assistant, 225 teaching hours for senior assistant, and 300 teaching hours for teachers elected to the scientific degree. For obligatory hours of teaching per academic year we used term *Norma hours* (an estimation of the time learners typically need to complete all learning activities such as lectures, seminars, projects, practical work, work placements, individual study required to achieve the defined learning outcomes in formal learning environments). Considering this criteria, we analized the author’s teaching time in *norma* hours since A05 (7 years as a assistant, 4 years as a senior assistant and last 3 years as a assistant professor). The results of these analysis are given in Figure 3.

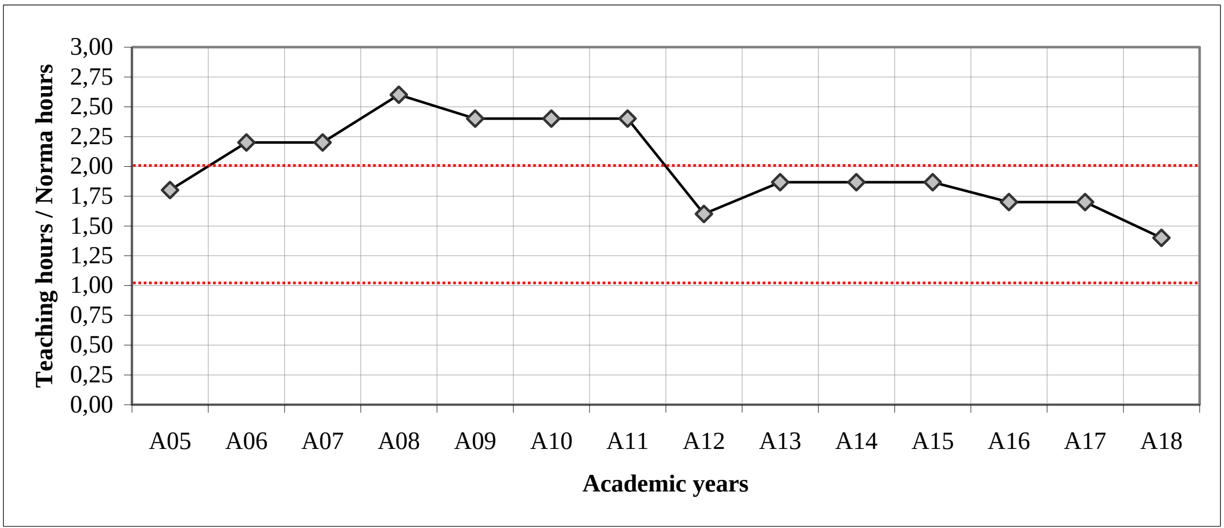

Figure 3. *Ratio of Teaching and Norma hours*

Analysing the ratio of author’s teaching hours with norma hours per academic year we found that during the last 14 academic years author averagely teached exactly double norma, in other words two full time job. Minimum ratio of 1,4 was in A18 (40% more than norma), and maximum of 2,6 in A08 (160% more than norma). Distribution of ratios have two modes: 2,4 (A09-A11) and 1,9 (A13-A15). Standard deviation of ratio was 0,363 (95% confidence interval from 1,8 to 2,2). Share of standard deviation in average value (coefficient of variation) is 0,18.

Correspondence analysis was performed for number of students (variable with frequences) enrolled in three mathematical undergraduate Bachelor's university programmes (column variables: M1, M2, M3) in period A05-A17 (row variables). The results of this analysis are given in Figure 4.

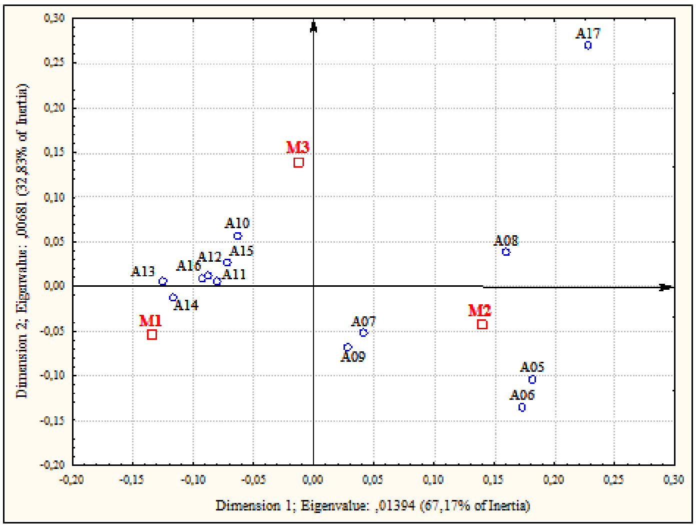

Figure 4. *2D Plot of Row and Column Coordinates*

This analysis shown that difference between the number of students on three different mathematical Bachelor's programmes is statistical significant (χ^2=80,11 ; df=24 ; p<<0,01). The origin on the map corresponds to the centroid of each variable. Dimension 1 is represented by the horizontal axis and Dimension 2, the vertical axis. The closer a row profile's vector location is to the origin, the closer it is to the average profile. In our case, M1/A14, than M2/A05, and M3/A10 were closest to their respective average profiles and therefore closest to the origin. Along Dimension 2, we see that M1/A17, then M2/A17, and M3/A06 have the most importance. These results indicate that the most important differences or largest deviation from independence in the sample are between M1/A17 (only 42 sudents of M1 in A17, while the 14 years average was 104). The other responses being closer to the origin imply that the deviations from the expected proportions are relatively small.

The success of studying at the Department of Wood Technology was analyzed by comparing the transience from the first to the second year of the Bachelor's programme, as well as by comparing the transience from the second year of the Bachelor's programme to the fifth year of the studing (2nd year of the Master's study). Percentage of transience of study compared to enrollment in the 1st year of studying are shown in Figure 5.

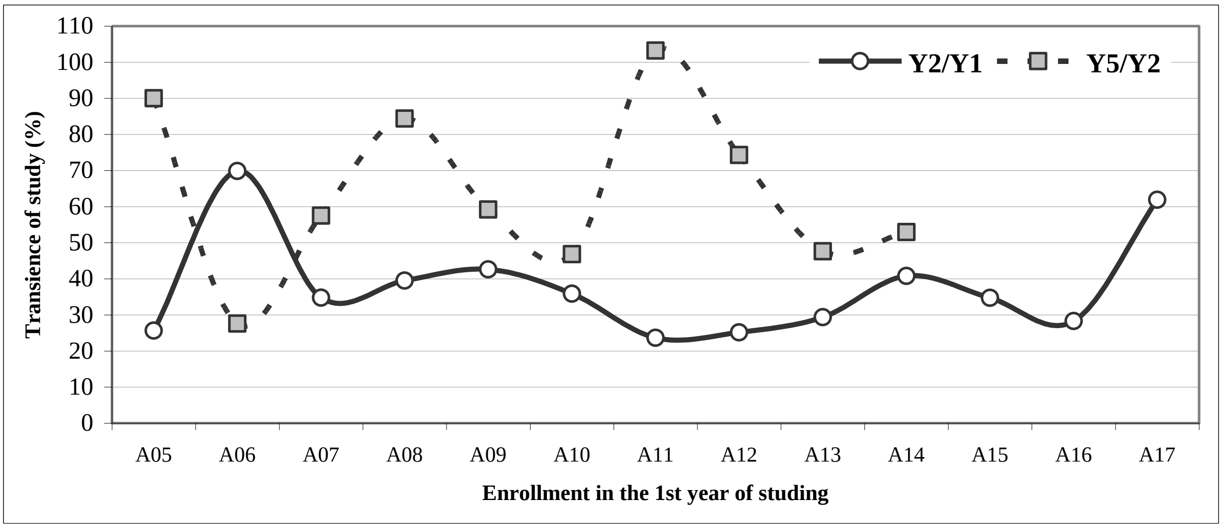

Figure 5. *Transience of studing Wood Technology*

Descriptive and inferential statistics were determined for transience from the 1st to the 2nd year (Y2/Y1), and transience from the 2nd to the 5th year (Y5/Y2), including the analysis of percentage of students involved in two Master's programmes (DP/S2 and DD/S3). The results are given in Table 4.

Table 5. *Statistics for transience of study*

Variable	Valid N	Mean	Std.Dev.	Conf.L. -95%	Conf.L. +95%	Minimum	Median	Maximum	Coef. Var.
Y2/Y1	13	37,9	13,9	29,4	46,3	23,7	34,8	69,9	0,37
Y5/Y2	10	64,4	23,1	47,8	80,9	27,6	58,3	103,2	0,36
DP/S2	10	67,0	8,1	61,2	72,8	54,5	65,3	81,5	0,12
DD/S3	10	33,0	8,1	27,2	38,8	18,5	34,7	45,5	0,24

According the results in table above, using the calculated 95% confidence intervals (Conf.L.) for analized period, and number of students involved in course M1 in A18, we predict that the number of students in 2nd year of Bachelor’s programme for the next academic year 2019/2020 for course S1 will be between 11 and 18 students. We also anticipate that the number of students in 2nd year for both Wood Technology Master’s programmes in academic year 2021/2022 will be between 12 and 21. Specially for the Wood Techology Processe programme in course S2 between 8 and 14, and for the Design of Wood Products programme in course S3 between 4 and 7 students.

4. CONCLUSION

Results of this research indicates that drop-out rates for the students of wood technology at Faculty of Forestry in Zagreb are the highest at the end of the first academic year. First-year students are particularly vulnerable to dropping out of higher education, since their expectations might be very different from what they actually encounter. Such mismatch can stem from the wrong choice of study programme, poor foreknowledge from basic subjects, as well as the feeling of helplessness and failure at the start of higher education studies.

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DEVELOPMENT OF LEARNING MANAGEMENT SYSTEMS IN THE CONTEXT OF EUROPEAN PROJECTS

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ABSTRACT

Learning management systems (LMSs) have become increasingly attractive in the past few years and have been used by the majority of educational institutions and training providers around the globe. Their development and vast use began with the dawn of this running century. Learning Management Systems are becoming more and more indispensable in education and in training, and for what it seems they will continue to be increasingly used, especially in Vocational Education due to their benefits emerged for both trainers and instructors.

Anaptyxiako Kentro Thessalias – AKETH-DCT (Developmental Centre of Thessaly) has a long term experience in the implementation of EU projects while has extensively applied LMSs in its educational strategy. The limitless accessibility and global character of education provided through the use of online learning platforms and tools have enabled AKETH-DCT to provide high quality vocational educational and training programs all-over Europe.

In this paper we will try to present the most important findings and conclusions regarding development of Learning Management Systems in the frame of EU funded projects such as Erasmus+.

Key words: Erasmus+, online course, VET, EQF, ECVET, learning outcomes, LMS

1. INTRODUCTION

Anaptyxiako Kentro Thessalias – AKETH-DCT, located in Trikala, Greece, is a nonprofit continuing vocational education & training (VET) centre/provider. AKETH-DCT was founded in 2004 in Trikala – Greece and as a nonprofit organization uses its surplus revenues to further achieve its objectives or mission. Its revenues derive by its activities operating as international VET provider, offering counseling services and providing e-solutions through AKETH lab. AKETH is aligned with the E.U. strategic framework about fighting the rising levels of unemployment –particularly among young people. It is the same risk which threats a high number of adult workers, resulting in phenomena of social exclusion and the increase of poverty. Such phenomena are more and more appearing, threatening the social cohesion and standard of living. The main way to confront the above is througn the improvement of provided education/training in terms of quality and efficiency. AKETH’s mission is to provide certified education & training opportunities, counseling & personal development in order to contribute in their life improving.

Anaptyxiako Kentro Thessalias – AKETH-DCT (hereinafter AKETH-DCT) has been involved in many regional, national and European programmes in various fields (energy, education, consultancy services, management, etc.). In 2010 AKETH was certified by the National Certification Center (EKEPIS) as a vocational training center. It has been awarded by the State Scholarship Foundation (IKY) in recognition of its contribution to the promotion of Vocational Education and Training Systems through the exemplary implementation of Leonardo Da Vinci projects (2011). At the European Level, AKETH-DCT has been involved as a partner and as a coordinator in numerous European projects, having acquired strong experience in management, coordination, implementation, dissemination and all other related activities. Our organization has been one of the first organizations participated in the development and specification of ECVET tools for specific qualifications such as event manager, nurse's assistants, etc Due to the long term experience and skilled staff on the field of ICT, AKETH-DCT has been acting mainly as the leader of Working Packages and Intellectual Output in EU projects which are dealing with the development of e-learning platform, ICT ,digital educational tools, and to the development of modern and attractive vocational and adult training curricula.

2. METHODOLOGIES AND PROCEDURES

AKETH-DCT has set a series of requirements, indicators, standards and procedures, which are derived of institutions mission and objectives, so to ensure the validity of any of its activities regarding vocational educational training and digital educational tools. In all of the developed developed LMS and training curricula the following aspects, methodologies and procedure are strictly applied.

- European Credit System for Vocational Education and Training (ECVET) Ecvet-toolkit.eu., 2019).
- European Quality Assurance in Vocational Education and Training (EQAVET) (Eqavet.eu., 2019).
- Development and Usage of Open Educational Recourses (OER) (UNESCO, 2019).
- Usage of quality and widely accepted digital tools and learning management systems such as Moodle, e-class, canvas, etc
- Collaboration with experts and high level authorities and institution for the development of training material

In order to give a wider and concrete overview of the aforementioned procedures and methodologies in the following sections an already developed (in the frame of an Erasmus+ project) learning management system will be presented and discussed.

3. THE CASE OF THE LEARNING MANAGEMENT SYSTEMS OF THE EU PROJECT "ESVET PROJECT

"Establishment of a Modular Ecvet System in Europe" (acronym ESVET) is an EU project Strategic Partnerships for vocational education and training funded under the frame of Erasmus+ programme (Erasmus+,2019) by the Turkish National Agency for Erasmus+ (Esvet.org, 2019). Coordinator of the project was Inovasyon Proje from Turkey, while organizations from 7 different countries were participated as partners (Greece, Turkey, Romania, Germany, Bulgaria, Portugal and Latvia).

At European level there is an increased demand for qualified staff in the organization of major events and on the other there is a lack of education and training programs (Presbury & Edwards, 2005). Event management is one of the 50 most popular professional careers in the world. Tourism and related sectors including event planning employ about 10% of the global workforce (Robinson et al., 2008). Event managers can be either self-employed entrepreneurs or employees in larger organizations such as: wedding venues, hotels, resorts, exhibition companies, concert organizers and conference organizers. 95% of event planners in Europe do not have a certificate. Their skills come from their work experience. In most European countries, the sector of event planning lacks professional cohesion, standards and educational / teaching paths. Within the European Union, only the United Kingdom and Germany have some national standards recognized by both industry and public authorities for event management. Responding to the needs of event planners at European level, this project created a modular training system in line with ECVET (CEDEFOP, 2013) principles in the field of Event Management. The ESVET project is a response to the needs of event managers who have low initial qualifications and encounter obstacles to the acceptance and certification of their professional experience. In order to improve the qualifications of workers in this sector, the project will draw up a European qualification standard for event management by describing managerial competences. It is intended to promote the recognition of learning outcomes for the event manager profile by developing a method of assessment using an ECVET and learning outcome-oriented approach (AKETH, 2019).

Figure 1. *Key figures and data of the ESVET project*

3.1 ESVET Training methodology

The developed by ESVET project training system encompasses the entire training process: training material, an online training platform, as well as a tool for evaluating and certifying the skills acquired through the whole process. In order to accomplished the aims and objectives of ESVET project a multistep procedure was designed and proposed consist on the following main steps:

- Analysis of the field and opportunities for education and training in event management
- Creation of the job profile of the event organizer technician
- Definition of the learning outcomes of the proposed training curricula
- Development of an holistic blended learning process
- Development of educational/training material in all partner languages plus English
- Development of the learning management systems (LMS) of the project based on Moodle
- Development of an assessment and recognition methodology examination digital tool

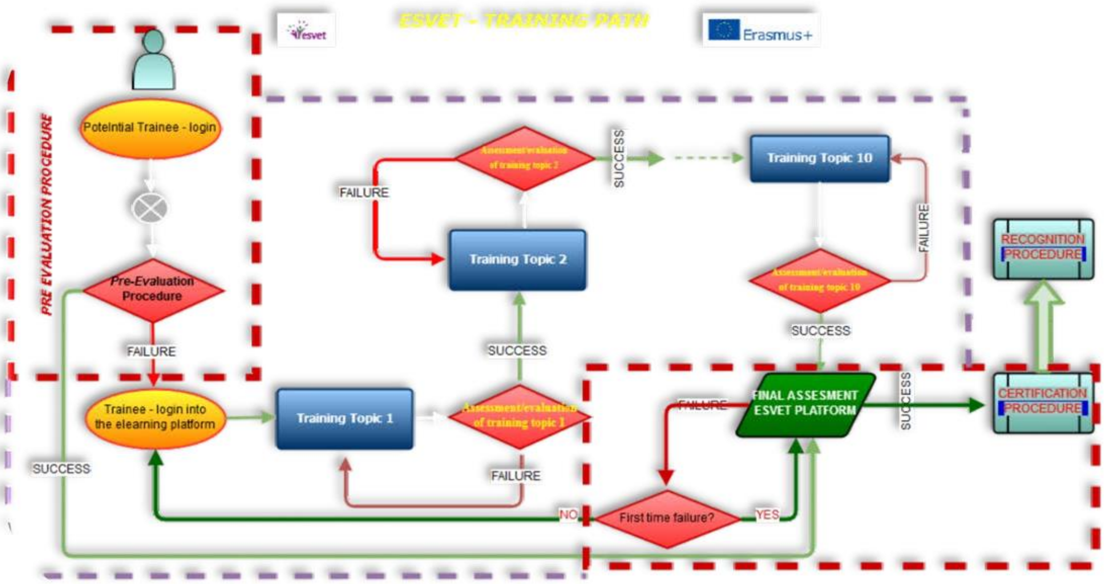

Figure 2. *The ESVET training Pathway*

The whole training and examination procedure can be divided in three main stages/phases: a) pre-evaluation of the potential trainees b) main training c) final assessment of the whole training period. In ESVET training pathway the following constrains have been decided and applied:

- each partner is responsible for the whole training procedure in his/her language
- ESVET project coordinator is the upper level responsible
- registration procedure is available all year around but assessment/review of the applications
- is done twice a year (before the pre-evaluation period)
- pre-evaluation (self-test) is available to potential trainees twice a year

- the pass level for the pre-evaluation (self-test) has been set to 70%
- each candidate (potential trainee) can take part in the pre-evaluation procedure only twice (no matter the time period)
- ESVET blended training using the online platform is also provided twice a year

The first action that a potential trainee has to take is to fill in the obligatory registration form which can be found on the official web site of ESVET project. By filling this registration form potential trainee has to declare either he/she wants to take the self-evaluation test so to have the change to proceed to the final examination of the ESVET training or he/she wants to participate in the blended training procedure and then (after successful completion of it) take the final examination. In both cases the potential trainee has to prove that has the Entry requirements of ESVET project:

- EQF level 4 completed
- Interest in acquire specialized knowledge in event organization.
- at least one year work experience in event organization or related functions.

Figure 3. *The ESVET LMS (http://etraining.esvet.org)*

The prior status evaluation procedure (self-test) is according to the concept for the online-based competence measurement and is to be a decision-making aid regarding the access or not to the online based learning procedure. Prior status evaluation procedure is on the form of a self test and each potential trainee can take it on his/her home on his/her own, respecting always the ESVET rules and procedures. If the pre-evaluation results are ≥60% then course leader informs potential trainee about next steps which include the participation to the final examination procedure. In case of less than 60% trainee has the option to retake the test, and in case of second failure (less than 60%) then he/she will be informed by the course leader about the details of the next steps (starting date of blended training procedure, enrollment procedure etc). If a candidate reaches ≥70%, he can register directly by the national ESVET certification partner for participating in the final examination and certification procedure.

ESVET proposed training curricula consists of ten Learning Units. The ESVET Event Organiser Technician Profile developed under the ESVET project is designed for EQF level 5, taking into account the complexity, range and level of learning expected. In this sense, it is a requirement that staff using the Profile have fundamental knowledge and specialized skills to be able to manage and supervise activities, in an autonomous and responsible way. The profile has allocated 96 learning hours and a workload of 250 hours in total and organized into ten learning units, corresponding to 10 ECVET points.

LEARNING UNITS	LEVEL EQF	LEARNING HOURS	WORKLOAD¹	ECVET POINTS
1. Event planning and design	5	12	25	1
2. Event coordination		12	25	1
3. Events Budget elaboration		10	25	1
4. ICT in event management		10	25	1
5. Event Marketing		10	25	1
6. Raising Support and Sponsorship		8	25	1
7. Relation with the Media		8	25	1
8. Event Protocol		8	25	1
9. Event safety and emergency		8	25	1
10. Event Assessment		10	25	1
EVENT ORGANISER - TECHNICIAN CURRICULUM	5	96*	250	10

Figure 4. *ESVET Learning Units description*

All Learning Units have the same "architecture" on their contents as seen in figure 5 below. In that way trainee is familiarized with the whole procedure and content. Training material of ESVET project has been developed in all partners' language plus English, while it contains interactive material by using Augment Reality Features. In that way the training material is not limited to what is written in the pages of it but includes more information which are available to trainee upon request of his/her using the specific software

Each partner was responsible for the development of the training material for one learning unit, the intro video and its evaluation questions according to their expertise and experience in the field. The training material is embedded into the e-learning platform though digital tools, while there is also presentation file of the learning unit developed by the same partner plus the possibility to download the learning unit material as a pdf file and use it locally offline.

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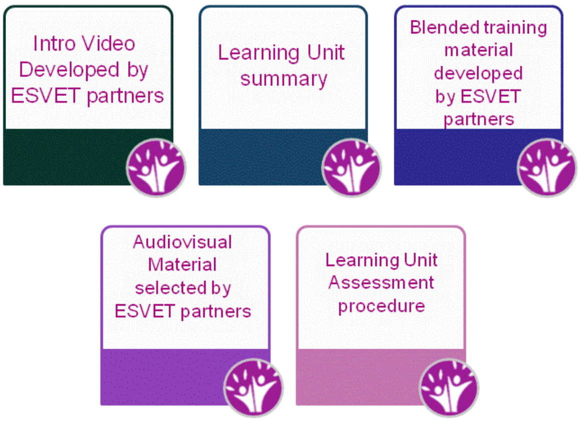

Figure 5. *SVET Learning Units Common Contents*

As already described and in order to help trainee deepen into the learning unit's topic, ESVET blended training material gives them the potentiality to access additional material (in case they wish) through the integration of Augment Reality content (mainly additional videos) to it by using the preselected software tool (application).

Another element/feature of ESVET online training and recognition methodology is the usage of synchronous (face to face) teleconferences between trainees and the responsible tutor. This tutor is authorised and recognised by ESVET consortium and is a official trainers of an ESVET partner. In these sessions trainees have a direct communication with the ESVET tutors and can interact so to raise any possible questions or to discuss on related to the learning unit topics. This blended training methodology leads to a secure provision of training and secures the pathway to the recognition of the received by the trainee training.

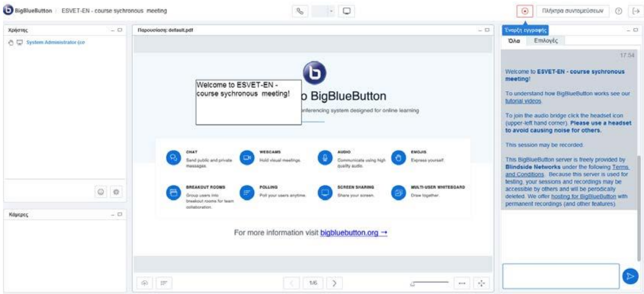

Figure 6. *ESVET synchronous teleconference*

In these sessions trainees have a direct communication with the ESVET tutors and can interact so to raise any possible questions or to discuss on related to the learning unit topics. This blended training methodology leads to a secure provision of training and secures the pathway to the recognition of the received by the trainee training.

Respect for diversity and equal opportunities are essential elements of culture. Access for people with disabilities to the fundamental right to learning should be ensured by both conventional and online learning environments. In the case of people with special educational needs, e-learning can often be the only solution for access to knowledge, information and the learning process in general (Gouvatzis, 2011). In ESVET LMS we used a digital plugin called «accessibility block». This plugin allows the conversion of speech into written text (text to speech) and automatic word pronunciation with synthetic voice of particularly high quality. Also, for the visually impaired or colorblind problems it offers the ability toenlarge text, color contrast, etc (Moodle.org, 2019).

In each learning Unit there is a separate assessment/evaluation test and only after successful completion of it the trainee can «move» to the next training topic. Each assessment test consists of questions (MC, fill in the blanks, right or wrong etc) randomly selected from the relevant ESVET question bank. The pass level for the between learning units assessment/evaluation test has been set to 60% while each trainee has only two attempts per evaluation quiz and if he/she fails on both of them then he/she is suspended from the training course. This procedure is repeated induring all ten learning units. At the end of the whole training procedure (which also means successful completion of all ten training topics) the trainee receives the ESVET certificate of attendance.

Figure 7. *ESVET Certificate for attending the blended training.*

This Certificate is recognised by all ESVET partners and has a unique certification code on its middle, which can be used for the authentication procedure of it so it can be tracked automated by the ESVET consortium members.

3.2 ESVET final assessment and recognition methodology

Each trainee, in order to receive the official ESVET qualification as «EVENT Technician manager», and the determined ECVET credits), has to take the relevant final assessment/evaluation test. For the final assessment, ESVET recognition methodology is based on the ECVET methodological tool regarding the recognition of the learning outcomes in terms of knowledge, skills and competences.

The ESVET assessment methodology was developed having in consideration each one of the Learning Units in terms of Knowledge, Skills andCompetences, aiming to assess in an objective and clear way the achievement of the expectedlearning achievements. Its based on CEMES method (Competence Evaluation Method for European Specialists) which is an online, multilingual method is able to evaluate and assess qualification and skill-regardless of how they are acquired (Red, 2006). The CEMES-Method of competence recognition as an examination method is a basis of a system of European Management Certificates (EMC). This method was awarded by the Helsinki Award of the European Commission as the Best European Project in 2006 (Cemes.eu, 2019).

In order to asses learning ourtcomes final assessment tool using the above described methodology uses:

- Multiple choice (MC) questions for the assessment of the knowledge. These questions are automatically evaluated by the examination/ assessment tool
- Open questions on the proof of acquired skills. The questions are randomly selected from a pool of questions. The answers are evaluated by an auditor
- Cases studies has been prepared by ESVET partners and are used in the final examination in order to ensured that the defined competences are available or the learning outcomes described have been acquired. The case studies are designed to include several units. However, the evaluation of these project work is not a per unit but a summary result. For evaluating a case study/project work, the examination platform offers various evaluation criteria, which can also be weighted to each other.

The examination for certification is carried out at a national ESVET certification center. The examination is carried out in the presence of a supervisor. he ESVET system automatically assigns the points for the MC questions. The points for the open questions and the case studies are awarded by an approved (by ESVET consortium) auditor. Then the ESVET-CEMES platform combines the achieved points of t he two written examinations for each learning unit. In order to assess whether thecertificate can be issued, it is necessary to summarize the individual results on the basisof the assessment methodology. After all individual assessments, the ESVET reviewsystem automatically summarizes the results.

The points achieved are included in the overall result with different weightings. Two cases are distinguished. a) If the learning platform has to be used, these weighting results:

- 10 % of the total score/grade comes from the e-learning
- 20 % of the total score/grade comes from multiple choice questions
- 30 % of the total score/grade comes from open questions
- 40 % of the total score/grade comes from the Case Study

On this basis, the system calculates the final result. In case that someone can go directly to the final exam after the pre-test, the following weighting applies:

- 25 % of the total score/grade comes from multiple choice questions
- 35 % of the total score/grade comes from open questions
- 40 % of the total score/grade comes from the Case Study

In case of the examination score is ≥70% the ESVET/CEMES examination platform automatically generates (as a pdf file which also appears on the trainee's screen) the Official Certificate ESVET EVENT ORGANISER – TECHNICIAN". ESVET certificate is printed on a pdf file which immediately appears on the e-learning platform and to the trainee's screen. This Certificate is recognised by allESVET partners and has a unique certification code on its middle, which can be used for theauthentication procedure of it so it can be tracked automated by the ESVET consortium members.

Figure 8. *Official Certificate ESVET EVENT ORGANISER – TECHNICIAN*

The online blended training and recognition methodology is in fully constrain with the of theEuropean Credit System for Vocational Education and Training (ECVET). This fact transformsESVET official Certificate into a tool that facilitates the recognition of learning outcomesbut always in accordance with national legislations in the country of interest.The proposed training and recognition methodology is efficient to be applied into mobility trainingperiod abroad and especially to one of the ESVET official partners and authorities. Finally theonline platform provides the ability for e-mobilities form countries and partners outside ESVETpartnership to ESVET partners, as they can access and receive teh official ESVET training.

4. CONCLUSION

The limitless accessibility and global character of education provided through the use of online learning platforms and tools have enabled AKETH-DCT to provide high quality vocational educational and training programs all-over Europe. Learning Management Systems offer a variety of solutions and tools regarding education and training. Anaptyxiako Kentro Thessalias in order to overcome the majority of the “questions” and in order to have a concrete answer to all the relative comments regarding the usage of LMS in official training curricula, has decide to follow a very strict and specific pattern which are in fully accordance with official methodological tools, training procedures and of course assessments methods. AKETH-DCT in the frame of various EU projects has develop numerous digital educational tools and LMS. In this paper an attempt was made to present one of the developed both LMS and training pathway. By the establishment of strong partnerships and under the frame of EU funded projects its shown that collaboration and mainly exchange of good practices and of course expertise may lead to the right paths of LMS and training curricula development. AKETH-DCT has been working on VET and adult training since its establishment and in the

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COMPARISON OF USING DIFFERENT GUSSET-PLATE MEMBER IN WOOD JOINTS

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ABSTRACT

In this study, lateral shear resistances of only glued joints constructed from three wood specie main member and two side members were investigated and compared. Scotch pine, alder and beech were used as main member (base member) while pine plywood and beech wood were used as side member (gusset-plate). Based on the results, in general, using beech wood gusset-plate in joints yielded significantly greater lateral shear resistances compared to the joint constructed from pine plywood gusset plate in each base member (Scotch pine, alder and beech). Changing wood base member from Scotch pine to Alder and Beech did not make any significant change in the joint with pine plywood gusset-plate. However, changing wood base member Scotch pine to Alder and Beech significantly increased the mean ultimate lateral shear resistances of the joints constructed from beech wood gusset-plate.

Key words: lateral shear, gusset-plate, glued joints, wood joints, Scotch pine, alder, beech

1. INTRODUCTION

A gusset-plate is a part which connects at least two members in a frame by fastener (Demirel et al. 2014a). It can be produced from wood, wood based materials or metal (Demirel et al. 2016). Gusset-plate joint is used in several areas such as building frames, bridge to connect truss members (Fang et al. 2014), roof construction (Wood and Dave 2006) and so on. It is also used in furniture frame construction especially in highly stressed connection such as stump to front rail joints and bottom-side rail to back-post connections in an upholstered sofa frame as shown in Figure 1 (Demirel et al. 2016). Figure 1 shows a sample where a gusset-plate connection used in sofa frame construction.

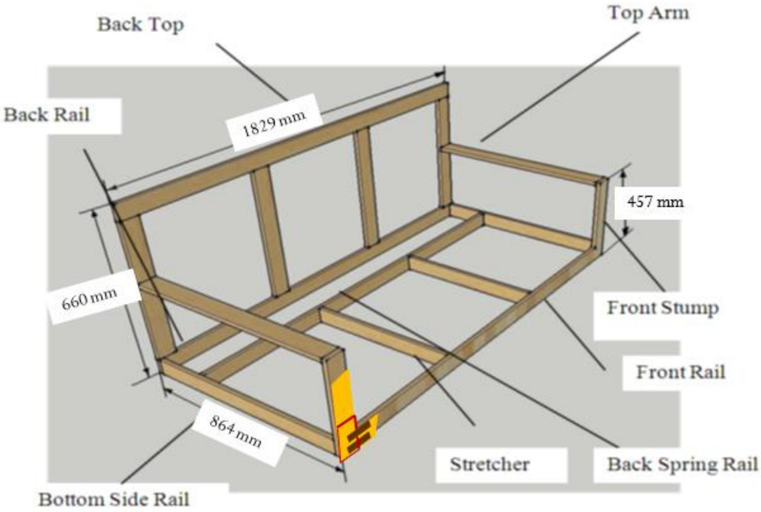

Figure 1. *A gusset-plate location in an upholstered sofa frame*

A gusset plate connect two frame members with only a metal fastener (Demirel et al. 2013,b Demirel and Zhang 2014b), or fastener and glue together (Demirel et al. 2018), or only glue (Demirel 2012, Kalayci 2019). Two placement patterns of gusset-plates are commonly seen in upholstered furniture construction: One wider gusset-plate or two narrower gusset plates attached to the same side of a joint as shown in Figure 1.

Demirel 2012 studied lateral shear resistances of gusset plate joints and two gusset plated located L-type and T-type joints constructed from OSB-I, OSB-II and, OSB-III with the core densities of 40.6, 43.4, 46.4 pcf, respectively. The gusset-plate joints were connected only glue, only staple, glue and staple together. Based on the results, the mean lateral shear resistances of the gusset-plates joints for OSB-I, OSB-II, and OSB-III were 1161, 1177, 1198 pound, respectively. Accordingly, OSB materials with different density did not make significant change in the lateral shear resistances of the joint with pine gusset-plate but the mean lateral shear resistances of joints constructed from OSB-III base member was marginally highest among the others. This was followed by OSB-II and OSB-I based joints.

There are limited studies on investigating lateral shear resistance of wood or wood based-gusset plate joints in a sofa frame especially for the joints which is subjected to lateral forces. Therefore, the main objective of this study to investigate the lateral shear resistances of gusset-plate joints. The specific objectives were 1) investigating the effect of using different gusset-plate material on the lateral shear resistances of the only glued wood joints, 2) investigating the effect of using different base material on the lateral shear resistances of only glued wood joint.

2. MATERIAL

Specimen Configuration

The general view of the joint samples for this study is shown in Figure 2. The specimen consisted of two principal structural members, a main member (base member) and a side member (gusset-plate), assembled together by only glue. The main members were Scotch pine, alder and beech with dimensions of 292 mm long by 178 mm wide by 18 mm thick. The gusset-plate were produced from pine plywood and beech wood with the dimensions of 152 mm long by 52 mm wide by 19 mm thick. Table 1 indicates the density values of base member.

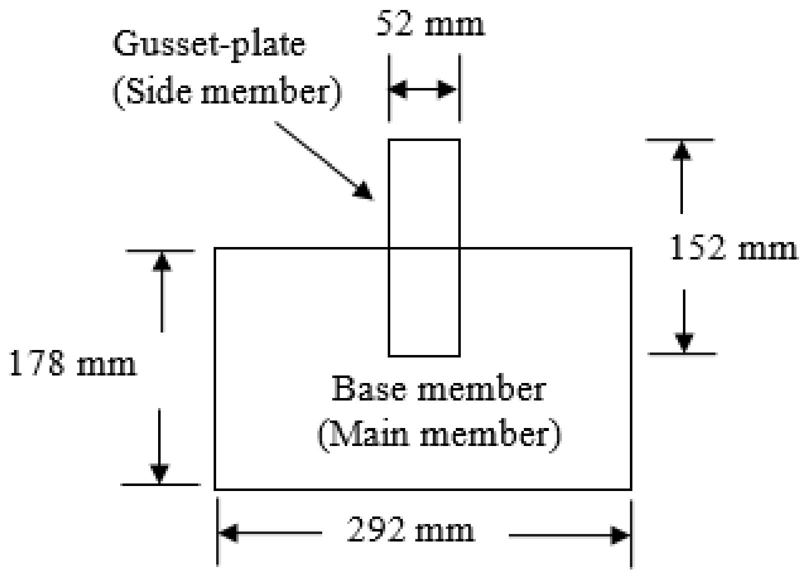

Figure 2. *General view of a glued gusset-plate wood joint connected with only glue.*

Table 1. *Mean densities of wood species*

	Scocth pine	Alder	Beech
Density	0,45 (C) (2)	0,51 (B) (1)	0,54 (A) (4)

Numbers in parenthesis indicate statistical difference and COV, respectively.

As shown Table 1, in order to see statistical difference between density values, a statistic was run for density values at 5 % significance level, and the results were evaluated with Least Significance Difference (LSD) value of 0,014. Based on the comparison, Scotch pine has the significantly lowest density, alder wood has significantly higher than Scotch pine, and beech wood has significantly the highest density value.

3. METHOD

Joint specimen preparation and testing

Prior to joint preparation, all cut base member and gusset-plates were conditioned in an equilibrium MC chamber controlled at (25±5) and 45 ± 5 percent relative humidity. All tests were carried out right after 48 hour for glue curing between the joints members in the laboratory at the temperature of 23 ± 2 º C and relative humidity of 50 ± 5 %. Figure 3 illustrates the test setup for measuring the lateral shear resistance of glue connected wood joints. All joints were tested on a Universal MTS Criterion 45 testing machine at a loading rate of 2,5mm/min in reference with ASTM D 1761 (ASTM 2010). In preparation, the joint sample was first clamped in Universal MTS machine and loading head was calibrated before loading. After the loading initiated, ultimate lateral shear load, load-displacement curves, and specimen failure modes were recorded.

Figure 3. *Test set-up for evaluating lateral shear load resistance of only glued gusset-plate joint.*

Experimental Design

A complete 3×2 factorial experiment with 10 replicates per combination was conducted to evaluate the effects of wood specie and gusset-plate type on the lateral shear resistance of joints. The three factors were base member wood type (Scotch pine, alder, and beech) and the gusset-plate type (pine plywood and beech). Therefore, a total of 60 joint specimens were tested.

4. RESULTS AND DISCUSSIONS

Failure mode and load-displacement curve

As failure mode, 15 of the joints constructed from beech wood gusset-plate were failed with both base member and gusset-plate rupture simultaneously. 13 of the joints were separated from connections points. Only two of them were failed with gusset-plate rupture. Figure 4 shows the failure mode of the joints with beech wood gusset-plates.

Figure 4. *Failure modes of the joints with beech wood gusset-plate: a) failure with base member and gusset-plate rupture; b) seperation from connection points; c) failure with gusset-plate rupture.*

On the other hand, As failure mode, 21 of joints constructed from pine plywood gusset-plate were failed with shear among the layer of gusset-plates. Eigth of the joints were seperated from connections points and only one of the joints were failed with base member and gusset-plate rupture.

Figure 5 shows the failure mode of joints with pine plywood gusset-plate.

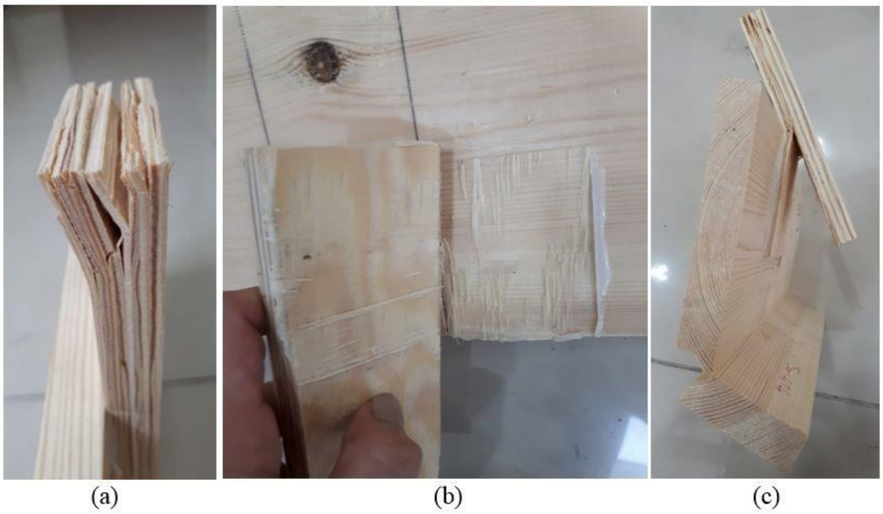

Figure 5. *Failure modes of the joints with pine plywood gusset-plate: a) failure with shear among the layer of gusset-plates; b) seperation from connection points; c) failure with base member and gusset-plate rupture.*

Typical lateral shear load-displacement curve of glued joints with beech wood gusset-plate is illustrated in Figure 6. In general the curve has two linear regions: first one is from 0 to proportional limit; second one is from proportional limit to ultimate point. After ultimate point, a sharp decrease was observed after loading. A sharp decrease after ultimate point is very common behavior for glue connected joints. Demirel 2012 plotted a similar look curve for the only glue connected joint with OSB base member.

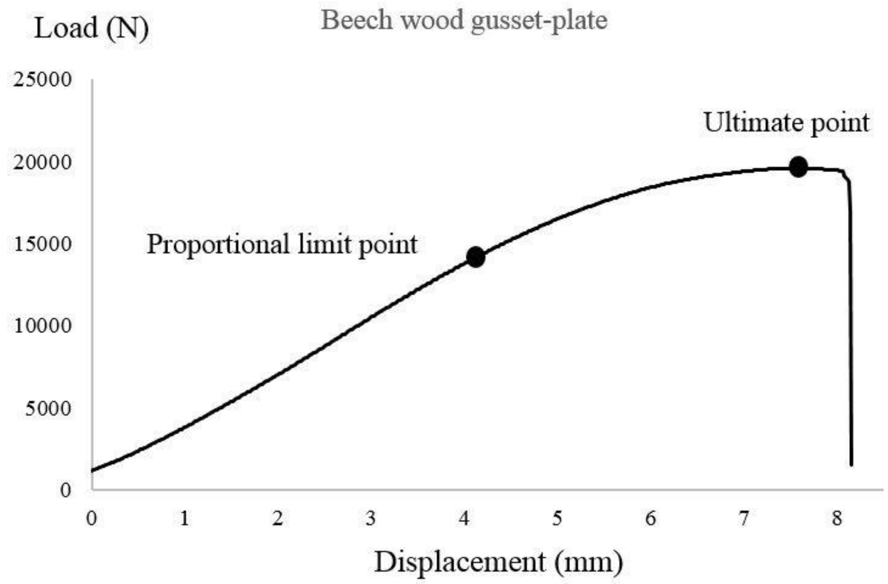

Figure 6. *A typical load-displacement curve for beech wood gusset-plate joints.*

On the other hand, a typical load-displacement curve of the only glue connected joints with pine plywood gusset plate in Figure 7 did not show a sharp behavior after ultimate point. This could be reason of failure mode because most of the joints with plywood gusset-plate failed with shear among gusset plate layers. This type of failure did not allow to show a sharp behavior after ultimate point.

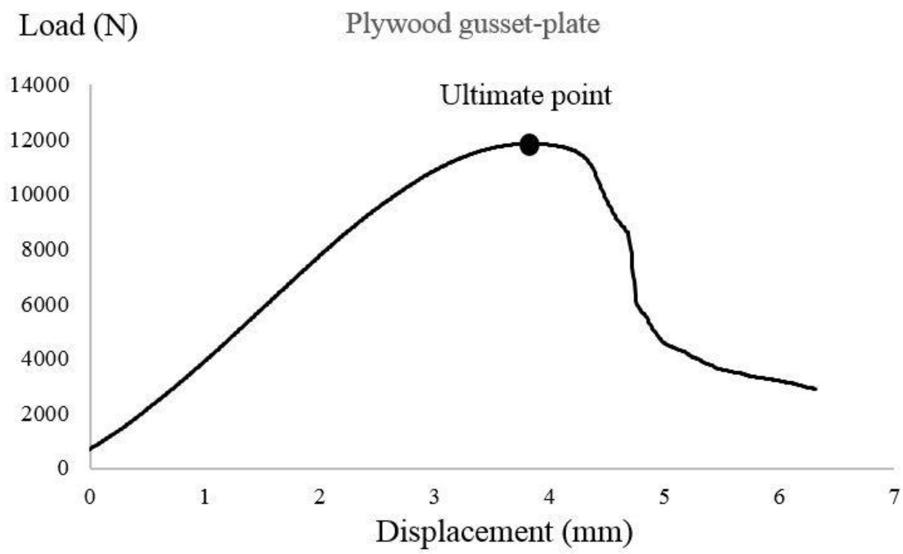

Figure 7. *A typical load-displacement curve for pine plywood gusset-plate joints.*

Mean Ultimate Lateral Shear Loads and Comparisons

A two-factor ANOVA general linear model procedure was performed for individual joint data to analyze main effects and the interaction on the mean ultimate lateral shear loads of only glued gusset-plate joints. Based on SAS analysis, following ANOVA table were obtained.

Table 2. *General linear model procedure output for main effects and interactions of 3 by 2 gusset-plate joints with 10 replication of each combination*

Source	DF	Type I SS	Mean square	F Value	Pr > F
Wood specie	2	243234566.3	121617283.2	24.65	<.0001
Gusset-plate	1	603409872.8	603409872.8	122.28	<.0001
Wood specie*Gusset-plate	2	118617572.5	59308786.2	12.02	<.0001

Based on Table 2, the interaction between wood specie and gusset-plate type is significant at 5 % significant level. Therefore, this interaction was analyzed. Accordingly, LSD multiple comparisons procedure at the 5 percent significance level was performed to determine the mean difference of those treatments using the LSD value of 1192 Newton.

Tables 3 shows mean comparisons of ultimate lateral resistance loads for gusset-plate type for each of wood specie in base member. Table 4 shows mean comparisons of ultimate lateral resistance loads for wood specie in base member for each of gusset-plate type. Each value represents a mean of 10 specimens tested.

Table 3. *Mean comparisons of ultimate lateral resistance loads for gusset-plate type for each of wood specie in main member*

Wood specie	Gusset-plate type	
	Pine plywood (N)	Beech wood (N)
Scocth pine	9168 (B)	11578 (A)
Alder	9540 (B)	17338 (A)
Beech	10842 (B)	19662 (A)

Based on the table, the joints with beech gusset-plate yielded significantly higher lateral shear resistances compared to the joints constructed from pine plywood gusset plate. This could be reason of failures mode of the joints. Most of the joints constructed from pine plywood gusset-plate were failed with shear among plywood layers. This kind of failure does not reflect the real strength of joint. The real strength is observed mostly with the joints separation from connection part (Kalayci 2019). Therefore the joints with plywood gusset plated yielded less strength than the joints with beech wood gusset-plate.

Table 4. *Mean comparisons of ultimate lateral resistance loads for wood specie in base member for each of gusset-plate type*

Gusset-plate type	Wood specie		
	Scotch pine (N)	Alder (N)	Beech (N)
Pine plywood	9168 (A)	9540 (A)	10842 (A)
Beech wood	11578 (C)	17338 (B)	19662 (A)

According to Table 4, increasing wood density (Scotch pine, alder, beech) is not significantly increased the lateral shear resistances of the face-to-face gusset plate joints with pine plywood gusset-plate. Demirel 2012 studied on the lateral shear resistances of the only stapled, only glued, and stapled and glued joints. What he found in his study is increasing OSB density among OSB-I, OSB-II, and OSB-III did not significantly increased the lateral shear resistances of the only glued OSB joint with pine plywood gusset-plate. However using beech wood gusset plate in the same wood joints make significant difference. Accordingly, increasing wood density significantly increased the mean lateral shear resistance of the only glued joint with beech wood gusset plate as shown in Table 4. In joints, material with higher density glued better to the other material compared to the material with lower density.

5. CONCLUSIONS

The joints constructed from three base members (Scotch pine, Alder, and Beech) and two gusset-plates (pine plywood and beech wood) were mechanically tested, their lateral shear resistances were investigated and compared. Results indicated that changing side member or gusset plate material from pine plywood to beech wood significantly increased lateral shear resistances of only glued wood joints. Additionally increasing wood density significantly increased lateral shear resistances of the glued joints with beech gusset plate, however; increasing wood density as base member did not significantly but marginally increased the lateral shear resistances of the joints with pine plywood gusset plate.

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NUMERICAL MODELING OF WOOD-ADHESIVE BOND-LINE IN MODE II FOR SPRUCE WOOD GLUED BY VARIOUS ADHESIVES

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ABSTRACT

Bond-line creates an interface between two glued surfaces and, therefore, its brings additional complexity into the mechanical behavior of glued component, especially around the bond-line region because an adhesive has a very different response to a mechanical stress than wood. From this perspective, the bond-line influences the total mechanical response of glued components by both its cohesive and adhesive behavior at wood-adhesive boundary. For timber constructions, there are many various adhesives one can use and each of them has a different mechanical characteristics, advantages and disadvantages.

The goal of this work was to create a numerical finite element models applicable for analysis of fracture problems in mode II. The models were developed for the adhesive that are often applied in timber constructions and wooden materials. The FE models include 2D geometry of the bond line and cohesive law fitted on the outputs of the experimental measurement. The experimental data for the developing numerical models were obtained using 3point end-notched flexure (3ENF) tests with the compliance-based beam method (CBBM) coupled with the digital image correlation to be able to obtain displacement slip needed for the development of the FE models. Furthermore, within the FE analysis, wood was modeled as orthotropic material including both elastic and plastic regions of deformation. The FE models were developed in Ansys computational system. The specific objectives of the work were following: 1) to create the cohesive zone models based on experimental data; 2) to develop parametric 2D and 3D model of the bond-line reflecting experimental data; 3) to analyze the influence of friction coefficient on resulting force-displacement outputs; and 4) to analyze plastic imprint into the specimens for Norway spruce and an influence of the fiber angle inclination.

Implementation of the cohesive law models of wood-adhesive system into the FE analysis was successful. The FE analysis provided the force-deflection response that was validated by the experiment work. The FE model showed that influence of the friction on the simulated force may be up to 5% of the maximal force which is not negligible effect. The imprint of the load head into specimen is substantial if span-to-height ratio is below 17. The influence of the fiber angle with respect to a longitudinal axis is rather high, i.e. angle of 14° means 30% reduction of maximal force.

Key words: mode II, spruce wood, finite element analysis, crack propagation, adhesive bond

1. INTRODUCTION

Wood is one of a few structural renewable materials with high strength-to-density ratio that can be widely used. The use of wood in constructions is limited by the size of the input source material. Therefore, there is always a need to use bonding techniques such gluing, to fully utilize the material potential. The potential can be easily seen in wood-based composites (WBC's) such as Glulam, Cross-Laminated Timber (CLT), plywood and many others. Using a full potential of the WBC's can be, and actually it already is, intensified by computational techniques that can be used to various purposes – structural analysis, optimizations etc. Since WBC's often contain bondline, the numerical modeling of bond line is also of big interest within the research. The bondline is an important feature in numerical models of WBC's. The bondline is often neglected and wooden parts are assumed to be perfectly and elastically connected, so there is no need to define material model of adhesive. Another approach is to define bondline as a separate material using cohesive zone model (CZM), which allows to model fracture phenomena – development and propagation of crack. With respect to this work and WBC's embedded in constructions, one of the important mode of crack propagation is in mode II – shear mode developing during bending or horizontal forces (Yoshihara, 2001).

Experimentally, fracture properties of wood has been measured using ENF in bending test for a long time. Yoshihara and Ohta (2000) showed that fracture properties of wood are dependent on a ratio of initial crack length and half span which has to be reflected in an experiment design. De Moura et al. (2006) employed so called equivalent crack approach and incorporated it into the compliance-based beam method (CBBM). This combination showed to be advantageous because it did not require tracking of crack propagation which was, to a convenience, derived directly from the current compliance. The equivalent crack length method applied on a pine wood was examined by Silva et al. (2006). These authors also developed the finite element (FE) model of a crack propagation of wood in mode II that was successfully verified using equivalent crack length approach. Silva et al. (2007) successfully tested procedure of equivalent crack experimentally and numerically on end load split (ELS) scheme when examining fracture properties of pine wood in mode II. Because of its relative ease, the ENF with equivalent crack approach is well suited for wood bonds (Xavier et al., 2011) and for determination of cohesive zone models of material itself or adhesive bonds that may be used in numerical simulations (Silva et al., 2014). Meite et al. (2013) employed optimization technique within a combination of finite element simulation and DIC analysis to characterize fracture behavior of Douglas fir wood (*Pseudotsuga menziesii* L.) in mixed mode. Both tools conveniently provided data that enabled separation of mode I and mode II without taking into account local elastic mechanical properties.

The goal of the paper is to develop a numerical model of crack propagation in mode II with use of elastic and plastic material models. The work should contribute to the bondline FE modeling used in WBC's analyses.

2. MATERIAL AND METHODS

Within the work, we developed two kinds of the FE model of 3point end-notched flexure (3ENF) test. The first one was two-dimensional (2D) model and the second was three-dimensional (3D). The 2D FE model was developed to investigate an influence of friction coefficient on force-deflection response. The 3D model was developed to investigate fiber angle declination and adhesive bond on force-deflection response as well as for stress distribution, imprint and strain energy in total model and under the loading head and above supports.

2D FE model

For a development of the 2D FE model (Figure 1), we used Ansys v 19.2 (Ansys Inc., USA). The FE model employed 4 different types of finite elements: 1) Plane183 for modeling the main body of the sample. This FE is quadratic element consisting of 8 nodes, each node has three degrees of freedom (displacements in X, Y and Z directions) that enables elastic orthotropic material properties; 2) contact elements Targe169 and Conta172 for modeling contact phenomena between the sample and supports and loading head. The supports and loading grip were modeled as perfectly rigid because they are made of steel and, hence, the contact pairs were defined as rigid-flexible; 3) Inter203 that is quadratic 6node element. This element was employed to model cohesive zone in the middle of the sample – in a position of highest shear stress – neutral axis. All the 2D analyses assumed plane stress with a real thickness (defined as real parameter).

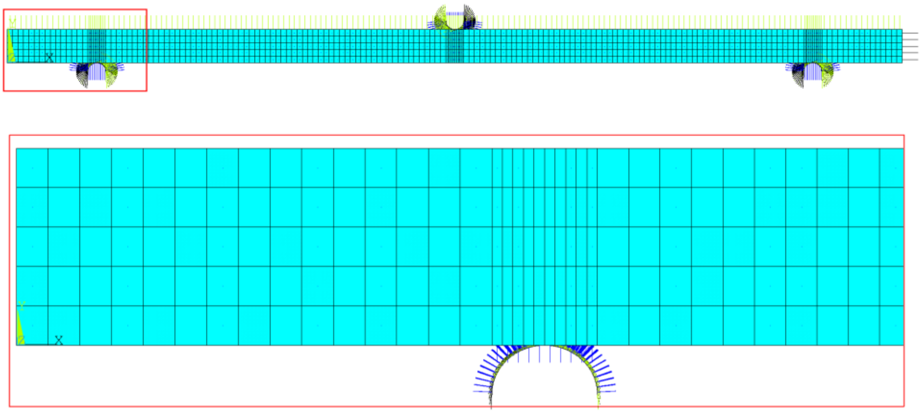

Figure 1. *Finite element mesh of 2D model , top – whole FE model of the analysis; bottom – detail on support and FE mesh including contact elements*

Boundary conditions of the 2D model reflected 3point end-notched flexure test (3ENF) test setup (Figure 2) and consisted of: 1) constraining all DOF's of the supports; 2) prescribing the displacement of the loading head to 10 mm aiming downwards. The displacement of the loading head was controlled via so called "pilot node" that was also used to investigate reaction forces during the analysis. All the defined contacts were set to "close gap", so contact began immediately at the first step of the analysis.

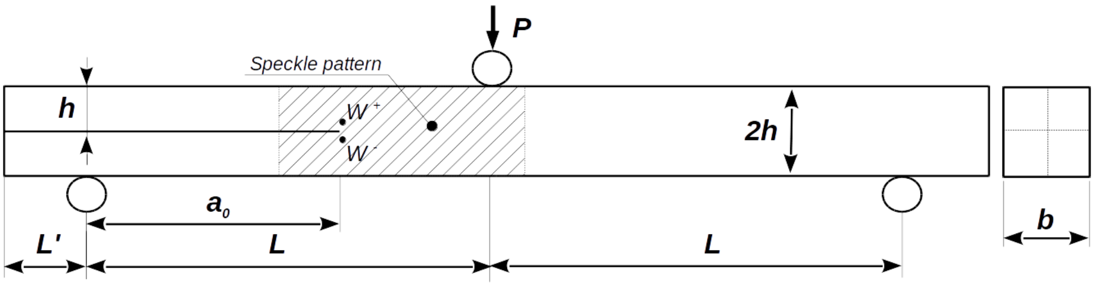

Figure 2. *Geometry of sample and sketch of the 3ENF test*

The analysis was solved with a nonlinear option "large deformation". Material model used for spruce wood was elastic orthotropic taken from Milch J. et al. (2016), it is as follows: E_L = 17 850 MPa, E_T = 289 MPa, E_R = 352 MPa, G_{LR} = 573 MPa, G_{LT} = 474 MPa, G_{RT} = 53 MPa, ν_{LR} = 0.023, ν_{LT} = 0.014, ν_{RT} = 0.557, where E_i is normal modulus, G_{ij} is shear modulus and ν_{ij} is Poisson's ratio. For the cohesive zone, we employed bilinear model of traction-separation law with maximal shear stress τ = 5 MPa and opening 0.05 mm at this level of shear stress.

3D FE model

3D FE model was developed also in Ansys v 19.2 (Figure 3). Due to different dimensionality, we used following types of finite elements: 1) Solid95 for modeling the main body of the sample. This FE is quadratic element consisting of 20 nodes, each node has three degrees of freedom (displacements in X, Y and Z directions) and it enables elastic-plastic orthotropic material properties. The FE plasticity follows the generalized Hill potential theory; 2) 3D contact elements Targe170 and Conta174 for modeling contact phenomena between the sample and supports and loading head, both are quadratic elements. The supports and loading grip were modeled as perfectly rigid similarly to 2D FE model; 3) Inter205 that is 3D quadratic 8-node element.

The analysis was solved with a nonlinear option "large deformation". Material model used for spruce wood was orthotropic elasto-plastic taken from Milch J. et al. (2016). The elastic part is the same as for 2D model, the plasticity was defined as follows: 1) three yield stresses in normal directions: σ_L = 49 MPa, σ_R = 6.4 MPa, σ_T = 7.1 MPa; 2) three tangent moduli in normal directions: $E_{L,tan}$ = 140 MPa, $E_{R,tan}$ = 1.8 MPa, $E_{T,tan}$ = 2.3 MPa; 3) three shear yield stresses: σ_{LR} = 6.7 MPa, σ_{RT} = 6.7 MPa and σ_{LT} = 3.1 MPa.; 4) three shear tangent moduli: $E_{LR,tan}$ = 5.73 MPa, $E_{LT,tan}$ = 4.74 MPa, $E_{RT,tan}$ = 0.53 MPa. The elasto-plasticity was simplified in a way that we assumed the same properties in tension and compression mode. For the cohesive zone, we employed bilinear model of traction-separation law with maximal shear stress τ = 5 MPa and opening 0.05 mm at this level of shear stress.

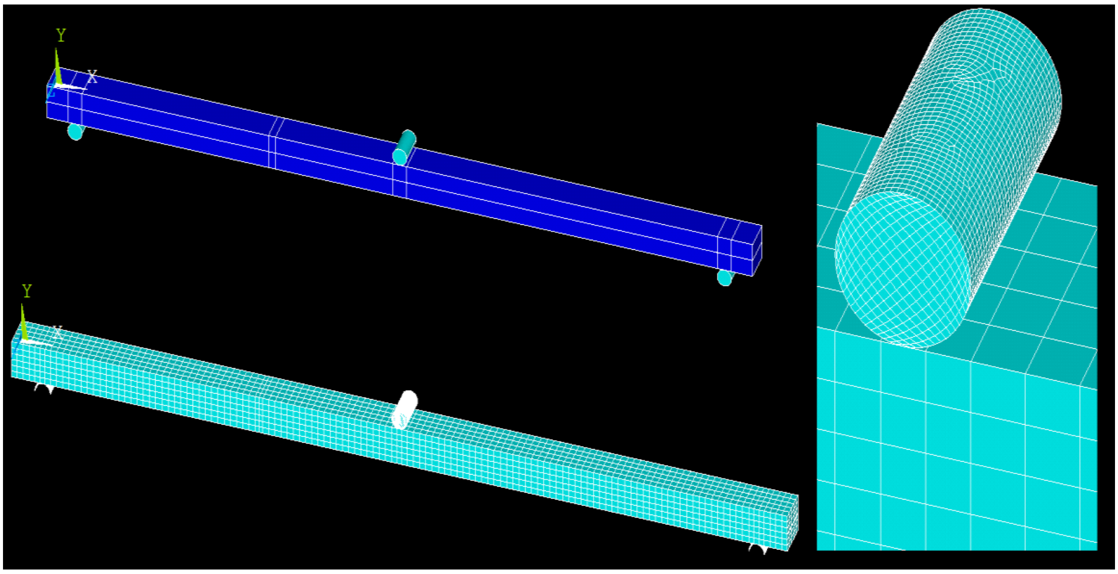

Figure 3. *Finite element mesh of 3D model , top – whole geometrical model, bottom – whole FE model, right – detail of FE mesh at the loading grips*

3. RESULTS AND DISCUSSION

2D FE model

The purpose of the 2D FE model was to analyze an impact of the friction coefficient on resulting force-deflection diagrams. The result of this analysis is showed in the Figure 3 that reveals that coefficient of friction (*f*) that is applied inside the introduced crack increases both stiffness and maximal force.

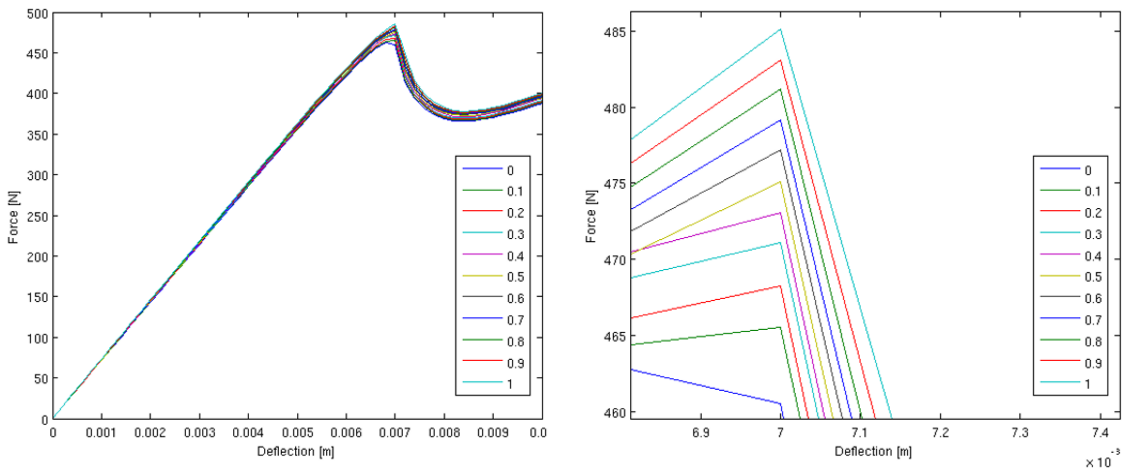

Figure 3. *left – influence of friction coefficient on force-deflection response in 2D FE model, right – detail of the maximal values for*

The effect of f on the maximal force (F_{max}) shows there is 5.2% difference when comparing scenarios with minimal and maximal f (i.e. $f = 0$ and $f = 1$). Despite the fact that it seems that f has a low impact on F_{max}, we have to recall that the 3ENF is used for measuring critical energy strain release rate ($G_{II,c}$) that is taken from the maximal force achieved. Therefore, even such a difference should not be neglected. From this point of view, it is fully justified to insert a Teflon paper into the introduced crack to reduce friction between the two parts during experimental measurement. The influence of the f on a stiffness (S) is lower and it is about 3%.

3D FE model

Influence of the span/height ratio

The first analysis focused on an influence of specimen slenderness – span to height ratio (S/h). The result of this analyses for various S/h ratios in terms of the total strain energy is depicted in Figure 4. In Figure 4 on the left, we may see the strain energies for the regions of the specimen above supports (1cm to each side from the center of the contact). We see that if the analysis is made around the supports, there are not many differences for S/h ratios above 15. It is also possible to see that there is not much differences in a summation of plastic energies for regions of supports.

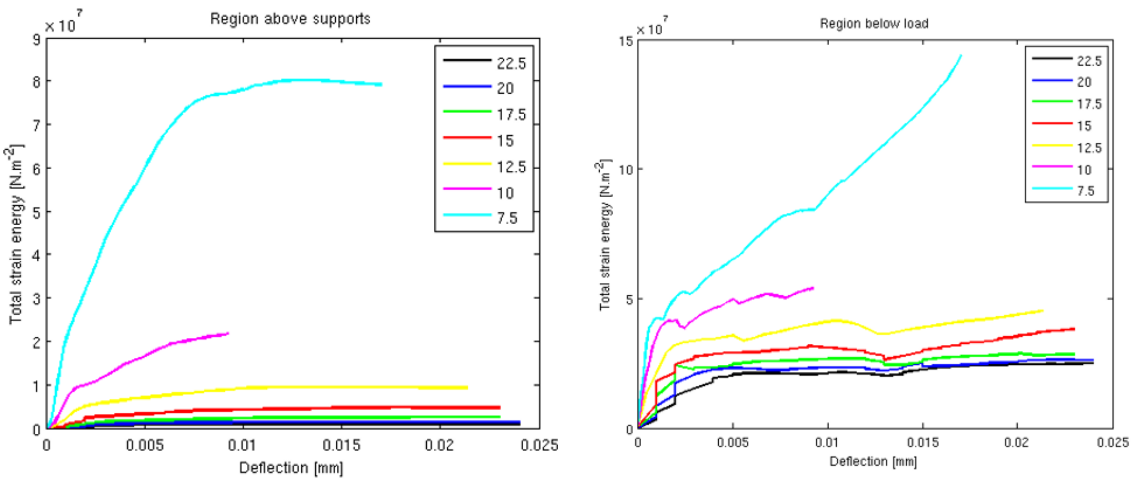

Figure 4. *Influence of span/height ratio on a total strain energy: left – regions above supports, right – region below the load head*

On a contrary, the situation is more clear for a region below the load head (Figure 4 right). We clearly see that S/h ratio above or equal to 17.5 means almost the same strain energy for plastic region of deformation. This means that the plastic imprint into the material is minimized and plastic deformation is done due to the bending itself, not due to the contact with load head. This finding agrees to the Yoshihara (2001) who stated that for 3ENF test, we shall use the S/h ratio above 17 to successfully obtain fracture properties such as $G_{II,c}$.

The distribution of the plastic strain energy for the S/h = 10 is depicted in the Figure 5. We can observe that on the tension side of the specimen, the plastic energy is logically distributed and reflects the material deformation due to bending. On the contrary, the significant imprint due to a contact with a load head (i.e. region below load head) leads to a different distribution and increased plastic strain energy.

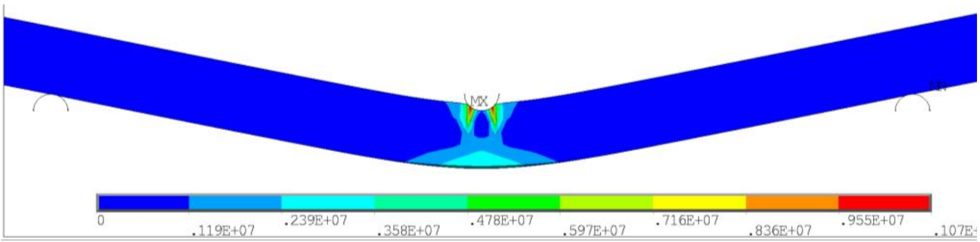

Figure 5. *Plastic strain energy distribution for scenario S/h = 10*

For a clarity, a stress distribution in the sample with S/h= 10 for the maximal deflection is depicted in Figure 6. Figure 6 left shows the stress parallel to fiber and we can clearly see the significant imprint into the material, and that the stress distribution at the compression side is strongly influenced by the load head. This influence is visible even more on a distribution of stress perpendicular to fiber (parallel to force) which is depicted in Figure 6 right.

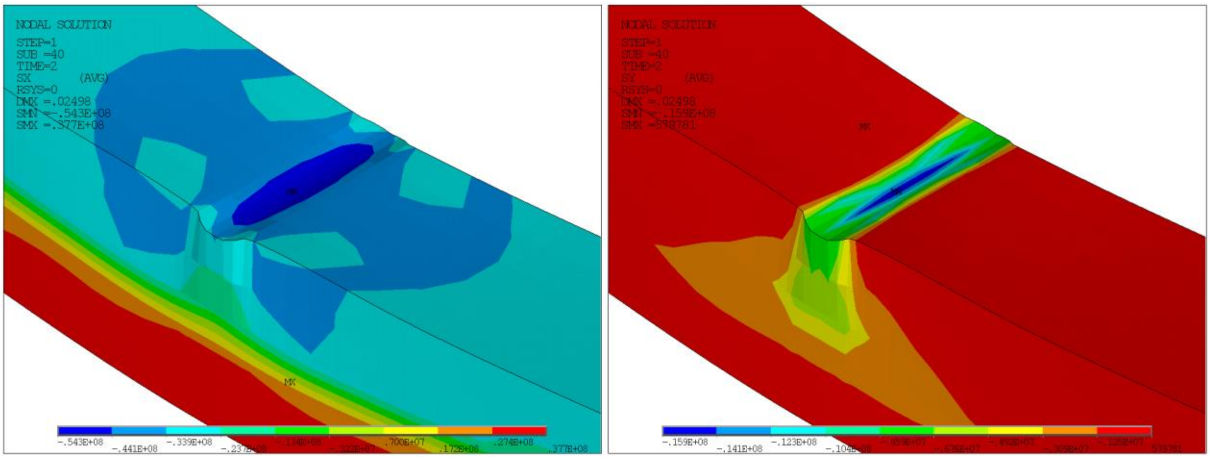

Figure 6. *Stress distribution for scenario S/h = 10 at maximal deflection, left – stress in X axis direction (fiber direction), right – stress in Y axis direction (perpendicular to fiber and parallel to applied force)*

Influence of the grain angle

The first analysis examined an influence of the grain angle inclination with respect to longitudinal axis of the sample. The angle was varied from 0 to 14 degrees with a step of 2° which resulted in 7 FE simulations. The results of these simulations are depicted in Figure 7 left. We clearly see that the angle inclination substantially influences both stiffness and maximal force. The inclination 14° resulted in maximal force equal to approx. 70% of force with zero inclination. The stiffness of the scenario with the inclination of 14° was 42% of stiffness with zero inclination.

The second analysis examined an influence of the grain angle inclination with respect to cross-section plane (radial-tangential plane) of the specimen. The angle was varied from 0 to 90 degrees with a step of 10° which resulted in 9 FE simulations. The angle 0° means that the bending force acted in radial direction, and the angle 90° represents a pure tangential loading. The results of these simulations are shown in Figure 7 right. We may see that the radial-dominated scenarios have slightly lower maximal forces (2% lower) than tangential-dominated scenarios and, moreover, they exhibit rather more brittle behavior than tangential-dominated scenarios – first 5 scenarios show a certain peak where failure of adhesive bond occurs, meanwhile the second 5 scenarios have rather wider plastic regions. The different behavior in radial and tangential directions reflect the difference in material properties in both directions.

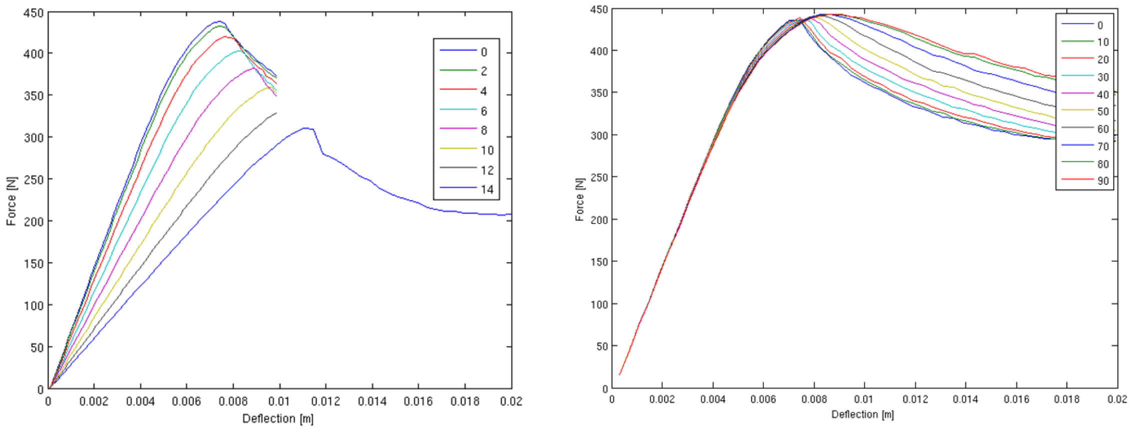

Figure 7. *Stress distribution for scenario S/h = 10 at maximal deflection, left – stress in X axis direction (fiber direction), right – stress in Y axis direction (perpendicular to fiber and parallel to applied force)*

4. CONCLUSIONS

Two parametric FE models that included cohezive zone model and orthotropic elasto-plastic material were created using APDL in Ansys FE package. The 2D FE models showed the influence of the friction coefficient on the outputs of 3ENF test. These results justified using Teflon paper to be inserted in the crack during the measurement to obtain more precise values of strain energy release rate (G_{II}). The 3D FE model showed that it is necessary to have span-to-heigth ratio over 17 to avoid plastic deformation below the load head which will consequently result in inducing a deformation of the sample only by a bending. The grain angle inclination, either with respect to longitudinal or perpendicular specimen axes, influences both stiffness and maximal forces (F_{max}). The longitudinal grain angle of 14° may cause 30% reduction in F_{max} and 42% in stiffness.

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URBAN FURNITURE DESIGN

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ABSTRACT

For the purpose of this work is designed exterior furniture and urban equipment or set of exterior furniture arranging urban area (park, square). By analyzing this type of furniture and it's needs there comes the need for design of several different pieces of furniture, including: chair (seating for one), two person bench, three person bench, flower pots, ambient lighting and bin.

By analyzing outdoor furniture and its needs from material aspect there are certain reasons why there is use of thermo wood, and what are the positive consequences of its use.

In the process of designing it's starting from the square as a geometric most stable shape and its further development and integration in the shape of the outdoor furniture. The anthropometric standards observed for this type of furniture and as well as the choice of material which should satisfy the requirements and needs of the desired look.

The ultimate goal is to get a quality seating and leaving outdoor in which the human factor is very important. Through better understanding of the parameters of ergonomics, the designer can improve health and safety in furniture. Actually obligation and task of the planner is to constantly monitor research in the field of ergonomics to implement, maintain and improve the design of furniture's.

Key words: ergonomics, anthropometry, bench, urban lighting, litter bins, urban area, pot, design, construction, material, thermo wood, environment, interaction

1. INTRODUCTION

The following stages of development were undertaken for the design of this set of outdoor furniture:

- research studying the square as a geometric shape its features meanings and semantics,
- anthropometric and ergonomic data for outdoor, public furniture,
- the choice of materials and their options as well as the main features that would make them suitable for this type of furniture
- design project for each individual piece in this set of furniture
- constructive elaboration of each piece of furniture cross sections and constructive ties
- perspective three-dimensional view of the whole set.

The square is one of the three basic forms that can be found anywhere and everywhere. No matter how complicated some objects may seem at first glance they can be reduced to basic shapes. If the object is reduced to its basic form then it can be more easily drawn and understood. However, function and structure do not always generate the most attractive form. By designing the square as the basic starting point, all the elements of this design are shaped. If we go from the postulate that: Shape is a functional relationship between man and space, then we understand even more specifically the subtle relationship between objects / furniture and people / users.

All solutions have been developed with the help of prior modular-proportional analysis. Symmetry has also been used as an important aesthetic factor. Man experiences the symmetrical image (composition in terms of an imaginary axis with two identical convergences ie sensations) as bilateral or rotational symmetry. Symmetrical shapes in the shaping of furniture are always associated with a proportional and harmonious relationship.

The main aesthetic idea behind the design of this set of urban furniture for cities, sidewalks, promenades or parks was simplicity. Then an attempt is made to maintain the repetition of the elements to simplify the product but also for unity in vision and to better fit into different city environments, cultures, habits of use.

Observation of user behavior has also been important for designers in improving their designs. Here the focus has been on the difference between designers' intentions and consumers' experiences. Thus, various communication models aimed at reducing the gap between the two have been explored in the design discipline (Crilly, Maier, & Clarkson, 2008). Carroll, Kellogg, and Rosson (1991) emphasize the co-evolution of tasks and artifacts and the iterative nature of this process. However, the role of actual tasks remains limited to providing new requirements for design. Carroll (2004) expands the design process to actual uses. However, her argument for "designing for appropriation" and "designing from appropriation" remains limited to differences between expected and actual requirements, a limitation that has resulted in a dichotomy between production and use (Suchman, 1994). Breaking from this dichotomous view, this study builds on recent work by such scholars as Suchman and Wakkary by deconstructing the term *user*, defining a user as a more creative and proactive agent. When *use* is detached from *design*, people's behaviors in relation to designed artifacts are no longer the result of design. Rather, they are creative processes referred to in this study as everyday design.

2. OBJECTS MATERIAL AND METHODS

Concept development and the phenomena of tradition and present due to our living, experience and education background, besides the esthetic of design, the way to eliminate the adverse impact to the environment is also what we concerned about Design is not only about using less harmful materials, but also about how our products can change people's behavior and guide them concern more about our environment. Outdoor furniture should be designed in a way to lead people to use them in an effective way in order to utilize the surrounding area. Meanwhile they would let the user experience the entertainment of personalizing the goods, and encourage them to maintain orderly life style, thus cause subconsciously beneficial impact on the environment. The project of this paper was to design a chair (seating for one), two person bench, three person bench, flower pots, ambient lighting and bin, which gave us the chance to challenge ourselves to create multi-function furniture. After we studied the furniture and product in today' s market, we realize that there is a large amount of multi-function pieces existed already, but some of them lost the uniqueness of the design when they are under the control of material usage, and the quality of these facilities is poor. They are more like contemporary cheap solution for 'urban people' instead of bringing good atmosphere. On the contrary, the Macedonian traditional outdoor furniture use precious hard wood as material and contain a significant authentic style and design, and the design contributes to the sustainability to the environment (Nikoljski P.E. 2016). As a result, we got the idea to carry forward the extraordinary strong points from traditional Macedonian furniture (such as visual wooden cut's and stability) and simplified the form, improve them and create the modern sustainable Macedonian outdoor furniture.

After assembling the form board pieces of the furniture together, the structure weakness is revealed on the connection between bench legs and base (Fig.1-12). To reinforce the construction, for the final product, both benches are constructed out of wooden pieces, and have metal legs made of steel ore aluminum. Wooden parts are produced to enhance the whole structure; it can give the base more support, and keep the safety of user when they sit on the bench. We hope that the laser cutting rapid automation gives designer the possibility to improve the form and save material cost at the same time.

3. RESULTS AND DISSCUSION

Furniture designing is a multidisciplinary profession that requires a good understanding of various aspects of the furniture production process: materials, technologies, marketing, market placement, economic profit, sociological and anthropological aspects (people, their way and culture of furniture use), then the city's urban landscaping policy and probably many more. Among all these factors we also distinguish the factor or relationship tradition - modernity, because we wanted to create furniture with identity, origin and certain semantic messages (Fig.1-12).

Macedonian traditional furniture decoration and woodcarving, usually presents a strong archaistic and sincere looking. In spite of the unbelievable achievements, after the western culture gradually infiltrate into our tradition culture, our traditional furniture is forgotten since the contemporary living style is different. In the old days, the sparsely land had small population, so the large-scale furniture could be easily placed outside. And due to the technology limitations, the pace of working and living was slow, so it provided more time for the artists and craft men to develop the traditional ornaments in architecture and all kinds of products. Moreover, the sophisticated decorations on furniture were also considered as the proof of art and craftsmanship. As time goes by, now the younger generation gets influence from the high-pace living style, and they prefer to see the exaggerated shapes and rich colors in contemporary art and design; the products that contain geometric shape and Minimalist design would immediately attract people. As a consequence, the conventional Macedonian household furniture that covered by the historical patterns and decorations get discarded because of the heavy visual effect. However, in our opinion, the traditional culture should be kept inside designer’s mind. No matter which country the designers come from, they should not forget the spirit and the strong point of their own tradition and craft technique, and our duty is to discover a efficient way to protect the advantage in our culture by using leading technology.

After the research, we found that the Minimalist style in nowadays design, aside from the effort of saving construction material, the design tries to meet the aesthetic appreciation at this moment after removing all the tedious details. In this way the design maintains the spirit of traditions and sustainability at the same time. To accomplish the goal of making multi-function product and bring some new elements into the traditional furniture, we studied the traditional furniture piece include chair, bed, cabinet, and table. To make the form more simplified, we ware following the concept from contemporary design, and take out the side panels from the structure, so the piece would not have a defined back and can be placed in all type of space, either the center or a side. The analysis of the user experience and the culture of using public furniture in our country did not lead to the solution of furniture without backing. Experiences show an extremely low culture of using public furniture and even worse use and maintenance hygiene, so we thought that simple wooden benches without a backrest would not be possible to leg or slab.

With the concept of contemporary design we could use contemporary materials such as thermo wood. Heat treatment significantly improves the properties of natural wood and expands range of its use. As a result of the modification, a thermo wood of Finnish wood species turns into a very durable and reliable building and finishing material. Finished products and sawn timber made of thermo wood have high moisture resistance and stable dimensions. The popularity of designing outdoor furniture with thermo wood has increased and continues to grow, because all of the products can be used outdoors, in any climate.

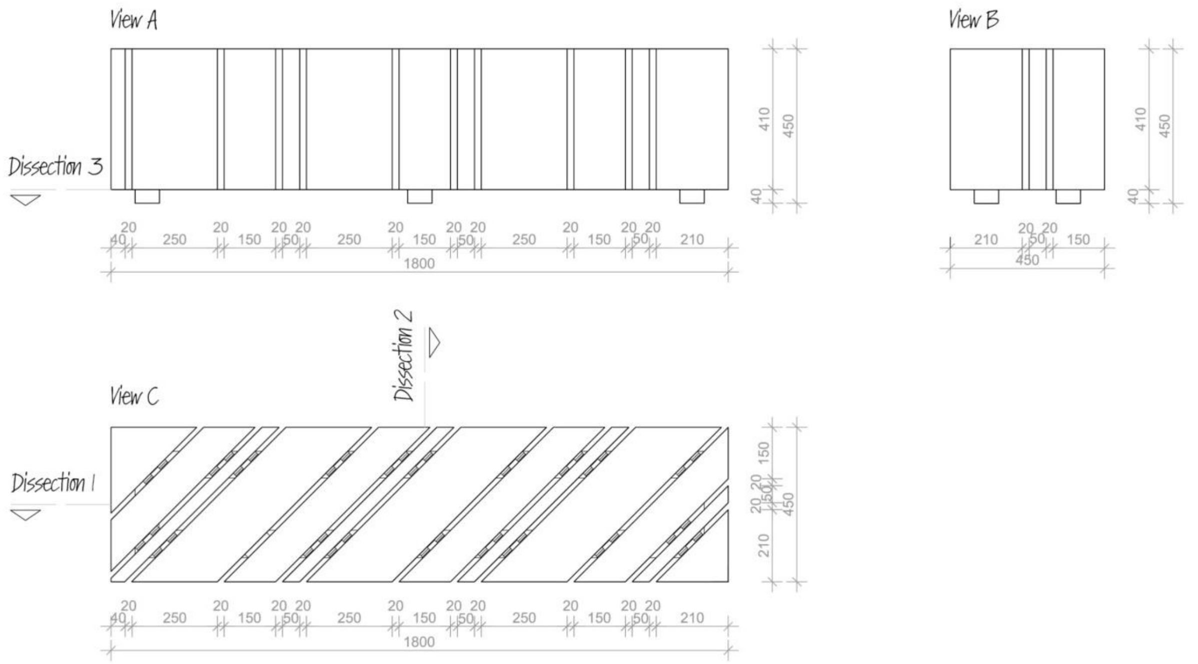
One of the most important technical characteristic of thermo wood is its dimensional stability. Lowered equilibrium moisture content of Thermo wood makes it dimensionally stable and the material retains its shape far better than untreated wood. Furthermore is non toxic material. Thermo wood is produced using only natural methods, heat and steam. All the products are completely natural and free of chemical additives. It’s resin free because resin is removed from the wood during the thermal modification process. As a result, the wood does not secrete resin even in high temperatures. Thermo wood does not react to changes in temperature or humidity as drastically as untreated wood. Material is proven to work well in different climates. Tests have shown that the thermal conductivity of Thermo wood is reduced by around 20-25% compared to untreated coniferous wood.

4. CONCLUSIONS

Furniture and product design has been our research focus for a long time, because we want to learn and understood how they can be widely used as daily tools to support human’s basic living and provide people a more delightful lifestyle. Especially in the field of the outdoor furniture. We found that today’s designers of furniture and industrial product aim to create a better artistic living environment together with the well-considered function, so they would directly influence people’s lifestyle and living quality. However, the more design we searched, the more problems we discovered - a large number of furniture and products in market are not sustainable at all, they would occupy a lot of outdoor space without the actual function, and their ostentatious ornaments make the product expensive without substance. With the rapid changes of the time, the concern about society and environment issue is urgent to be considered in the design process. The shortage of natural resources and its high price is another issue that today's people need to take into consideration. Limited availability of wood, iron, steel and many other raw materials has become a growing concern in these days. However, for furniture construction and product design, these materials are widely used for manufacturing. A lot of different materials and new technologies have been experimented and used for production, yet it still costs a lot to pay for the advanced technology and rare material. For example, 3D printing technology is extremely popular in recent years, but the raw materials, like special plastic powder for printing, are still expensive, and the size of printing usually has limitations.

We probably need to do more researches and tests to make this type of technology become more affordable and sustainable. Still another, we are living in a highly diversified society, the users of furniture and product would have a lot of different requirements based on their background, personal preference and some other factors, even each members from a family might has their own habits and needs, so it requires the products and furniture that is applicable for all different types of environment, or can be easily transformed with a variety of function. The multi-function method and space sustainability should be considered when people do furniture and product design. They would fit into the limited space better, and carry out all kinds of duties at the same time.

Design and art should always be created based on needs of the society and solve the issues to provide people a better living environment, that is why the multi-function furniture and product design needs more attention and development. This research and working process give me the opportunity and new skills to create the object that supports Green Design. Within the support of all kinds of software and progressive techniques, the design of outdoor bench would follow the principles of space and environment improvements. The final product should contain the basic traditional culture characteristics, ergonomic function and eco-design concept. For next step, we would like to make a full-scaled product with the correct material and add proper joint's to attain the goal of assembling and disassembling. We believe that in future, the multi-function outdoor furniture and product would greatly improve the quality of people's life on this planet.



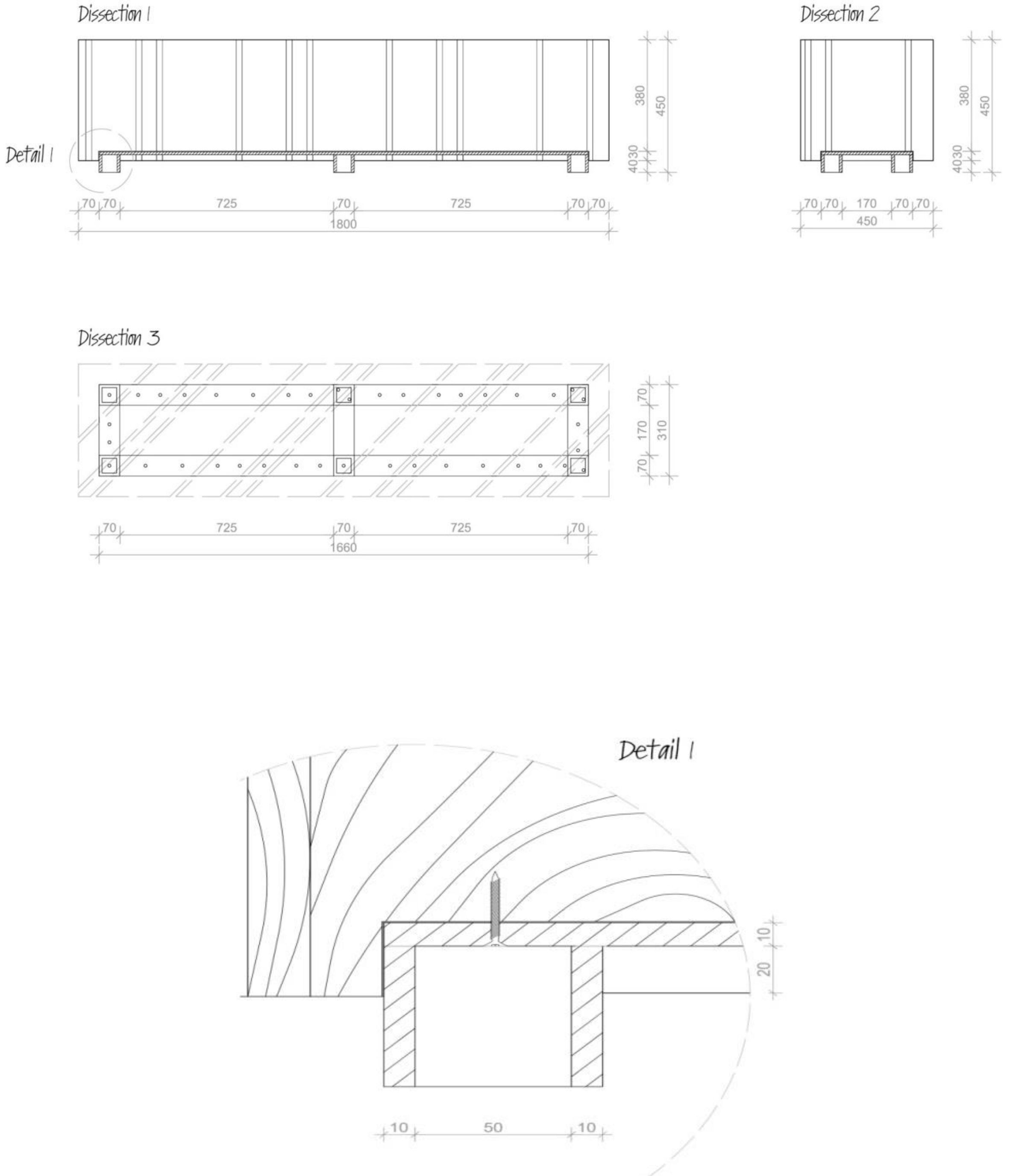


Figure 1- 4. *tree seat bench - basis, dissection, detail, perspective view*

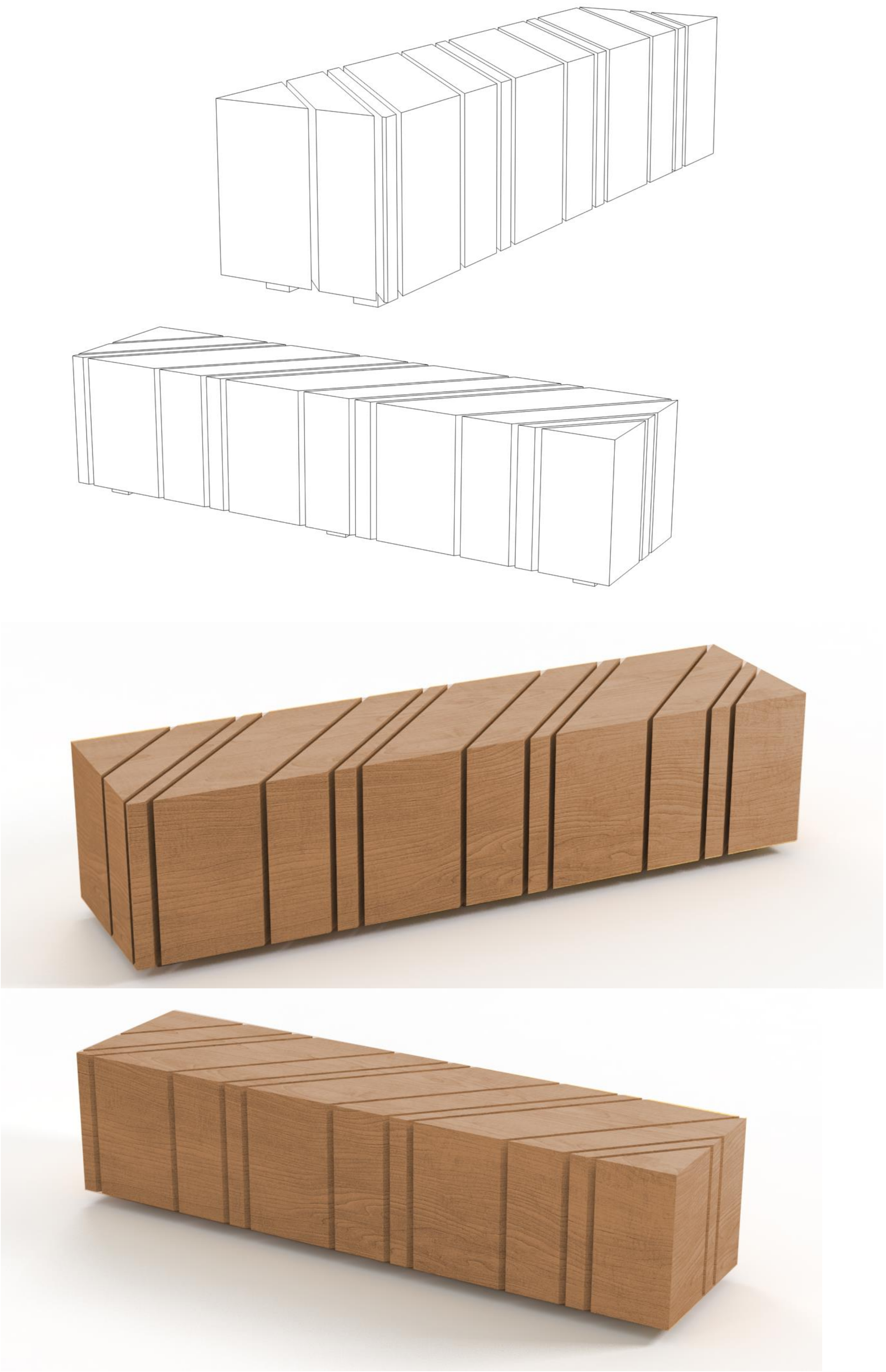


Figure 5. *Tree seat bench - 3D*

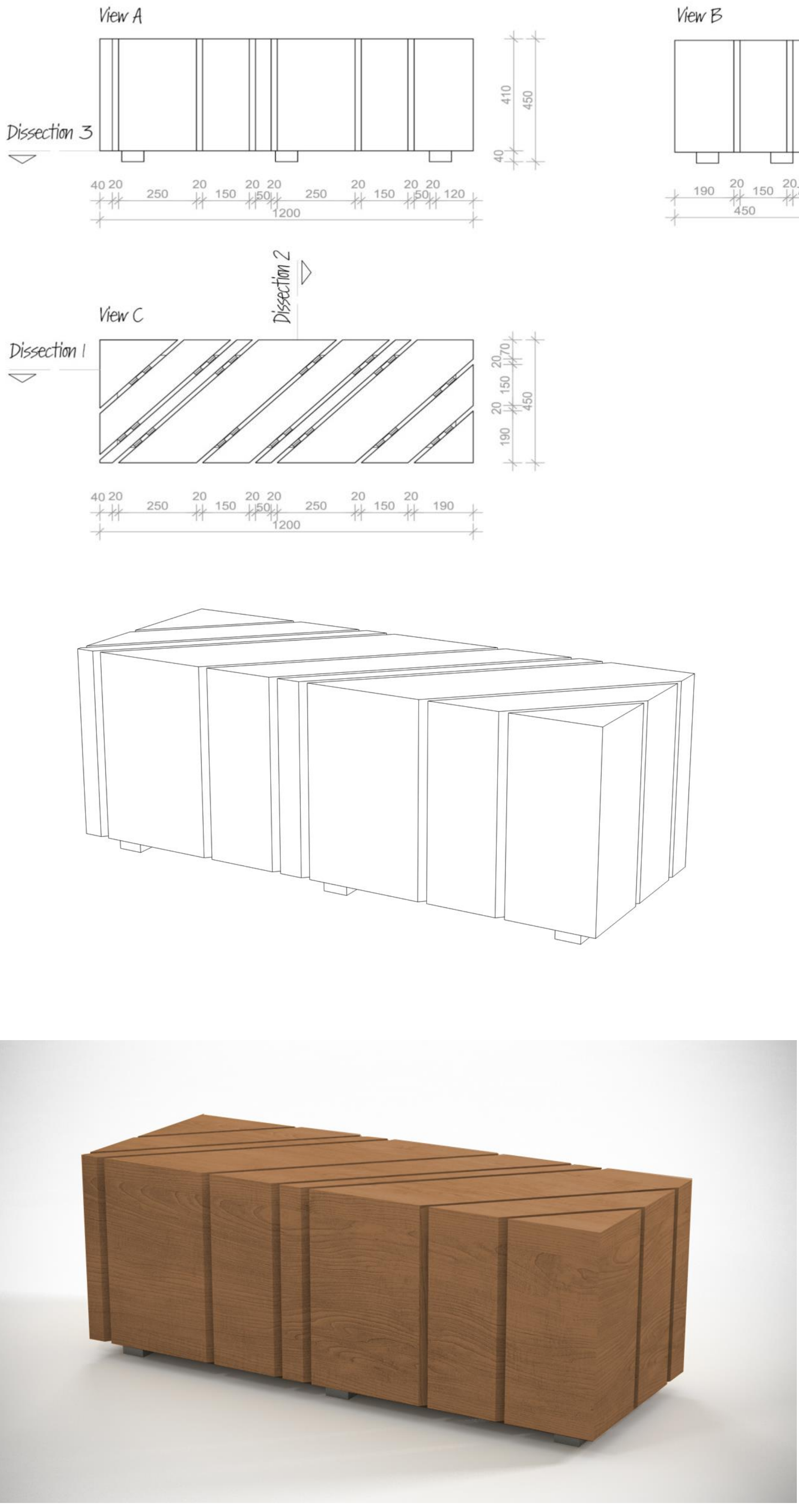


Figure 6-9. *Two seat bench - basis, perspective view, 3D.*

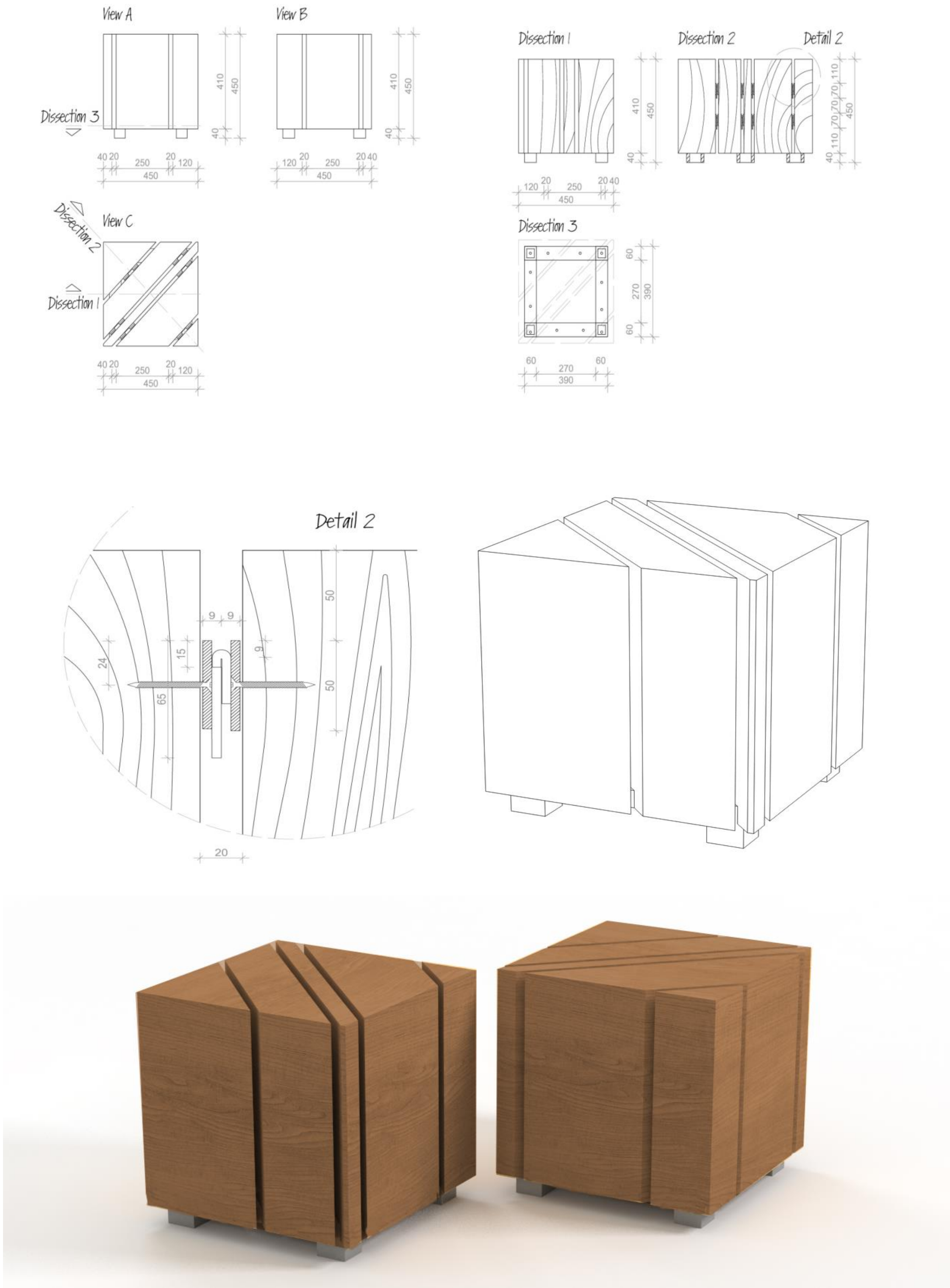


Figure 10-14. *One seat (outdoor chair)- basis, dissection, detail, perspective view, 3D.*

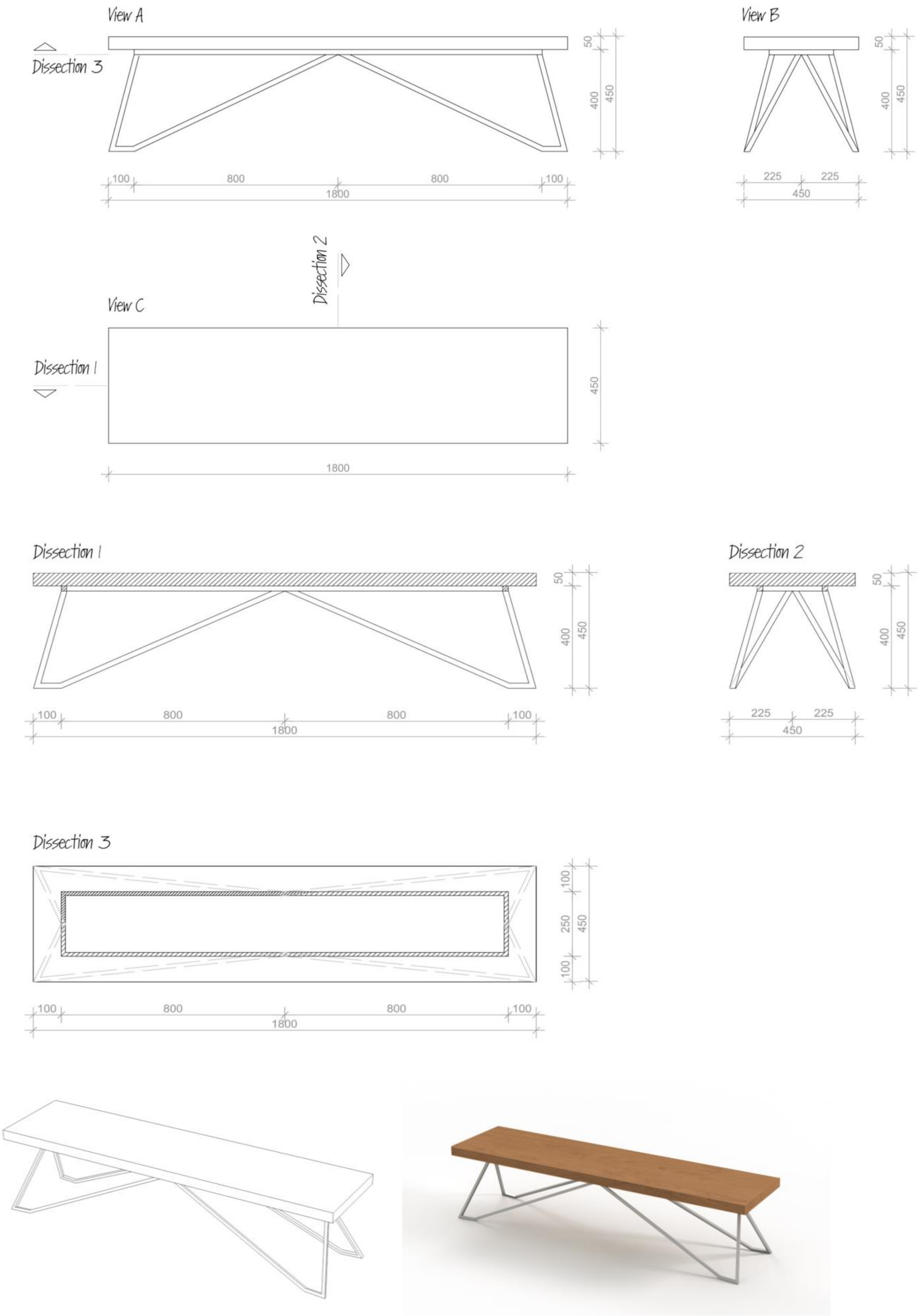
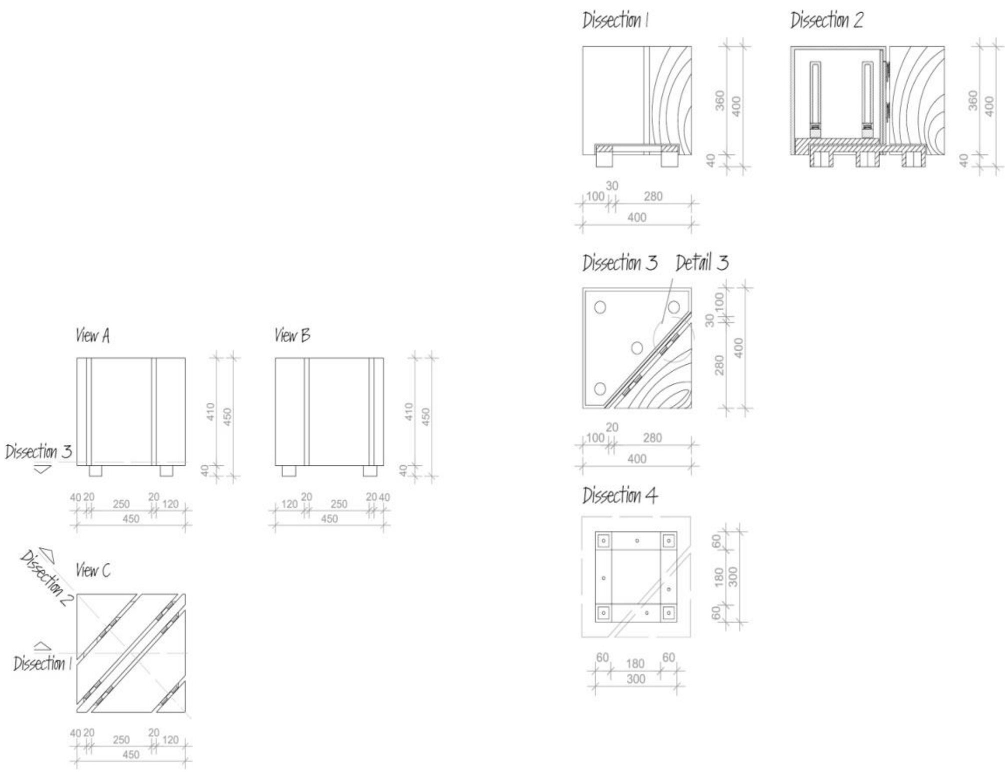


Figure 15-19. *Two seat bench - basis, dissection, detail, perspective view.*

Figure 20. *3D view of whole set of urban furniture*



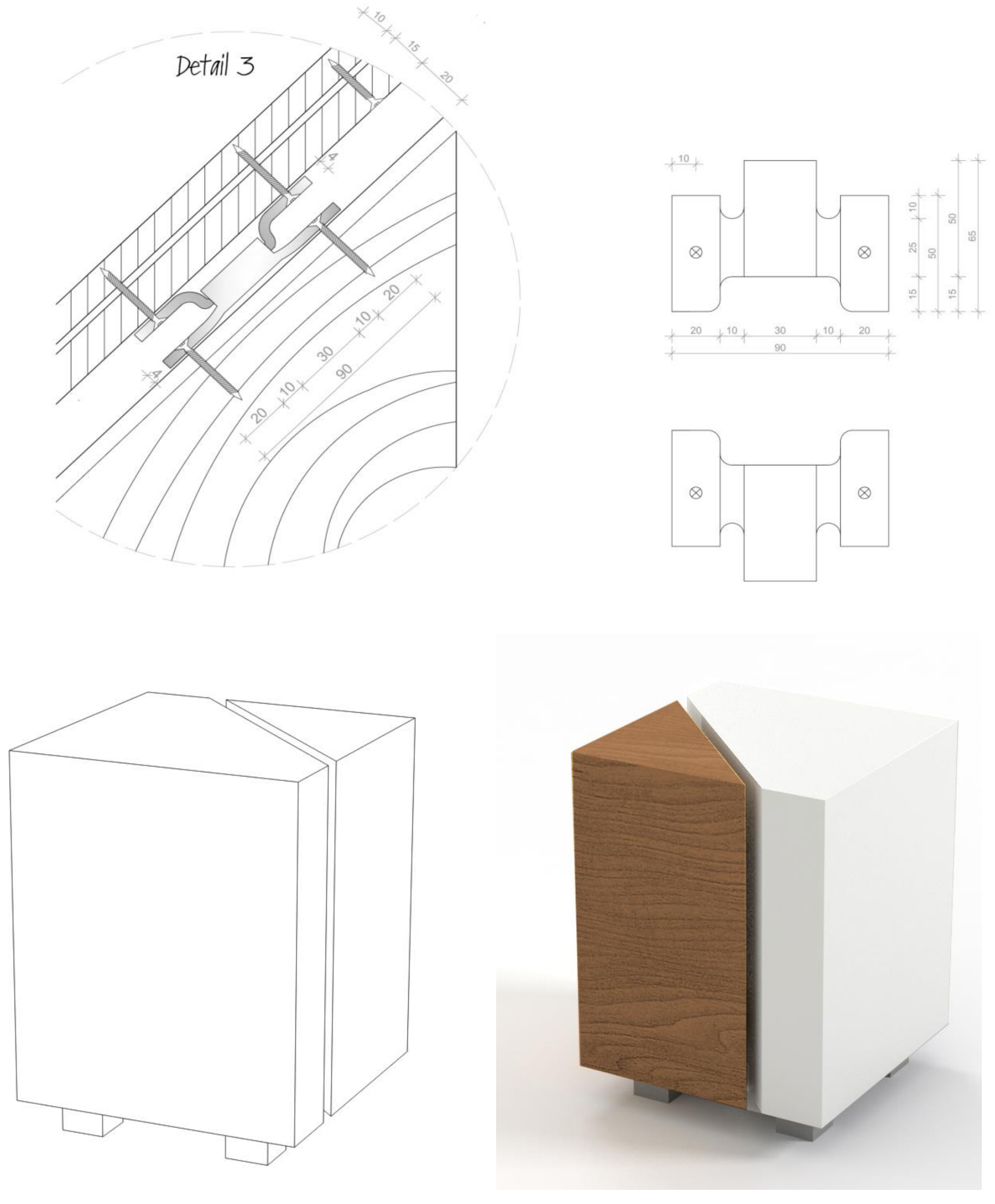


Figure 21-24. *Outdoor urban light - basis, dissection, detail, perspective view, 3D.*

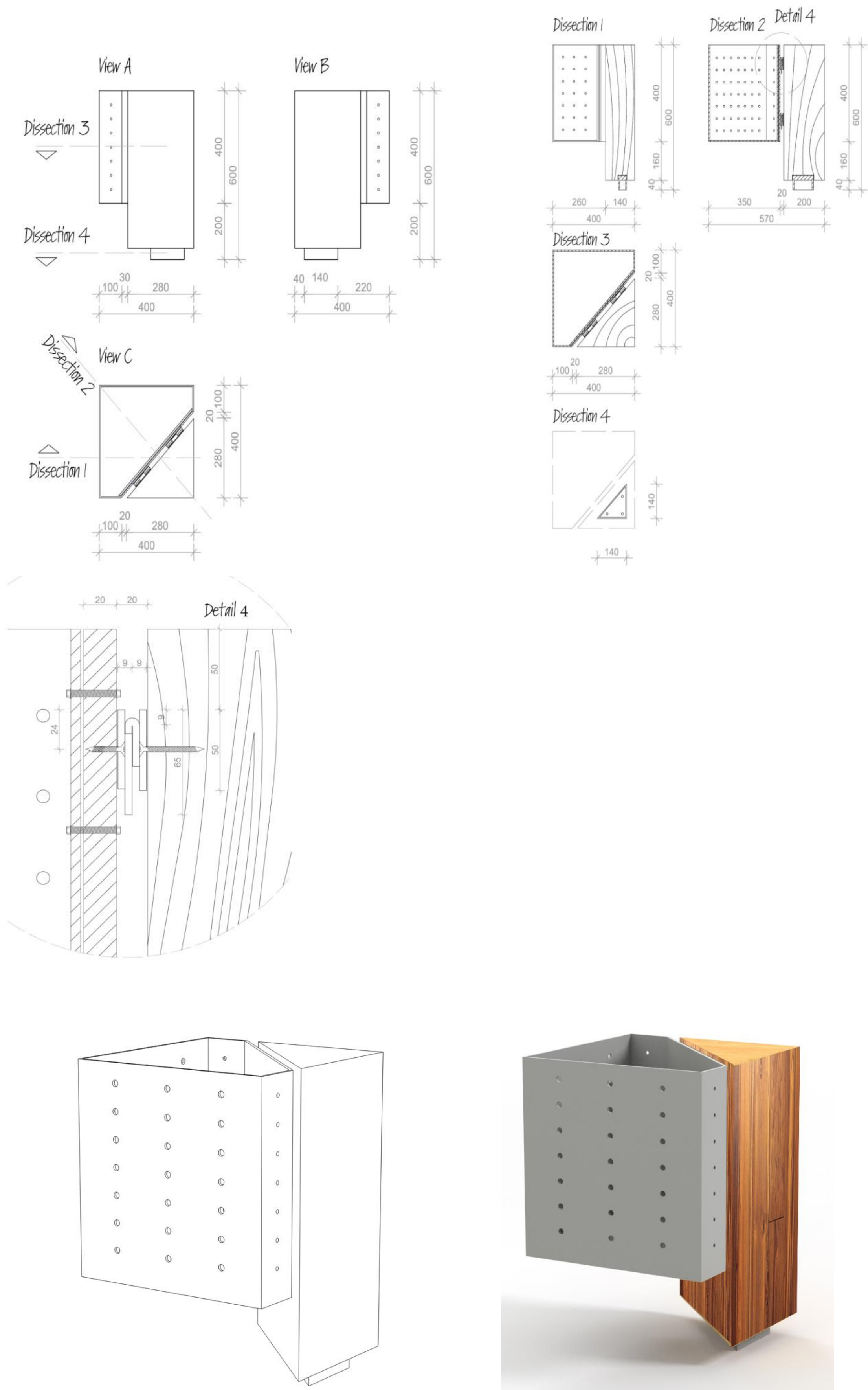


Figure 25-29. *Outdoor urban light - basis, dissection, detail, perspective view, 3D.*

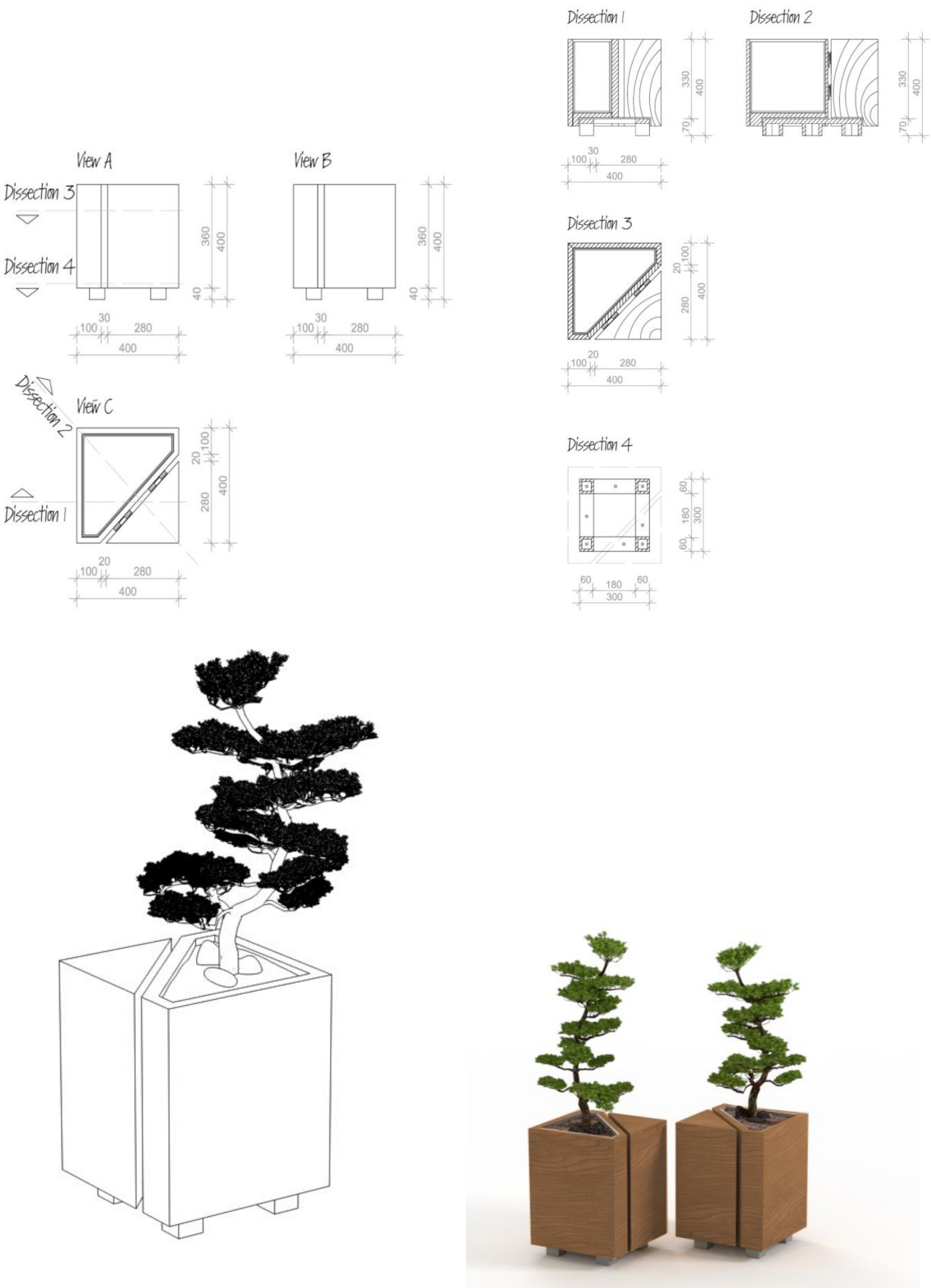


Figure 29-34. *Outdoor urban bin - basis, dissection, detail, perspective view, 3D.*

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QUALLITY OF THE WOODEN MATERIAL IN OUTDOOR FURNITURE

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ABSTRACT

The aim of this paper is to analyze the quality of the wooden material in outdoor furniture. For the purpose of this work is designed exterior furniture and urban equipment or set for garden. By analyzing this type of furniture and it's needs from anthropometrical point of view there comes the need for design of several different pieces of furniture, including: chair, armchair, stool, two person bench, 3 person bench, rectangular table, square table, swing and matching flower pots.

On the other side by analyzing outdoor furniture and its needs from material aspect there are certain reasons why there is use of thermo wood, and what are the positive consequences of its use.

The ultimate goal is to get a quality seating and leaving outdoor in which the human factor is very important. Through better understanding of the parameters of ergonomics, the designer can improve health and safety in furniture. Actually obligation and task of the planner is to constantly monitor research in the field of ergonomics to implement, maintain and improve the design of furniture's.

Thereby are observed anthropometric standards for this type of furniture as well as the chosen material which satisfy the conditions of permanent use and desired look.

Key words: ergonomics, anthropometry, human factor, design, construction, material, thermo wood, environment, interaction

1. INTRODUCTION

The following stages of development were undertaken for the design of this set of outdoor furniture:

- research studying the triangle as a geometric shape its features meanings and semantics,
- anthropometric and ergonomic data for outdoor furniture,
- the choice of materials and their options as well as the main features that would make them suitable for this type of furniture
- design project for each individual piece in this set of furniture
- constructive elaboration of each piece of furniture cross sections and constructive ties
- perspective three-dimensional view of the whole set

'Material' has been a central point of research and practice agendas for decades in product design (Ashby & Johnson, 2009; Manzini, 1986). Most of the seminal works have centralized around how to guide designers in selecting proper materials within the *shape* and *manufacturing process* limitations and/or requirements (Ashby, 1999; Ashby & Cebon, 2007; Mangonon, 1999). More recently, a newly founded research direction that scrutinizes materials' active role in shaping our experiences with products has gained attention among scholars (Ashby & Johnson, 2009; Karana, 2009; Karana, Pedgley, & Rognoli, 2014; Pedgley, 2009; Rognoli & Levi, 2004; van Kesteren, 2008; Zuo, 2010). Many influential studies have been conducted to inform how we sense materials (Fenko, Schifferstein, & Hekkert, 2010; Howes, Wongsriruksa, Laughlin, Witchel, & Miodownik, 2014; Laughlin, 2010; Rognoli, 2010; Sonneveld, 2007; Westeils, Schifferstein, Wouters, & Heylighen, 2013), how we attribute meanings to materials (Karana, 2009), and how materials elicit emotions (Ludden, Schifferstein, & Hekkert, 2008). Nevertheless, how to design for experiences with and for a particular material at hand remains poorly understood to date, even if that material is wood.

2. RESULTS AND DISSCUSION

The triangle is one of the three basic forms. Each of the basic forms has its own morphological and semantic features. The triangle is the most stable form because of the three points of support. Triangles are the strongest shape. When a force is added to a triangle it is spread evenly through all three sides. Eye movement when observing the triangle is always directed dynamically to one of the bases. Semantically analyzed, the triangle carries a long history of hidden meanings or more specifically identifications. From a design point of view, different triangles have clearly defined visual characteristics that cannot be derived from their true shape, but only from the structural skeleton that creates it. The structural skeleton of each triangle derives from its contour. It is the simplest structure to be obtained from a given shape. The placement of the triangle can dramatically change the character of the visual form (Arnheim, R. Art and visual perception, 1981). The two pictures (Fig. 1) are triangular, but their shapes differ. The version, a' rises from the solid base to the sharp peak, while in version, b' the wide and hard top holds the balance of the sharp peak difficult and uncertainly. A triangle is a form in which each color has a different value. In fact, each color is accentuated by a certain form, and by another muted. The triangle most accentuates the yellow color (Fig. 2) according to Kandinsky (Kandinsky, W. for Spiritual in Art, 1995) when the yellow color is in a triangular or other pointed form, it sounds stronger.

The proportions expressed in figures 1: 1.618 represent the golden intersection. One way to achieve this proportion is by drawing a five-pointed star in the right pentagon. In this way we also get the so-called “golden triangle” (Fig. 3). This triangle has two angles of 72 degrees and one angle of 36 degrees. If the base of the triangle is conditionally assumed to be 1 in length, then the inclined sides (proportional to the base side) are 1,618 in length. This proportion represents the so-called "golden number". Simply put, this ratio is approximately 2: 3 and this ratio and proportion have been used in shaping objects, furniture, interiors, and architecture since ancient times and were considered aesthetically beautiful (Pythagoras, The Order and the Doctrine of Pythagoras, 2009).

The fractal structure of the equilateral triangle (Fig. 4) and the fractal of the proportional gradient of the golden triangle are an interesting basis for designing different variations of ornaments in the interiors. Applications of the triangular ornament were a characteristic feature of the interiors in the old eastern civilizations.

If we analyze it in the Christian context in the middle Ages, the triangle is a symbol of the Holy Trinity - the unity of the Christian religion. The equilateral triangle is a symbol of perfection. The triangle as a decorative element is very present in the interiors of the old and traditional Macedonian houses, ranging from the stool chairs through the stylized trim/carved decoration to the triangular patterns of carpets, embroidery on clothes, tablecloths and other decorative items that adorned the houses.

When designing the furniture in this paper, two triangles are taken as the starting point: the equilateral and the triangle derived from the golden triangle (2:3) but due to dimensional needs and functionality, it is modified to a triangle with two angles of 80 degrees, and one angle is 20 degrees (Fig. 5, 6).

Consideration of function and ergonomics and utilization of advanced technology are the main factors in furniture product design.

There is no doubt that ecologically friendly materials and implementation of mass-production will contribute to make sustainable environment, so addition to the adaptable function of the product, appropriate manufacture method should be adopted in today's furniture and product design. Within the assistance of Autodesk CAD and 3D Max software, the entire components design representation can be easily finished and prepared for Computer Numerical Control Cutting. Before processing the fabrication of this furniture, a small scaled model can be made by laser cutting technology for testing the visual effect and stability.

The following material is provided for making of this garden furniture: teak wood or maple wood obtained by a thermo wood procedure for seats and legs. The bearing structure and joints are made of cast aluminum with anthracite and silver effect. This is important because it is visible and aesthetically complements the design of the furniture. If this material proves to be economically expensive to carry the bearing structure, machined steel can be selected (Fig.5-13). The final appearance of the garden sets should be silver cast aluminum with teak wood and / or anthracite cast aluminum combined with maple wood. That way we get contrast (Fig.13).

When designing this set of garden furniture, the idea was to maintain the repetition of the elements due to the following factors:
1. Functionality - The set would be intensively exposed to the sun and rain so it had to go with a full/empty structure;
2. Production - To simplify the production process;
3. Layout - The aesthetics of full/blank and repetition of the motif add dynamics to the look.

In designing the furniture of this research paper, it was observed to maintain the repetition of the elements for both visual unity and simplification of the production process. The thickness of the boards is 1.5; 2; and 3cm. all lamellae are 2.5 cm wide and 1.5 cm thick. And the legs of all elements are 10 degrees sloping. The drawings in the paper show their detailed elaboration (Fig. 5-13)

Nowadays Computer Numerical Control technology is one thing to achieve the goal of making sustainable products. Not only for making mock-up models, in furniture industry, Computer Numerical Cutting technologies are widely used in order to save labor and economize the time as well. When less people get involved into the production process, the manufactory can successfully pay less for employment, and then reach the goal of reducing product cost. And the advanced technology would help accelerate the speed of fabrication- as long as the pattern gets created inside of Autodesk software, they can be quickly transferred into the cutting path for machine and become extremely accurate rather than handcrafting, and large number of components could be made in a short period of time and ready for the final assembling.

Design of the furniture shows us that main part of it is wooden so we decided that we could use Thermo wood as main product material[1]. In the process of heat treatment of thermo wood only steam and material heating at temperatures from 190 to 212 ºC are used. Heat inside the thermal modification chamber is slowly raised up to a high temperature. The whole process can last as long as 110 hours. When the process is complete, the moisture percentage of the material is around 4–7%. Lowered equilibrium moisture content remarkably enhances the wood’s dimensional stability. Thermo wood obtained in this way is completely natural and does not have any chemical additives. The technology of processing raw materials Thermo Wood® does not violate the natural characteristics and properties of wood. The patented method is based on a gradual temperature modification of wood when its physical and chemical properties are constantly changing[2].

Improved natural longevity - Due to the breakdown of sugar particles (hemicelluloses), the thermo wood does not contain sufficient nutrient concentrations for mold and fungus (COMO certificate). The resistant’s of thermo wood is measured with standards (letter “D” stands for “Durability”) belongs to the second class of resistance to rotting (EN 350-2). Timber lumber and products belonging to the first and second class of resistance to rotting, can be used outdoors without any additional processing.

Non toxic and chemical free - thermo wood is a reliable natural material produced using only natural processing methods: in the production process, only heat and steam are used without the use of any chemicals. During the process of modifying the raw material, steam plays the role of a protective gas, which protects the material from splitting and damage.

Improved thermal insulation - The tests have shown that as a result of the modification, the thermal conductivity of thermo wood is reduced by 20-25% compared to untreated materials of

[1] The study of the properties of thermo wood and the advantages of its use began in the 1930s in the USA and Europe, but at that time the process of production of this material did not reach an industrial scale. Only decades later, the VTT Technical Research Institute of Finland became interested in this idea again. In the result there followed the development of new technology for heat treatment of wood, obtaining a patent and launching the Thermo Wood® brand in the late 1990s in Finland.

[2]Thermo Wood® is a registered trademark and it can only be used by companies that are members of the International Heat Treatment Association. So, the quality of these products is controlled by an external independent party.

various coniferous species. So, the thermo wood is the most suitable material for windows and exterior doors, cladding of façades, outdoor furniture, exterior and interior decoration of saunas and baths.

Resin free - Due to the high temperature of Thermo wood treatment process, resin is removed from the wood. As a result, using this material we can be sure that even at high temperatures it will not produce resin.

Thermo wood is hypoallergenic and safe - During the production process all harmful organic compounds and unsafe emissions, which deteriorate the air quality and can cause an allergic reaction, are removed from the thermo wood. Studies have shown that in pine thermo-D there are twenty times less emissions and compounds than in untreated pine. Because of all these factors thermo wood is the best raw material too.

About the metal segments of the furniture we found that aluminum frames would be better choice for our set of outdoor furniture. Aluminum is the most common type of outdoor furniture frame material. Aluminum is a light weight and durable metal. Perfect for outdoor furniture and is the least expensive type of furniture frame to make because of an abundance of aluminum, according to the scientists.

There are two main types of aluminum outdoor furniture frames to consider, cast and wrought aluminum. Aluminum provides comparable durability to cast and wrought aluminum but usually with a more attractive price point (durability 20+ years).

Cast Aluminum (lean al.) - This frame material is heavier and more design oriented than aluminum**.** The only difference is that the molten aluminum is poured into a cast mold, allowing for intricate designs and shapes that would otherwise not be possible to make. Standard aluminum outdoor furniture is usually hollow, unlike cast aluminum that is slightly heavier but denser and more durable.

Wrought Aluminum - Wrought Aluminum is bent and manipulated into shape and reinforced over and over. Wrought aluminum offers similar design characteristics as its wrought iron counterpart. This could be an option if outdoor furniture is placed on more temperature changeable places and if we are looking for more iron look.

Choosing the right frame material is the most important thing to consider when designing outdoor furniture. It will determine how durable the furniture can be and how long it will last. Outdoor furniture is an investment for the city that’s way we must choose quality material. The strongest and most reliable frames for outdoor furniture are: aluminum, cast aluminum, wrought aluminum, wood/ teak or thermo wood, stainless steel, wicker (woven) and wrought iron.

Us a traditional material wood is naturally beautiful, and gives a comfortable feeling to any outdoor furniture. However, wood requires refinish and maintenance every two years minimum to maintain the color and protective finish.

Stainless steel offers a modern style to any outdoor space. Proven as a superior outdoor material, it has found its way into outdoor furniture with amazing results. With its resistance to corrosion and oxidation, it makes an excellent choice (durability 20+ years).

Wrought Iron is one of the most durable and longest lasting type of outdoor furniture available, many times lasting decades. Truly an investment that keeps on giving, wrought iron furniture is also the heaviest frame (durability 25+ years).

We decided that if the project price becomes too high, we will decide to go with some type of galvanized pure steel like metal galvanized steel[3] - which is almost pure steel, slightly alloyed to form a protective patina layer in order to be resistant to all weather conditions. The patina layer initially has a reddish-brown color, becoming darker over time. In industrial or aggressive environment, patina layer forms more quickly and the color becomes darker than in cleaner rural areas. However, a protective layer of patina cannot be formed if the surface of the steel is constantly wet or dirty. When

[3] Metal galvanization means full immersing a metal product in molten zinc. Most often the coating thickness of the product is up to 100 microns. This thickness protects the product from possible adverse environmental effects, and does not expose to electrochemical effects. Galvanizing is selected to process metal structures because of its advantages which make this technology much better than the others. If the product is galvanized, it serves much longer than a product that was not protected from corrosion.

used properly, it is expressive, durable and does not require maintenance. Over time corrosion can cause great damage to the metal structure, making it more fragile. It is the galvanizing process that makes the metal product more qualitative. Almost all metal structures can be galvanized. Due to all these advantages, hot-dip galvanizing services are often used in urban construction. Only at first glance galvanizing is a simple procedure. In fact, the technology includes 5 stages; each of them is of great importance and influences the final result[4]. UV resistance shows how well the coating retains its original color and gloss level in accordance with EN10169. The higher the grade, the better the resistance. The corrosion activity categories describe outdoor climatic conditions in accordance with EN12944. The higher the category, the more aggressive the environment is.

3. CONCLUSIONS

Although furniture and products that we use everyday are always smaller than buildings and are placed inside or outside of the building, furniture/ product design and architecture still have some common characteristics- from the functional perspective of view, both of these design aim to create the device that could provide practicability and convenience to human’s daily lives; from the design and esthetic aspect, the challenge to maintain the stable structure and function with small material waste exist in both design areas. Thus, the furniture and product design can be treated as a type of “mini architecture”. Like Outdoor furniture or Green Architecture design, the furniture and product design can also achieve sustainability with structure innovation, space flexibility and material saving. This paper has been concerned with how to proceed when a certain geometrical form such as triangle is a starting point of departure in the design process and the functionality of the product is the expected outcome.

This paper has been concerned with how to proceed when a ‘material’ is the explicit point of departure in the design process and ‘experience’ is the expected outcome. Material driven design, which represents our first attempt to facilitate such projects, considering both technical properties of materials and their experiential qualities in relation to how they are received by users. The method suggests that when a material is the point of departure in the design process, the designer takes a journey from material properties and experiential qualities to materials experience vision, from materials experience vision to experiential qualities and to material properties, and finally to products. Activities to support this journey are organized under four main steps as: understanding the material, technical and experiential characterization, creating materials experience vision, manifesting materials experience patterns, designing material/product concepts.

[4] 1. Degreasing. Metal constructions should be thoroughly cleaned from greasy stains or oils in order to create a reliable protection against corrosion.
2. Etching. At this stage the metal is cleaned of the already accumulated corrosion. It is important for parts that have already been in operation.
3. Washing. Removes various particles left after etching.
4. Drying. Specialists heat the product with the help of special equipment up to 100 degrees. Due to the high temperature, the flux salts are drying.
5. And, finally, the process of galvanizing. As we noted above, the product is completely immersed in molten zinc, due to which it acquires a zinc sheath. It should be noted that all processes occur exclusively in technological conditions, where objects are placed into special tanks.

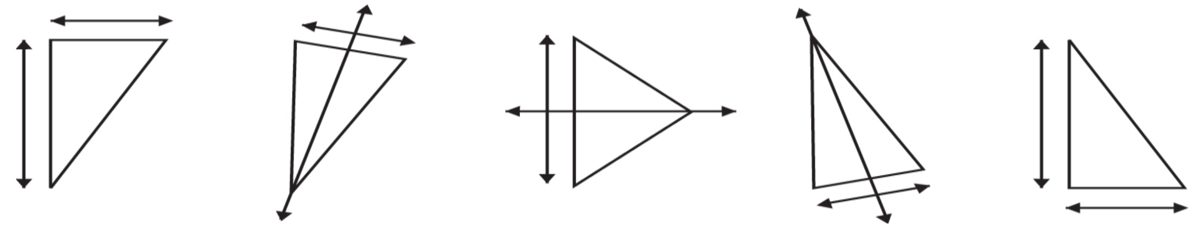
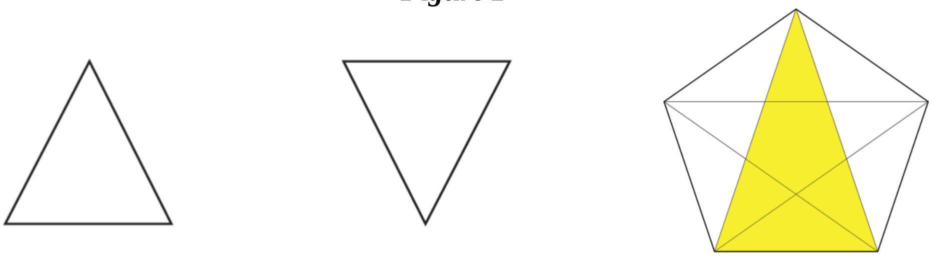


Figure 1



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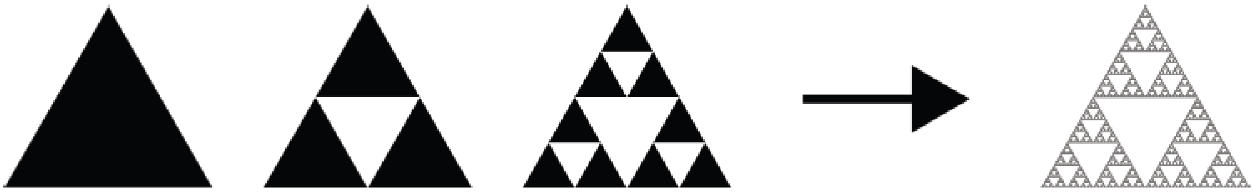


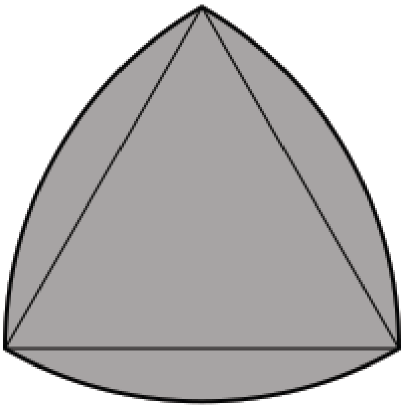


Figure 3.

Figure 4.

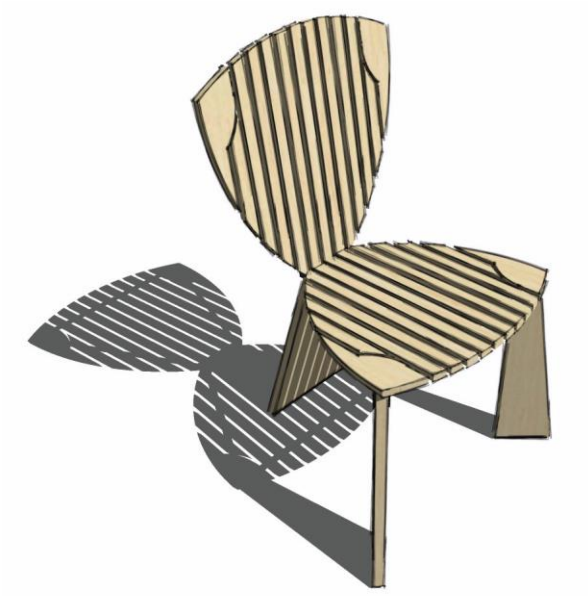


Figure 5.

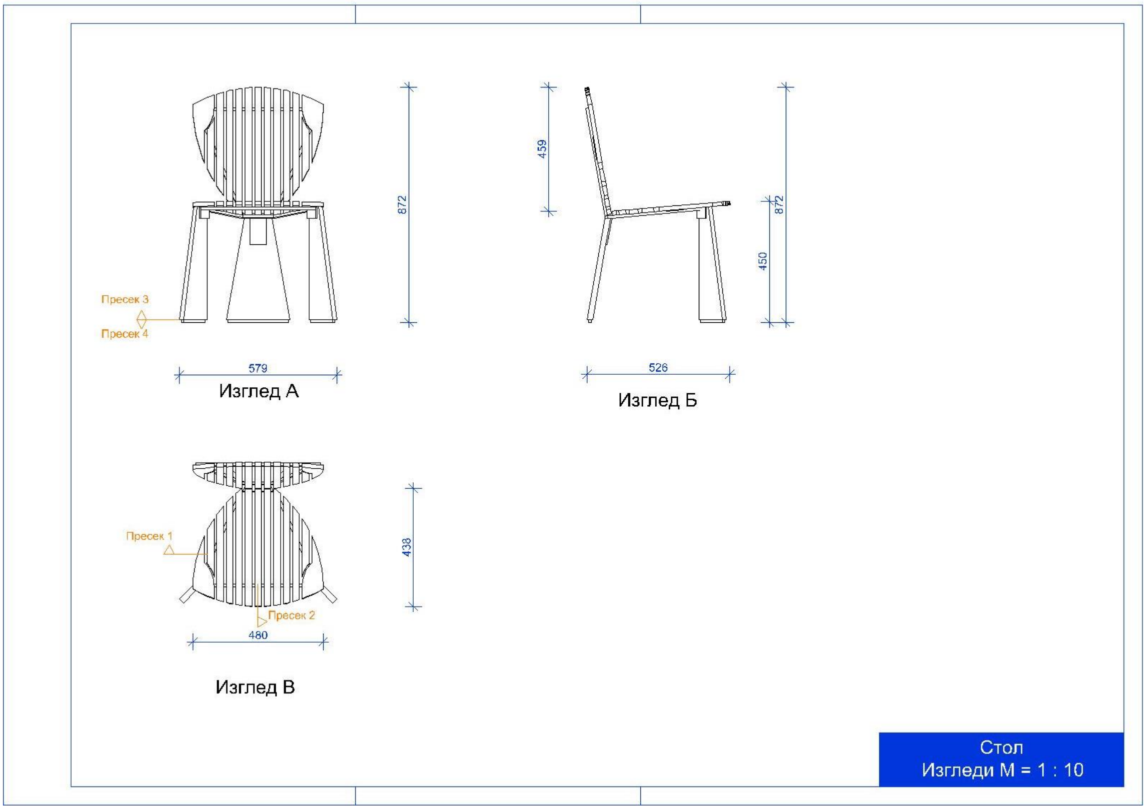

Пресек 3
Пресек 4
872
579
Изглед А
459
872
450
526
Изглед Б
Пресек 1
Пресек 2
438
480
Изглед В
Стол
Изгледи М = 1 : 10

Figure 5a.

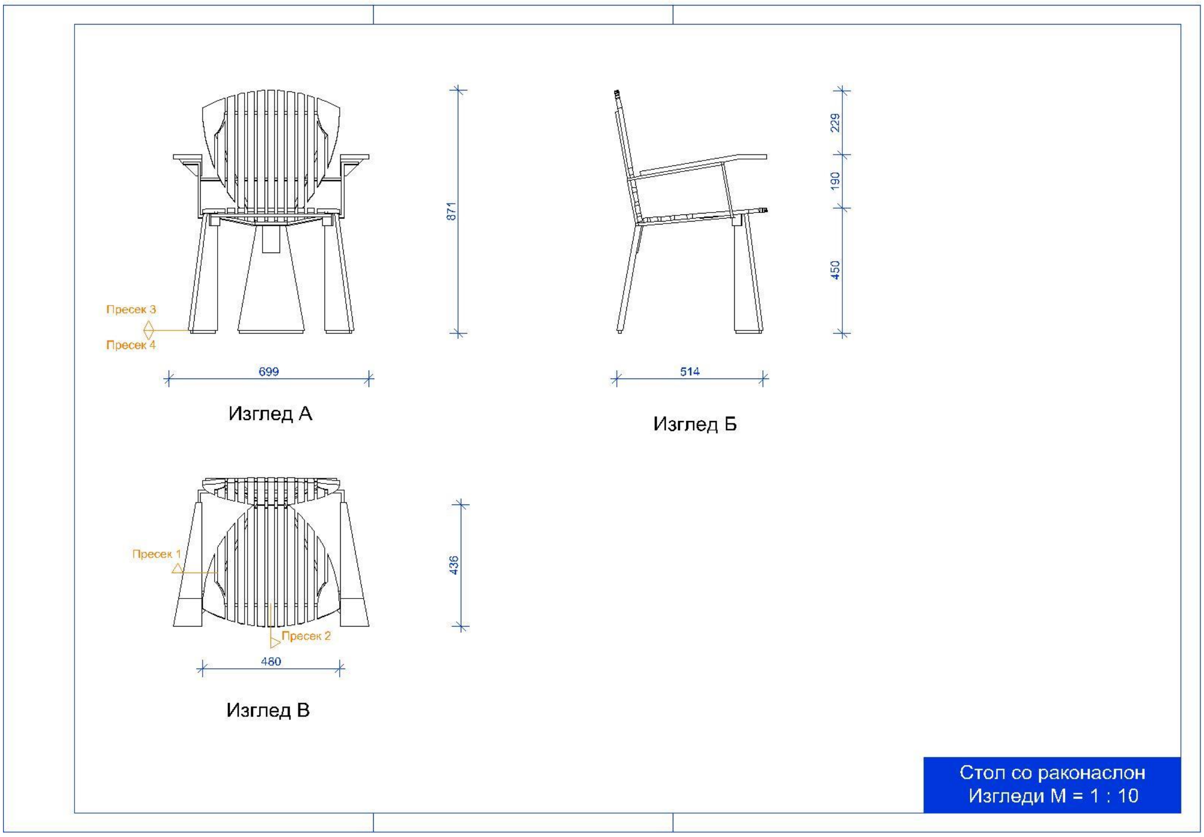
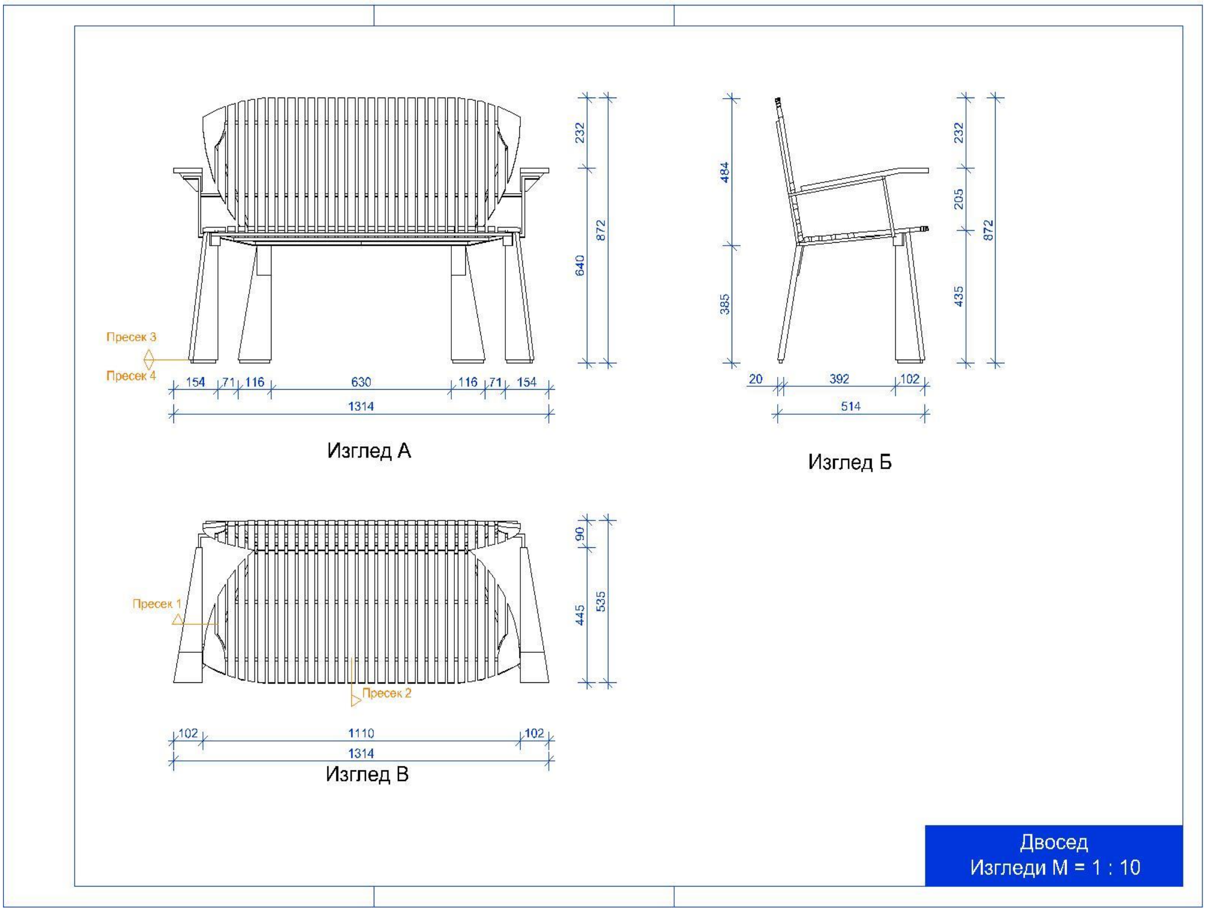
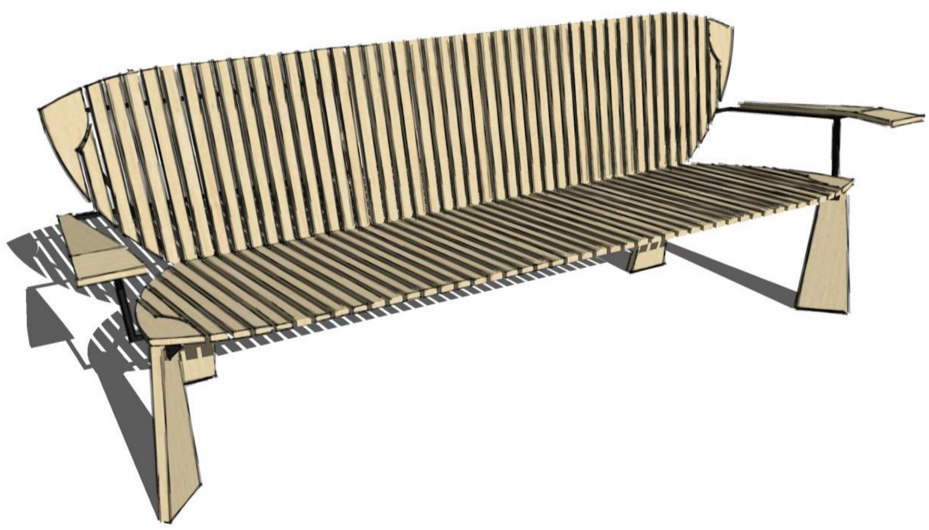

Пресек 3
Пресек 4
699
Изглед А
871
229
190
450
514
Изглед Б
Пресек 1
Пресек 2
480
436
Изглед В
Стол со раконаслон
Изгледи М = 1 : 10

Figure 6.


Пресек 3
Пресек 4
154
71
116
630
116
71
154
1314
232
872
640
Изглед А
484
385
232
205
435
872
20
392
102
514
Изглед Б
Пресек 1
Пресек 2
90
445
535
102
1110
102
1314
Изглед В
Двосед
Изгледи М = 1 : 10



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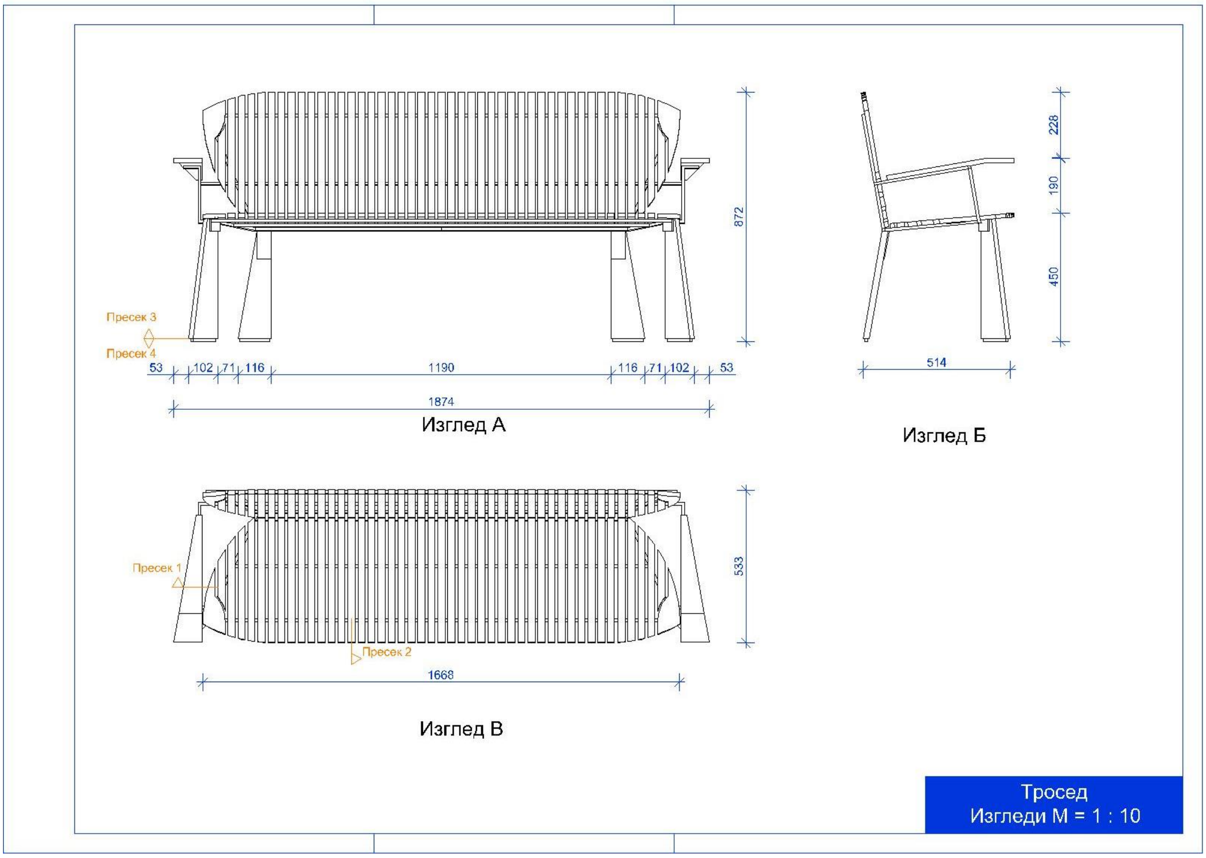

Пресек 3
Пресек 4
53
102
71
116
1190
116
71
102
53
1874
872
Изглед А
228
190
450
514
Изглед Б
Пресек 1
Пресек 2
533
1668
Изглед В
Тросед
Изгледи М = 1 : 10

Figure 8.

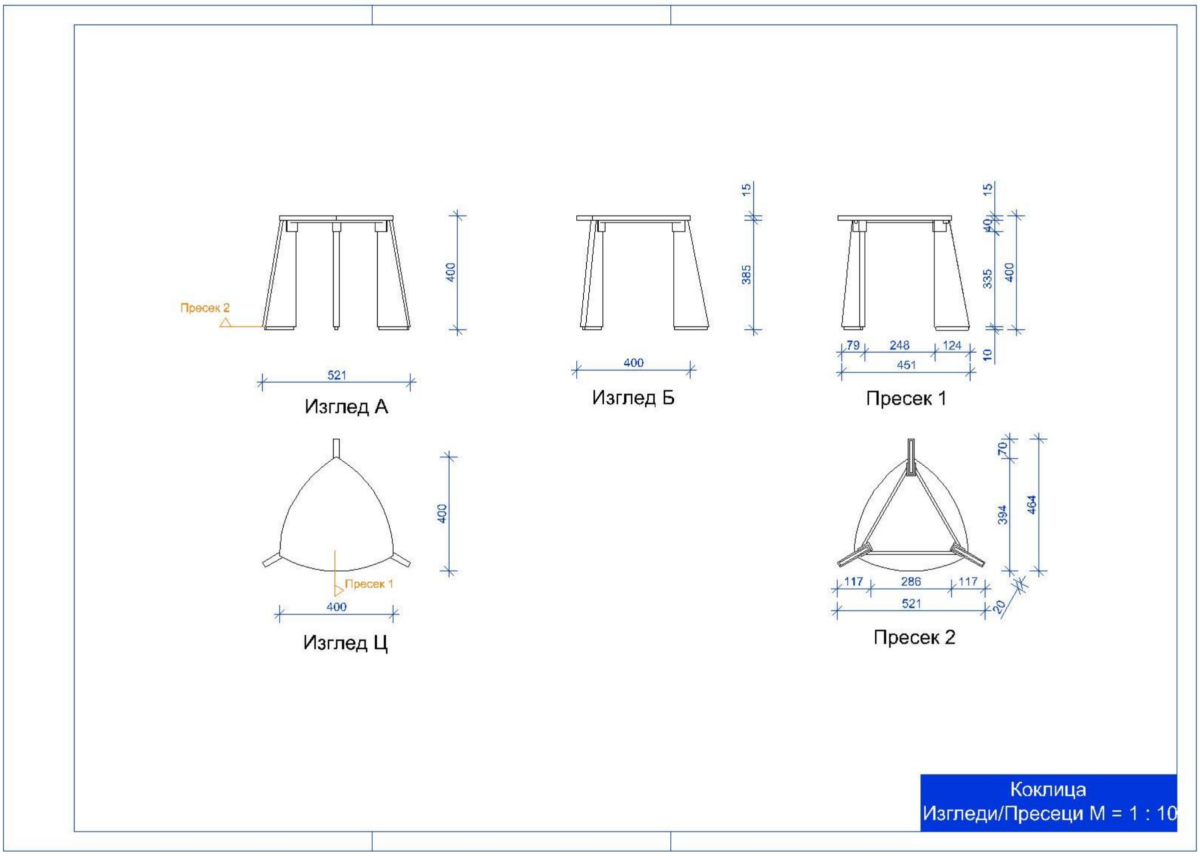
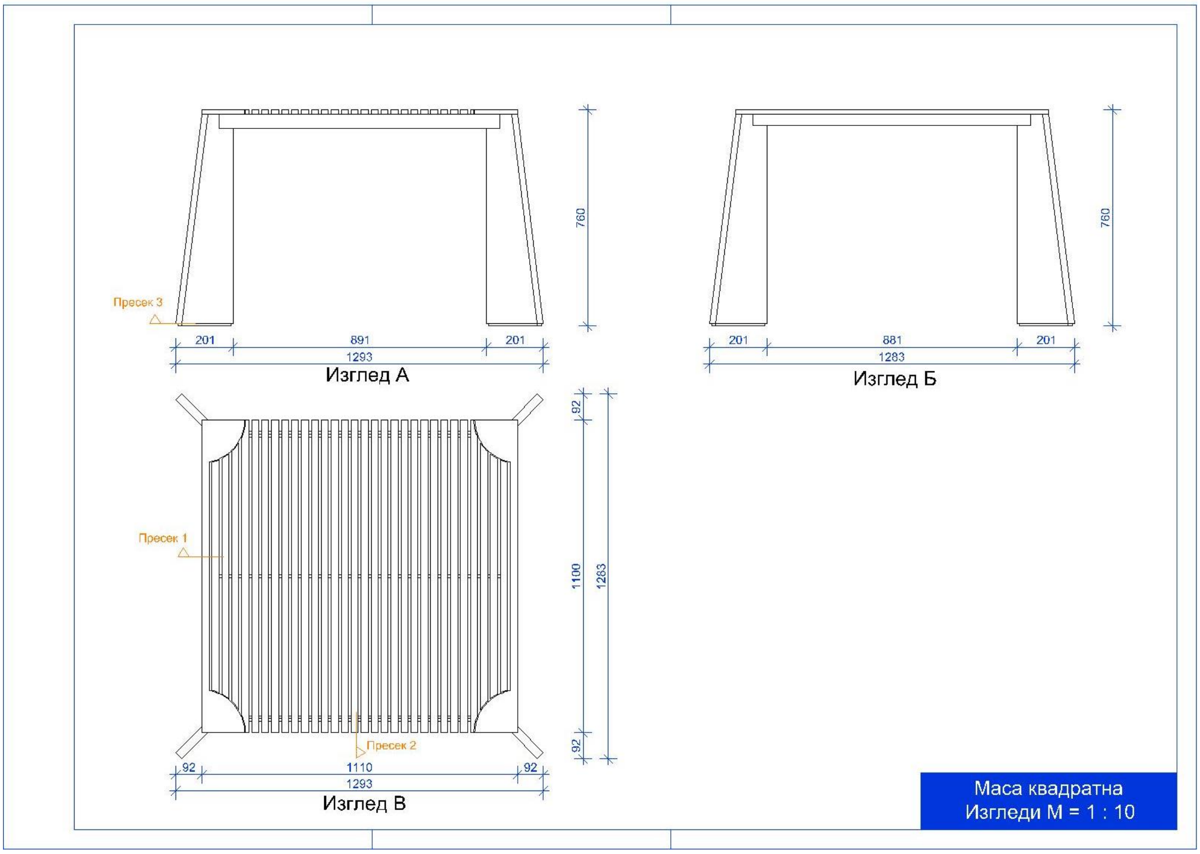

Пресек 2
400
521
Изглед А
15
385
400
Изглед Б
15
40
335
400
10
79
248
124
451
Пресек 1
400
Пресек 1
400
Изглед Ц
70
394
464
117
286
117
521
20
Пресек 2
Коклица
Изгледи/Пресеци М = 1 : 10

Figure 9.


760
Пресек 3
201
891
201
1293
Изглед А
760
201
881
201
1283
Изглед Б
92
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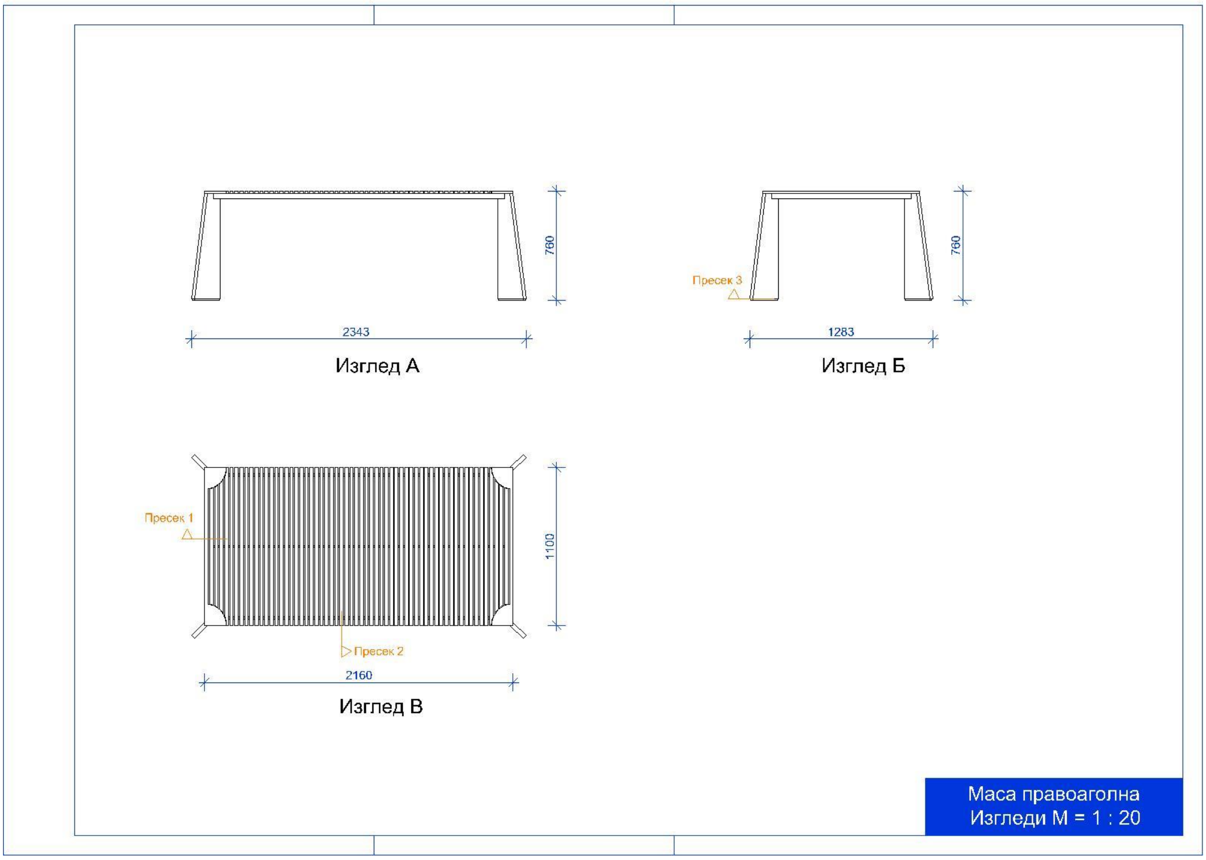
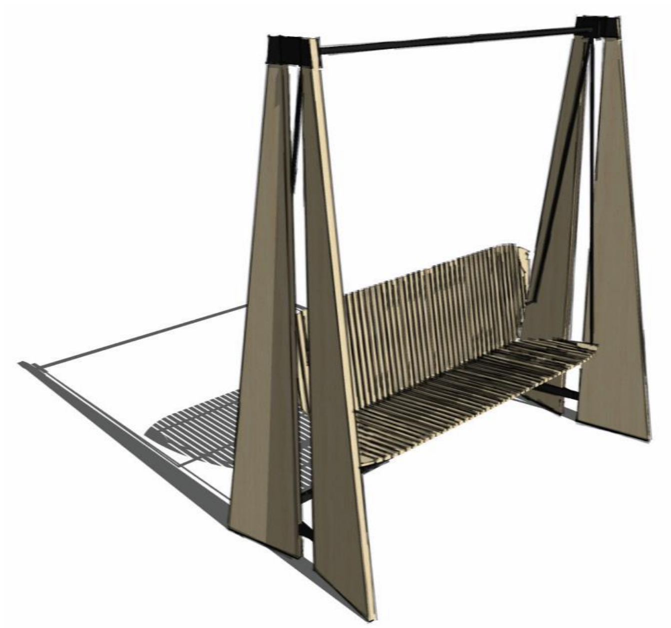
1100
1283
92
Пресек 2
92
1110
92
1293
Изглед В
Маса квадратна
Изгледи М = 1 : 10

Figure 10.


760
2343
Изглед А
760
Пресек 3
1283
Изглед Б
Пресек 1
1100
Пресек 2
2160
Изглед В
Маса правоаголна
Изгледи М = 1 : 20



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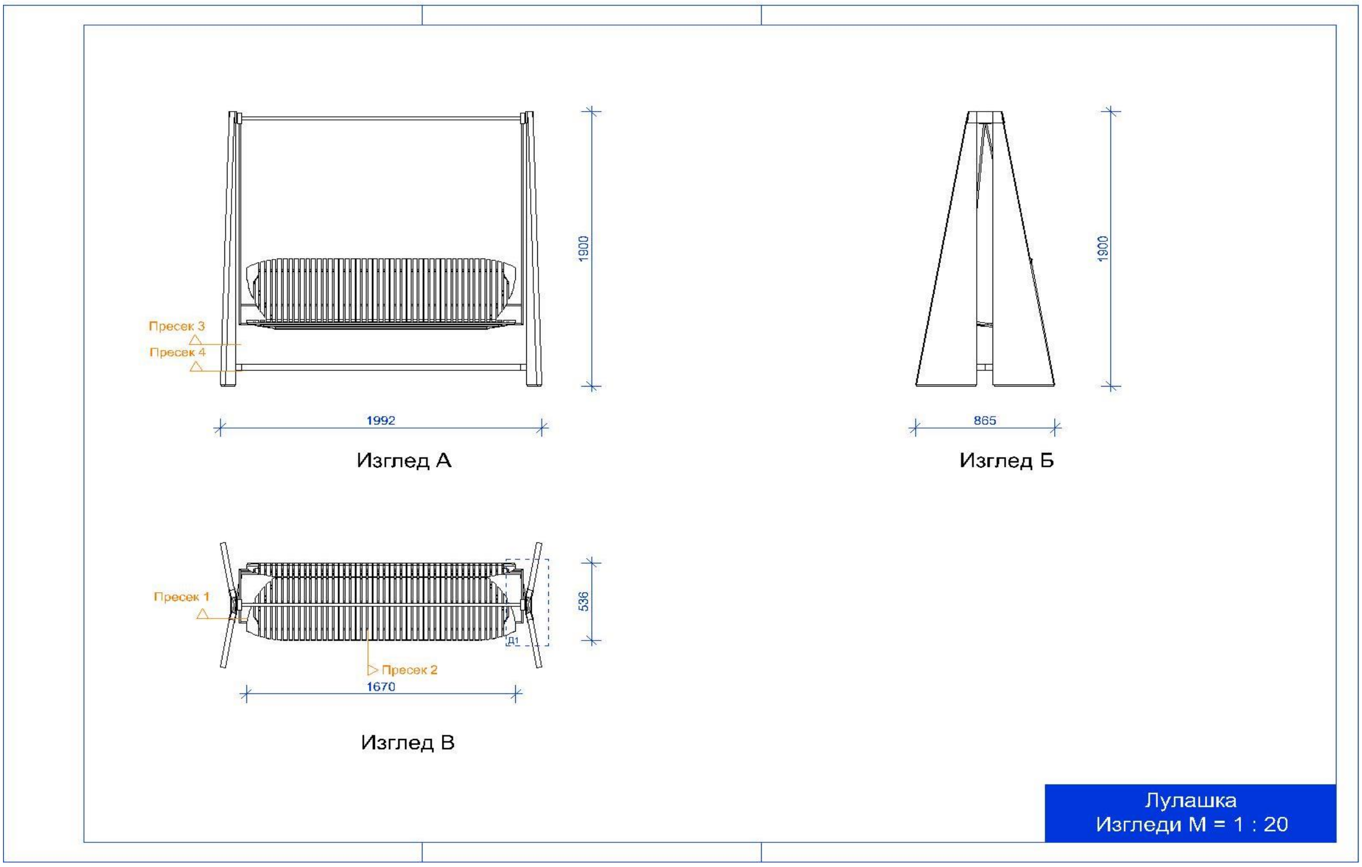
Пресек 3
Пресек 4
1900
1992
Изглед А
1900
865
Изглед Б
Пресек 1
536
Д1
Пресек 2
1670
Изглед В
Лулашка
Изгледи М = 1 : 20

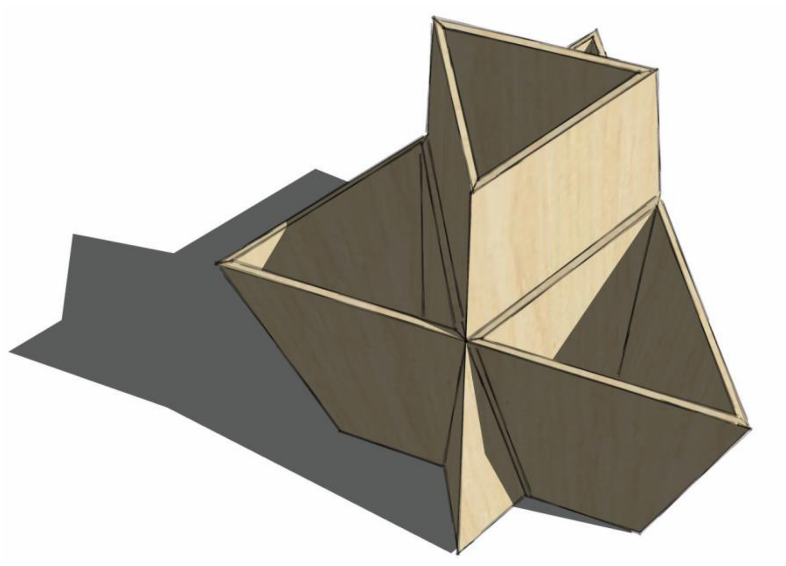

Figure 12.

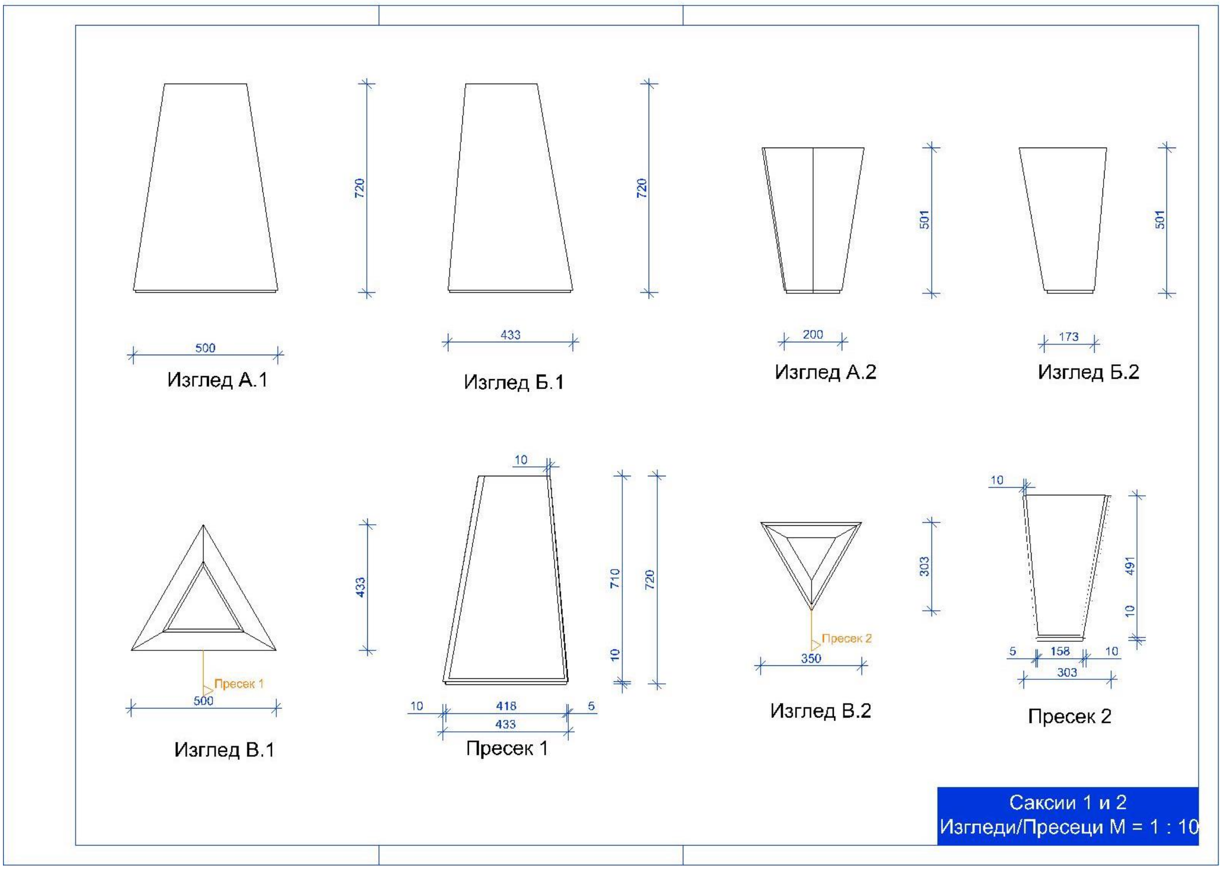
720
720
501
501
500
Изглед А.1
433
Изглед Б.1
200
Изглед А.2
173
Изглед Б.2
433
Пресек 1
500
Изглед В.1
10
710
720
10
10
418
5
433
Пресек 1
303
Пресек 2
350
Изглед В.2
10
491
10
5
158
10
303
Пресек 2
Саксии 1 и 2
Изгледи/Пресеци М = 1 : 10

Figure 13.

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FOLK TREASURE IN SPACE AND ART

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ABSTRACT

Directly inspired by the rich Macedonian cultural and historical heritage, and above all the miscellaneous treasury of artefacts which continuously unite various eras, I have triggered a new and unexpected display of inventive opportunities with a specific creative sensitivity. It is closely related to the ethnic motifs of our folk treasure and the natural materials, such as wood, fabrics, ceramics, lace, pearls, mother-of-pearl, and copper, which brought warmth to each of our homes not such a long time ago.

This magnificent synthesis of the most unexpected elements as fragments that are met and found in a different parallel dimension does not arouse only curiosity and a sigh, but it also triggers a thought, an urge for insight, a return deep into the past and a stroll through the history of the seemingly little things.

Their multiple purposes indicate undoubtedly the susceptibility of their use in various spaces, such as the family houses' interiors, the ethnic restaurants, hotels' lobbies, airports, and congress halls to which instantaneously the value of recognition, warmth, peculiarity, authenticity, and an opportunity to ennoble even the most modern space is given.

Key words: tradition, ethnic motifs, interior, design, furniture, natural materials, lace, wood, copper

1. INTRODUCTION

During the 19th century, the interest of the scientists for each and every type of folk art aroused and developed, while at the end of the 20th century and the beginning of the 21st century, two-dimensional and three-dimensional art, simply named *Folk Art*, became part of many occupations as a contrast to the same formal types of creativity of high art, both stylistic and individual. Folk art is neither individual nor collective. It is a piece of work by an individual which is owned by everyone. As of individuality, the folk works of art might seem rough, static, and unchangeable at first sight. Yet, these characteristics and the tradition embedded in each form of expression make folk art timeless.

Folk art is flexible, incomplete, and always open to new changes, but only in accordance with its own choice and under its given historical conditions. It changes, separates and unites in the rhythm of its creator. Being inspired by the Macedonian nation and the design of furniture introduced by the Macedonian people, I bring the past and the present closer together by taking into consideration values of material and spiritual nature and tending to present and recommend them in future. It is a complex story which is also simple at the same time. It is a story which is heard even today in our daily life, which is retold in the rituals of food making, the process of maintaining personal hygiene, praying, and in everything that gives meaning and form to life itself in an artistic context. In these preserved folk works of art, the artistic language is often used as a means to express the long-established experience of the generations, and every single thing that is created, that continues to exist or that changes in its own pace. With the analysis of this content and its presentation in a different light, an attempt is made to enrich the present with the spirits of the past and to create an atmosphere of a warm Macedonian home which is filled with genuine family values.

2. APPLICATION AND FUNCTION OF DESIGNER ELEMENTS IN CREATING MODERN INTERIORS WITH ELEMENT OF FOLK

The folk works of art incorporate motifs of one or several styles of art in their expression of design. The mixture of styles and elements which belong to different eras is a result of both a continuous and almost undiscriminating borrowing of art at various artistic levels and the impact of the rural conservatism. People generally adhered to one accepted form: the old was kept and it existed simultaneously with the new, while the new stood next to the newer ones and thus elements of different origin were being connected with each other in a single whole.

The material which is used, the ornaments, colours and techniques, and even the form and shape reflect the useful values and functions of a particular object, for example, work, festive, ceremonious, or ritual clothes; gender difference; age: a child, old, young; as well as the social status of the owner, like: a bride, a wife, a widow, a girlfriend, poor, or wealthy.

Figure 1. *Beginning of a mutual life of young people*

Figure 2. *Objects for maintaining personal hygiene*

Figure 3. *Utensils*

Figure 4. *Objects for religious purposes*

Figure 5. *Presentation of ambient*

The foundation on which the work and its form is created is of extreme importance. One and the same piece of work looks differently when it is made of wood or when it is painted, when it is made either of clay or ceramics, or when it is woven, embroidered or knitted. Each of these materials that are used to create these pieces of work determine the specific style and design that is going to be used, and therefore, very often there is a similar artistic expression on different objects made of the same material.

Figure 6. *Lamp made of wood with The Great Mother Goddess traditional element of clay*

Figure 7. *Presentation of ambient with traditional elements*

The game of colours and shapes, materials, fabrics, embroidery and lace is an inexhaustible challenge. It is a game that stirs fantasy to make the interpretation carry a recognizable stamp of a creative sensiblity. The dynamics of the spectre of colours of the traditional treasury in red, yellow and white hues perfectly reflects the tendency for cheerfulness and cleanliness of the spirit that unites the traditional values and elements.

Figure 8. *Lamp with decorative lace and kitchen utensils made of copper and porcelain*

3. COCLUSION

The principles and elements together with the understanding of the structural and decorative design create a firm ground as a stepping stone for further evaluation of any design. The synthesis of detalis made by the diligent hands of the creators of national treasure that are introduced and incorporated in space, creates specific interiors that require a 3D intervention. The idea is to easily sense the presence of someone who looks in the mirror, dresses up, grinds coffee in a grinder, and to even sense the smell of the coffee or the tobacco from a pipe by creating fragments of a past reality and thus revealing how these elements were actually used. From a present perspective, these windows to the past, these pieces of furniture that have undergone modern intervention, and this pleasant atmosphere created by the entire design tell us a story of our mutual past that we all have, in one way or another, from our ancestors, genes, and the souls of our dearest that are present in our daily life.

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SCREW WITHDRAWAL RESISTANCE OF COMPOSITE WOOD-BASED PANELS (PART II)

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ABSTRACT

The aim of the research presented in the paper is to determine the screw withdrawal resistance of composite wood-based panels intended for use in construction.

For this purpose, three experimental wood composite panels were made by combining particleboards and constructive peeled veneers of beech, black pine and poplar with thickness of 1,5 and 3,2 mm. The core layer of the composite panels was made of single-layer particleboard with thickness of 16 mm which was overlaid on both sides with two-ply cross-laminated veneers. Models of composite panels were made by combining a different veneer species for particleboard overlay (beech/black pine, poplar/black pine and poplar/beech).

Water-soluble phenol-formaldehyde resin was used for particle bonding and veneering.

The results from the research showed that the different combination of veneer species used for particleboard overlay significantly impact the screw withdrawal resistance of composite panels.
According to the obtained values of the screw withdrawal resistance, composite panels can be used in construction.

Key words: composite wood-based panels, particleboard, veneer, beech, black pine, poplar, phenol formaldehyde resin, screw withdrawal resistance

1. INTRODUCTION

Composite wood-based panel represent a composition of particleboard and veneers (particleboard core overlaid with peeled veneers) which combine structural efficiency with favorable manufacturing cost (Biblis and Chiu, 1974). These kinds of panels are intended for structural use in construction.
Properties of composite panels made from various core and face materials were investigated by many authors (Hse, 1976; Biblis and Mangalousis, 1983; Biblis 1985; Chow *et al.*, 1986; Dimeski *et al.*, 1996 and 1997; Miljković *et al.*, 1997; Mihajolva *et al.*, 2005; Iliev *et al.*, 1994, 2000, 2005, 2006, 2010; Buyuksari, 2012; Jakimovska Popovska *et al.*, 2015, Jakimovska Popovska *et al.*, 2017, Jakimovska Popovska and Iliev, 2017).

Researches that concern the dimensional stability of the panels under water impact were conducted by Iliev, 2006; Jakimovska Popovska *et al.*, 2014; Mihajolva *et al.*, 2005. Possibilities for improving the water resistance properties of composite panels were investigated by Hse *et al.* (2012). Iliev (2000) and Norvydas and Minelga (2006) studied the impact of the number of the veneers on composite panel's properties.

Beside other physical and mechanical properties of composite wood-based panels that are important for structural use in construction, the screw withdrawal resistance is also an important property that can show the behavior of the assemblies of this kind of wood-based panels made with screws. The strength and stability of the structures made from particleboards depend very much on the fastening that holds the parts of the structure together (Miljković and Popović, 2004).

The withdrawal resistance of composite panels made from single-layered particleboard overlaid with single veneers and cross-ply laminated veneers was studied by Jakimovska Popovska *et al.*, 2016 and Jakimovska Popovska and Iliev, 2017. Studies about the screw holding performance of wood-based materials were carried out by many authors (Eckelman, 1975 and 1988; Miljković *et al.*, 2007; Erdil *et al.*, 2002; Điporović-Momčilović *et al.*, 2006), which studies can be used to develop estimates of face and edge screw holding strength that can be used in the product engineering of constructions made from wood-based materials.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

Three experimental composite wood-based panels were made by combining single-layered particleboard and peeled beech, black pine and poplar veneers. The core layer of composite panels was a single-layer particleboard with thickness of 16 mm which was overlaid on both sides with two-ply cross-laminated veneers from beech, black pine and poplar with thickness of 1,5 and 3,2 mm, where the veneers with thickness of 1,5 mm represent the surface layers of the panels (Fig. 1). All three composite models have a different combination of veneer species for particleboard overlay.

Mix of equal weight ratios of particles for core and surface layer was used for manufacture of the single-layered particleboards, where water solution of phenol-formaldehyde resin was used as an adhesive for particle bonding with 16 % dry matters content on dry wood basis. The characteristics of the resin and pressing parameters used for manufacture of the single-layer particleboards are described in previous paper (Jakimovska Popovska and Iliev, 2017).

The particleboards were overlaid with two veneer sheets on each side of the panels. A combinations of beech, black pine and poplar veneers with thickness of 1,5 and 3,2 mm were used for overlay. The orientation of the adjacent veneers was at right angle, where the surface veneers with thickness of 1,5 mm were oriented parallel to the longitudinal axis of the particleboard. A water-soluble phenol-formaldehyde resin with 48,85% dry matters content was used for veneer bonding. Wheat flour was used as filler and 15 % water solution of $Ca(OH)_2$ as catalyst. The binder was applied on both sides on the inner veneers with thickness of 3,2 mm in quantity of 180 g/m^2.

The veneering was made in a hot press using specific pressure of 15 kg/cm^2, pressing temperature of 155°C and pressing time of 20 minutes. The composite panels were overlaid with phenol-formaldehyde resin impregnated paper during the hot pressing process.

The produced panels have moisture content of 8,5 % and dimensions of 545×435 mm^2, with thickness range from 23,02 to 23,34 mm depending on the model.

According to this methodology three models of composite wood-based panels were made:

– model B-BP: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated beech and black pine peeled veneers (black pine surface layers);

– model P-BP: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated poplar and black pine peeled veneers (black pine surface layers);

– model P-B: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated poplar and beech peeled veneers (beech surface layers).

The configuration of the structure of the composite panels is shown on figure 1.

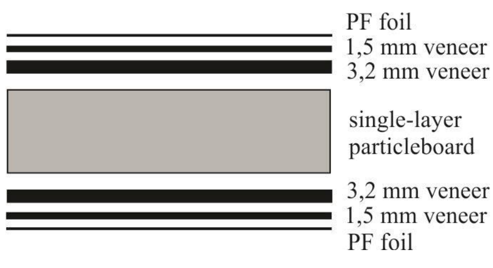

Figure 1. *Pattern of the structure of composite panels*

The screw withdrawal resistance of composite panels was tested according to MKS D.C8.112/82. This property was tested in two directions: perpendicular to the plane of the panel, i.e., when the screw was driven in the surface of the panel and in plain of the panel (the screw was driven in panel's edge).

Nine test specimens of each model were made with dimensions of 100×50×d mm. Slotted flat countersunk head wood screws according to the standard DIN 97 were used for these tests. The technical parameters of the screws and dimensions of the screw holes pre-drilled in the panels are given in previously published paper (Jakimovska Popovska and Iliev, 2017).

The tests were performed on universal testing machine, measuring the maximal force of withdrawal.

The specific screw withdrawal resistance perpendicular to the plane of the panel was calculated using the following equation:

$$Z_{\perp}=\frac{F}{d\times\pi\times(d_1-2)}\ [\mathrm{N/mm^2}],$$

where F is maximal force of screw withdrawal [N], d is diameter of the screw [mm] and d_1 is the thickness of the panel.

The specific screw withdrawal resistance parallel to the plane of the panel was calculated using the following equation:

$$Z_{\parallel}=\frac{F}{d\times\pi\times l}\ [\mathrm{N/mm^2}],$$

where F is maximal force of screw withdrawal [N]; d is diameter of the screws [mm] and l is the depth of driving of the screw in to the panel's edge.

The obtained data were statistically analyzed. One way ANOVA was used to determinate the significance of the effect of veneer overlay on panel's screw withdrawal resistance perpendicular to the plane of the panel. Tukey's test was applied to evaluate the statistical significance between mean values of the property of composite panels with different veneer overlay (different panel models).
Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The values of the density of composite models are shown in table 1.

Table 1. *Statistical data for density of the composite panels*

Model	***N***	***Mean***	***Min***	***Max***	***95% Confidence Interval for Mean***		***Std. Deviation***	***Std. Error***
		kg/m³	***kg/m³***	***kg/m³***	***Lower Bound***	***Upper Bound***	***kg/m³***	***kg/m³***
B-BP	9	721,22[a]	697,00	773,00	704,36	738,09	21,94	7,31
P-BP	9	681,89[b]	651,00	714,00	662,33	701,45	25,44	8,48
P-B	9	719,33[a]	644,00	756,00	690,50	748,16	37,51	12,50

The mean values with the same letters are not significantly different at 0,05 probability level

The highest density of composite models is achieved in model B-BP, i.e. in model overlaid with beech and black pine veneers. The ANOVA (F(2,24)=5,24; p=0,013) and Tukey's test for the density of the composite panels showed that the model made with poplar and black pine veneers (P-BP) statistically differs from other two models. Different combinations of veneers for particleboard overlay will produce panels with different density depending on the wood species used for veneer production.

The analysis of variance of the obtained data for the screw withdrawal resistance perpendicular to the plain of the panel (ANOVA: F (2; 24)=4,107; p=0,029) showed that the differences between the mean value of this property of at least two models are statistically significant, which means that the combination of different wood species used for particleboard overlay has significant impact on this property. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean value of this property between models P-BP and P-B. The differences in the mean values of screw withdrawal resistance perpendicular to the plain of the panel between model B-BP and model P-BP, as well as between models B-BP and P-B are not statistically significant.

The highest mean value of this property is achieved in composite model that is overlaid with beech and poplar veneers, while the lowest value is achieved in model made with black pine and poplar veneers.

The analysis of variance of the obtained data for the screw withdrawal resistance parallel to the plain of the panel (ANOVA: F (2; 24)=17,317; p=0,000) and post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences between the mean values of this property of all composite models. These differences can be a result of an inadequate mixture of particles for production of single-layered particleboards that is obtained with mixing of equal weight ratios of particles for core and surface layer. Further investigations are needed to confirm this statement. The edge withdrawal resistance also depends on the quality of the bonds between particles (Miljković, 1991).

Table 2. *Statistical data for screw withdrawal resistance perpendicular to the plain of the composite panels*

Model	*N*	*Mean*	*Min*	*Max*	*95% Confidence Interval for Mean*		*Std, Deviation*	*Std, Error*
		N/mm²	*N/mm²*	*N/mm²*	*Lower Bound*	*Upper Bound*	*N/mm²*	*N/mm²*
B-BP	9	12,81[a,b,c]	11,27	14,99	11,96	13,66	1,10	0,37
P-BP	9	11,31[b]	9,89	13,19	10,42	12,19	1,15	0,38
P-B	9	13,24[c]	8,71	15,33	11,66	14,81	2,05	0,68

The mean values with the same letters are not significantly different at 0,05 probability level

Table 3. *Statistical data for screw withdrawal resistance parallel to the plain of the composite panels*

Model	*N*	*Mean*	*Min*	*Max*	*95% Confidence Interval for Mean*		*Std, Deviation*	*Std, Error*
		N/mm²	*N/mm²*	*N/mm²*	*Lower Bound*	*Upper Bound*	*N/mm²*	*N/mm²*
B-BP	9	2,04[a]	1,75	2,37	1,89	2,18	0,19	0,06
P-BP	9	2,65[b]	1,89	3,43	2,25	3,06	0,53	0,18
P-B	9	3,24[c]	2,50	4,18	2,86	3,63	0,50	0,17

The mean values with different letters are significantly different at 0,05 probability level

The obtained values of screw withdrawal resistance of the experimental composite panels are within the limits of the values listed in the literature from the similar researches. Jakimovska Popovska and Iliev (2017) give the values in the limits of 11,92 to 14,11 N/mm^2 for screw withdrawal resistance perpendicular to the plain and from 2,65 to 3,00 N/mm^2 for screw withdrawal resistance parallel to the plain of the composite panels made with two-ply cross-laminated veneers. Iliev (2000) gives the values in the limits of 9,95 to 11,90 N/mm^2 for screw withdrawal resistance perpendicular to the plain and from 5,42 to 7,92 N/mm^2 for screw withdrawal resistance parallel to the plain of the composite panels made with single beech veneer overlay. Same author gives the values within the limits of 9,69 to 12,95 N/mm^2 for screw withdrawal resistance perpendicular to the plain of composite panels made two-ply cross-laminated beech veneers and values within the limits of 4,19 to 7,21 N/mm^2 for screw withdrawal resistance parallel to the plain of the panel. Miljković *et al.* (1997) give the value of 12,13 N/mm^2 for composite panel made with two-ply cross-laminated black pine veneers. Jakimovska Popovska *et al.* (2017) give the values in the limits of 11,12 to 13,00 N/mm^2 for screw withdrawal resistance perpendicular to the plain of the composite panels with single veneer overlay and values in the limits of 2,61 to 2,71 N/mm^2 for screw withdrawal resistance parallel to the plain of the composite panels.

4. CONCLUSIONS

On the basis of the obtained results from the conducted research can be concluded that the combinations of veneers from different wood species used for particleboard overlay in production of composite panels has significant impact on the values of screw withdrawal resistance perpendicular to the plain of the composite wood-based panels. The highest mean value of this property is achieved in composite model made with beech and poplar veneer overlay.

By combining the water resistant particleboard as core layer and peeled constructive veneers for particleboard overlay, composite wood-based panels for structural application in construction can be made.

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CHARACTERISTICS OF COMMERCIAL ORIENTED STRAND BOARDS (OSB) PRESENT ON THE MARKET

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ABSTRACT

The paper analyzes the properties of oriented strand boards (OSB) present on the market in our country. In past years there is an increased interest for construction of wooden buildings where the wood-based panels are one of the basic materials for structural and non-structural use. In such buildings different types of OSB can be used as load-bearing members or as general purpose board, as well as in dry or humid conditions depending on the place of incorporation in the building.
It is important to take an overview of the characteristics of these panels that are present in the market in our country, which will contribute in better understanding of the proper use of OSB according to their physical and mechanical properties.

Commercially produced OSB panels taken from one company from wood-based panel market were tested. Evaluation of the quality of the panels was made on the basis of the obtained results for the physical and mechanical properties of the panels. Properties of OSB panels were tested according to the national MKC standards and European norms.

Tested OSB panels taken from the market are not fully in accordance to the technical specification given by the manufacturer of these boards and the requirements of the standards for OSB panels for use as structural load-bearing panel. There are some deviations found in the quality of the panels in different panel’s direction regarding to the obtained values of some of the tested properties.

Key words: wood-based panels, oriented strand boards (OSB), physical properties, mechanical properties, construction

1. INTRODUCTION

Oriented strand boards (OSB) represent engineered wood-based panels made from large wood strands bonded together with an adhesive on the base of a synthetic resin. The wood strands used in OSB production have a length at least twice their width and they are orientated in predetermined directions in each layer to simulate some of the characteristics of plywood (TRADA, 2012). OSB is usually composed of three layers with the strands of the outer two layers orientated in a particular direction. In OSB panels with oriented layers, it is often hard to see the orientation because there is quite a large degree of variability in this orientation among adjacent strands in the panels from any one production line, as well as between panels from different producers (Panel Guide V4).
A typical production process involves reducing wood down to strands that are cut parallel to the grain and dried in a rotary drier. After drying, these strands are generally sprayed with a synthetic resin binder and wax. The three main adhesives used in the production of OSB are phenol-formaldehyde (PF), isocyanates (MDI or PMDI) and melamine-urea-formaldehyde (MUF). These are either used on their own or the core and the surface layers may use two different types of adhesive. The resinated strands are than formed into a mat (forming the board in layers), where the strands for the surface layers are oriented predominantly in one direction, while the strands for the core layer are either randomly orientated or orientated at right angles to those in the surface layers. The resinated mat is

pressed to a required density and thickness, usually in a multi-daylight press or a continuous press (Wood Panel Industries Federation).

Typical densities of OSB panels range between 600 and 680 kg/m^3 (Wood Panel Industries Federation).

OSB panels produced in the European market are specified and classified according to the requirements defined in the EN 300. According to that classification, the requirements for the following types of OSB are specified in the standard:

– OSB/1 - General purpose, non-load-bearing panels, and panels for interior fitments for use in dry conditions;
– OSB/2 - Load-bearing panels for use in dry conditions;
– OSB/3 - Load-bearing panels for use in humid conditions;
– OSB/4 - Heavy duty load-bearing panels for use in humid conditions.

According to the European Panel Federation data (2017) the OSB panels suitable for structural and non-structural use in dry conditions, accounted for 10% in 2016 (European Panel Federation, 2017). The load-bearing panel, suitable for structural use in humid conditions (OSB/3) is the major OSB type, which accounted for approximately 85% of the whole European output. The Heavy duty load-bearing OSB panels (OSB/4) accounted for 5% of the European OSB production (Mantanis *et al.*, 2017).

The OSB panels should generally be kept away from direct contact with water. OSB panels suitable for use in humid conditions are in a certain degree resistant to short-term wetting and high humidity, but are not intended for exposure to prolonged wetting (Wood Panel Industries Federation, 2014).

Because of its composition and characteristics, OSB is primarily used in construction where it is widely used for flooring, flat roof decking, roof sarking and wall sheathing. OSB panels are also used for packaging and in furniture production. OSB panels with a surface coating are available for non-structural applications, such as site hoarding.

Beside plywood as wood-based material, OSB panels are one of the mostly used wood-based panels in construction sector in our country. These panels are imported from other countries. For proper use of OSB panels it is essential for designers of wooden buildings, constructors and users to be familiar with the properties of these panels.

Also in past years in our country there is an increased interest for construction of wooden buildings where the wood-based panels are one of the basic materials for structural and non-structural use. In such buildings different types of OSB can be used as load-bearing members or as general purpose board depend on the place of incorporation in the building. Very often, buyers and users of wood-based panels are not familiar with different types of OSB panels, their categorization and characteristics that are intended for different application. That is way it is important to take an overview of the characteristics of these panels that are present in the market in our country, which will contribute in better understanding of the proper use of OSB according to their physical and mechanical properties.

For better understanding of OSB panels and their proper end use by constructors and designers, physical and mechanical properties of OSB panels present in the market are tested.

2. MATERIALS AND METHODS

For the realization of the research, oriented strand boards were taken by random choice from the storehouse of the company „Mikrotim“ from Kumanovo and transferred to the Laboratory for wood-composite materials at the Faculty of Forestry in Skopje. The OSB panels were product of the company „Kronospan Bulgaria EOOD-Burgas“ from Bulgaria. The product dimensions of the panels were 1220×2440×18 mm.

Test specimens for determination of the physical and mechanical properties according to the national and European norms were cut from the panels. The following properties were tested: density (MKS D.C8.114), moisture content (MKS D.C8.103), thickness swelling and water absorption (MKS D.C8.104), modulus of rupture (MOR-bending strength) and modulus of elasticity in bending-MOE (MKS EN 310), internal bond-IB (MKS EN 319), compressive strength (MKS D.A1.110) and hardness according to Janka.

Thickness swelling and water absorption are tested after 24 hours immersion in water, which is a standard treatment and after prolongation of the treatment up to 72 hours in order to see the behavior of the OSB panels during exposure of high humidity conditions and prolonged water impact.

The bending strength and modulus of elasticity in bending, as well as compressive strength were tested in five directions, i.e., parallel and perpendicular to the length of the panel and at the angles of 22,5°; 45° and 67,5° to the panel's length. Tests in different directions of the OSB panels will provide data for the strength characteristics of the OSB panels in different direction related to the structure of OSB.

The obtained data were statistically analyzed. One way ANOVA was used to determinate the significance of the effect of the direction of the force in bending and force of compression on the OSB bending strength and modulus of elasticity in bending, as well as on OSB compressive strength. Tukey's test was applied to evaluate the statistical significance between mean values of the properties in different panel direction.

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The obtained results for the physical and mechanical properties of OSB panels are shown in Table 1.

The mean value for thickness swelling after 24 hours immersion in water is above 20% (22,12%). The European norm EN 300 for OSB panels defines the maximal value for thickness swelling after 24 hours for different types of OSB as follows: for OSB/1 max 25%, for OSB/2 max 20%, for OSB/3 max 15% and for OSB/4 max 12%. According to these limitations, the tested OSB panels meet the requirements for general purpose OSB for non-load-bearing panels, and panels for interior fitments for use in dry conditions (OSB/1). The obtained mean value for this property does not corresponds with the maximal allowed value of 20%, which is stated in the technical specification of the boards given by the manufacturer „Kronospan Bulgaria EOOD-Burgas“ from Bulgaria. The manufacturer categorizes the tested OSB panels as type OSB/2 (load-bearing panels for use in dry conditions) which does not corresponds with the obtained values from the investigation of the thickness swelling.

The multiple layer mat structure of OSB has an influence on panel properties, notably on thickness swelling (Wang *et al.*, 2004). The thickness swelling is affected by many parameters that are related to mat structure, such as: number of layers, orientation, furnish quality, species, the ratio on a weight basis of face material to core materials, resin type, resin ratio, wax type, wax ratio etc. (Wang *et al.*, 2004).

Thickness swelling is one of the basic properties that determine whether the panel will be used in dry or humid conditions. That is way it is very important for constructors and designers to be aware of the climate conditions in which the OSB panels will be used.

The intensity of thickness swelling is highest in the first period of immersion in water (24 h). By prolonging the water treatment for 48 and 72 h, the thickness swelling increases, but with lower intensity.

The values of the water absorption of OSB correspond with those one of the thickness swelling. The tested panel has high values of water absorption, which is most intense in the first period of immersion (after 24 h). After 48 and 72 h immersion in water, the values of this property increase but with lower intensity.

According to the obtained value of internal bond, the tested OSB meets the requirements for all types of OSB panels including type OSB/4 for heavy duty load-bearing panels for use in humid conditions. The standard EN 300 defines the following minimal values of internal bond for OSB with thickness from 18 to 25 mm: for OSB/1 min 0,26 N/mm^2; for OSB/2 and OSB/3 min 0,3 N/mm^2 and for OSB/4 min 0,4 N/mm^2.

The OSB hardness test is not mandatory, and there is no sufficient literature data to make a comparison of the obtained value of hardness.

The statistical data for the bending strength and modulus of elasticity in bending of tested OSB are shown in Table 2 and 3.

The analysis of variance of the obtained data for bending strength (ANOVA: $F(4;51) = 35{,}016$; $p \ll 0{,}001$) showed that the there are statistically significant differences in the mean values of MOR in different directions of the panel at 0,05 probability level. The highest value of MOR is achieved in direction parallel to the length of the OSB panel, while the lowest value is achieved in cross-length direction. The values of MOR at the angles of 22,5°; 45° and 67,5° are between the values at these two directions (parallel and perpendicular to the length), whereas by increasing the angle, the value of bending strength is decreasing. Compare to the mean value of MOR parallel to the length of the panel, the mean value of MOR perpendicular to the length of the panel and at the angles of 22,5°; 45° and 67,5° to the panel's length is lower for 46,32%, 15,91%, 31,14% and 37,45%, respectively. The post-hoc Tukey's test showed that there are no statistically significant differences in the mean value of MOR perpendicular to the panel's length and at the angle of 67,5°, as well as between MOR at the angle of 45° and 67,5° to the panel's length.

The differences in the values of bending strength in different directions of OSB panel are a result of the orientation of the wood strands in panel structure. The orientation of the wood strands along the length of the panel in the face layers of the OSB panel has direct impact on achieving higher values of bending strength in this direction.

Table 1. *Statistical data for physical and mechanical properties of OSB panel*

Property	***N***	***Mean***	***Std. Deviation***	***Std. Error***	***95% Confidence Interval for Mean***		***Min***	***Max***
					Lower Bound	***Upper Bound***		
Density (kg/m^3)	12	599,91	22,51	6,50	585,60	614,21	554,80	634,67
Moisture content (%)	12	8,51	0,17	0,05	8,40	8,61	8,34	8,88
Thickness swelling after 24 h (%)	12	22,12	1,05	0,30	21,45	22,78	19,48	23,64
Thickness swelling after 48 h (%)	12	22,77	1,16	0,34	22,03	23,51	19,75	24,18
Thickness swelling after 72 h (%)	12	23,88	1,15	0,33	23,15	24,61	21,06	25,39
Water absorption after 24 h (%)	12	75,35	2,70	0,78	73,64	77,07	70,50	80,13
Water absorption after 48 h (%)	12	86,06	2,90	0,84	84,22	87,90	80,50	90,98
Water absorption after 72 h (%)	12	89,15	2,71	0,78	87,43	90,87	84,11	93,91
IB (N/mm^2)	10	0,40	0,05	0,02	0,36	0,44	0,32	0,50
Janka hardness (N/mm^2)	12	30,39	4,21	0,86	28,61	32,24	24,53	39,24

Table 2. *Statistical data for MOR in different directions of the panel*

Force direction	*N*	*Mean*	*Std. Deviation*	*Std. Error*	*95% Confidence Interval for Mean*		*Min*	*Max*
					Lower Bound	*Upper Bound*		
Parallel	10	19,17^{a}	2,47	0,78	17,41	20,94	15,02	23,35
Perpendicular	12	10,28^{b}	1,46	0,42	9,36	11,21	8,12	12,92
Angle 22,5°	11	16,12^{c}	2,54	0,76	14,41	17,82	12,72	20,46
Angle 45°	11	13,20^{d}	1,59	0,48	12,13	14,27	10,88	17,01
Angle 67,5°	12	12,00^{b,d}	1,59	0,46	10,98	13,00	9,04	15,57

The mean values with the same letters are not significantly different at 0,05 probability level

Table 3. *Statistical data for MOE in different directions of the panel*

Force direction	*N*	*Mean*	*Std. Deviation*	*Std. Error*	*95% Confidence Interval for Mean*		*Min*	*Max*
					Lower Bound	*Upper Bound*		
Parallel	10	2636,25^{a}	294,93	93,26	2425,27	2847,23	2080,06	3147,39
Perpendicular	12	1408,25^{b}	175,22	50,58	1296,91	1519,58	1090,77	1628,90
Angle 22,5°	11	2183,51^{c}	194,89	58,76	2052,58	2314,44	1876,27	2471,10
Angle 45°	11	1987,54^{c}	196,51	59,25	1855,52	2119,56	1634,59	2254,00
Angle 67,5°	12	1597,05^{b}	157,29	45,41	1497,11	1696,98	1335,80	1862,36

The mean values with the same letters are not significantly different at 0,05 probability level

The analysis of variance of the obtained data for modulus of elasticity in bending-MOE (ANOVA: $F(4;51) = 60,996$; $p<<0,001$) showed that there is a statistically significant differences in the mean value of this property in different panel directions at 0,05 probability level. The post-hoc Tukey's test showed that MOE parallel to the panel's length statistically differs from the MOE in all other directions of the panel. There are no statistically significant differences in the mean value of MOE perpendicular to the panel's length and at the angle of 67,5°, as well as between MOE at the angle of 22,5° and 45° to the panel's length.

The anisotropy of the OSB panel also can be seen from the polar diagram of bending strength shown on Figure 1.

The obtained values of bending strength meet the requirements for load-bearing panels (type OSB/2 and OSB/3) defined in the standard EN 300.

EN 300 defines the minimal value of 3500 N/mm^2 for MOE parallel to the panel's length for load-bearing panels OSB/2 and OSB/3 and minimal value of 1400 N/mm^2 for MOE perpendicular to the length of the panel. The obtained value of MOE parallel to the length of the panel is lower than the minimal value given by the manufacturer of the tested OSB boards. The tested OSB panel does not meet the requirements of the standard EN 300 for load-bearing panels in relation to the MOE parallel to the panel's length. According to the this obtained value and defined requirements by the standard, the tested OSB can be used only as general purpose, non-load-bearing panels, and panels for interior fitments for use in dry conditions (OSB/1).

By comparison of the obtained values of MOE with the values given in panel guides and technical documents (Cai and Ross, 2010; EPF-European panel federation; Structural Board Association, 2004; Stark *et al.*, 2010; Youngquist, 1999) can be concluded that this OSB can be use as general purpose board in dry conditions and does not meet requirements for structural load-bearing panels in wood constructions.

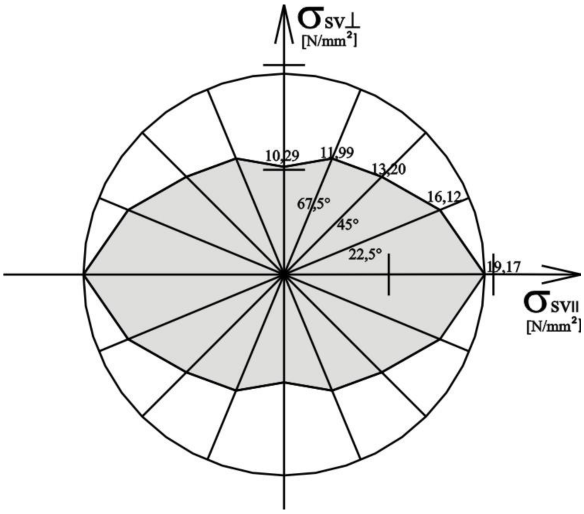

Figure 1. *Polar diagram of bending strength of OSB panel*

Figure 2. *Standard deformation of the test specimens during testing the bending strength*

The statistical data for the compressive strength of tested OSB are shown in Table 4.

Table 4. *Statistical data for compressive strength in different directions of the panel*

Force direction	***N***	***Mean***	***Std. Deviation***	***Std. Error***	***95% Confidence Interval for Mean***		***Min***	***Max***
					Lower Bound	***Upper Bound***		
Parallel	12	12,20[a, c]	1,23	0,35	11,42	12,98	10,65	14,40
Perpendicula r	10	8,95[b]	0,79	0,25	8,39	9,52	7,43	9,96
Angle 22,5°	11	12,98[c]	1,25	0,38	12,14	13,82	10,27	14,84
Angle 45°	12	11,48[a, d]	1,02	0,29	10,83	12,13	9,80	12,87
Angle 67,5°	12	10,38[d]	1,00	0,29	9,74	11,01	9,08	11,97

The mean values with the same letters are not significantly different at 0,05 probability level

The analysis of variance of the obtained data for compressive strength (ANOVA: $F(4;52) = 22,883$; $p<<0,001$) and post-hoc Tukey's test showed that the there are statistically significant differences in the mean values of compressive strength in different directions of the panel at 0,05 probability level. The highest value of this property is achieved when the direction of the force of compression is at the angle of 22,5° to the length of the OSB panel, while the lowest value is achieved when the compression force is perpendicular to the panels length. By increasing the angle between the direction of the force of compression and the length of the panel in the range between 22,5° and 90°, the value of compressive strength is decreasing.

The differences in the values of compressive strength in different directions of OSB panel are a result of the orientation of the wood strands in panel structure. The orientation of the wood strands along the length of the panel in the face layers of the OSB panel has direct impact on achieving higher values of compressive strength when the force of compression is parallel to the length of the panel and when it is at the angle of 22,5°.

The polar diagram of compressive strength is shown on Figure 3.

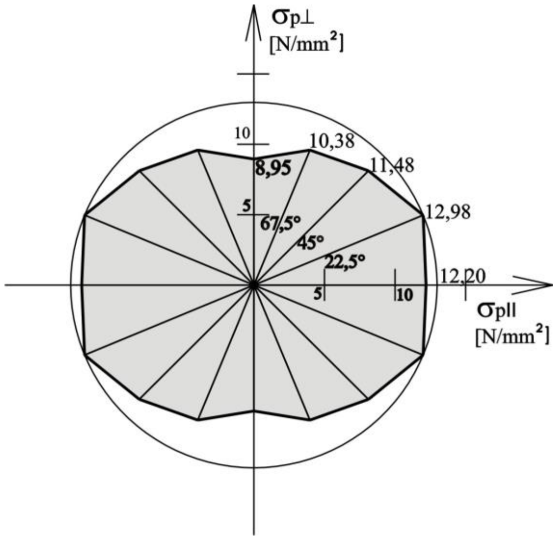

Figure 3. *Polar diagram of compressive strength of OSB panel*

Figure 4. *Standard deformation of the test specimens during testing the compressive strength*

4. CONCLUSIONS

Oriented strand boards are one of the most rapidly used wood-based panels for construction due to its good physical and mechanical properties. Proper application of OSB demands understanding of the basic physical and mechanical properties of the panels, especially of those one present on the market. Very often, buyers and users of wood-based panels are not familiar with different types of OSB panels, their categorization and characteristics that are intended for different application.

There are deviations found in the quality of the panels regarding to the obtained values of some of the tested properties in different direction of the panel. For some of the tested properties the OSB panels meet the requirements of the standard for load-bearing panels but only in one direction of the panel (such as the case with the MOE in bending). The obtained high value of thickness swelling defines the tested OSB panels as general purpose boards for use in dry conditions, which does not correspond with the obtained values of some of the mechanical properties according to which the OSB can be classified as load-bearing panel.

Tested OSB panels taken from our market are not fully in accordance to the technical specification given by the manufacturer of these boards and the requirements of the standards for OSB panels for use as structural load-bearing panels. On the basis of the specifications given by the manufacturers, the importers can introduce these panels as load-bearing panels for structural application, which does not correspond with the real quality of the boards. This is an issue that we must pay attention to.

The obtained results from this research can give directions for appropriate application of these panels according to their quality characteristics. In the same time, the importers of panels in the Republic of Macedonia can gain a better insight in the quality of the panels that they import.

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VARIATIONS OF THE HARDNESS OF BALKAN BEECH WOOD (*FAGUS MOESIACA CZ.*)

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ABSTRACT

The aim of this research is to determine the significance of the impact of the origin of wood trees (generative or vegetative), height of the cross-section (1,3 and 5,3 m above ground) and relative age of annual rings (distance from pith in radial direction) in which the measurements are made, on the variation of wood hardness, at near same ecological factors.

For determination of wood hardness Brinell method is used, and for statistical processing of the data from the measurements, software package SPSS Statistics 21 is used.

On the basis of the obtained values form the tests for normal distribution of the hardness and analysis of the homogeneity of the variance, as well as on the basis of multiple comparison for determination of statistical significant differences between average values of wood hardness from different tree trunks, cross-section and age, it is found that the trees from vegetative origin produce wood with significantly higher hardness compare to the trees form generative origin. Among the two cases, the wood hardness of section 1,3 m is significantly higher than the wood hardness of section 5,3 mm. The increment of the relative age of annual rings in trees from vegetative origin in certain interval is followed by increment in wood hardness, whereupon the wood hardness decreases, while in trees from generative origin, first in certain interval the hardness is decreased, whereupon it is increased.

The obtained results of these researches, supplemented with the comparative researches of processing of standard (from generative origin) and nonstandard (from vegetative origin) timber should be taken in consideration when choosing the technological process.

Key words: wood hardness, variation factors, vegetative origin, generative origin, height of trunk section, relative age of annual rings

1. INTRODUCTION

It is now believed that on the Balkan Peninsula, excluding its farthermost southeastern part, which is occupied by the range of oriental (Eastern) beech *Fagus orientalis* Lipsky, Balkan beech *Fagus moesiaca* Czeczott is present [2]. Apart from generating, the Balkan beech is also renewed along a vegetative way. It is an important biological property that distinguishes it from common beech (Fagus sylvatica Line). This made it possible for the representation of spatial plantations that quantitatively in our country dominate over the plantations of generative origin.

In world’s professional literature, there are numerous data on the technical properties of wood from *Fagus sylvatica* as summated Linnaeus specie. Within these, there are also data on the hardness of the wood which are important for its application, and determine the hardness and quality of the processing tool. The values for hardness in the direction of wood fibers in the common beech obtained by the Brinell method range around 70 MPa [4].

The data on the hardness of the Balkan beech are limited and they mainly refer to wood of generative origin or the origin is not taken into account [1, 5, 6]. Through the selection of test material from vegetative and generative trees that are growing at near same ecological factors, thereto taking care of the height of the cross-section above ground surface from which we take the research material to be 1,3 and 5,3 m, as well as the relative age of the annual rings grouped in segments of 10, within which we place the measuring points for determining the hardness of the wood, we establish conditions for determining the significance of the origin of the trees, the height of the cross-section and the relative age of annual rings, as variation factors. This, in addition to the theoretical significance, is the basis for the possibilities for compensation of beech wood from generative origin, which is deficient, with a beech of vegetative origin.

2. ORIGIN OF THE MATERIAL FOR INVESTIGATION

The material for our research was taken from the forest-spatial unit "Mavrovo" from sections 5a and 5b.

Subsection 5a covers an area of 48,20 ha. It is a beech plantation of mesophile growth location. The altitude above sea level ranges from 1500 to 1620 m with north to northwest exposure and a slope of the land of 15 to 20%. The geological base is silicate rocks, and the soil is sour brown forest soil, medium deep, sandy loam, skeletal and sufficiently humus. The plantation is of a generative origin (high forest), and it has an irregularly selective structure, with quality trees and in good health.

Subsection 5b covers an area of 10,50 ha. It is a beech plantation of mesophile growth location. The altitude above sea level ranges from 1400 to 1560 m with west to northwest exposure and slope on the land of 15 to 25%. The geological base is silicate rocks, and the soil is sour brown forest soil, medium deep, sandy loam, skeletal and sufficiently humus. The plantation is of vegetative origin (low forest) with a uniform structure, with medium quality of trees and in good health.

From the above mentioned, it can be seen that the trees from vegetative and generative origin develop with approximately the same ecological factors [7, 8].

3. METHOD OF THE EXPERIMENTAL WORK

Of the two subsections (5a and 5b), 3 trees from each generative and vegetative origin are cut by the method of random selection. When selecting the trees, it was insisted the trees to be dominant, straight and have full woody trunks. The pronounced extension of the trunks at the base and their distribution in groups were features characteristic for the trunks of subsection 5b, declared by the Forest management plan for the forest management unit “Mavrovo” 1986-2005, as a low forest plantation with a uniform structure, while in the trees of subsection 5a these features have not been noticed and the plantation have been declared as a high forest plantation with an irregularly selective structure.

The trees from vegetative origins were with the age of the trunk base: 68, 72 and 82 years, diameter at chest height (1,3 m): 22, 20 and 27 cm, and total height: 21,20, 19,80 and 22,20 m. The trees from generative origin were with age of the trunk base: 140, 140 and 160 years, diameter at chest height (1,3 m): 29, 22 and 32 cm, and total height 28,60; 25,60 and 29,40 m.

The wood hardness is tested on prismatic segments on which are accurately counted for 10 annual rings from the hart to the periphery of the trunk. The form and dimensions of the test specimens differ from those prescribed by the Standard for determining the wood hardness according to the Brinell method, but the achieved number of measurements and positive empirical findings for insignificant differences in the obtained results are in addition to the aim of the research. During testing, the moisture content in the wood ranged from 9 to 10%, so the values obtained for the hardness were additionally reduced to 12% humidity, i.e, in the standard dry condition, using the standard formula for this purpose [3].

Statistical software SPSS Statistic 21 was used for statistical analysis of the obtained data from the measurements.

4. RESULTS FROM THE EXPERIMENTS

The wood hardness at trees from vegetative origin at height of cross-section of 1,3 m above ground surface summated for all three trunks is obtained on the basis of 270 measurements. It was ranging in the limits of 64,70 to 94,60 MPa with an average of 80,05 MPa, standard deviation of 6,49 MPa and standard error of standard deviation of 0,40 MPa.

The variations of the wood hardness in radial direction from the pith to the periphery of the cross-section we presented it by histogram on figure 1.

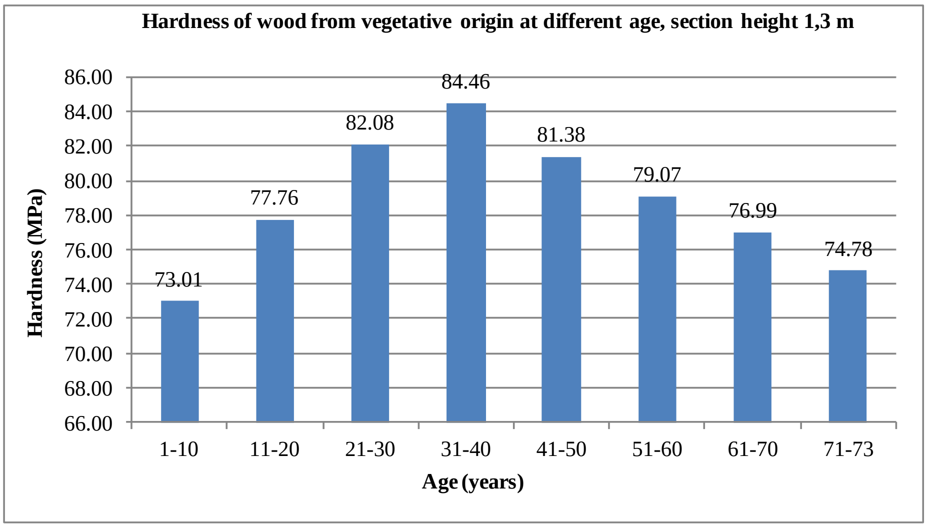

Figure 1. *Variation of the wood hardness in radial direction of the cross-section at 1,3 m height at trees from vegetative origin*

The wood hardness at trees from vegetative origin at height of cross-section of 5,3 m above ground surface summated for all three trunks is obtained on the basis of 253 measurements. It was ranging in the limits of 64,70 to 89,30 MPa with an average of 77,35 MPa, standard deviation of 5,59 MPa and standard error of standard deviation of 0,35 MPa.

The variations of the wood hardness in radial direction from the pith to the periphery of the cross-section we presented it by histogram on figure 2.

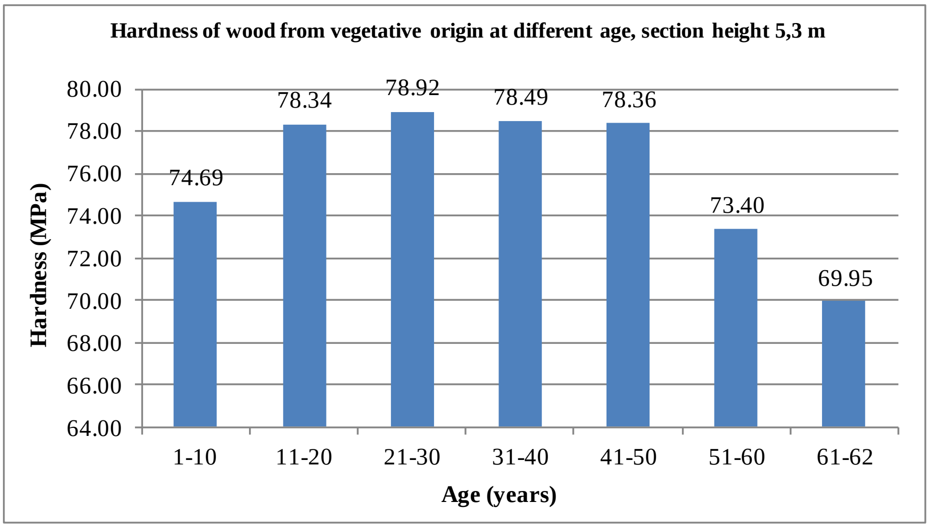

Figure 2. *Variation of the wood hardness in radial direction of the cross-section at 5,3 m height at trees from vegetative origin*

The wood hardness at trees from generative origin at height of cross-section of 1,3 m above ground surface summated for two trunks is obtained on the basis of 277 measurements. It was ranging in the limits of 53,40 to 84,30 MPa with an average of 65,53 MPa, standard deviation of 6,25 MPa and standard error of standard deviation of 0,38 MPa.

The variations of the wood hardness in radial direction from the pith to the periphery of the cross-section we presented it by histogram on figure 3.

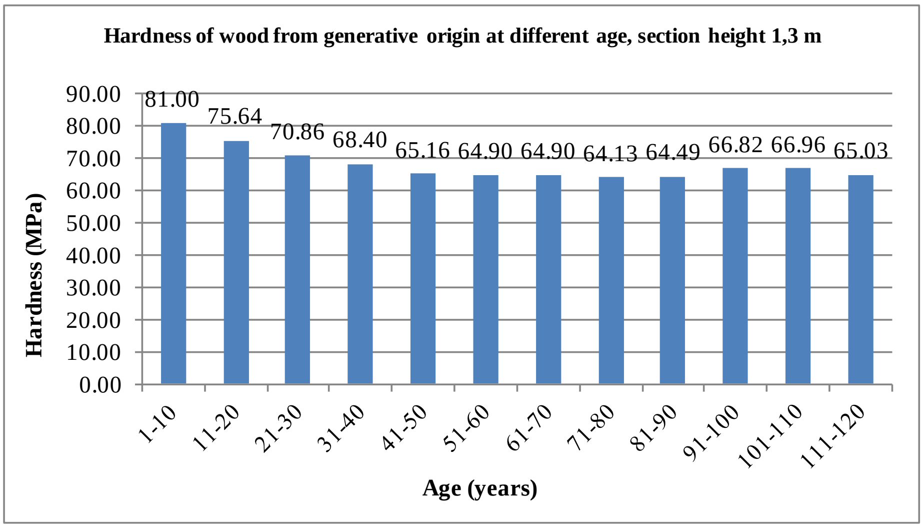

Figure 3. *Variation of the wood hardness in radial direction of the cross-section at 1,3 m height at trees from generative origin*

The wood hardness at trees from generative origin at height of cross-section of 5,3 m above ground surface summated for all three trunks is obtained on the basis of 410 measurements. It was ranging in the limits of 48,00 to 84,30 MPa with an average of 62,96 MPa, standard deviation of 6,52 MPa and standard error of standard deviation of 0,32 MPa.

The variations of the wood hardness in radial direction from the pith to the periphery of the cross-section we presented it by histogram on figure 4.

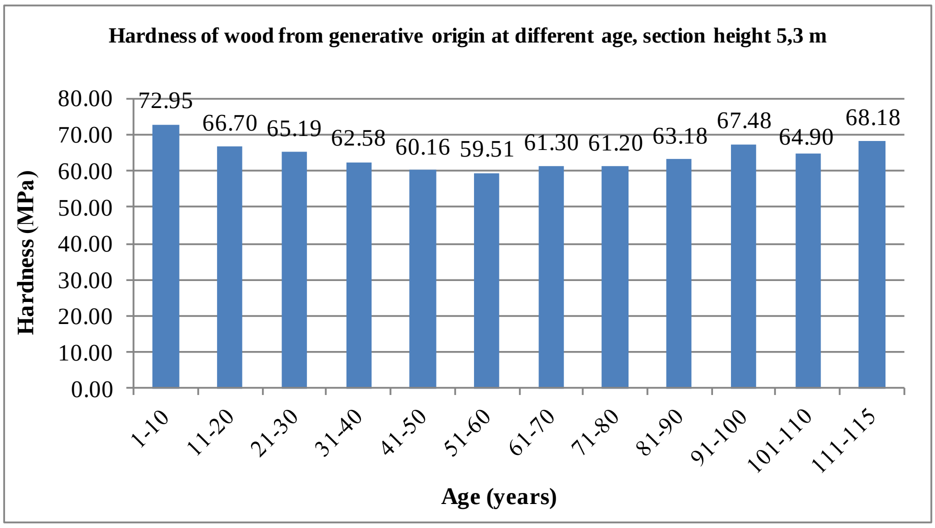

Figure 4. *Variation of the wood hardness in radial direction of the cross-section at 5,3 m height at trees from generative origin*

5. DISSCUSSION

The Balkan beech (*Fagus moesiaca* Czeczott) of vegetative origin produces a wood with a significantly higher hardness than the Balkan beech of generative origin from trees that developed in near same ecological factors. In both cases, the hardness of the wood at the tree section of 1,3 m above the ground surface is significantly higher than the hardness of the wood at the tree section of 5,3 m above the ground surface.

At both sections, the increase in the relative age of the annual rings, in the trees of vegetative origin for a certain period of time, is accompanied by an increase in the hardness, followed by its decrement, whereas in the trees of generative origin, in the first period we have a decrement of the hardness, followed by its increment.

The mean values of the wood hardness in the direction of the wood fibers from the Balkan beech of vegetative origin obtained by the Brinell method are higher than the values of hardness in common beech (*Fagus sylvatica* Line).

Regardless of the fact that beech forests of vegetative origin (low forests) are biologically predetermined to create small-sized timber, in conditions where a lack of standard timber is present, and the development of final processing and tailored sawn-wood production influences the interest in production and processing of a small-diameter timber, the rational exploitation of low beech forests, which are quite present in our country, should get in particular significance.

The obtained results of these researches, supplemented by comparative researches of the processing of the standard (large-size) and non-standard (small-size) timber, when choosing the technological procedure, should be taken into consideration.

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DETERMINATION OF THE FIBER SATURATION POINT OF AUTOCHTHONOUS AND ALLOCHTONOUS WOOD SPECIES

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ABSTRACT

The aim of this research is to determine the fiber saturation point of wood from *Fagus moesiaca, Quercus sessilis, Quercus conferta, Robinia pseudoacacia, Pinus nigra, Pinus silvestris, Abies alba, Picea excelsa*, *Pseudotsuga menziesii*, *Cupressus arizonica*, *Sequoiadendron giganteum*, *Pinus strobus* and *Larix decidua*, as a contribution to the utilization of wood.

The material used for investigation was collected from twenty-eight methodologically selected localities.

The obtained average values of fiber saturation point are based on wood density and volume shrinkage, in accordance with the standard for wood investigation.

The results from investigation of fiber saturation point of wood from autochthonous species are within the limits of the up to now empirical and scientific knowledge. The obtained values for the allochthonous species that are subject of our investigation, can significantly impact on further introduction.

Key words: fiber saturation point of wood, autochthonous and allochthonous species, nominal density, volume shrinkage, durability

1. INTRODUCTION

Thefiber saturation point of wood is its characteristic state of humidity, where the walls of the cells are saturated with water, and their lumens filled with air. It represents the maximum content of hygroscopic water in the wood.

The condition, at which the free water completely evaporated, while the total hygroscopic water in the wood has been left, has great theoretical and practical significance. The theoretical significance sublimates the analytical correlation between the change of the hygroscopic water and the properties of the wood, and the practical significance becomes obvious when making drying regimes and assessing the utility and durability of the wood.

At the fiber saturation point, the wood has maximal dimensions, and the lowest mechanical properties. With the loss of hygroscopic water, the wood begins to decrease the dimensions - it shrinks, and increases the mechanical properties.

The fiber saturation point is different for different wood species and is usually between 20 and 40% moisture content, with an average of 30 % [1, 6, 7, 8, 9].

The wood of the species with a low fiber saturation point can be used in humid environment because the natural mechanical properties retain for a long time in a quality condition, while the wood species with a high fiber saturation point between 30 and 40 % can be used in places where the humidity of the environment is below that point.

The fiber saturation point affects the durability of the wood. The wood of species with a lower fiber saturation point is with greater natural durability and vice versa, the wood of species with a higher fiber saturation point has less durability, excluding the impregnated wood.

The methods for determining the fiber saturation point are based on the observation of the variations of some physical and mechanical properties of the wood depending on the change of its moisture content. These variations become obvious within the hygroscopic region where they have a characteristic trend of change, and with the exceeding of the fiber saturation point they remain almost unchanged.

In our research, we determine the average values of the fiber saturation point in the wood of autochthonous and allochthonous species on the basis of its volume shrinkage and the nominal density. With this we can foresee the utility of the wood from the aspect of the humidity of the environment in which its durability is used. This is of particular importance to the wood of allochthonous species whose introduction for economic purposes is not older than fifty years.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

The values for the fiber saturation point of the wood of autochthonous and allochthonous species are determined indirectly as a quotient of the volume shrinkage of the wood and its nominal density, which were the subject of our already presented and published research [10, 11].

3. RESULTS FROM THE RESEARCH

The histograms of the mean values of the nominal density, the volume shrinkage and the fiber saturation point of the wood from autochthonous and allochthonous species, subject of our investigations, are given on Figures 1, 2 and 3.

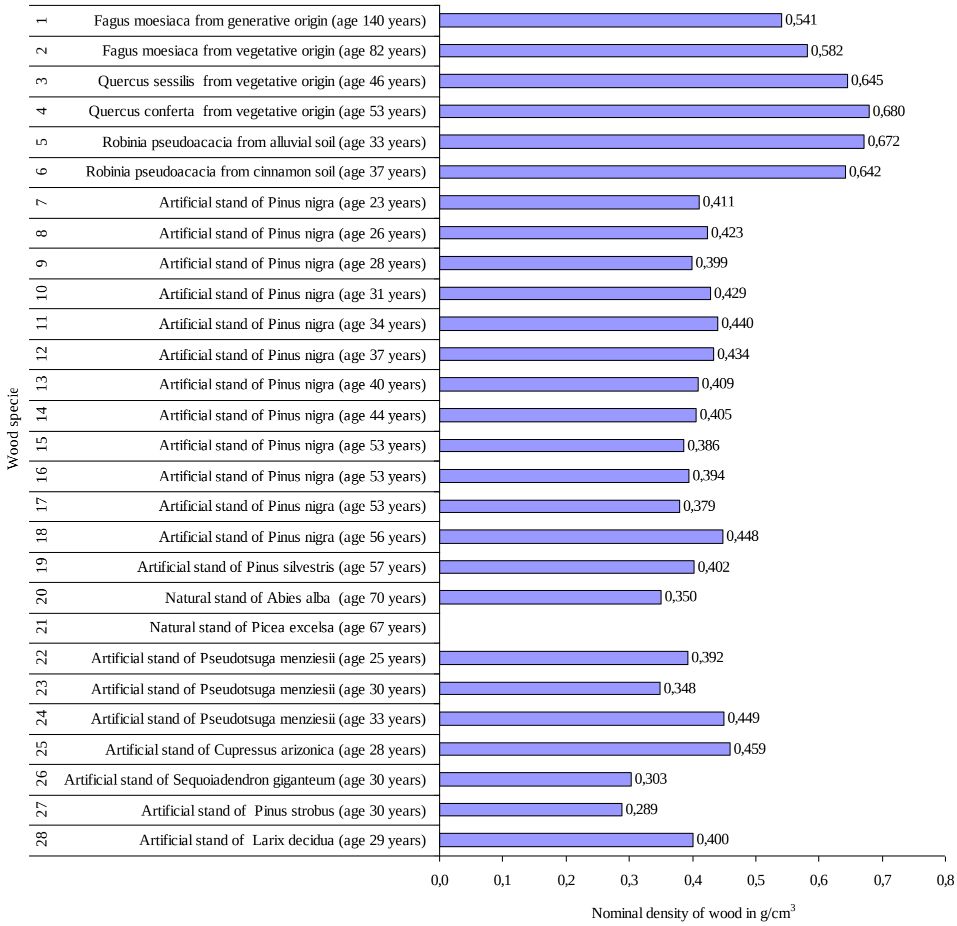

Figure 1. *Nominal density of wood from autochthonous and allochthonous species*

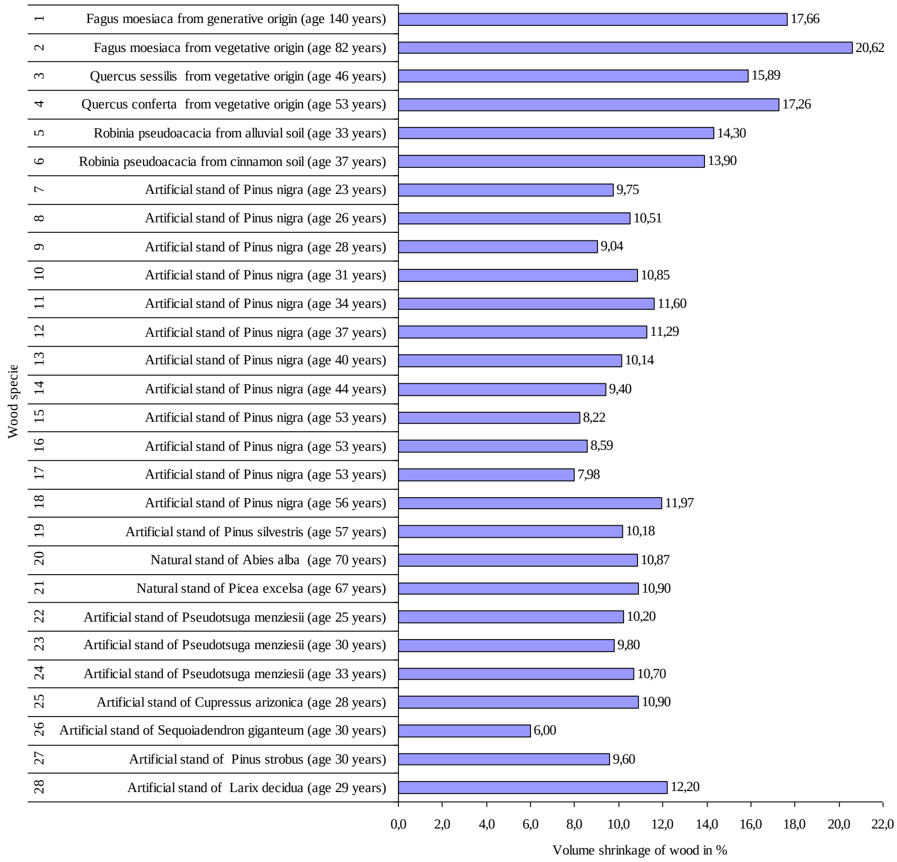

Figure 2. *Volume shrinkage of wood from autochthonous and allochthonous species*

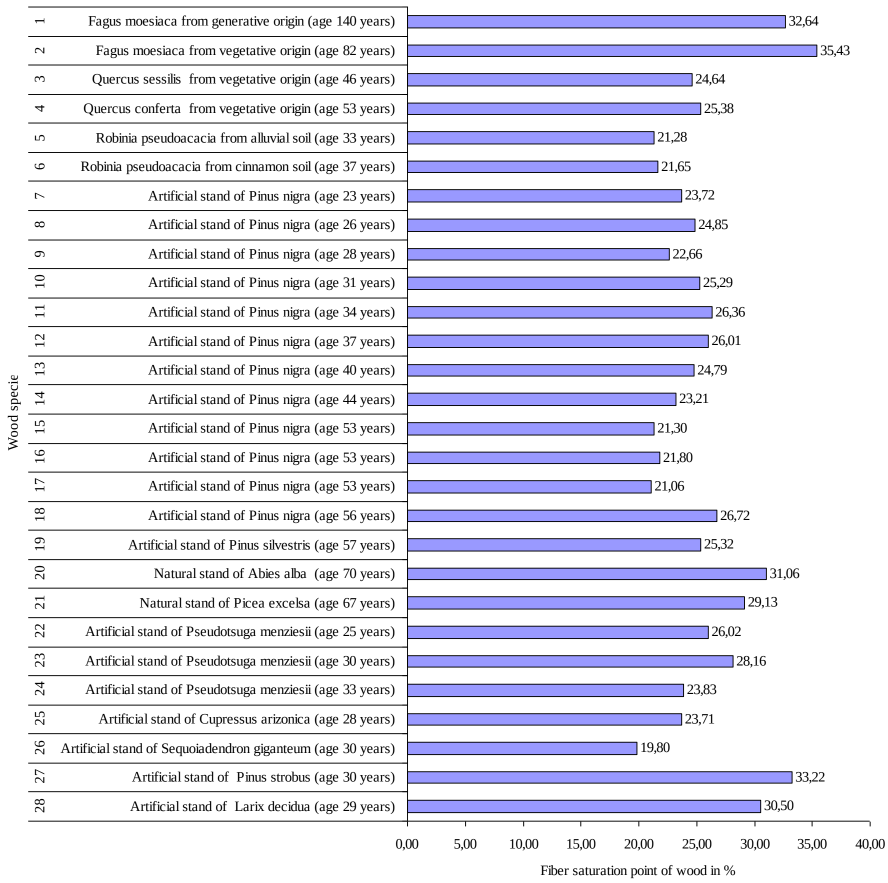

Figure 3. *Fiber saturation point of wood from autochthonous and allochthonous species*

4. DISCUSSION

The fiber saturation point of the wood of Balkan beech *(Fagus moesiaca)* from generative origin (32,64 %) is lower by 7,87 % compared to the fiber saturation point of the beech wood from vegetative origin (35,43 %).

The fiber saturation point of the Cornish oak *(Quercus sessilis)* (24,64 %) is lower for 2,92 % compared to the fiber saturation point of Hungarian oak *(Quercus conferta)* (25,38 %).

The fiber saturation point of the wood from black locust *(Robinia psedoacacia)*, which developed on alluvial soil (21,28 %) is lower for 1,71% compared to the fiber saturation point of the wood from black locust that developed on cinnamon soil (21,65 %).

The fiber saturation point of the wood from black pine *(Pinus nigra)* artificially raised plantations is lowest in the locality of „Pochivalo” in the region of Shtip (21,06 %), and highest in the locality of „Ramnoborje” in the region of Pehchevo (26,72 %) .

The fiber saturation point of the wood from white pine *(Pinus silvestris)* (25,32 %) is lower for 5,24 % compared to the fiber saturation point of the wood from black pine (26,72 %) which whom it develops in the artificially raised plantations in the locality of „Ramnoborje” in the region of Pehchevo.

The fiber saturation point of the wood from fir *(Abies alba)* and spruce *(Picea excelsa)* from natural stands is 31,06 % and 29,13 %, respectively.

The fiber saturation point of the wood from Douglas fir *(Pseudotsuga menziesii)* is highest from the plantation in the locality of „Ramnoborje” in the region of Pehchevo (28,16 %), lower from the plantation in the locality of „Gorici” in the region of Belchishta (26,02 %) and lowest from the plantation in the locality of „Vitachevo” in the region of Kavadarci (23,83 %).

The fiber saturation point of the wood from cupressus aphid *(Cupressus arizonica)*, giant redwood *(Sequoiadendron giganteum)*, mountain pine *(Pinus strobus)* and European larch *(Larix decidua)* is 23,71 %, 19,80 %, 33,22 % and 30,50 %, respectively.

The differences between the average values of the fiber saturation point of wood from different species are understandable by themselves, and they are genetically conditioned. However, variations in the fiber saturation point within the same species, and even when using the same method for determination is much more difficult to explain. It is considered that the best method for determining the fiber saturation point of wood is by means of the electrical conductivity, followed by the determination by the strengths, while the determination by volume shrinkage is the most accessible and simplest method [7, 8, 9].

When comparing the obtained mean values for the fiber saturation point of the wood from artificially raised plantations of *Pinus nigra* and *Pinus silvestris* as autochthonous species, i.e. *Pseudotsuga menzisii*, *Cupressus arizonica*, *Sequoiadendron giganteum*, *Pinus strobus* and *Larix decidua* as allochthonous species, we also had in mind their age of about thirty years, at which irrespective of the dimension of the trunk, the wood leaves the juvenile and enters the adult development phase. The wood formed in these two phases is with a different structure that determines the variability of the technical properties.

The presented mean values for the fiber saturation point of wood from all investigated species are within the limits determined by other authors.

The fiber saturation point of wood from investigated species is highest in the Balkan beech *(Fagus moesiaca)* of vegetative origin (35,43 %), and lowest (19,80 %) in the giant redwood *(Sequoiadendron giganteum)*.

The obtained data on the fiber saturation point of wood from autochthonous species enrich the existing mosaic of scientific knowledge, while the determined average values for the fiber saturation point of the wood from allochthonous species are the first of that kind in our country. In both cases they are the basis for making drying regimes and the evaluation of the utility and durability of the wood.

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LUMBER VOLUME YIELD FROM BLACK WALNUT (*JUGLANS NIGRA* L.) LOGS

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ABSTRACT

This paper experimentally and theoretically researches the performance indicators of sawmill processing of black walnut (*Juglans nigra* L.) logs in sawn boards. The research covered the veneer and sawmilling logs of the black walnut classified according to the Croatian standards. For the requirements of the experiment, the logs at the sawmill were classified into four qualitative classes: 1st class veneer logs, 2nd class veneer logs, 1st class sawmilling logs and 2nd class sawmilling logs. Logs were sawn up in the 30 and 50 mm nominal thickness of sawn boards. A mechanized line based on vertical log band saw with hydraulic carriage was used for primary sawing up. The 1st class veneer logs proved to produce the best lumber volume yield results. The 2nd class sawmilling logs proved to produce the worst volume yield results.

Key words: Black walnut (*Juglans nigra L.*), veneer log, sawmilling log, sawmilling, sawn board, lumber volume yield

1. INTRODUCTION

Black walnut (*Juglans nigra* L.) is a species of the eastern part of North America, which was introduced in Europe in 1629 (Jovanović, 1985). It was initially grown as a park type, and later to the present day, it is increasingly used as an economic species. Black walnut is poorly represented in wood species in Croatia. In the total wood stock in the Republic of Croatia, it is represented only by 0.1%. Black walnut comes exclusively as part of a forest community and very rarely can it be found as part of an orchard or courtyard. The tradition of cultivating a black walnut culture in a community with one or more autochthonous or alohton tree species has been more than a hundred years old in the area of Eastern Slavonia. In the area that is being managed by the Croatian Forests, the site of the forest Vinkovci, facility Vukovar and Ilok Forestry, the seed was brought in 1899 (Herman, 1971). The reason for the introduction of black walnut in the forest was drying oak (Sevnik, 1926). The cultures of black walnuts of the Vukovar region are developed in the community of the oak-tree forest and the common hornbeam (*Carpinus betulus* L.) with turkey oak (*Quercus cerris* L.) (Rauš, 1969), which represents a transitional forest-based community. Matić & Prpić (1983) state that black walnuts are suitable for afforestation in protected habitats of oak trees where they will produce valuable wood masses.

Due to the poor presence in forests as well as other fruit trees, the black walnut is processed in small quantities in Croatian sawmills and veneer factories. The black walnut final industrial processing in Croatia almost does not exist, but it serves as a raw material for some foreign industries in the production of exclusive furniture and other luxurious items. Accordingly, its processing processes are less explored. But on the other hand, as a very appreciated type of wood, it also gives a certain interest in a number of unknowns in this case, sawmilling processing.

Given that in this part of the research we will deal with walnuts some research results related to sawmill processing of this species of wood will be stated.

Dunmire et al. (1972) found that a volume yield of black walnut low quality and small-sized round wood used to produce the sawmill products is in the range from 26 to 47%.

Rosen et al. (1980) explored the utilization in sawmill processing of short low-quality sawmill raw material of black walnut. Primary orientated cutting is carried out by live sawing technique. After orientated sawn boards were dried to 8% moisture content and reduced to a final thickness and classified into three classes of quality. Based on these findings, the authors have drawn diagrams predicting utilization of such logs due to their length and thickness of the sawn board to be sawn from them. It was also found that the volume yield, and therefore the financial effect when processing such sawmill raw material, is up to 15% smaller, as opposed to the standard sawmill raw materials processing.

Stewart et al. (1982) analysed the economic acceptability of processing of thin and short low-quality round wood with a diameter of 15 cm and more, and length of 0.6 m and more, on three hypothetical sawmills. The cost-effectiveness of investing in facilities that worked on such raw material was also considered. The analysis was based on observations at several existing sawmills. Each hypothetical sawmill was equipped with conventional machines, or with innovative machines. Basic materials were unedged sawn boards obtained from thin big tooth aspen (*Populus grandidentata* Michx.), black walnut and black cherry (*Prunus serotina* L.) round wood. The results show that the most economically favourable is processing of black walnut followed black cherry and at the end the big tooth aspen. In general it was found that the larger sawmill and the more valuable wood species, the greater the economic acceptability of processing. Comparing the conventional and innovative type of processing, given the energy costs and actual cost, innovative methods have demonstrated better results.

Huber et al. (1983) continued with similar studies. This time they studied the actual cost of processing of thin and short low-quality sawmill raw material of poplar (*Populus* spp.), black cherry, silver maple (*Acer saccharinum* L.), american aspen (*Populus tremuloides* Michx.) and black walnut. The final products were elements for furniture production. This research was carried out on a hypothetical example using a computer program, and the points of equalizing costs were analysed. Point of equalizing was determined so that the amount of small diameter round wood was increased until the number of elements obtained after processing was not equal to that obtained from the standard round wood. The black walnut showed the highest point of equalizing costs; primarily because of the high cost of standard sawmill raw materials. The conclusion was that thin and short low-quality sawmill raw material from valuable wood species has a wide area for competition with the classic sawmill raw material.

An interesting study was conducted by Phelps and Chen (1989). They have studied the properties of logs and wood of plantation grown and naturally grown black walnut. The quality of logs and sawn boards, wood shrinkage, wood defects, the percentage of core, increment and specific density were compared. It was shown that sawn boards of naturally grown black walnut are a class better than sawn boards of plantation grown black walnut. Logs made from plantation trees had more knots, because of dead branches, which could have been avoided if the trees on plantation were let to grow for about eight years; because it would then be about the same age as the trees that have grown naturally. This would increase the quality of sawn boards from marginal parts of the logs from plantation trees. The results obtained indicate that to get higher quality logs in plantation cultivation the trees would have to grow closer together the first 10 to 15 years, and then thinning was done. Logs from the plantation had 20% less core than from naturally grown, and 40% faster growth. Finally, they found that the plantation grown trees were younger and shorter, with a faster growth rate and a lower core percentage than naturally grown trees. Wood from plantation trees was of lower quality than from naturally grown, because it had more knots. All the sawn boards dried well, shrinkage was within the permitted and drying did not change the quality of wood. No difference in specific density between plantation and natural trees was noticed; but it clearly changed from the core to the bark. They found that the properties of wood were affected by the age, genotype and the environment, but it is not known to what extent.

Prka et al. (2001) and Ištvanić at al. (2011) have studied the volume yield of logs of common walnut (*Juglans regia* L.) at certain stages of sawmill processing. The results have shown that the volume yield of class I. logs when making sawn boards is around 72%, and for the class II. 69%. Volume yield of logs in the form of dimension stocks and raw parquet steaves amounted for class I.

about 35%, and for the class II. about 26%. Volume yield and the financial returns of sawing these wood species is very similar to sawing pedunculate oak (*Quercus robur* L.), sessile oak (*Quercus petraea* Matt.) and common European beech (*Fagus sylvatica* L.). Volume yield in parquet production is closely correlated to volume yield in primary and secondary sawmills. Therefore, the volume of finished two-ply parquet, as the final product, increased in the plant where this research was conducted and also increased in the processing of higher-quality class sawlogs.

Ištvanić et al. (2016) have studied the volume yield of small-sized round wood of common walnut in Croatia. The results have shown that the volume yield of round wood during its processing into sawn boards ranged from 54.34% to 88.83%. Volume yield of round wood during its processing into dimension stock and raw parquet staves ranged from 17.01% to 52.14%.

Rabadjiski et al. (2015) researched the impact of quality, diameter and length of common walnut logs on volume yield in the production of unedged, halfedged and edged boards. They were logs from 36 to 55 cm diameter. Depending on their length, the logs were distributed into the four group: 1.5 m, 2.0 m, 2.5 m and 3.0 m. These results showed volume yield of round wood was 61.24 to 68.10 %. Relation between volume yield and group of length in walnut logs is determined using function: $Y = -8.08x^2 + 38.68x + 21.15$ with coefficient on correlation 0.973.

2. AIM OF RESEARCH

In Croatian forests, fruit trees are represented by only 0.5%. The most important species are: common walnut, wild cherry (*Prunus avium* L.), sweet chestnut (*Castanea sativa* Mill.), black walnut, olive (*Olea europea* L.), wild apple (*Malus communis* L.), wild pear (*Pyrus pyraster* L.), mountain ash (*Sorbus aucuparia* L.), service tree (*Sorbus domestica* L.) etc. It should be mentioned that although very attractive and somewhat unique, the demand for these species of wood depends on the trends in design and design of furniture.

Most of the black walnut logs, whether of logs for processing in cut veneer or sawmill processing, end up in Western European countries, and most often in Italy. Similar destiny is also made with sawmill products of black walnuts either in the form of sawn boards or wooden elements. The final product of black walnut in Croatia almost does not exist, possibly as a semi-finished product in the form of mass glued wooden boards and prefabricated parquet.

Because of its high value, as well as a small number of articles (especially from the point of view of sawmill processing), the black walnut in Croatia is a very interesting species for research. Therefore, the aim of this research is to experimentally and theoretically investigate one of the indicators of the success of sawmill processing of black walnut logs, which is the volume yield in the processing of logs in sawn boards

3. OBJECTS AND METHODS OF RESEARCH

In the youth, black walnut is a particularly beautiful tree because of its pyramidal crowns and large leaflets, and as an adult tree planted in parks and other urban forestry areas, it gives a rich shade. They grow over 30 m and sometimes up to 50 m and reach a 2 (3) m diameter chest. Broad branches are crowned, so the trunk does not reach the top of the trellis. An old tree with a crowned crown, especially if grown apart, may have thick branches, 10 m or more. The stump is high, dark. The early young tree is grayish-gray to grayish-brown and smooth. The rampage begins in the third or fourth year. In old trees, the tree is deeply oblong and dark brown to grayish. The leaves are aromatic when they last, (4) 6 to 12 (19) cm long, (1.5) and 2 to 5 (8) cm wide, eyelid, long and pointed to the tip. The fruit is rounded or slightly melted, 3.5 to 6 cm in diameter and aromatic.

Sawmill and veneer logs are produced from the technical round of black walnuts. It is also possible to technically use the underground part (stump and root). Most commonly, black walnut trees are treated like other types of sawing and cutting on a veneer knife. Sawn timber and veneers are further used to produce every kind and finest exclusive furniture, interior decorations, special products for various purposes and especially for making hunting rifles gunstock.

The black walnut is very valuable, colored heartwood and diffuse-porous wood species. The wood has a remarkable glossy texture and firmness and is very durable. It is resistant to the action of various fungi and insects. In anatomical terms, it resembles common walnut. Fresh wood smells like asphalt.

The color of black walnut wood is very recognizable from its chocolate to purple-brown color of the heartwood and whitish to the yellow, gray and grayish and light-colored sapwood. The color on the fresh cross section is changed by the drying and the flow of time from the turquoise green to the bluish that loses itself and passes into a characteristic chocolate-brown color. By thermal processing, weaving, it comes to equalizing the color of the obstinate and unresponsive part.
Black Walnut wood is easily handled by all tools and machines. It is very easy to coat with waxes and easily polishes. The adhesion also suits well, as well as the fastening of bolts and nails, which hold great.

3.1. Log selection and measurement

The study is based on Black walnut trees harvested from Croatia the site of the forest Vukovar, facility Jelaš. The logs were graded according to Croatian norm regulations HRN-D.B4.028 and HRN-EN-1315-1. A total of 137 Black walnut logs were separated into four grades. The 1st grade veneer logs consisted of 7 logs. The 2nd grade veneer logs consisted of 49 logs. The 1st grade saw logs consisted of 54 logs. The 2nd grade saw logs consisted of 27 logs. The minimum log length was 1.6 meter, but they could also be longer. The minimum mid-diameter was 19 cm, but they could also be greater (figure 1, 2 and 3).

All sample logs were measured without bark by length and mid-diameter. Descriptive statistics were executed for all analysed variables: Average, standard deviation, minimum, median, and maximum. For log mid-diameter and length, the significant, difference in medium values and group of data were verified. These parameters enabled the analysis of raw material structure for experimental sawing. Individual log volume calculated according to equations (1). For statistical data analysis on the volume yield Microsoft Office Excel was used.

$$V_{\log} = \frac{D_{\mathrm{mid}}^{\;2} \cdot \pi}{4} \cdot L_{\log} \tag{1}$$

where: $V_{\log}$ – log volume, m^3; D_{mid} – mid diameter of the log, m; $L_{\log}$ – log length, m.

3.2. Processing logs in the primary sawmill

The primary sawmill, where this study was conducted, was located in Kapela Podravska, Croatia. Mill equipment included a 1400 mm log band saw headrig, with automatic hidraulic-operated carriage, an edger and a cross-cut circular saw.

Logs were processed individually on the log band saw using the live sawing method. All sawn boards produced in this research were intended for further processing at the same facility, and therefore were not separated according to quality. Boards were produced with a nominal thickness of 30 and 50 mm and with 22 % moisture content (figure 1.). Taking shrinkage into account, the target saw thickness was 32 and 55 mm. Since the boards were not edged, width oversize was not calculated.

The oversize for the sawn board nominal length was at least 2 cm. The 30 mm boards were sawn from the outer portion or jacket of the log. Thicker boards were sawn from the center part of the log. All sawn boards produced from the sample logs were measured for thickness, width, and length according to EN 1309-1 and EN 1313-2 and sawn board volume was calculated based on these parameters. The amount of coarse saw residue (slabs, log end off-cuts, edgings, trimmings etc.) and sawdust were not measured and were not included in the research.

In a primary sawmill, lumber volume yield is defined as the ratio of the sawn board volume and log volume according to equation (2):

$$Y_{\mathrm{Volume\ log}\rightarrow\mathrm{board}} = \frac{V_{\mathrm{board}_{30}} + V_{\mathrm{board}_{50}}}{V_{\log}} \bullet 100 \tag{2}$$

where: $Y_{Volume\ log \rightarrow board}$ – lumber volume yield, %; V_{log} – log volume, m^3; $V_{board\ 30}$ – sawn board volume of a nominal thickness of 30 mm, m^3; $V_{board\ 50}$ – sawn board volume of a nominal thickness of 50 mm, m^3.

Figure 1. *Black walnut logs and sawn boards*

4. RESULTS AND DISCUSSION

The total of 5.794 m^3 of 1st class veneer logs was sawn into 3.888 m^3 sawn boards, 28.016 m^3 of 2nd class veneer logs was sawn into 18.821 m^3 sawn boards, 17.917 m^3 of 1st class saw logs sawn sawn into 11.570 m^3 sawn boards and 4.758 m^3 of 2nd class saw logs was sawn into 3.035 m^3 sawn boards. Descriptive statistical analysis of data on its dimensions is shown in Tables 1. and 2. Each log quality group is presented separately. Comparison of log mid-diameter and length are shown in Figures 2 and 3. Lumber volume yield of is presented in Table 3 and in Figure 4.

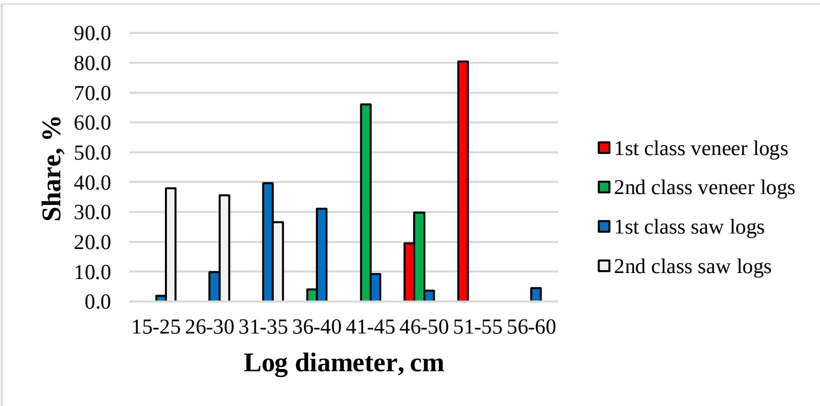

Figure 2. *The share of diameters by class logs*

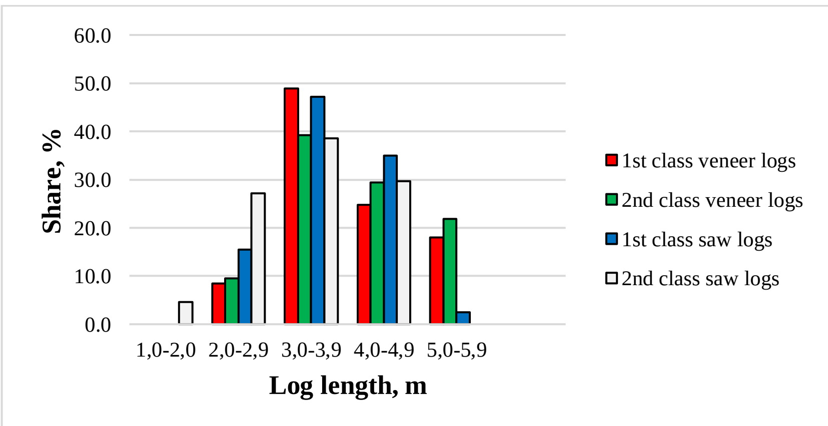

Figure 3. *Proportion of the length of logs by class*

***Table 1**. Descriptive statistics for the dimensions of Black walnut logs*

Log size	1st class veneer logs					
	N	Min.	Median	Max.	Average	Std. dev.
Length, m	7	2.40	3.50	5.00	3.59	0.86
Mid diameter, cm	7	48.00	51.00	65.00	53.14	5.93
Volume, m^3	7	0.492	0.781	1.433	0.828	0.334
Log size	**2nd class veneer logs**					
	N	Min.	Median	Max.	Average	Std. dev.
Length, m	49	2.20	3.60	5.80	3.84	0.96
Mid diameter, cm	49	38.00	43.00	49.00	43.16	2.99
Volume, m^3	49	0.276	0.506	0.995	0.572	0.185
Log size	**1st class saw logs**					
	N	Min.	Median	Max.	Average	Std. dev.
Length, m	54	2.00	3.40	5.20	3.47	0.77
Mid diameter, cm	54	22.00	34.00	58.00	34.46	6.10
Volume, m^3	54	0.087	0.317	0.792	0.332	0.134
Log size	**2nd class saw logs**					
	N	Min.	Median	Max.	Average	Std. dev.
Length, m	27	1.60	3.20	4.40	3.18	0.78
Mid diameter, cm	27	19.00	25.00	33.00	26.07	3.81
Volume, m^3	27	0.060	0.166	0.338	0.176	0.071

***Table 2.** Descriptive statistics for the dimensions of Black walnut sawn boards*

Sawn board size	1st class veneer logs					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	64	1.1	3.2	5	3.22	0.9135
Width, cm	64	13	40	51	36.8	9.87350
Volume, m^3	64	0.00693	0.06122	0.12810	0.06107	0.03358
Sawn board size	**2nd class veneer logs**					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	217	1	3.5	5.2	3.51	0.90504
Width, cm	217	11	26	38	25.17	7.09482
Volume, m^3	217	0.0042	0.03072	0.08325	0.03099	0.01556
Sawn board size	**1st class saw logs**					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	377	1	3.25	5.2	3.22	0.90
Width, cm	377	11	25	49	24.54	7.71
Volume, m^3	377	0.00290	0.03285	0.08325	0.03212	0.01783
Sawn board size	**2nd class saw logs**					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	116	0.7	2.95	4.4	2.90	0.94187
Width, cm	116	11	20	31	19.51	5.19949
Volume, m^3	116	0.00281	0.02605	0.05400	0.02616	0,01473

Table 3. *Lumber volume yield of all logs*

Class of logs	$Y_{Volume\ log \rightarrow board}$					
	N	**Min.**	**Median**	**Max.**	***Average***	**Std. dev.**
1st class veneer logs	7	62.9	65.8	72.1	67.3	3.7
2nd class veneer logs	49	54.6	66.6	78.1	66.6	5.0
1st class saw logs	54	52.3	65.1	81.6	65.1	6.1
2nd class saw logs	27	48.0	63.7	82.5	63.8	9.4

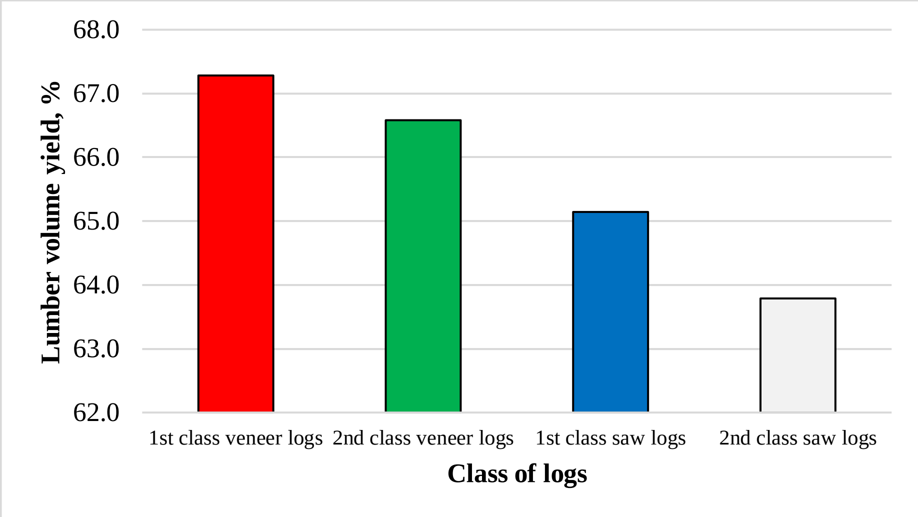

Figure 4. *Comparison of average lumber volume yields*

In analyzing the results of lumber volume yield, results indicated that the best yield came from 1st class veneer logs, followed by 2nd class veneer logs, and then equally by 1st and 2nd class saw logs. These results appear to be correlated to the quality and dimensional structure of the log being sawn. Statistical analysis indicates that, in both quality grades veneer logs, have somewhat greater dimensions in terms of diameter and length (Tables 1 and Figures 2 and 3.). In producing unedged sawn boards, these factors can have a significant effect on the volume yield. This was reflected in the results of the veneer logs.

The results obtained compared to Dunmire et al. (1972) showed more values. Compared with the previous researches on the performance of sawmill processing of common walnut Rabadjiski et al. (2015) obtained the same results or somewhat worse Prka et al. (2001) and Ištvanić et al. (2016). The circumstances and the conditions of these researches should take into account when we making comparisons.

5. CONCLUSION

- Black walnut is a poorly represented in wood species in Croatia and grows only in the area of Eastern Slavonia,
- Research on the success of sawmill processing of black walnuts in these areas is very rare,
- Lumber Volume yield of the 1st class veneer logs was 67.3%, the 2nd class veneer logs were 66.6%, the 1st class saw logs were 65.1%, and the 2nd class saw logs were 63.8%,
- The 1st class veneer logs proved to produce the best lumber volume yield results. The 2nd class sawmilling logs proved to produce the worst volume yield results,
- Overall, the research results confirm increased volume yield with better logs quality and diameter. The results indicate a possibility of rational processing of the researched black walnut logs in sawmills,
- It would be interesting to conduct a further researches of sawn boards, first in elements, then in glued massive wood panels.

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MAXIMUM QUANTITATIVE YIELD OF HARDWOOD LOGS IN THE TECHNOLOGY OF SAWMILL PROCESSING

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ABSTRACT

This paper deals with the analysis of the maximum quantitative yield of beech, poplar, oak, chestnut and walnut sawmill logs. Beech logs were I - st, II - nd and III -th class of quality, poplar logs I - st, II - nd class of quality and oak, walnut and chestnut logs I - st class of quality. Maximum quantitative yield of beech logs from experimental tests ranges between 44,18 % and 51,50 %, the average value being 45,50%.Maximum quantitative yield of poplar logs were higher and ranged between 56,87% and 58,30%, the average being 58,30%.The average values of maximum quantitative yield of oak, walnut and chestnut logs varies from 66,82% for oak, which is the highest value, 58,00 % for walnut and 68,20% for chestnut.

Key words: quantitative yield, logs, beech, poplar, oak, walnut, chestnut

1. INTRODUCTION

In the analysis of the maximum quantitative yield of the hardwood logs into the sawmill assortments are included logs of beech, aspen, oak, walnut and chestnut. Regarding the class of quality they are from I, II and III class. Beech logs have a length of 3.0, 4.0 and 5.0 m and mean diameter ranging between from 25.0 to 70.0 cm. The logs of the aspen are 2.0, 3.0 and 4.0 m long, and the average diameter ranging between is 35.0 to 85.0 cm.

The oak and chestnut logs, due to the small quantities are I class of quality and have a length of 2.0, 2.5, 3.0 and 4.0 m and mean diameter ranging between of 34.0 to 55.0 cm .

Based on the composition of the sawing disposition, the raw material is specifically sawed into assortments with previously known dimensions.

2. WORKING METHOD

Before starting the processing, the raw material was purified from impurities (mud, sand, etc.) and the length and diameters were measured. Based on these data the log's volume is calculated. The analysis was covered 165 beech logs I / III class of quality, 60 aspen logs I / II class of quality, 20 oak logs I class of quality, 20 walnut logs I class of quality and 25 chestnut I class grades of quality.

Technologically, the logs were first sawn on logs band saw, and the secondary processing involved transverse and longitudinal cutting.

Appropriate mathematical formulas were used to calculate the results.

The analysis was made on the basis of the outgoing data: wood species, annual number of logs, log dimensions, drop in log's diameter, class of quality of the logs and level of processing of the saw mill assortments.

3. RESULTS AND DISCUSION

Having applied the technological procedure and sawing disposition, the results are related to:
- max. quantitative yield of beech logs, I / III class of quality;
- max. quantitative yield of aspen logs, I / II class of quality;
- max. quantitative yield of oak logs, I class of quality;
- max. quantitative yield of walnut logs, I class of quality and
- max. quantitative yield of chestnut logs, I

3.1 Quantitative yield of beech logs, I, II and III class of quality

The results are shown in Table1.

Table 1. *Balance of quantitative yield of beech logs, I, II and III class of quality*

BALANCE	Class of quality			Quantitative yield	
	I	II	III	V_o	P
	V_1 (m^3)	V_2 (m^3)	V_3 (m^3)	(m^3)	%
Sawn wood	144,2	100,80	286,26	531,26	22,10
Beams from the heart wood for pallets	41,2	116,21	402,95	560,36	23,40
			TOTAL:	1092,00	45,50
Coarse waste	105,1	164,90	545,1	814,55	33,90
Sawdust	36,4	54,34	182,2	272,55	11,40
Shrinkage allowance	33,1	44,31	143,5	220,90	9,20
			TOTAL:	1308,00	54,50
TOTAL QUANTITY OF LOGS I/II CLASS OF QUALITY				2400,00	100,00

Max. quantitative yield from saw mill processing of 2400 m^3 beech logs, I/III class of quality is 45,50%.

3.2 Quantitative yield of aspen logs, I and II class of quality

The results from the from practical testing are presented in Table 2.

Table 2. *Balance of quantitative yield of aspen logs, I and II class of quality*

BALANCE	Class of quality			Quantitative yield	
	I	II	III	V_o	P
	V_1 (m^3)	V_2 (m^3)	V_3 (m^3)	(m^3)	%
Lumber 32,0 mm in thickness	6,8	21,9	-	28,7	28,70
Lumber 50,0 and 60,0 mm in thickness	8,2	18,5	-	26,7	26,70
Laths	0,8	2,1	-	2,9	2,00
			TOTAL:	58,3	58,30
Coarse waste	4,2	16,5	-	20,7	20,70
Sawdust	3,0	9,6	-	12,6	12,60
Shrinkage allowance	2,0	6,3	-	8,3	8,30
			TOTAL:	41,7	41,70
TOTAL QUANTITY OF LOGS I/II CLASS OF QUALITY				100,00	100,00

3.3 Quantitative yield of oak logs, I class of quality

The results are shown in Table 3.

Table 3. *Balance of quantitative yield of oak logs, I class of quality*

BALANCE		Quantitative yield	
		V_o	P
		(m^3)	%
1.	Lumber 32,0 mm - 42,0 mm in thickness	7,3	21,12
2.	Lumber 50,0 mm - 60,0 mm in thickness	14,7	43,36
	TOTAL (1+2):	22,0	64,48
3.	Coarse waste	5,4	15,76
4.	Sawdust	3,6	10,66
5.	Shrinkage allowance	3,0	9,10
	TOTAL (3+4+5):	12,0	35,52
	TOTAL (1-5)	34,0	100,00

3.4 Quantitative yield of walnut logs, I class of quality

The results are shown in Table 4.

Table 4. *Balance of quantitative yield of walnut logs, I class of quality*

BALANCE		Quantitative yield	
		V_o	P
		(m^3)	%
1.	Lumber 25,0 mm - 42,0 mm in thickness	7,0	20,55
2.	Lumber 50,0 mm - 60,0 mm in thickness	16,0	46,27
	TOTAL (1+2):	23,0	66,82
3.	Coarse waste	4,7	13,76
4.	Sawdust	3,3	9,82
5.	Shrinkage allowance	3,0	9,60
	TOTAL (3+4+5):	11,0	33,18
	TOTAL (1-5)	34,0	100,00

3.5 Quantitative yield of chestnut logs, I class of quality

The results are shown in Table 5. In the saw mill processing technology of raw materials, the logs are of different types of wood, different sizes and class of quality. For these reasons, the quantitative yield of logs is different and ranges from 48.0 to 70.0%.

According to Milčovski (2014), during the processing of walnut logs with a length of 1,5 m to 3,0 m from the II class of quality it was found that the quantitative yield ranges from 61,0 % to 64, 0%, and for logs of III class of quality from 48,0 % to 56.0%.

The author Rabadjiski (1991), during the processing of beech logs, I/III class of quality, with a diameter of 26.0 to 55.0 cm and a length of 4.0 m, concluded that the average quantitative yield with gater is from 46,28 up to 57,48% and with a band saw from 48.19% to 58.92%.

Šoškić and Popović (2004), during the processing of beech logs, I class of quality concluded that the quantitative yield of the raw material is ranged from 47.0 to 62.0%, an average of 60.0%. For the II of quality, average is 54,0% and for those of the III class 49,0%.

Table 5. *Balance of quantitative yield of chestnut logs, I class of quality*

BALANCE		Quantitative yield	
		V_o	P
		(m^3)	%
1.	Lumber 25,0 mm - 42,0 mm in thickness	7,4	23,05
2.	Lumber 50,0 mm - 60,0 mm in thickness	14,6	45,15
	TOTAL (1+2):	22,0	68,20
3.	Coarse waste	4,2	13,18
4.	Sawdust	3,0	9,22
5.	Shrinkage allowance	2,8	9,40
	TOTAL (3+4+5):	10,0	31,80
	TOTAL (1-5)	32,0	100,00

4. CONCLUSIONS

Based on multi-month surveys, we can make the following important conclusions:

1. Beech logs

I / III class of quality, quantity of logs 2400 m^3, quantitative yield for logs of I class of quality is 51,50%, quantitative yield for logs of II class of quality is 45,21%, quantitative yield for logs of III class the quality is 44,18%, the quantitative yield for logs of the I / III class of quality is 45,50%, the final percentage of the maximum quantitative yield of the I / III class quality logs is 42,48%. The value of 45.50% was decreased by 3.08%, which is the value of the sawdust from the processing of beams from the zone of the heart wood into pallets and the quantity of waste (coarse waste and sawdust) is 1104.0 m^3 or 773t.

2. Aspen logs

I / II class of quality, quantity of logs 75 m^3, quantitative yield for logs of I class of quality is 63,24%, quantitative yield for logs of II class of quality is 56,87%, quantitative yield for logs of I /II class of quality is 58,30%, the quantity of waste (coarse waste and sawdust) is 60,0 m^3 or 31,2t.

3. Oak, Walnut and Chestnut logs

I class of quality, quantity of logs: oak 34 m^3, walnut 34 m^3 and chestnut 32 m^3, quantitative yield for logs of oak, I class quality is 66.82%, quantitative yield for logs from the walnut, I class quality is 58,00%, quantitative yield for chestnut logs, I class of quality is 68,20%, total quantity of waste (bulk coarse waste and sawdust) is 24,0 m^3 or 16,8 t.

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ANALISIS OF POTENTIAL FOR DEVELOPMENT OF RURAL TOURISM THROUGH THE PRISM OF ARCHITECTURE AND DESIGN IN THE REGION OF MALESIA

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ABSTRACT

The motive for such a study was the valorization and categorization of architectural heritage in some rural areas in North Macedonia that are located close to larger urban areas and the possibility of sustainable spatial development as well as the promotion of rural areas through action in areas such as architecture, urbanism, spatial planning, environmental protection, development of the civil sector and development of rural tourism.

For this purpose, we analyzed several rural entities and villages in Malesija region. We selected the locations because they are located close to larger town centers such as Struga and Ohrid, and the possibilities for development of rural tourism.

Key words: rural tourism, rural architecture

1. INTRODUCTION

The mountainous area of Malesia, located in southwestern part of N.Macedonia, belongs to the Struga region. It is an area whose villages are mostly of a broken type or combination, in which the Macedonian architecture, typical of this region, is preserved. Due to influences from the outside world, as most of the population in this area were migrant workers, but also because of historical events, the villages in Malesia were often burned to the ground and rebuilt. Today the villages of Malesia are almost deserted due to the factor of village-to-town migration that began in the aftermath of World War II, yet in the summer many former permanent residents return and enjoy nature and their former homes. The countryside is surrounded by beautifull forests and especially rich flora and fauna.

The Malesia area is a mountainous area in southwestern Macedonia near to touristic cities Struga and Ohrid that extends north to Stogovo Mountain to Debarca Zupa, east to Karaorman Mountain, where it borders the Debarca area, west to the Black Drim River and south to Struga Field. The narrower area covers the villages of Arjanovo (Rzanovo), Selci, Zakamen, Lokov, Burinec, Prisovjani and Zbazdi.

Zbazdi is a mountain village located at an average altitude of 1060 m. It is surrounded by tall mountain ranges and mountain branches. The village of Zbazdi is located on the west, southwest side of Mount Karaorman, at an altitude of 1060 m, surrounded by thick oak and beech forests, to the south by the village of Prisovjani and the most remote village in the area. To the west it borders the villages of Lokov and Globocica, to the north with the village of Rzanovo and to the east its area extends through Karaorman to the village of Pesocan. The village church in this village, St. The Mother of God is one of the oldest churches in Malesia and is believed to date from the beginning of the 17th century.

In the written records for the first time the village is mentioned in the beginning of the XIX century under the name Zobozdi ”

The houses are stone with loggia, teal, have a lower level, and on the "house" floor and rooms. Mostly they were built from the so-called "black stone", which abounds near the village attar. Like other villages in Malesia, most villagers were migrant workers who used to work as confectioners and sugar growers in the past. Craftsmanship as well as the search for a better life are some of the reasons why this region is almost uninhabited today.

Lokov, formerly known as Lokve, is located on the western part of the area at 1340 m above sea level and overlooks the villages of Zbazdi and Rzanovo. Although it is the highest village, it is located on a plain. The houses were built of stone and there was a school in his attic since ancient times, and there are three churches and two monasteries. This village is divided into several neighborhoods: Upper Neighborhood, Lower Neighborhood, Na Rid, U Belchevci and is of a broken type. Most of the crops here were cultivated with various cereals, potatoes, fodder, and livestock was developed as it is abundant with numerous pastures, with a large number of pastures throughout Malesia.

Locals were known mainly as bricklayers, especially stone. There is evidence that many buildings in Struga were made of stone by Lokovski masters. ”

The water supply system in Lokov was built in 1928. Often throughout history Lokov was burned to the ground, but his inhabitants always rebuilt it. During World War II the village of Lokov was burned down almost completely, and today there are mostly new buildings in it.

Arjanovo or Rzanovo is a compact village situated on a slightly rounded slope, north of Malesia, at an altitude of 1260 m. Located north of Zbazdi, they are separated by the Bigla Mountain Pass, bordered by the village of Lokov on the west, and Karaorman Mountain on the north and east. In its surroundings there are limestone rocks with poor vegetation. The road leading to Rzanovo is dirt and in poor condition, and it was built by the residents themselves in 1975.

The villages Selci and Burinec are villages that are built opposite each other, at 1050 m altitude, are separated by a distance of 2 km by air and divides the Slileska River. The village of Burinec is the smallest village in Struga Malesia and was often considered in the past to be a continuation of the village of Selci and is located at an altitude of 1050 m. Both villages are surrounded by dense oak, beech and chestnut forest, which abounds in wildlife. It is divided into two neighborhoods, with a gender breakdown as in the Selci, but also in all other villages in the region.

2. SPATIAL AND FUNCTIONAL ANALYSIS OF THE HOUSES IN MALESIA

The potential of the natural beauty in this region is undeniable, but the real pearl of Malesia is the traditional village house, which in its untouched and unchanged form is a monument of perfection achieved by the builder adapting it to the everyday needs of the individual, using local materials . The traditional village house in Malesija is primarily functional and adapted to existing field conditions. With its preserved form and architectural - ethnological features, the Manor House is a valuable sample and representation of the Macedonian traditional construction and undoubtedly needs to be separated and preserved as an important cultural - historical monument. The villages of Lokov, Selci, Burinec, Rzanovo, Zbazdi and Prisovjani are representatives of the narrower Malesia, whose houses because of their indigenous architectural appearance are the focus of this paper and refer to them. The primary emphasis is on the grounds of the living spaces and their decoration, but also on the whole house and its value from the perspective of the possibility of developing rural tourism as an option for their preservation, lest they fall into oblivion and the disgust of time.

The constructive system, as a combination of massive and skeleton, is of particular importance and has played an important role in the process of standardization, as it is itself an instrument for the formation of the architectural space.

The ground floor facilities in the buildings are as a rule economical and economical, with a kernel and cell, while on the floor are the living rooms: the house and the room (s). In original objects there is often no sanitary node (it is outside), while later parts are adapted for that purpose. The porch, the porch and the loggia are three characteristic elements that define the main facade of the buildings.

"The porch in front of the house is an airy space under the shade, it is an extremely spatially-plastic element."

The porch is a passage room, ie its function is primarily to allow communication between the ground floor and the floor of the house through stairs that continue from it leading to the stele or the chardonnay. As a room that is usually located on the ground floor, it is in the immediate vicinity of the house, uniting all the other surfaces in the house. This room can be of indoor or outdoor type.

According to the form the porch is predominantly rectangular or square, very rarely of irregular shape. The porch on the ground floor of the houses is located on the side where the entrance is located.

Very often the porch facilities also have verandas, balconies or balconies on the floors. It can be said that the function of the porch and the loggia was primarily to enable communication at all levels of the house. The beginnings of the construction of the rampart and porch were born from the porch connected to the steps of the entrance, gradually developing in parallel with the development and complexity of the house. The stele was mounted on the ceiling beams that were spread out about one meter from the building and were always connected to the roof construction. The spatial closure of the surface of the body is accomplished by placing vertical planks - parties, all over the height of the floor, holding out the beams that separate the upper part of the house from the coral, which also fulfills the function of ventilation, and enriches the facade decoration. . The width of the stele was usually one meter and often extended around the house to the toilet, also called the word ale. The alley was mostly built on the back of the building or as a continuation of the stele, and sometimes as a separate building in the courtyard of the house itself. In some houses the middle room that fulfills the function of a porch, has no front wall and connects to the stele, increasing the room itself and its functionality. "The floor of the loggia is either of planks, or of short planks nailed to one another, and there is a loan attached to them. The loggia is enclosed in a height of one meter, or more with wooden boards - pieces ”

The loggia, which can be defined as a retrofitted double veranda on most of the front wall, mostly appears in front of the building entrance in an orthogonal form connected to the pillar wall, through the attic beams on the ground floor and first floor and covered with a roof over the city. Depending on the needs and desires of the hosts, it could be open or closed, or partitioned with boards. "Functionally defined and defined as a space, the loggia appears on the floor of the house."

The width of the loggia was not very large, but sufficient to accommodate a loom, a bed or bedding, a barn, and the like. The main housing unit is the "house", a space where most of the day is spent cooking, eating, sometimes sleeping, living at the same time. In it is the fireplace, where all actions take place. The rooms are sleeping rooms, they are beautifully decorated, and they are also used as guest rooms.

3. TYPOLOGICAL ANALYSES

"The typological diversity of architectural forms depends on the layout of the objects, their horizontal and vertical development at the base of the structure of the object." With the change of social conditions, but also of the economic and social situation of the family as an individual is a right proportionally related to the development of the house. In this respect, we distinguish two types of development of the village house: horizontal and vertical development, ie the addition of new units in it, which inevitably evolved, and thus the culture of living grew. "The basic elements of skeletal construction are:

1. Continuous beam, 2. Freehold (pillar), 3. Sloping beam (beam).

This means that the skeletal system consists of horizontal and vertical structural elements, which are elastically attached to the sloping element, in a stable whole whose basic form is a triangle, or without the sloping element, in a rectangle or square. " To make a typological analysis of the houses we will refer to their horizontal and vertical development as starting points. In terms of vertical development, attention will be paid to the floor of the house, in other words the vertical direction. Horizontal development refers to the increase in the number of rooms on the living room floor - popularly called "mattress", but also to the ground floor. The appearance of the porch and the loggia, which give a distinctive stamp to the maelstrom house, is a typical typological feature of the exterior appearance of the buildings.

3.1 TYPOLOGICAL ANALYSES ACCORDING TO THE VERTICAL DEVELOPMENT OF THE HOUSE

In the typological analysis of houses, the basic rule applies the flooring of the house, as well as its construction in relation to the materials used, in this case stone and wood, as well as the methodology for building the walls and their placement, in other words the vertical direction. In terms of vertical development in this analysis we will consider precisely the floor. Malesia houses were dominated by ground and floor houses, as well as two-storey houses, and rarely three-storeys, with different variations, the lower part being for cattle and food storage and the upper for living.

It should be noted that more multi-storey houses were built near steep slopes and then the first floor was treated as winter and the third as summer and served as a reception. They were always built on the top floor mounted on the ceiling beams that were leased out within a meter of the building and were always connected to the roof construction.

One should also mention the loggia, which forms part of the general contents of the house, connecting the other rooms. Accordingly, the vertical development of the buildings in Malesia can be classified into the following groups:

- House with ground floor and barn, undermined at the base,
- House with ground floor and floor and
- Multi-storey house;

3.2 TYPOLOGICAL ANALYSES ACCORDING TO THE HORIZONTAL DEVELOPMENT OF THE HOUSE

Horizontal habitat development preserves their expansion based on socio-economic needs and historical developments. As the needs of the owners increased, the number of rooms in the house increased.This analysis is a representation of the spatial resolution of the house, which enables it to determine its typological profile in this respect.

For example, an increase in the number of separate rooms, that is, in addition to the main room "house", which is located on the floor and represents a winter apartment where the fireplace is located, also the room - a room for sleeping or receiving guests.

The number of floors on the floor depended on the size of the family. In terms of the number of additional rooms beside the main "house" room, there are two types of buildings:

- With one room
- With more rooms

In the lower part of the house beside the coral there is often another room - an oak which is used for disposing of objects but was once used for temporary accommodation of the bridegroom and the bride. In terms of organization on the ground floor there are:

- Houses with only economic premises on the ground floor and
- Houses with economic and commercial premises on the ground floor;

As part of the horizontal development of the buildings in this area we can notice the fraternity houses, although the independent houses are dominant, so we do the following typification:

- Detached house and
- Fraternal House;

3.3 TYPOLOGICAL ANALYSES BY THE TYPE AND ARRANGEMENT OF THE LOGGIA AND THE TERACE

The typical appearance of the exterior of the buildings is the appearance of the porch, balconies, terraces and verandas. "The mansion houses, those of the more intelligent inhabitants, on one side, usually the one in the south (in winter to heat the house in the sun), had a 'loggia'." In this region it is typical to use a narrow form of loggia or rug that was placed on one or two sides of the house, usually longer, and less frequently around all four walls. The beginnings of the creek and loggia were born from the porch connected to the steps of the entrance, gradually developing in parallel with the development and complexity of the house

Depending on the layout and type of the loggia we can classify houses in Malesia ie "The central loggia is most commonly used which maintains the ideal symmetry of the object, both in terms of spatial conception and layout of facade elements. . "

According to the layout of the loggia we can divide the houses into:

- House with a central loggia,
- House with corner loggia and
- House with a front loggia;

Depending on whether the loggia is partitioned or not, we distinguish:
- House with open loggia and
- Closed loggia house;

While based on the layout of the loggia with respect to the spatial volume of the base we distinguish:
- A house with an airy ejected loggia and
- A log house that follows the line of the building's basic size;

Houses that have a loggia are still called open houses, while those without a loggia are called closed houses.

For houses with cast iron, depending on whether the cast iron is cast only on one side of the facade or extends to several sides relative to the base, there are the following types of house:
- Single sided house
- House with multiple side rails;

4. FIELD LAYOUT OF THE OBJECTS

Depending on the layout of the terrain, objects can be undermined, almost to the first floor, or freely elevated in space. During their construction, the front - entrance side was always oriented towards the sunniest direction. The construction was done by installing one side, that is, a wall in the ground, which imposed the terrain itself and the place where it was built, by a hill or slope, and that side was the back, usually the north side. So the entrance to the ground floor was located on the front wall. As the first type in this typological division we will mention the house whose basic form is a square with many variations. The construction was carried out by installing one side, namely a wall in the ground, which allowed the choice of the site where it was built, by a hill or slope, and that side being the back, usually the north side. Therefore the entrance to the ground floor had to be located on the front wall. The ground floor was constructed of thick stone supporting walls 60cm to 1m wide and served as a support for the construction of the upper walls. The upper walls were 20cm narrower than the lower walls. During the construction of the floor, almost always on the south side of the building, the walls are laid, and the north part is built on foundations excavated in the slope. The upper floor entrance is on either side or rear of the building.

The second type of houses are those that are built on a rectangular basis and their characteristic is that they are not always built by digging up to the height of the first floor, as is the case with the houses with a square base, and unlike from the previously described houses the ground floor rooms have the same number of rooms as those on the floor. Accordingly, this type of house usually consists of three rooms: a loggia - the central room, a side room - a room and a kitchen with a fireplace.

Figure 1.

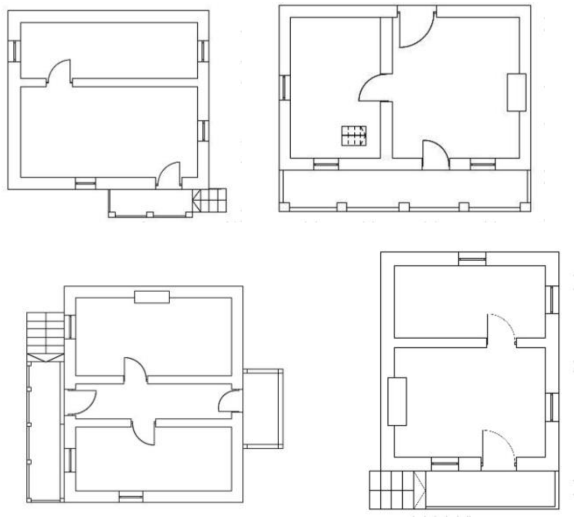
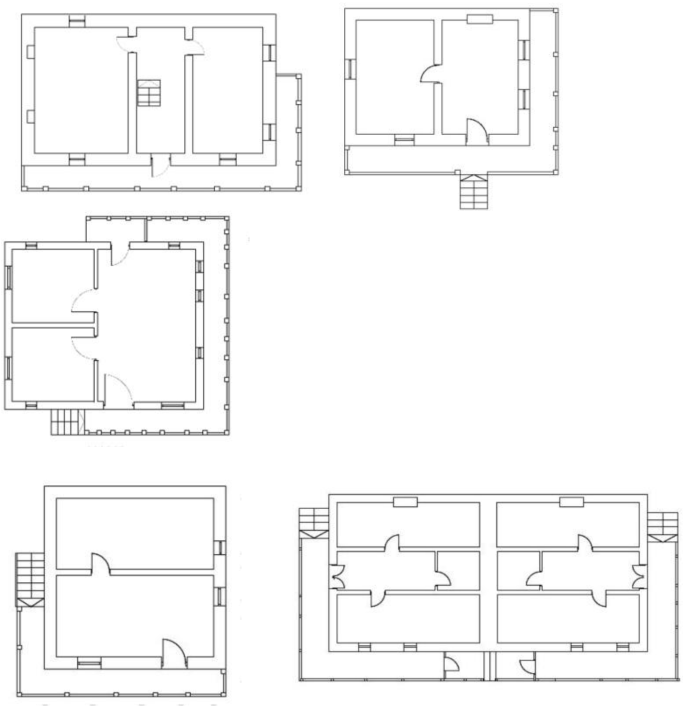
DISPOSITION OF TELIZ (TERACE)	
ONE SIDED	
SIDEWAYS	

Figure 2.

5. CONCLUSION

Maintenance of already existing road infrastructure, easier and better access to these villages

- One of the most important priorities is the improvement of the road infrastructure in the villages themselves (asphalting the buildings themselves and preventing the creation of canals along the road that quickly ruin the existing road).
- Categorization of those potential objects that would in the future be accommodation facilities for tourists and visitors and their reconstruction in the traditional style.
- Training of the population planning to deal with tourism, by issuing accommodation facilities and other types of services that would meet the needs of tourists. Such training would be: foreign language courses, communication skills, accelerated courses in tourism and hospitality, etc.
- Establishment of associations at the municipal level (Struga) that include these villages, which would be related to handicrafts, catering, trade and so on. These associations through the organized meetings with the municipality would improve their work, the provision of services (meeting the needs of tourists).
- Enrichment of rural areas with various types of animation activities by the local population.

These would include: preparation of traditional dishes, presentations of vegetable and fruit farming, domestication of animals, horse riding, fruit harvesting, mountain slopes walks, mountain biking, designing of clay pottery, etc.






Figure 3

Table 1.

VALORISATION OF SOME INDICATORS IN VILLAGES OF MALESIJA											
CULTURAL VALUES						QUALITY OF THE SPACE					
	1	2	3	4	5		1	2	3	4	5
Historical						Quality of drinking water					
Artistic						Quality of infrastructure					
Architectural						Quality of the air					
Richness of contents						Quality of diversity of informations					
						Quality of road infrastructure					
						Quality of organization of living in the villages					

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RESEARCH ON THE EFFECTS OF THE CUTTING SPEED ON CUTTING FORCE AND THE CUTTING POWER IN THE PROCESS OF MILLING

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ABSTRACT

The processing of wood on a milling machine is a complex process that includes several factors, which affect product quality, tools performance and process safety. It also affects the productivity of the machine and the economics of the overall production process. These are the main reason why the optimal determining of woodcutting process today attains greater importance in the wood processing industry.The research was focused on creating a mathematical model of the interaction mechanism between tool and wood as a workpiece. Analytical tool is designed for determining some important factors in the wood cutting process – cutting force, cutting power, etc. All of these factors are calculated as a function of exactly defined input parameters, grouped in several categories.The mathematical model is supported with appropriate software.

Key words: milling, woodprocessing, woodcutting tools, cutting force, cutting power

1. INTRODUCTION

The quality of wood cutting process has a significant importance on processing with a milling machines, such as: tool efficiency, work safety, economy and productivity of the process.

Investigating the wood cutting process in details is very important, which will result in selection of the optimal parameters for different operating modes.

The mathematical model of the wood cutting process is designed on the base of empirical correlation of important parameters in the process of wood cutting with milling machine, obtained by series of experiments.

Mathematical model offers the possibility to determine some important factors in the process of cutting as the cutting force, cutting power, wear of the tool, surface quality etc.

All these factors are correlated with exactly defined input parameters, previously set and grouped into several categories:

- geometric characteristics of tool;
- kinematic, dynamic and technological characteristics of tool
- cutting speed, feed rate, cutting height, dimensions of tool, type of cutting, etc.
- characteristics of material subject to processing (wood species, mechanical properties, the direction of cutting).

The simulation model is supported with appropriate software program.

2. METHODS

The objectives of this research were realized using a specially designed computer application for wood cutting process simulation. For the simulation of the wood cutting process on milling machine, following parameters were defined as constant values:

- mill cutter diameter	20[mm]
- number of blades	4
- cutting height	5[mm]
- cutting width	6[mm]
- blade initial oblique radius	11[μm]
- cutting angle	55[°]
- cutting feed rate	15[m/min]
- cutting type	transversally
- wood species	beech / silver pine

The spindle speed is variable input parameter in the researched cutting process in the range of 1800 rpm up to 6000 rpm.

In the process of wood cutting, cutting force and cutting power are the main output parameters, while the chip length, chip thickness, feed per tooth, teeth pitch, average kinematic cutting angle, cutting speed, average pressure on front side, fictive specific force on back side are secondary parameters.

3. RESULTS AND DISCUSION

The efect of the cutting speed on cutting force and cutting power in the process of wood cutting on milling machine (beech and pine) are shown on Table 1 and Table 2 respectively. In order to get better presentation of obtained results, the results are also shown graphically (Figure 1;2.).

Table 1. *Influence of spindle speed/cutting speed on cutting force and cutting power during processing of beech on milling machine*

Spindle speed	[min^{-1}]	1800	2400	3000	3600	4200	4800	5400	6000
CONSTANT PARAMETERS									
Number of blades	-	4	4	4	4	4	4	4	4
Mill diameter	[mm]	20	20	20	20	20	20	20	20
Cutting height	[mm]	5	5	5	5	5	5	5	5
Cutting width	[mm]	6	6	6	6	6	6	6	6
Blade initial oblique radius	[μm]	11	11	11	11	11	11	11	11
Cutting angle	[°]	55	55	55	55	55	55	55	55
Cutting feed rate	[m/min]	15	15	15	15	15	15	15	15
Chip length	[mm]	10	10	10	10	10	10	10	10
Cutting type	transversall cutting								
Wood species	beech								
VARIABLE PARAMETERS									
Chip thickness	[mm]	1,04	0,78	0,62	0,52	0,44	0,39	0,34	0,3
Feed per tooth	[mm]	2,08	1,56	1,25	1,04	0,89	0,78	0,69	0,62
Teeth pitch	[mm]	15,7	15,7	15,7	15,7	15,7	15,7	15,7	15,7
Avg. kinematic cutting angle	[°]	30,01	30,01	30,01	30,01	30,01	30,01	30,01	30,01
Cutting speed	[m/s]	1,80	2,50	3,10	3,70	4,30	5,00	5,60	6,20
Avg. pressure on front side	[N/mm^2]	12,8	12,9	12,99	13,08	13,17	13,27	13,36	13,45
Fict.spec.force on back side	[N/m]	3413	3413	3413	3413	3413	3413	3413	3413
OUTPUT PARAMETERS									
Start cutting force	[N]	70,94	57,16	49,03	43,33	39,5	36,43	34,24	32,64
End cutting force	[N]	72,68	58,89	50,78	45,06	41,25	38,16	36	34,43
Start cutting power	[W]	127,6	142,8	151,9	160,3	169,8	182,1	191,7	202,3
End cutting power	[W]	130,8	146,5	157,4	166,7	177,3	190,7	201,5	213,4

Table 2. *Influence of spindle speed/cutting speed on cutting force and cutting power during processing of pine on milling machine*

Spindle speed	[min^{-1}]	1800	2400	3000	3600	4200	4800	5400	6000
CONSTANT PARAMETERS									
Number of blades	-	4	4	4	4	4	4	4	4
Mill diameter	[mm]	20	20	20	20	20	20	20	20
Cutting height	[mm]	5	5	5	5	5	5	5	5
Cutting width	[mm]	6	6	6	6	6	6	6	6
Blade initial oblique radius	[µm]	11	11	11	11	11	11	11	11
Cutting angle	[°]	55	55	55	55	55	55	55	55
Cutting feed rate	[m/min]	15	15	15	15	15	15	15	15
Chip length	[mm]	10	10	10	10	10	10	10	10
Cutting type	transversall cutting								
Wood species	silver pine								
VARIABLE PARAMETERS									
Chip thickness	[mm]	1,04	0,78	0,62	0,52	0,44	0,39	0,34	0,3
Feed per tooth	[mm]	2,08	1,56	1,25	1,04	0,89	0,78	0,69	0,62
Teeth pitch	[mm]	15,7	15,7	15,7	15,7	15,7	15,7	15,7	15,7
Avg. kinematic cutting angle	[°]	30,01	30,01	30,01	30,01	30,01	30,01	30,01	30,01
Cutting speed	[m/s]	1,80	2,50	3,10	3,70	4,30	5,00	5,60	6,20
Avg. pressure on front side	[N/mm^2]	8.02	8.38	8.68	8.99	9.3	9.65	9.96	10.27
Fict.spec.force on back side	[N/m]	2629	2629	2629	2629	2629	2629	2629	2629
OUTPUT PARAMETERS									
Start cutting force	[N]	46,53	38,87	34,25	30,98	28,83	27,11	25,89	25,02
End cutting force	[N]	47,86	40,21	35,6	32,31	30,18	28,45	27,24	26,4
Start cutting power	[W]	83,7	97,1	106,1	114,6	123,9	135,5	144,9	155,1
End cutting power	[W]	86,1	100,5	110,3	119,5	129,7	142,2	152,5	163,6

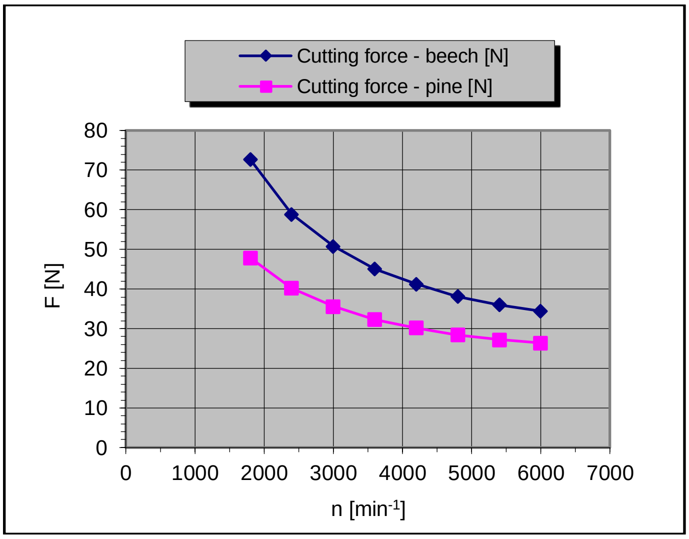

Figure 1. *Relation between cutting force and spindle speed during milling of beech and pine*

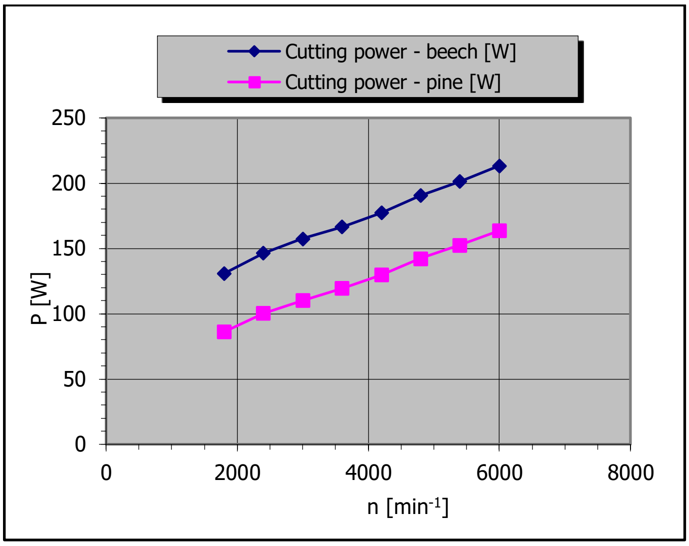

Figure 2. *Relation between cutting power and spindle speed during milling of beech and pine*

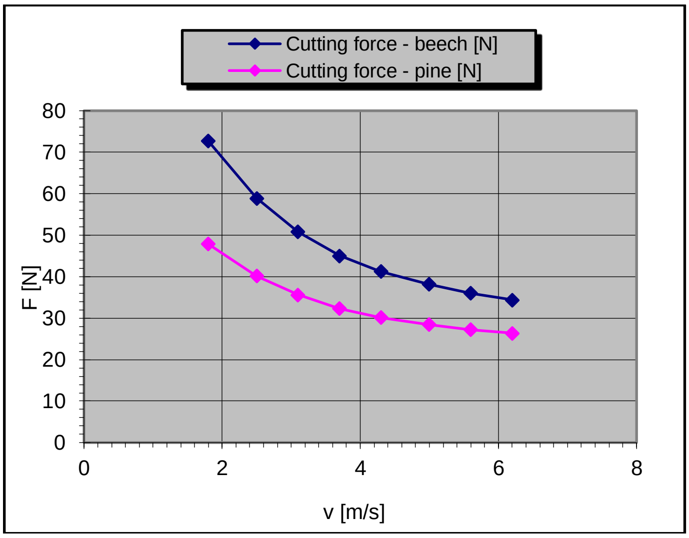

Figure 3. *Relation between cutting force and cutting speed during milling of beech and pine*

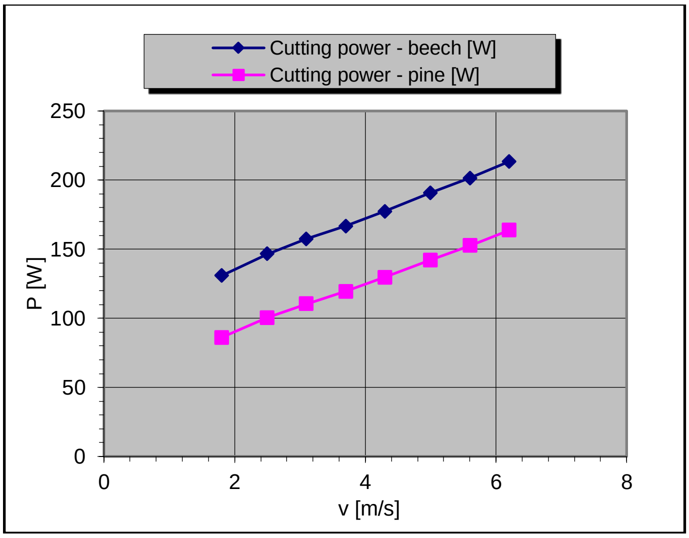

Figure 4. *Relation between cutting power and cutting speed during milling of beech and pine*

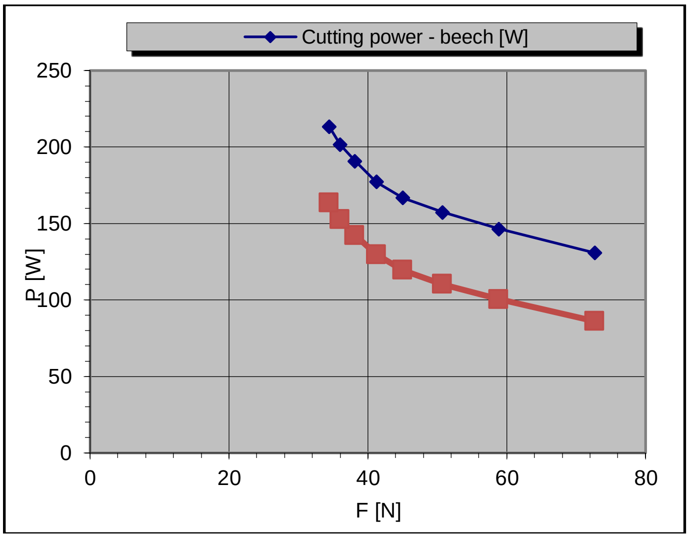

Figure 5. *Relation between cutting force and cutting power during milling of beech and pine*

Based on the data shown in Tab.1 and Tab.2, it can be concluded that there are eight different values of spindle speed selected, starting from minimal value of 1800 min^{-1} to max. of 6000 min^{-1}, with step by 600 min^{-1}. Besides the influence of spindle speed on cutting force and cutting power, this parameter has influence also on value of the cutting speed, feed per tooth and chip thickness.

Figure 1 shows that the impact of spindle speed on cutting force is inversely proportional, where the degree of decrease is more noticeable when cutting beech.

The same conclusion can be drawn from Figure 3, which shows the impact of the cutting speed on the cutting force.

The diagrams in Figure 2/Figure 4 show the influence of spindle speed/cutting speed on the value of the cutting power. It can be concluded that the impact is directly proportional, with approximately linear dependence.

The diagram in Figure 5 shows the dependence between the cutting force and the cutting power.

4. CONCLUSION

According to the presented data and results obtained during simulating wood cutting of beech and pine on milling machine, it can be concluded that:

- Investigations on the impact of spindle speed and cutting speed on milling process were carried out using the computer simulation program.
- Elementary output parameters which are the base for assessment of cutting process are cutting force and cutting power.
- Increase in spindle speed reduces the cutting force, which is particularly noticeable at lower spindle speeds.
- The spindle speed and the cutting power are in approximately linear dependence, with power increasing moderately with an increase in spindle speed, approximately 10% for every 1000 min^{-1}.
- By increasing the tangential cutting speed, which is kinematically related to the spindle speed, the cutting force decreases, while the cutting power increases approximately proportionately, by 8-10% for every 1 m/s increase in cutting speed.
- The results obtained from the program correspond to the real situation of wood milling with tolerances due to the complexity of the interaction between the tool and physical and mechanical characteristics of wood.
- In the analytical procedures for defining the system, modifications and changes in the program are relatively simply based on data from new experimental research.
- Simulation programme for wood milling cannot replace classical experimental research, but it can be a good base for comparison based analysis.

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EXAMINATION OF SOME STRENGTHS OF DISMOUNTABLE CORNER JOINTS IN THE CONSTRUCTION OF FURNITURE MADE OF PARTICLE BOARDS

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ABSTRACT

The results from the research on destructive bending moments of corner joints of structural elements made of particle boards, where these joints are used mainly in construction of storage furniture.

It was found that the type of joints has significant influence on the destructive bending moment. This is defined by the type and size of joint elements and the area of the contact surfaces of the joints. Also we investigated the influence of use of the product on the destructive moment of different type of joints.

It is recommended that the research results are taken into consideration in strength design of furniture.

Key words*:* dismounteble corner joints, destructive bending moments, norms for destructive bending moment

1. INTRODUCTION

Norms for the destructive bending moments of end corner open are worked out on the basis of the experimental research on the same types of joints of structural elements with a cross section 50 x 30 mm (Kyuchukov et al, 2014). The samples for the test are manufactured from particle board.

2. MATERIALS AND METHODS

The following types of end joints are tested: metal angle connector with screws (Figure 1), plastic angle connector with screws (Figure 2) and minifix connector (Figure 3). The parameters of the joints correspond to the Bulgarian State Standard 5527-73 and are given at figures 1 to 3.

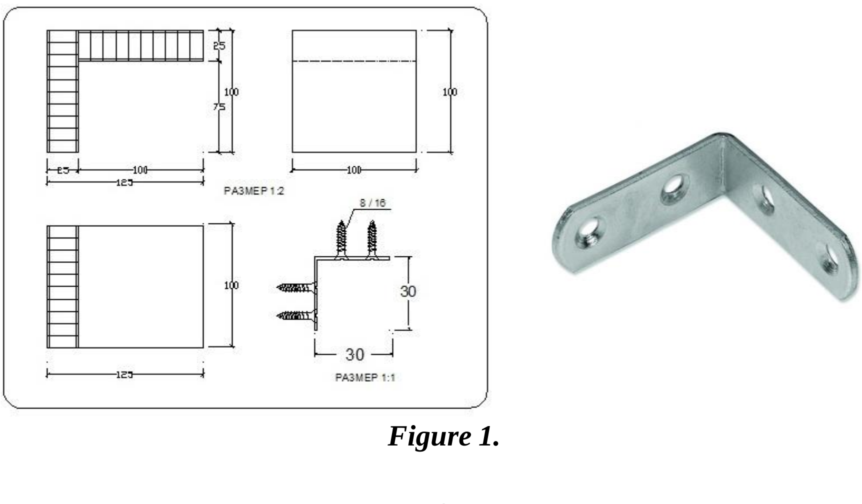

Figure 1.

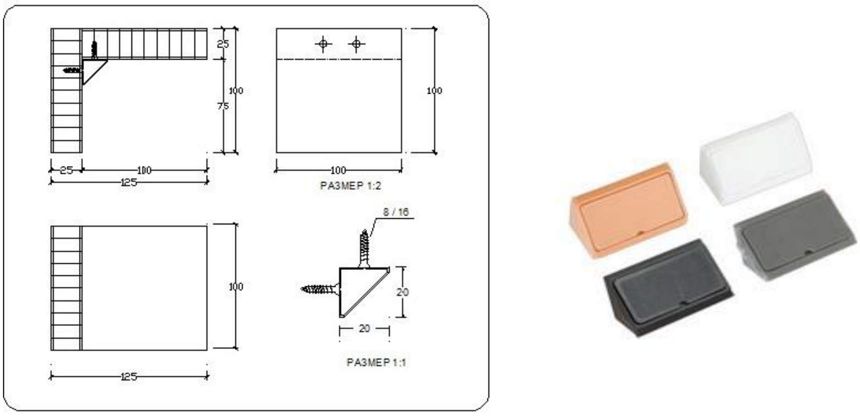

Figure 2.

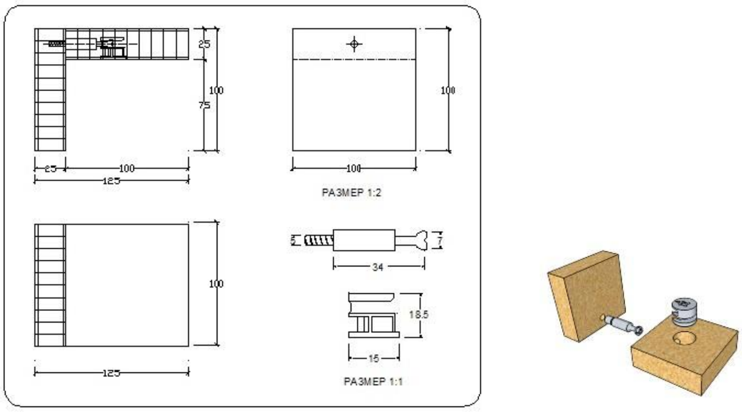

Figure 3.

There were 3 groups of specimens, 1st group were specimens who were taken directly from the product which was previously tested according to MKS EN 14073-1, MKS EN 14073-2, MKS EN 14073-3, MKS EN 14074)directly cut of from the product, second group are specimens who are also taken from a tested product but they are first dismounted and then cut of from the product and the third group which are specimens made for testing and comparison (no previous tests done).

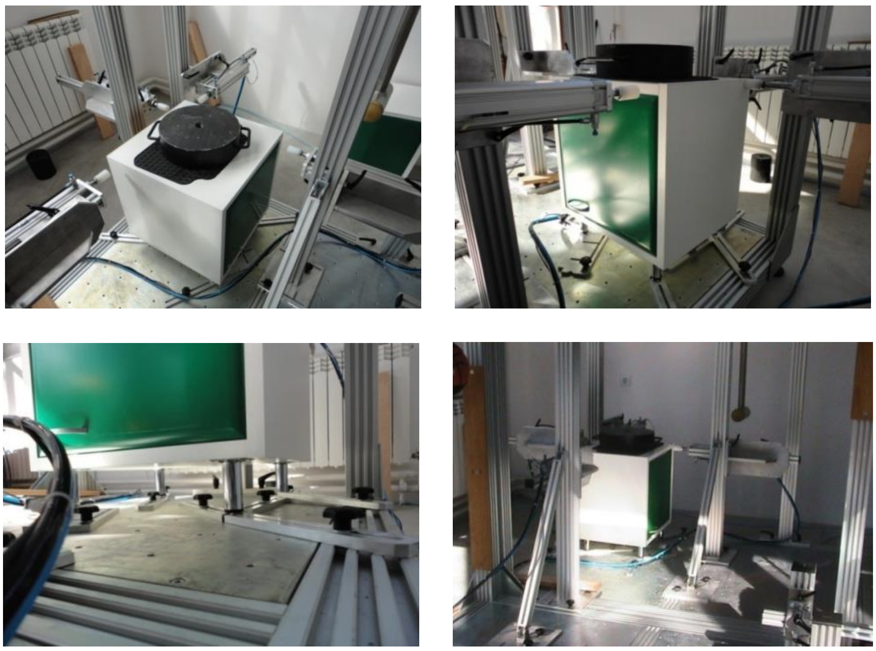

Figure 4.

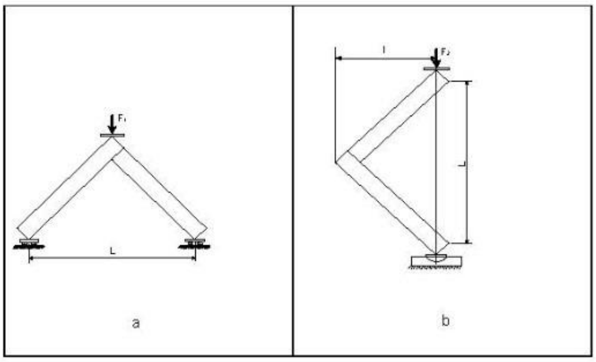

Figure 5. *Scheme for testing of test samples of end corner joints:*
a – in arm opening bending load; b – in arm compression bending load

The destructive bending moments M_1 under arm opening bending test and M_2 under compression bending test have been calculated correspondingly by formulas (1) and (2).

$$M_1 = \frac{F_1.L}{4} \quad (1)$$
$$M_2 = F_2.l \quad (2)$$

where
F_1 – failure force in arm opening bending test in N
F_2 – failure force in compression bending test in N;
L – span distance of arm opening bending test in m
l – arm of bending in compression bending test in m

The results from the experiments are processed by the variation statistics methods.

The norms for the destructive bending moments of the corner joints of the frame structural elements are worked out on the basis of the results of the previously published experimental research (Kyuchukov et al, 2014), taking into account the dispersion of the data from the experimental research according to the Gauss law of normal distribution.

The normative values for the destructive bending moments of the tested corner joints of the frame structural elements made of solid spruce wood are determined by the formulas (3) and (4).

$$M_{1\text{ norm}} = \overline{x_1} - \alpha.s_1 \quad (3)$$

$$M_{2\text{ norm}} = \overline{x_2} - \alpha.s_2 \quad (4)$$

where
$\overline{x_1}$ is the mean value of the destructive bending moment of the joint at arm opening bending load, Nm; $\overline{x_2}$ – the mean value of the destructive bending moment of the joint at compression bending load, Nm;
α – the coefficient of uniformity;
s_1 – the mean square deviation at arm opening bending load, Nm;
s_2 – the mean square deviation at arm compression bending load, Nm.

The coefficient of uniformity α specifies the range of the experimental data spread. In the theory of probability it is given a proof that all the variants of experimental data practically lie into the limits $\bar{x}$ ± 3s, and over 99 % of the data lie into the limits $\bar{x}$ ± 2,5s. On the grounds of that fact it can be assumed that the lower bound $\bar{x}$ – 2,5s can be accepted as a normative bound of the relevant strength characteristic of the tested types of corner joints of the frame structural elements made of solid spruce wood. The mean square deviation s is a function both of the data spread about the mean and the number of the tested samples. It is determined the average variation coefficient v_{av} to eliminate the influence of the accidental factors of particular samples of the given type of joint. In the arm opening bending test v_{av} = 12,6 %, and in the arm compression bending test v_{av} = 12,5 %. On this basis the value of the mean square deviation for each type of joint is specified by the formulas (5) and (6).

$$s_1 = \frac{v_{\text{av}}}{100} \cdot \overline{x_1} \quad (5)$$

$$s_2 = \frac{v_{\text{av}}}{100} \cdot \overline{x_2} \quad (6)$$

The normative values for the destructive bending moments of the tested end corner open joints in arm opening and arm compression bending load are determined by the formulas (7) and (8).

$$M_{1\,\text{norm}} = \overline{x_1} - 2{,}5.s_1 \quad (7)$$

$$M_{2\,\text{norm}} = \overline{x_2} - 2{,}5.s_2 \quad (8)$$

3. RESULTS

The results from the research are presented graphically on figures 5 and 6. From the data shown on the figures it is obvious that the destructive bending moment depends on the type of the joint as well as the scheme at which the joint was loaded

The type of the joints has a considerable influence on the destructive bending moment. This is defined by the type and dimensions of the joint elements.

Number	GROUP 1 (N.м)	GROUP 2 (N.м)	GROUP 3 (N.м)
1	42,75	33,833	40,708
2	36,5	29,375	38,937
3	11,104	9,208	11,667

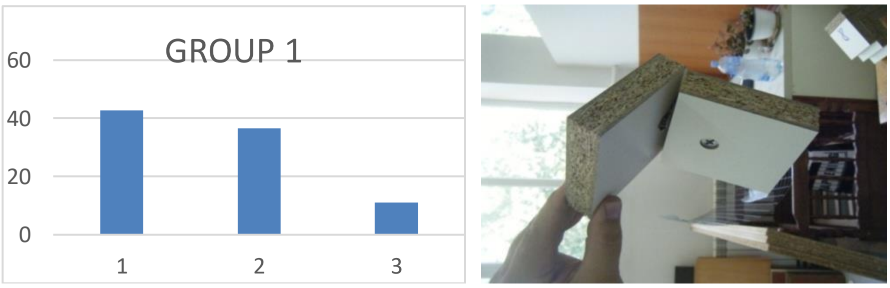

Figure 6. *Group 1, specimens taken directly from the previously tested product (directly cut of)*

Figure 7. *Group 2, specimens taken from the previously tested product (dismounted and then cut of the product)*

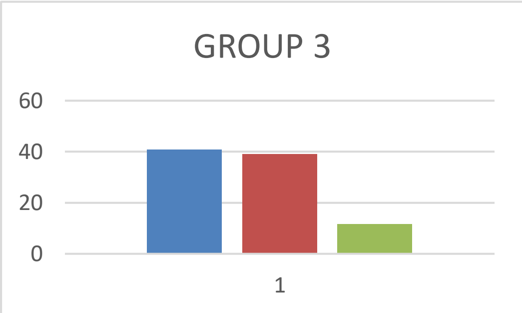

Figure 8. *Group 3, specimens made only for testing (no previous test done)*

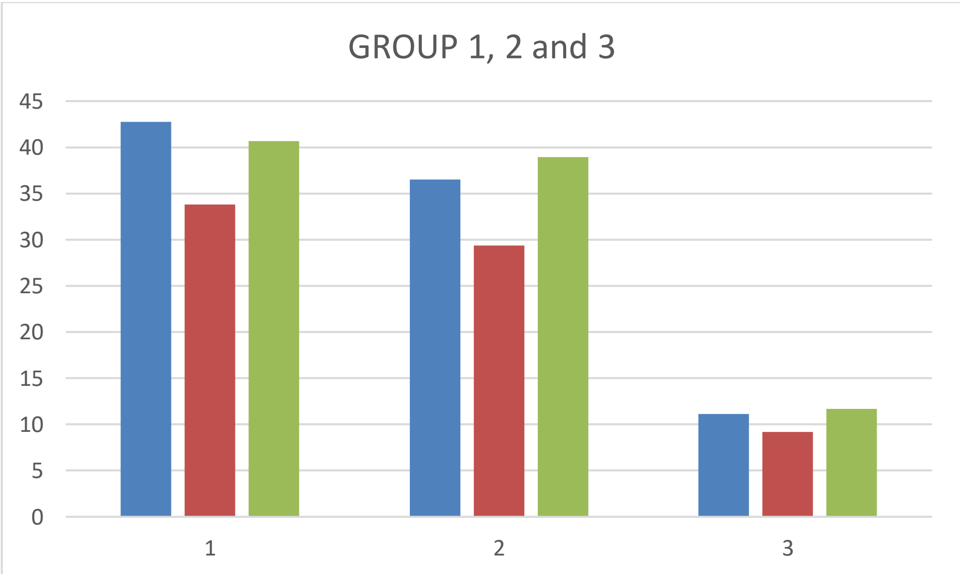

Figure 9. *Comparation of the results from the three groups and three different joints*

4. CONCLUSION

The results from the carried out research give reason to make the following more common conclusions:

1. According to the value of the destructive bending moment the tested types of corner joints are set in following hierarchical order:

- ,etal corner joint;
- plastic corner joint;
- minfix corner joint;

2. The difference of the strength of the joints who where directly cut of from the product and the joints made only for testing are small.

3. The difference of the strength of the joints who where dismounted and then cut of from the product and the joints made only for testing is 20% .

4. It is recommended that the strength characteristic of the tested joints should be taken into account in the strength design of the sitting furniture, tables and beds.

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THE EFFECT OF THE TIME AND TEMPERATURE OF SATURATED WATER STEAM ON THE ACIDITY AND WOOD COLOUR IN THE PROCESS OF THERMAL MODIFICATION OF SILVER BIRCH WOOD COLOUR

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ABSTRACT

The aim of the paper is to determine the correlation between the change in acidity and the colour of wood species *Betula pendula Rot.* in the CIE-L*a*b* colour space in the process of heat treatment of woodturning blanks with the dimensions of 40 x 90 x 800 mm with the saturated water steam in the range of temperatures from t = 105 to 135 °C and the time of heat treatment from τ = 3 up to 12 hours. Wet silver birch wood changes pH in the range of pH = 5.3 ÷ 3.2 due to partial hydrolysis of hemicelluloses and extraction of water-soluble substances and loses whiteness (gets darker). By increasing the value of the coordinate of the red color a* and slight changes on the coordinate of yellow color b * acquires the color levels of varying intensity of brown color.

Colour coordinates of birch wood in the CIE L*a*b* colour space with dependence on temperature of saturated water steam *t* and the time of heat treatment *τ* are described using the equations:

$$L^* = 83.6232+0.4815\cdot t-1.9377\cdot\tau -0.0041\cdot t^2-0.0068\cdot t\cdot\tau +0.1091\cdot\tau^2,$$

$$a^* = 6.7847-0.0795\cdot t+1.2265\cdot\tau+0.0007\cdot t^2-0.0026\cdot t\cdot\tau-0.0511\cdot\tau^2,$$

$$b^* = 19.8107-0.0014\cdot t +0.7326\cdot\tau-9.3472E\text{-}5\cdot t^2-0.0027\cdot t\cdot\tau-0.0255\cdot\tau^2.$$

Key words: wood, silver birch, CIE-L*a*b* colour space, heat treatment, saturated water steam

1. INTRODUCTION

Wood located in the environment of hot water, saturated water steam or saturated humid air is heated and its physical, mechanical and chemical properties changes. Mentioned facts are used in technology of steam bending and boiling during veneers and plywood, bent furniture or pressed wood manufacturing processes. *Kollmann and Gote (1968), Nikolov, Rajčev and Deliiski (1980), Sergovsky and Rase (1987), Lawnniczak (1995), Trebula (1996), Deliiski and Dzurenda (2010).*

Thermal treatment processes of wood with saturated water steam, in addition to specific physico-mechanical changes of wood, are accompanied by chemical reactions such as partial hydrolysis and extraction leading to a colour change as well *Melcer et al. (1989), Bučko (1995), Kačík (2001), Geffert, Vybohova and Geffertova, (2018).* In the past, colour modification, especially wood darkening, was used to remove undesirable differences in colour of lighter sapwood and darker heartwood, or to remove wood stains resulting from steaming or moulding. Recently, the research has been aimed at the colour change of specific wood species to more or less distinctive hues or imitation of the exotic wood species *Tolvaj et al. (2009), Dzurenda (2014), Barcik, Gašparík and Razumov (2015), Baranski et al. (2017) Hadjiski and Deliiski (2016), (Dzurenda 2018).*

Using the coordinates of the CIE-L*a*b*colour space is one of the ways to quantify the given optical wood property objectively. Lab colour space (according to CIE – Commission Internationale de Eclairage) in accordance with ISO 7724 is based on the measurement of three parameters: lightness L* represents the darkest black at L* = 0 and the brightest white at L* = 100. The value of a* is a measure of the red–green character of the colour, with positive values for red shades (+a*), and negative values for green (-a*). The value of b* gives the yellow–blue character with positive values for yellow shades (+b*) and negative for blue (-b*).

The aim of the paper is to determine the dependence of the acidity and the colour of the wood species *Betula pendula Rot.* in the CIE-L*a*b*colour space resulting from the processes of heat treatment – modification of wood with saturated water steam at the following range of temperatures from t = 105 to 135 ^{O}C for τ = 3 to 12 hours.

2. MATERIALS AND WORK METHODS

Silver birch wood in the form of woodturning blanks with the dimensions of 40 x 90 x 800 mm and moisture content of w = 40 - 55 % was thermally treated with saturated steam in the pressure autoclave APDZ 240 (Himmasch AD, Haskovo, Bululharsko) in the company Sundermann s.r.o. Banská Štiavnica. Modes of colour modification with saturated water steam are shown in Figure 1. Description of modes of thermal colour modification of silver birch wood with saturated water steam is mentioned in Table 1.

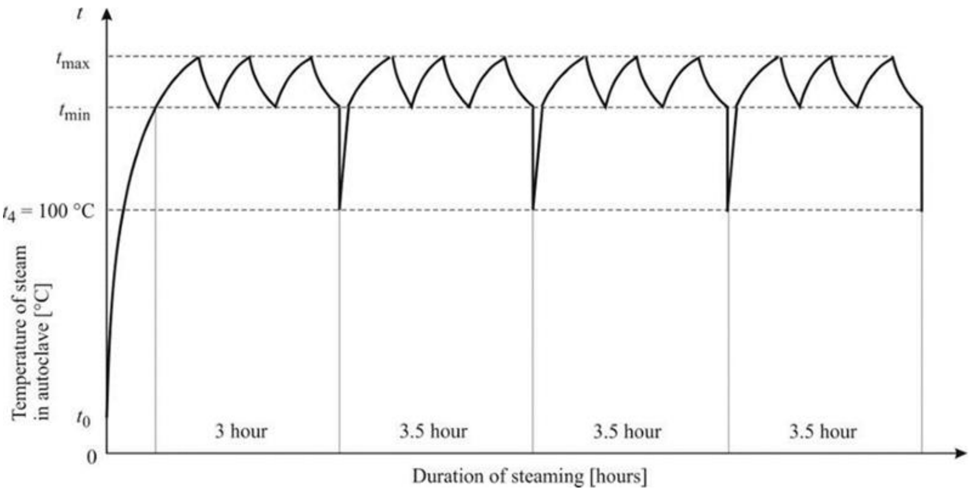

Figure 1. *Mode of colour modification of silver birch wood with saturated water steam.*

Table 1. *Mode of colour modification of silver birch wood with saturated water steam.*

Temperature of saturated water steam	t_{min}	t_{max}	t_4	Time of thermal colour modification of wood			
Mode I	102.5	107.5	100	$τ_1$ = 3 h	$τ_2$ = 6 (+0.5[a]) h	$τ_3$ = 9 (+0.5[a]) h	$τ_4$ = 12 (+0.5[a]) h
Mode II	122.5	127.5	100				
Mode III	132.5	137.5	100				

Note: [a] technological pause

Before heat treatment, as well as after its finishing and cooling the wood, the pH value of wet wood was measured. Forasmuch as the diameter of sensor head of the potentiometer used to measure pH is d = 10 mm and it cannot be placed (immersed) into the solid material, the hole with the diameter of 12 mm was formed in the place of measurement with the accu drilling machine. Sawdust resulting from drilling was poured into the hole and the sensor head LenceFET+H 22704-010 of the pH meter SENTRON SI 6OO was inserted into wet sawdust.

Thermally treated wood of silver birch woodturning blanks, as well as thermally untreated samples were dried to report the moisture content of *w* = 12 ± 0.5 % in a conventional wood drying kiln KAD 1x6 (KATRES Ltd.). Subsequently surfaces and edges were processed using Swivel spindle milling machine FS 200.

Colour of silver birch woodturning blanks in the CIE-L*a*b*colour space was determined using the Color Reader CR-10 (Konica Minolta, Japan). The light source D65 with lit area of 8mm was used.

Lightness coordinates L* and coordinates a* and b* in the CIE-L*a*b* colour space on the samples of heat-treated as well as non-heat-treated wood was carried out after drying on the planed surface in the middle of the side and loading surfaces at a distance of 300 mm from the forehead. The measurement was performed on 75 pieces of blanks.

Values of colour coordinates of thermally treated as well as untreated silver birch wood are presented using a formula $x = \bar{x} \pm s_x$, i.e. average measured value and standard deviation.

Total colour difference ΔE* is determined according to Formula 1, in accordance with the standard *ISO 11 664-4* as the result of the difference in the colour coordinates ΔL*, Δa*, and Δb* following the measurements of the wood colour of treated as well as untreated birch woodturning blanks:

$$\Delta E^* = \sqrt{\left(L_2^* - L_1^*\right)^2 + \left(a_2^* - a_1^*\right)^2 + \left(b_2^* - b_1^*\right)^2} \qquad (1)$$

where: L^*_1, a^*_1, b^*_1 values of the coordinates in the wood colour space of the surface of dried milled thermally traeated silver birch wood

L^*_2, a^*_2, b^*_2 values of the coordinates in the wood colour space of the surface of dried milled thermally traeated silver birch wood

Rate of change in the wood colour and hues during the processes of thermal treatment following the total colour difference ΔE* is classified according to the chart mentioned by the authors: *Cividini et al (2007)* shown in Tab. 2.

Table 2. *Classification of the total colour diference ΔE**.*

0.2 < ΔE*	Not visible difference
0.2 < ΔE* < 2	Small difference
2 < ΔE* < 3	Colour difference visible with low quality screen
3 < ΔE* < 6	Colour difference visible with medium quality screen
6 < ΔE* < 12	High colour difference
ΔE* > 12	Different colours

3. RESULTS

According to the authors *Perelygin (1965), Makoviny (2010), Klement, Réh and Detvaj (2010)* the wood colour of the wood species *Betula pendula Rot.* is light white-brown. The colour of silver birch in the CIE-$L^*a^*b^*$ colour space is described by the authors: *Babiak, Kubovský and Mamoňova (2004),* with the coordinates: L^* = 78.07; a^* = 5.92; b^* = 20.02. In our research, L* = 83.7 ± 1.3; a* = 6.8 ± 0.6; b* = 19.8 ±0.9 were the values of coordinates in CIE L*a*b* colour space measured on the planed surface of silver birch wood when the moisture content was w ≈ 12 %.

Acidity of wet thermally untreated birch wood at a moisture content of 53.9% was pH = 5.3 ± 0.2. The pH values of the wet heat treated silver birch after cooling are shown in Tab. 3. In Table 3 there are also the coordinates L*, a*, b*, which describe the color of the dried thermally treated birch wood on the planed surface.

Table 3*. Values of the moisture content, acidity and coordinates L*, a*, b* of silver birch wood in the process of thermal treatment.*

Temperature of saturated water steam	Moisture content of wood	Time of thermal colour modification of birch wood			
		3 hours	6 hours	9 hours	12 hours
t_I = 105 ± 2.5 °C	w ≈ 45.5 %	pH = 4.9 ± 0.1	pH = 4.7 ± 0.1	pH = 4.6 ± 0.2	pH = 4.4 ± 0.3
	w ≈ 11.5 %	L* = 80.7 ± 1.2	L* = 75.8 ± 1.2	L* = 74.7 ± 0.8	L* = 71.3 ± 1.2
		a* = 8.5 ± 0.8	a* = 10.7 ± 0.7	a* = 10.5 ± 0.7	a* = 10.5 ± 0.8
		b* = 19.2 ± 0.6	b* = 21.1 ± 0.5	b* = 21.4 ± 0.6	b* = 19.8 ± 0.4
		ΔE* = 3.5	ΔE* = 8.9	ΔE* = 9.8	ΔE* = 12.9
t_{II} = 125 ± 2.5 °C	W ≈ 43.8 %	pH = 3.9 ± 0.1	pH = 3.8 ± 0.2	pH = 3.7 ± 0.3	pH = 3.6 ± 0.2
	w ≈ 11.8 %	L* = 73.9 ± 1.1	L* = 66.6 ± 1.2	L* = 64.3 ± 1.2	L* = 63.8 ± 1.2
		a* = 10.3 ± 0.8	a* = 11.9 ± 0.7	a* = 12.5 ± 0.7	a* = 12.2 ± 0.8
		b* = 19.8 ± 0.9	b* = 18.9 ± 0.5	b* = 18.5 ± 0.5	b* = 19.8 ± 0.4
		ΔE* = 10.4	ΔE* = 18.8	ΔE* = 20.2	ΔE* = 20.6
Temperature of saturated water steam	Moisture content of wood	Time of thermal colour modification of birch wood			
		3 hours	6 hours	9 hours	12 hours
t_{III} = 135 ± 2.5 °C	W ≈ 46.5 %	pH = 3.6 ± 0.1	pH = 3.4 ± 0.2	pH = 3.2 ± 0.1	pH = 3.2 ± 0.1
	w ≈ 11.7 %	L* = 65.1 ± 1.9	L* = 59.9 ± 1.5	L* = 55.6 ± 0.9	L* = 53.5 ± 0.7
		a* = 11.6 ± 0.6	a* = 12.5 ± 0.4	a* = 12.5 ± 0.3	a* = 12.1 ± 0.4
		b* = 18.7 ± 0.6	b* = 19.4 ± 0.5	b* = 19.5 ± 0.6	b* = 18.8 ± 0.4
		ΔE* = 19.2	ΔE* = 24.4	ΔE* = 28.8	ΔE* = 30.6

Correlation between the values pH of silver birch wood when the temperatures ranging from t = 105 °C to 135 ° and the length of thermal treatment process was up to τ ≤ 12 hours is presented using the 3D diagram in following graph:

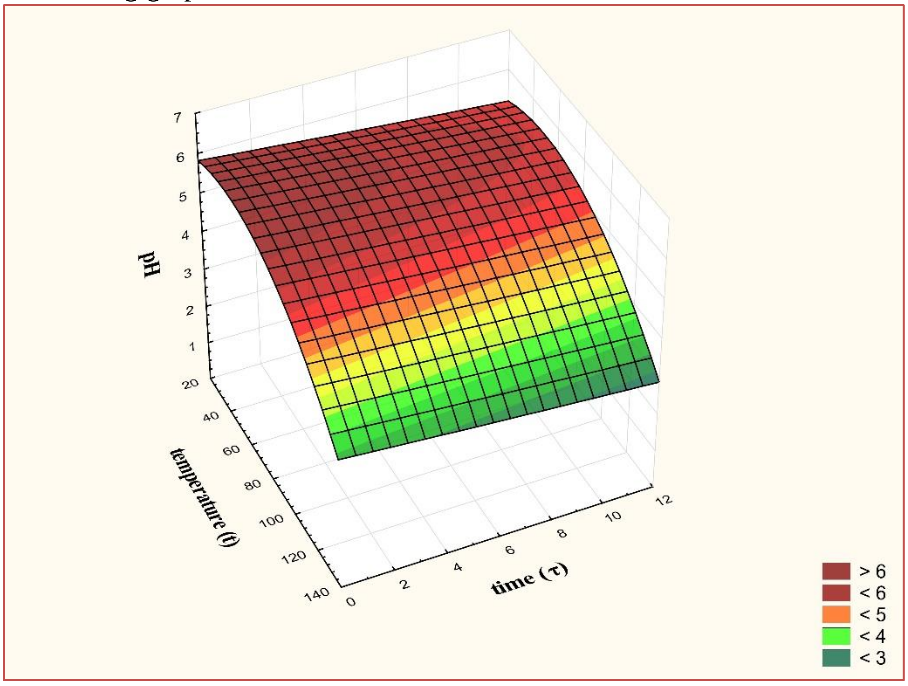

Figure 2. *3D diagram pH – t – τ*

The changes in the lightness coordinate L* in the CIE-L*a*b* colour space of silver birch woodturning blanks resulted from the process of thermal modification of colour with saturated water steam with the temperatures of t_I = 105 ± 2.5 °C, t_{II} = 125 ± 2.5 °C, t_{III} = 135 ± 2.5 °C for τ = 3, 6, 9, 12 hours are shown in Figure 3.

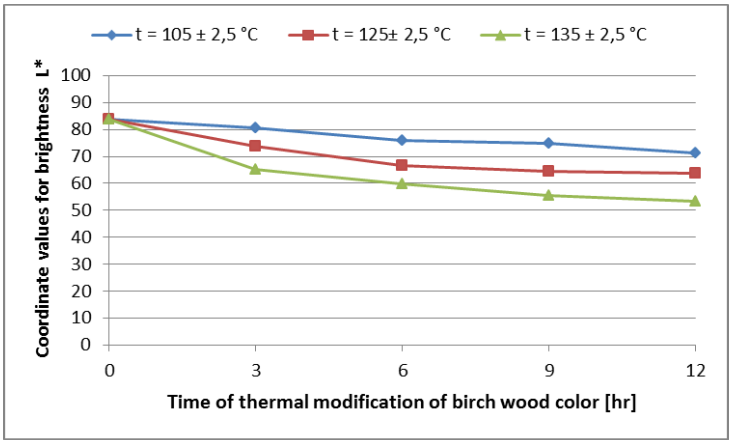

Figure 3. *Value of coordinate L* in the process of thermal treatment of birch wood*

Dependence of the lightness L* in the CIE L*a*b* colour space of thermally treated silver birch wood in the form of sawn timber and woodturning blanks with h ≤ 40 mm with the temperature of saturated water steam ranged from t = 105 to 135 °C and the time of the process of thermal treatment to τ ≤ 12 hours is described using the equation:

$$L^* = 83.6232+0.4815\cdot t-1.9377\cdot\tau -0.0041\cdot t^2-0.0068\cdot t\cdot\tau +0.1091\cdot\tau^2 \quad (2)$$

The changes in chromatic coordinates: red colour a^* and the yellow one b^* in the CIE-L*a*b* colour space of the silver birch wood resulting from the thermal modification of wood colour with saturated water steam with the temperatures of t_I = 105 ± 2.5 °C, t_{II} = 125 ± 2.5 °C, t_{III} = 135 ± 2.5 °C for τ = 3, 6, 9, 12 hours are illustrated in Fig. 4.

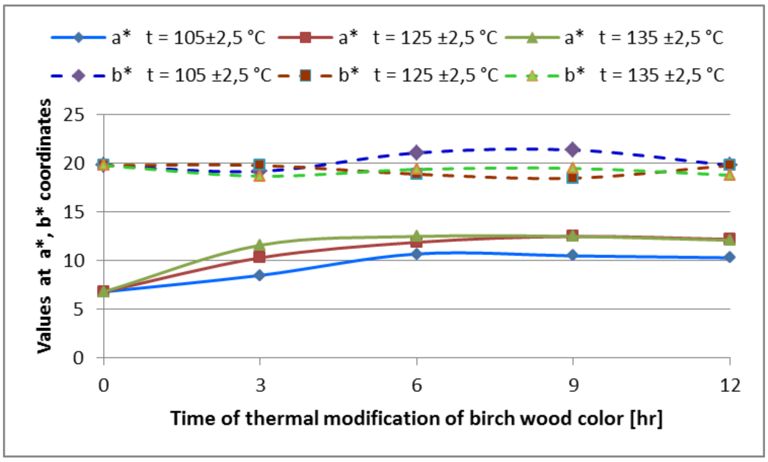

Figure 4. *Coordinates of red colour a* and yellow colour b* in the process of thermal treatment of birch wood*

Dependence of the red colour a* and yellow colour b* in the CIE L*a*b* colour space of thermally treated silver birch wood in the form of sawn timber and woodturning blanks with h ≤ 40 mm on the temperature of saturated water steam ranging from t = 105 to 135 °C and the time of heat treatment process of τ ≤ 12 hours is described using the equation:

$$a^* = 6.7847-0.0795\cdot t+1.2265\cdot\tau+0.0007\cdot t^2-0.0026\cdot t\cdot\tau-0.0511\cdot\tau^2 \quad (3)$$

$$b^* = 19.8107-0.0014\cdot t +0.7326\cdot\tau-9.3472E\text{-}5\cdot t^2-0.0027\cdot t\cdot\tau-0.0255\cdot\tau^2 \quad (4)$$

The changes in colour of thermally treated silver birch wood by the modes with saturated water steam with the temperatures of t_I = 105 ± 2.5 °C, t_{II} = 125 ± 2.5 °C, t_{III} = 135 ± 2.5 °C for τ = 3, 6, 9, 12 hours is illustrated using total colour difference ΔE* in Fig. 5.

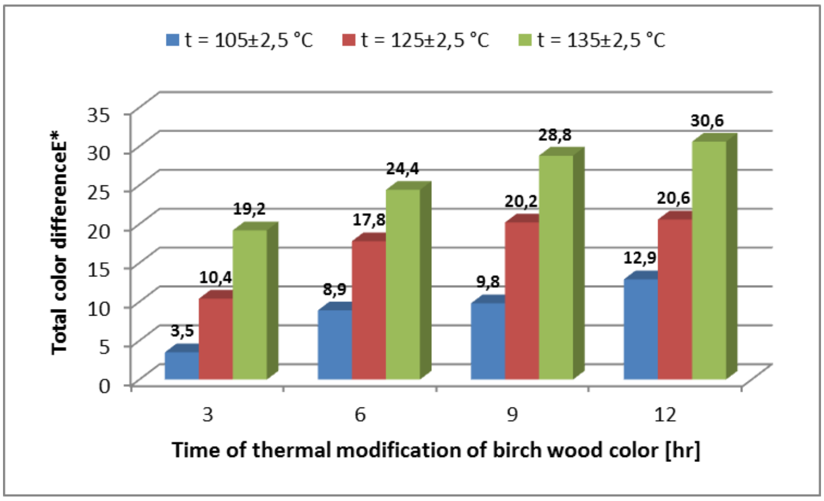

Figure 5. *Values of total colour difference of birch wood in the process of thermal treatment*

4. DISCUSSION

Measured pH values of silver birch in the process of heat treatment confirm the knowledge about the hydrolysis of polysaccharides in wet wood during the application of heat. Products of hydrolysis and extraction after wood boiling or other heat treatment processes mentioned in works: *Melcer et al (1989), Kačík (2001), Laurova et al (2004), Samešova, Dzurenda and Jurkovič (2018)* were quantified using the hydromodulus or created condensate. Measuring the pH value of wet wood using the potentiometer SENTRON SI 600 with the sensor head LenceFET+H 22704-010 can be considered unique. This way, wood hydrolysis and its effect on the wood colour change can be monitored. Following the measured values of acidity of wet wood resulting from the given modes of heat treatment of silver birch wood, the fact that the temperature affects the hydrolysis of hemicelluloses and the change in the chromophore system of wood more significantly than the time of heat treatment process can be stated.

The colour of silver birch in the process of heat treatment with saturated water steam changes from light white-brown to light brown at the temperature of saturated water steam of t = 105±2,5 °C and the time of heat treatment of τ = 6 – 12 hours through brown hues resulting from the application of saturated water steam with the temperature of t = 125±2.5 °C for 6 to 12 hours up to brown colour of silver birch wood at the temperature of t = 135± 2.5 °C for τ = 9 – 12 hours of heat treatment.

Following the visual control of wood colour on the edges of silver birch woodturning blanks, as well as following the measurement of individual chromatic coordinates, the fact that the colour through the thickness of woodturning blanks is coloured equally can be stated. Hydrolysis and wood colour modification processes can occur especially during relatively fast heat treatment process of woodturning blanks or sawn timber with the thickness of h ≤ 40 mm with saturated water steam to required temperature through the thickness of the wood *Deliiski (2003, 2007, 2011), Dzurenda (2018)*. Following the mentioned fact, thermally treated sawmill products can be used to produce lamellae for flooring or other 3D processing of solid timber without any change in colour in the cross section of wood emerged.

Colour changes in silver birch wood ΔE* resulting from the heat treatment with saturated water steam with the temperature of t = 105±2.5 °C at the time of thermal modification for up to 3 hours are considered not significant change in colour, not visible with the naked eye. Following the conditions of heat treatment of silver birch at the temperature of saturated water steam of t = 125± 2.5 °C with the colour difference: ΔE* = 17.8 ÷ 20.6, silver birch wood is classified as wood changing the colour to brown hues visible with the naked eye. The colour of silver birch resulting from the heat treatment with saturated water steam with the temperature of t = 135±2.5 °C for more than 6 hours is unique rich brown.

A decrease in the lightness of silver birch wood thermally treated with saturated water steam and an increase in the values of total colour differences ΔE* in the CIE-$L^*a^*b^*$ colour space is in compliance with the knowledge about colour changes of wood in the heat treatment processes by steaming presented in the works: *Molnar and Tolvaj (2002), Dzurenda (2014, 2018),* as well as by high temperature drying in the environment of overheated water steam *Klement and Marko (2009),* or by heat treatment processes during thermowood manufacturing *Barcik, Gašparík and Razumov (2015).*

Irreversible colour change of silver birch wood resulting from the process of thermal treatment – colour modification of wood with saturated water steam widen the possibility for the use of birch wood in the field of construction to produce flooring, panelling and, solid wood furniture or toys.

5. CONCLUSION

The paper presents the results of experimentation monitoring acidity and color change of birch wood in the process of thermal treatment of wood by saturated water vapor in the temperature range T = 105-135 ° C for τ 3-12 hours.

Wet birch wood changes pH in the range of pH = 5.3 ÷ 3.2 due to partial hydrolysis of hemicelluloses . Wood acidity measurement was performed with a SENTRON SI 600 potentiometer with LenceFET + H probe 22704-010. It follows from the measured values that the temperature factor has a more pronounced influence on the size of the hemicellulose hydrolysis and the change of the chromophore system of the wood than the thermal treatment time.

Birch wood in the process of thermal treatment loses whiteness (gets darker) and shall colors from pale brown to brown. The coordinates of the color of birch wood in the color space CIE L * a * b * depending on the temperature of the saturated water vapor t and the time of thermal modification of the color τ describe the equations:

$L^* = 83{,}6232+0{,}4815\cdot t-1{,}9377\cdot \tau -0{,}0041\cdot t^2-0{,}0068\cdot t\cdot \tau +0{,}1091\cdot \tau^2$,

$a^* = 6{,}7847-0{,}0795\cdot t+1{,}2265\cdot \tau+0{,}0007\cdot t^2-0{,}0026\cdot t\cdot \tau-0{,}0511\cdot \tau^2$,

$b^* = 19{,}8107-0{,}0014\cdot t +0{,}7326\cdot \tau-9{,}3472E-5\cdot t^2-0{,}0027\cdot t\cdot \tau-0{,}0255\cdot \tau^2$.

The aforementioned modifications of the color of birch wood achieved by the thermal process of saturated water vapor extend the possibilities of using color scales birchwood in the construction-firearm area for the production of flooring, cladding, as well as structural-artistic, design in the manufacture of solid wood furniture, toys or other utility and decorative objects.

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CARE AND MAINTENANCE OF LEATHER UPHOLSTERED FURNITURE WITH TRADITIONAL LEATHER CONDITIONERS

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ABSTRACT

The upholstery leather in the fu niture is exposed to intensive wear conditions and dust. Periodic cleaning and maintenance is necessary in order to maintain its properties. In the period of use the leather loses its natural fats, absorbs salts then becomes hard and cracks.

Care and maintenance of leather in the upholstered furniture is a system of activities such as prevention, cleaning and conditioning of the leather. All these activities are interconnected to maintain the quality of the leather. The main task of the care products and maintaining of leather is its adjustment to the conditions of use, removal of deformations that occurred during use and prepare for its further use.

The aim of this paper is to review the method of maintenance of the leather in the upholstered furniture as well as to compare the classical care products with the commercial ones through a review of literary and experiential data.

Commercial conditioners do not satisfy the needs for conditioning the leather properties over a long period of time. Traditional conditioners made from animal fat, oils and waxes such as tallow, lanolin, fish oil and beeswax enhance collagen fibrils, maintain elasticity, contribute to hydrophobicity and increase its organoleptic properties.

Key words: upholstery leather, leather furniture maintenance system, traditional leather conditioners, animal fats and waxes

1. INTRODUCTION

According to international quality assurance systems for furniture, all furniture quality features are determined by: functionality, durability, surface resistance and material quality and accuracy of processing. In order to preserve the quality of the furniture in its service life it is necessary to maintain it.

Maintenance of furniture is the preservation of its materials, surfaces and shape, in addition to all factors of use in its original state. This means, first of all its proper use and care (Smithsonian Institution, 2019). The upholstered furniture is most often exposed to a high frequency of use, primarily as furniture for home use, working offices, seats in vehicles, furniture of special importance - antique furniture. Leather as a material in upholstered furniture is always in a trend and most often, through use it gets a patina, so its aesthetic value increases. It is also the most resistant material for upholstery, with the highest resistance to scratches (Goodrich Global, 2016).

The leather production industry aims to produce a product with a high aesthetic effect and a long service life. But the consistency of the leather and its properties over a longer period of time depends most on maintenance (Lange, 1982; John, 1996). The main aims of leather maintenance are: its adaptation to the conditions of use, removal of signs of use and aging, and preparation for further use.

Today, a lot of commercial care products in the form of pastes, creams, oils and sprays are available for maintaining the leather. They are made for one purpose - to maintain the leather and its properties in the initial shape. However, the leather is one of the first materials that a man has started to use in his life and thus has developed a variety of means and ways to maintain it, which in the beginning were primarily animal fats and oils.

This paper has a review character. We want to analyze and explain the needs for the maintenance of leather furniture, as well as commercial products and their efficiency compared to some of the methods and traditional materials and recipes. The paper reviews the needs for maintaining upholstered leather furniture, then scientific observations and experiential facts from maintenance of the leather.

2. NEED FOR LEATHER MAINTENANCE IN THE FURNITURE

The environment in which leather furniture is used has its own distinctive abiotic factors that depend on the climate in the interior: relative humidity, air temperature, light, gases, smoke and dust in the air. In addition to the stated importance, biotic factors include: perspiration and mechanical loads. Changes in the properties of the leather as well as its consumption is a consequence of a complex and interaction of chemical changes in the material and mechanical loads. All these factors contribute to the oxidation and hydrolysis of the material, the consequence of which is gradual degradation.

The sun's rays are partially absorbed, partially refracted from the surface of the leather. Solar radiation causes color changes and degradation of collagen, which is the basic building protein in the fibers of the leather. Even more severe degradation occurs from ultraviolet radiation that is not visible to the human eye. This radiation has a wavelength less than 400nm and possesses high energy that can break up the macromolecular connections in the collagen. The phenomenon is known as photolysis and occurs in the presence of oxygen from the air. In particular, photooxidation degrades the protein chain of the collagen, reducing mechanical properties, cracks on the surface, color changes, and reduction in the pH of the leather (Florian, 2006). Light is indispensable in the home, and the recommended lighting values in the interiors according to (NOAO, 2019) are light levels from 50 to 2000lux, specifically in homes around 150lux. The (Canadian Conservation Institute, 1992) set limit values for the light levels that are not harmful to the leather in the furniture. According to him, the recommended values for furniture and leather products are: light levels up to 50lux and ultraviolet radiation up to 75μW / m^2. From the presented data it can be seen that the light levels in the homes is three times greater than the prescribed lower limit value for maintaining the leather. So the leather in the upholstered furniture is constantly exposed to illumination. Radiation can be reduced by using furniture covers and not exposed to direct sunlight (for example, up to a window).

The leather is exposed to the relative humidity of the air. With the change in relative humidity in the air, the percentage of water in it changes.Water in the leather acts on the hydrolysis and oxidation of collagen. The increased hardness and rigidity of the leather are due to the cycles of changing the relative humidity and air temperature. By increasing the relative humidity of the air, the leather absorbs water and when the humidity in the air decreases in the leather a process of water desorption occurs. Over time and cycles of change, these two values equalized, part of the collagen becomes hydrophilic and the leather becomes hard. Leather should not be exposed to extreme change in relative humidity in the air. Very dry conditions when relative humidity is less than 40%, cause moisture loss in the leather and it becomes hard and non-elastic. Figure 1 shows the appearance of dehydrated leather furniture. The high relative humidity in the air above 65% causes hydrolytic reactions to degradation of the collagen fibers on the leather, which is accompanied by the appearance of mold and color change - staining. Gradual changes in relative humidity of the air are not a problem, because the leather can be gradually adapted, but rapid and abrupt changes are extremely harmful (Angus, Kite, Stuge, 2006). The optimal and recommended conditions in the interior of the leather are relative air humidity from 50 to 55% and temperature (from 20

+/ - 2 °C). Regarding these factors, the leather does not differ from other organic materials. It responds rapidly to environmental changes and therefore requires preventive maintenance.

Figure 1. *Furniture with dehydrated and damaged leather*

Exposing one material to heat means transferring a portion of the kinetic energy, which causes an increased molecular motion and an increased rate of chemical reactions in the material. In the case of a polymer, it is manifested by the breakup of the polymer chain links. Long-lasting exposure of the leather at increased temperature reduces moisture hydration from the air, which keeps the elasticity and the leather becomes hard and cracks. Figure 2 shows the appearance of cracked leather. Normal and constant room temperature does not affect harmfully, but in rooms that are occasionally used and because of this are occasionally warming, temperature changes are a kind of "stress" for the leather in the furniture. In this sense, leather furniture must not be exposed to a direct heat source. According to the literature (Bacardit et al., 2012) factors: relative humidity, air temperature and ultraviolet radiation have the greatest impact on leather aging, and the most influential is humidity.

Figure 2. *Hard and cracked leather*

Air pollution, chemical substances and dust particles also act on leather furniture. Chemical substances such as: nitrogen, oxygen, carbon dioxide and ozone, react with leather matter. Oxidation builds acidic compounds that act degrading to the leather. Particles that accumulate in the form of dust fill the pores of the leather, which makes the process of sorption or its "breathing" difficult, making it easier to get mold. The dust is hygroscopic, additionally attracts moisture that dehydrates the leather. The fine dust particles act abrasively on the surface of the leather (Storch, 1987). The presence of metal particles in the air further degrades. The dust is particularly intrusive and very difficult to remove from the surface of the leather that has been neglected for a long time (Canadian Conservation Institute, 1992).

Human body perception was established as a very influential factor in leather degradation in furniture (Bowes, 1963). Perspiration is mainly composed of: sodium chloride, lactic acid, amino acids and urea (Montain, Cheuvront, Lukaski, 2007). These chemical compounds act degrading to collagen, especially chromium-tanned leather (Haines, 1991c). The perception also causes a change in leather color in darker tones, which can be seen in the following Figure 3.

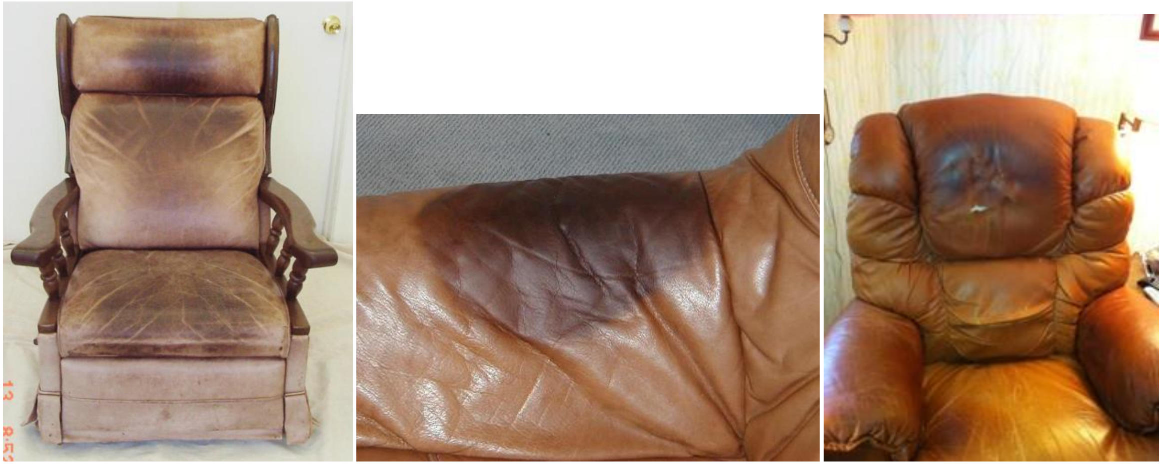

Figure 3. *Perspiration effect on the leather in upholstered furniture*

Mechanical loads occur during regular furniture exploitation, and on upholstered furniture they are extremely intense. Loads may be dynamic, as a result of: sitting, standing, backrest and arms, or static, such as: long-term load with body weight when sitting, lying down or a similar position, etc. These burdens cause deformation of the leather that is stressed, structurally on: stretching, pressure, bending, twisting, etc., and surface to: wear, abrasion and scratching. According to the (Canadian Conservation Institute 1992; Storch, 1987; Waterer, 1971; Plenderleith, 1970; Guldbeck, 1969), most of the mechanical damage occurs in places where the leather is folded. In these places there is a cracking and splitting of the material.

All these factors, which are based on the conditions in the environment in which the furniture is used, interact with the leather in upholstered furniture, and in order to maintain the quality of the leather as a material it must be properly maintained.

3. LEATHER MAINTENANCE SYSTEM IN UPHOLSTERED FURNITURE

The manner of maintaining leather furniture depends on the frequency of use, the exposure, duration and intensity of the action of the aforementioned factors. Leather furniture maintenance systems mainly contain the following three groups of activities: prevention, cleansing and conditioning of the leather.

Prevention means control of the conditions in the environment of use and exposure of furniture to the destructive factors affecting the climate in the interior. These factors have previously cited as abiotic factors: temperature and relative air humidity, UV rays and heat, air pollution, dust, smoke and chemical evaporation and biotic factors: perspiration, mechanical and a surface load. Prevention in the sense of using coverings for the surface protection of leather furniture.

Cleaning should be periodic, depending on the effect of the abiotic climate on the interior and the frequency of use of leather furniture. We noted that the upholstered leather furniture is exposed to dusting in use, and if this contamination is allowed to be excessive, then cleaning is not possible or is complicated (Rausch, 2006). Periodic cleaning is based on brushing the surface with soft fibers or using a vacuum cleaning machine (Canadian Conservation Institute, 1992). If necessary, the leather is also wiped with wet cotton rug to remove the residual dust and sweat residues. This is especially important, to be done before conditioning of the leather. Soaps and detergents are not adequate to cleaning the leather due to their alkaline pH (the leather has a pH of about 5.5) and these alkalies act degrading (Canadian Conservation Institute 1992; Storch, 1987).

Conditioning is the most important stage of leather maintenance. Fats are an integral part of the natural skin, which is why some of the fats are added to the processing. During processing, fats prevent the collagen fibers from interconnecting, which is especially important when the leather is drying. Fat also impregnates the leather and restores the previously lost fats, which are necessary for further exploitation (Bogacki, 2005), when aging loses some of the fat, it becomes hard and cracks. Conditioning is actually maintaining the natural properties of the leather at the optimum level. This concept of "feeding" or restoring lost fats was scientifically confirmed by Walter (Weterer, 1972). With the increase of fat in the leather, it increases its flexibility (Plenderleith, 1946). It is well known that conditioning is combined with hydration. It is best to perform conditioning while the leather is wet because the water acts as a medium which allows deeper penetration of fat (White, 1856, Blockey, 1919). According to recent studies (Jarnagin and Knopp 2009), water and fats are key to "rejuvenating" the leather, penetrating deeply into collagen fibers that are making the leather soft and flexible. The amount of added fat should be in proportion to the density of the fibers of the leather (Stambolov, Van Soest, Hallebeek, 1984).

4. COMMERCIAL CONDITIONERS OF MAINTAINING LEATHER IN UPHOLSTERED FURNITURE

Commercial conditioners are offered in multiple shapes and with different consistency like oils, soaps, pastes and sprays. Some of them are multipurpose, for simultaneous cleaning and conditioning and some just for conditioning the leather.

4.1. Neatsfoot oil - bone oil

The use of Neatsfoot oil for leather maintenance dates from 18 cetury. It is yellow color, and is obtained by boiling of bones. In the past it was used as pure crude oil, and today it is used as a commercial product mixed with mineral oil and some vegetable oils, most often with soya oil. The composition also contains solvents. Characteristic of it is that it quickly penetrates into the leather, absorbs, and much darkens. It acts oxidizing on the leather.

Figure 4. *Commercial types of Neastfoot oil - Bone oil*

4.2. Saddle Soap - Soap for leather

Conditioner that has a long tradition of use. It is used at the same time as a cleanser and conditioner. It is a soap with the addition of lanolin and bee wax. This agent has a basal character with pH 10, acts alkalizing on the leather that usually has acidity pH 5. Saddle soap reacts by naturally occurring oils in the leather, leaving white spots on the surface of the leather. Conditioner is mainly degrading.

Figure 5. *Commasional Forms of Seaddle Soap*

4.3. Pastes with animal fats and oils

Pastes that are composed of animal fats and oils with waxes or resins dissolved in solvents. They have fats and oils from: mink, cattle, whales, bears, etc. Besides the fats, they contain waxes, pine resin and solvents such as turpentine or other oil solvents. The best known is the mink based grease based product, "Mink oil". Some of them contain a large percentage of solvents, thus achieving past form.

Figure 6. *Mink oil – conditioner*

On a market are also available cosmetics cleansers, soaps and detergents and some of them are shown on Figure 7.

Figure 7. *Comercial cleaners and conditioners*

The listed commercial agents (including those based on animal fats and oils) also contain solvents that further dissolve occurring fats in the leather. The solvents are degrading both to the leather and to the coatings and colors used for surface treatment of the leather (Soest , 1984; McCrady, 1993). Also, the mineral oils that are part of some of these agents are not related to the collagen, they do not "feed" the leather improperly. According to some authors (McCrady E, 1993) as the criterion for selecting and using commercial maintenance means are the current visual effects on the leather. Unfortunately, it does not pay attention to the long-lasting effect that in the long term is negative and degrading to the leather.

5. TRADITIONAL CONDITIONERS AND MAINTENANCE OF THE LEATHER

Fats and oils of animal origin for the treatment and maintenance of leather have been used long ago. The first literary data date back to the 19th Century (White F, 1856; Blockey, 1919; Newbury, 1940). During that period, tallow, lard and lanolin were used, and fish oil.

Traditional leather conditioners were often combinations of fats and oils with the addition of bees wax. The role of wax is to fill the pores and thereby prevent dehydration of the leather. The most commonly used combination was tallow and fish oil in the same ratio, but very good results were achieved with the addition of bees wax (Blockey, 1919). There are also traditional recipes derived from craft workshops, composed of 50% tallow, 25% lard and 25% bees wax (or lanolin instead of lard), which are also used today by craftsmen and individuals (Horse & Hound, 2012) . Figure 8 shows the appearance of a combination of these conditioners. These traditional recipes do not contain soaps or solvents. They have the ability to migrate through surface coatings of the leather (Angus, Kite, Stuge, 2006).

Figure 8. *Traditional conditioner made of animal fats and bees wax*

The author Tusk (Tusk, 1983) lists some facts to use fats and oils to maintain the leather. Porous and fibrous structure of the leather requires conditioning, and according to it, the fats will reduce the friction that occurs in the tanning process between the collagen fibers and increases the durability of the leather. Then, with increasing fat, the stretching strength of the leather decreases, but the probability of dehydration decreases. Fat reduces porosity and prevents the penetration of chemicals. Leather oxidation decreases if the fats have a large number of unsaturated fatty acids and thus increase the chemical stability of the leather. At the same time, the aesthetic effects of the leather are improved.

According to authors (Ludwick, 2012; McCrady, 1983; Kite, Thomson, Angus, 2006), the leather conditioners: reduce aging (degradation), improve appearance and maintain firmness and flexibility.

Natural fats of the same species: animal - leather - fat, are of better quality than other fats to be used for further conditioning the leather (Santos et al, 2005; Nasr, 2017).

The leather that is treated with fats has high organoleptic properties, it is soft and gives a feeling of fulfillment (Sandhya, et.al. 2015). The leather oiled with fish oil has a strong characteristic scent and increases the natural intensity of the scent of the leather.

The only disadvantage of these traditional conditioners is the slow absorption of fat in the leather, which can last up to three days, while the surface of the leather is slick.

6. CONCLUSIONS

According to this review of the needs and possibilities for care and maintenance of leather in the upholstered furniture, and presented in order to maintain the quality of the material and surfaces for the general quality of the product, the following conclusions can be made:

- Care and maintenance of leather in the upholstered furniture is a system of activities such as prevention, cleaning and conditioning of the leather. All these activities are interconnected to maintain the quality of the leather.

- Commercial leather conditioners do not meet the needs for maintaining leather quality over a long period of time.
- Traditional leather conditioners wich is made of animal fats, oils and waxes strengthen collagen fibers on the leather, maintain flexibility, improve hydrophobicity and increase its organoleptic properties.
- The most commonly used traditional conditioner contains 50% tallow, 25% lard and 25% bees wax.
- Conditioning is combined with hydration. It's best to perform conditioner while the leather is wet because the water acts as a medium which allows deeper penetration of fat
- Disadvantage of these traditional conditioners is the slow absorption of fat in the leather.

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CONTINUAL VACUUM DRYING OF BEECH WOOD (*FAGUS SYLVATICA* L.) WITH DIFFERENT THICKNESS

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ABSTRACT

Drying in a vacuum has long time is considered as an attractive method for wood drying wood because drying rates are usually high and degrade is minimal. As compared with drying at the atmosphere pressure the principal advantage of vacuum drying of materials is that it provides certain intensification of this process and enables to carry it on lower temperature. The objective of this study is to evaluate the vacuum drying of beech wood with different thickness in terms of drying time, drying rate, moisture content variation and quality of drying. To evaluate the effect of the wood size on the drying rate, three different thicknesses 25, 38 and 50 mm were dried in a several runs in continues vacuum drying with the maximum temperature of 60 ^{o}C from different initial MC to 10 % final MC, at a pressure of about 600 mm Hg. Data analysis indicated high differences between various drying times and drying rates of different thickness of wood. Specimens 25 mm from MC of 60 % dried the fastest 47.6 h with average drying rate of 1,208 %/h . Specimens 32,0 mm dried slower 70.4 h, 0.837 %/h and those of 50 mm dried the slowest 90.5 h, 0,617 %/h. Additionally, the experiments also demonstrated that for all three specimens thickness below the fiber saturation point (FSP) the drying rate are significantly smaller about 50 % compared with rates above FSP. According to the International standard for evaluation of drying quality, it was observed that the drying quality was good, with no color change not any visible drying defects. This experiment also indicates that that is possible to dry beech lumber in continues vacuum with reasonable drying rates in contrast to the conventional drying.

Key words: beech wood, vacuum drying, drying time, drying rate, quality classes

1. INTRODUCTION

Present period in the Republic of Macedonia is characterized by the growth of small and middle enterprises manufacturing joinery and constructive products and furniture. Such production requires high – quality wood drying.

Vacuum drying processes can offer substantial benefits over conventional convective wood drying techniques due to the reduction in drying times and the increased product quality. The lowered boiling temperature of water in a partial vacuum allows free water to be vaporized and removed at temperature below 100 ^{o}C and drying rate is therefore increased without the dangers of defects in the wood.

At present there are four basic types of vacuum drying based on heat transfer to the wood: conduction by direct contact with hot plates or electric heating blankets, convection using superheated steam, convection using hot air in cyclic system, and radio – frequency dielectric heating as stated by Chen and Lumb (1995), and Trebula *et al* 1993.

Cividini (1993) reported that in 1962, Pagnozii built an experimental drier of limited diameter (800 mm) with electrical resistance plates working in continuous vacuum and with a storage capacity of 0,5 m^3. Its main goal was to exploit the high output of the heating transmission by the contact between wood and plates. In 1966 he built an experimental a semi – industrial cylindrical plant for normal dimension sawn timbers which could dry both in continuous and discontinuous vacuum. The 1966 can be considered the original year in which industrial vacuum drying process was born, this because since that date, a spreading application of these driers started in the industrial practice. Moreover in vacuum driers is possible not only a considerable drying reduction, but even a lowering of the differences between divers species and the different mixtures of thickness.

Many authors have dealt with vacuum wood drying researching (Simpson 1987, Chen and Lamb 2001, Harris and Taras 1984, Wengert and Lumb 1982, Lamb and Wengert, 1993, Avramidis *et al.* 1994, Trebula *et al*. 1993, Kanagawa and Yisujima 1993, Trofatter *et al.* 1986, Jung *et al.* 1999, Moldrup 1992.

Some of the authors concern the vacuum drying rate. Avramidis *et al* (1994) concluded that the vacuum drying rate is inversely proportional to ambient partial air pressure, and that is comparable with the drying rates obtained by high temperature drying above 100 ^{o}C. Harris and Taras (1984) investigated drying process on 100 mm thick red oak. They found that vacuum drying process took about 88 hours from initial MC of 67% to final MC of 7%, whereas with conventional drying of oak with same size it took 53 days to dry to 8% final MC. Trebula *et al.* (1993) analyzed influence of pressure on the rate of vacuum – radiating drying of beech. They concluded that the drying rate and intensity of water evaporation from wood increases with the decreasing value of the pressure of the steam – air mixture in the drying medium. Drying speed is related to the species, especially the permeability of the species (Kanagawa and Yasujima 1993).

Drying test with the vacuum dryer showed lower lumber degrade than in conventional kiln drying (Wengert and Lamb 1982). After vacuum drying lumber have similar color to the one before drying (Moldrup 1992).

The objective of this study is to evaluate the continual vacuum drying of beech wood with different thickness and initial MC in terms of drying time, drying rate, moisture content variation after drying and quality of drying.

2. MATERIALS AND METHODS

The high quality beech (*Fagus Sylvatica* L) boards used for the experiments came from a sawmill in Gostivar. This specie is the most commercial hardwood specie in the Republic of North Macedonia.

The boards were 25 mm, 38 mm and 50 mm in thickness with different initial moisture content (MCi). All boards free of visible defects were cut into 180 cm long pieces and to the width between 10 and 15 cm. Several kiln drying experiments were carried out in the vacuum dry kiln shown in Figure 1. After the initial heating up phase is completed, the complete drying process is carried out under vacuum of about 600 mm Hg. The energy need to evaporate the water from the wood is supplied by a direct contact with Al plates heated by electrical resistance Different drying rate were obtained by varying the wood thickness and initial moisture content above and below FSP – fiber saturation point.

***Figure 1.** Vacuum dry kiln*

Initial and final moisture content of wood was determined by gravimetrical method (EN 13183–1). MC during drying was a continuously measured on the basis of electric resistance (EN 13183–2).

The drying rate was calculated as the difference between the MC before and after certain drying period, divided by the time.

At the end of drying, a quality check of the dried lumber was performed on wood samples with the determination of the following parameters: difference between the average final moisture content and the required final moisture content (Eg. 1), fluctuation of the final moisture content (Eg. 2), moisture gradient (Eg. 3) and casehardening (ENV 14464).

$$Wd = \frac{\sum_{i=1}^{n} Wa}{n} - Wk \, , \qquad (1)$$

where:

Wd - difference between the average final moisture content and the required final moisture content %;

n- number of samples

Wa - average final moisture content of samples %;

Wk - required final moisture content of samples %.

$$Wf = Wmax - Wmin \qquad (2)$$

where:

Wf - range of the final moisture content %;

$Wmax$ - maximum moisture content in samples, %;

$Wmin$ - minimum moisture content in samples %.

$$\Delta W = Wc - Ws \qquad (3)$$

where:

ΔW - moisture gradient of lumber %;

Wc - moisture content of the sample middle layer %;

Ws - moisture content of the sample surface layers %.

The samples for determination of drying quality characteristics are shown in Fig. 2.

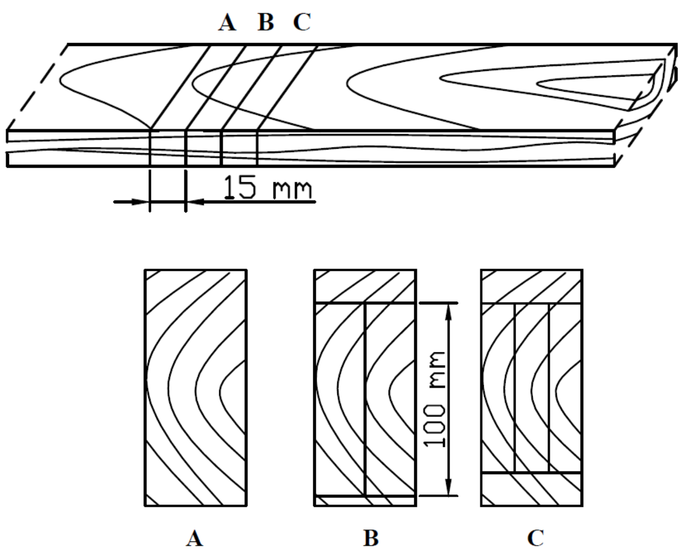

Figure 2. *Samples for determination of drying quality characteristics*

3. RESSULTS AND DISCUSSION

3.1 Drying kinetics

Figures 2 show the drying curves of three runs, with curves of wood temperature and temperature of heating plates. It can be notice that the MC drying curves for all three sizes of specimens show a similar shape. The internal wood temperatures rapidly reached initial set temperature in several hours and then increased slowly during the late stage of drying nearly same as platen temperature for all drying runs.

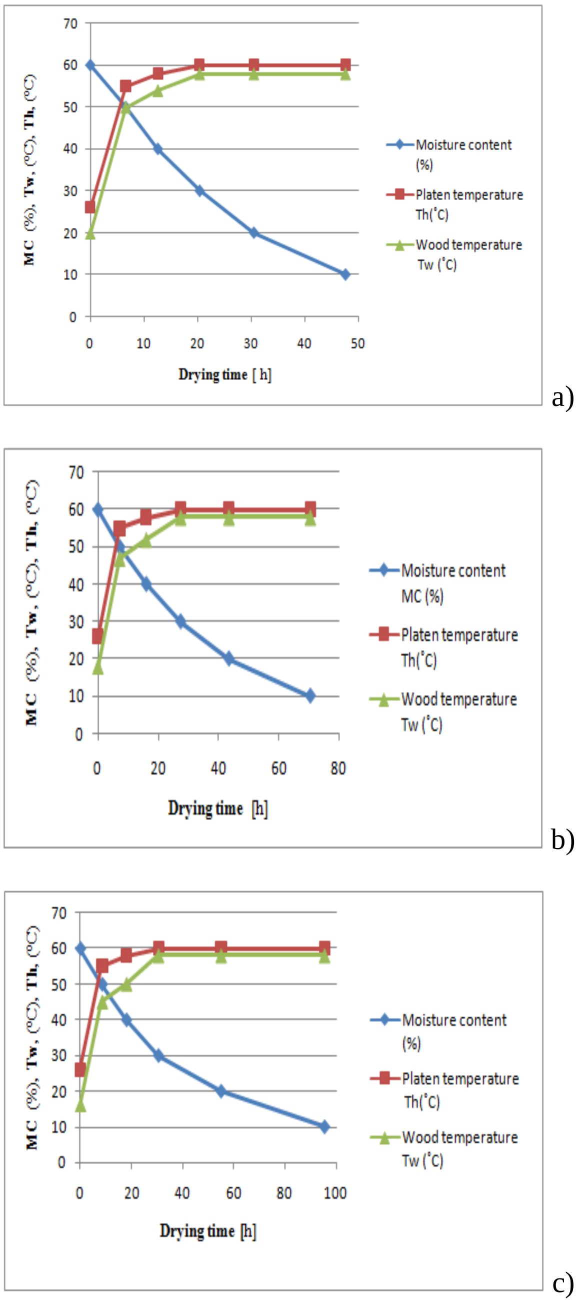

Figure 3. *Drying curves of beech wood with thickness: a) 25 mm; b) 38 mm; c) 50 mm*

3.2 Drying time

The results of drying time of each test run for vacuum drying of beech wood with different initial MC and different thickness are given in table 1.

Table 1. *Drying time of each test run*

Run No	**Lumber thickness** (mm)	**MC$_i$** (%)	**MC$_f$** (%)	**Drying time** (h)		
				Green – 30 %	30 % – 10 %	Green – 10 %
I	25	61.5	9.8	20.4	27.2	47.6
II	25	50.3	9.6	13.7	24.1	37.8
III	25	42.3	9.2	6.6	26.1	32.7
IV	38	60.5	9.4	27.4	43.0	70.4
V	38	51.2	9.9	36.8	39.5	60.1
VI	38	40.6	9.2	8.1	39.9	48.0
VII	50	60.2	9.4	35.8	54.7	90.5
VIII	50	51.1	9.6	47.6	53.1	76.1
IX	50	41.2	9.7	11.6	52.3	63.9

From the results in Table 1 we can notice that the average initial MC determined by the oven – drying method varied between 61,5 % (run I) and 40,6 % (run VI). The average final moisture content was (run VI) and 9,9 % (run V). The shortest drying process for the MC range between 30% and 10% was achieved in run III (24.1 h) for thickness 25 mm, followed by run V (39.5 h), for thickness 38 mm. The longest drying time was recorded in the run VII (54,7 h) for thickness of 50 mm.

As for total drying time range between 60 -10%, the shortest time was recorded in run I (47.6 h) followed by run IV (70,4 h) and the longest (90.5 h) was in run VII. Assuming that FSP is 30 %, in all runs, more time was required to remove the moisture content below FSP (30 -10 %) than above it. It ranged from 57,1 % to 60,4 % of drying time for the whole MC range (60 -10%).

It can be concluded that for the similar MCi and MCf, the results of drying time for all three thicknesses is considerably quicker than conventional drying. The drying time are quoted with 40.8 hours for 25 mm compared to 330 h using conventional processes of beech (Marinescu *et al*), 71,4 h for 38 mm beech compared to 288 h (Milic *et al*), and 79,2 h for 50 mm beech, compared to conventional drying of 528 hours. (Zlateski,1999).

3.3 Drying rate

The drying rate was determined above FSP, below FSP and for whole drying process as well. These results are presented in Table 2.

Table 2. *Average drying rate of each test run*

Run No.	**Lumber thickness** (mm)	**MC$_i$** (%)	**MC$_f$** (%)	**Average drying rate for the MC ranges** (%/h)		
				Green – 30 %	30 % – 10 %	Green – 10 %
I	25	61.5	9.8	1.488	0.787	1.208
II	25	50.3	9.6	1.464	0.875	1.170
III	25	42.3	9.2	1.515	0.797	1.036
IV	38	60.5	9.4	1.134	0.498	0.880
V	38	51.2	9.9	1.009	0.523	0.766
VI	38	40.6	9.2	1.235	0.527	0.763
VII	50	60.2	9.4	0.869	0.373	0.671
VIII	50	51.1	9.6	0.889	0.382	0.636
IX	50	41.2	9.7	0.864	0.396	0.552

From the Table 2 we can state that at the equal initial and final MC the drying rate decreases with increasing the thickness of the wood. Drying rate for 25 mm thickness is between 1.036 (run III) and

1.208 %/h (run I). For 38 mm in thickness from 0.763 (run VI) to 0.880 %/h (run IV) and for 50 mm in thickness 0.552 (run IX) to 0.671 %/h (VII).. The different drying rates in continuous vacuum drying, is affected by the thickness mainly due to the amount of heat transfer. A thinner specimen will absorb more heat energy per unit volume. As a result, thinner specimens will dry faster than a thicker specimen.

Comparable results for drying rate can be found in the works of Trebula *et al* (1993) and Gorišek *et al*, (2007).

The experiments also demonstrated that in all cases drying rate above the fiber saturation point (FSP) is much higher compared with rate below FSP. It ranged from 0,373 %/h (run VII) to 1,515 %/h (run III). The possible explanation for the experiments results is that at early stage of drying there is sufficient free water within wood to be heated, boiled and easily transferred through capillary flow from wood interior to wood surface than bellow FSP where the water transferred through diffusion flow (Avramidis *et al*, 1994).

3.4 Drying quality

Table 3 shows the results of evaluation of drying quality of dried beech lumber based on the difference between the average final moisture content and the required final moisture content, fluctuation in the final moisture content, moisture content gradient and state of casehardening.

Table 3. *Evaluation of the quality of dried lumber*

Quality characteristics		**Thickness of dried lumber**		
		25 mm	38 mm	50 mm
Difference between average final moisture content and required moisture content	W_d	0.2 %	0.5 %	0.3 %
Range of the final moisture content	W_f	0.9 %	1.4 %	1.2 %
Casehardening (mm)	G	0.3	0.7	0.5
Moisture gradient of lumber	W_g	0.5 – 0.9 %	0.7 - 1.4 %	1.1 - 1.5 %

Based on the comparison of the experimental measured values of quality characteristics with the values of individual quality classes, it can be concluded that the dried beech lumber with the thickness 25 mm fulfills the criteria of the first quality class according to the analysis of the following quality characteristics: W_d = 0.2 % ≤ 0.5 %, W_f = 0.8 % ≤2.4 %, W_g = 0.5 – 0.9 % ≤ 1.5 % and G = 0.3 mm < 1 mm. Further, quality evaluation of the dried beech lumber 38 mm in thickness with characteristics W_d = 0.5 % ≤ 0.5 %, W_f = 1.4 % ≤ 2.4 %, W_g = 07 – 1.4% ≤ 1.5 % and G = 0.7 mm < 1 mm, as well as beech lumber 50 mm in thickness with the characteristics W_d = 0.3 % ≤ 0.5 %, W_f = 1.5 % ≤ 2.4 % ,W_g = 1.1 – 1.5% ≤ 1.5 % and G = 0.5 mm < 1 mm fulfill the criteria for placing the dried beech lumber into the first class of quality.

4. CONCLUSION

The trials carried out using beech wood clearly showed that the vacuum system can be used to rapidly dry beech in various thicknesses and initial MC, without visible drying defects. During vacuum drying of wood the major factors affecting drying rate are the thickness and MC of the wood.

It can be conclude, that different drying rate for different thicknesses in continuous vacuum drying, is affected by the thickness mainly due to the amount of heat transfer. A thinner specimen will absorb more heat energy per unit volume. As a result, thinner specimens will dry faster than a thicker specimen. The experiments also demonstrated that in all cases drying rate below the fiber saturation point (FSP) is much higher compared with rate above FSP.

It was confirmed that, the vacuum drying is the faster than conventional drying of wood and sufficient to obtain the first class of drying according to standards. Discoloration was not observed because boards were not exposed to high temperature for long period and the absence of oxygen. The drying cost and energy consumption are major questions regarding vacuum drying especially versus conventional kiln drying. Other studies will be required to determine this comparison.

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