Róbert Németh

&

Alfred Teischinger

editors

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PREFACE

New challenge of hardwood utilization

Hardwood is sometimes referred to the pearl of the forests. Hardwood utilization is more complex than softwood processing and there are great challenges for a competitive hardwood process chain. Due to many reasons such as changes in silviculture, changing ecological conditions the share of hardwoods in Europe’s forests is growing and hardwood processing and utilization gains more and more importance. The overall objective of the proposed action is an improvement in competitiveness of European hardwood products by creating a Pan-European network with special emphasis on supporting early stage research.

A competitive and innovative hardwood process chain has to be developed by new allocation concepts to overcome the lack of economical efficiency of the mostly small enterprises with scattered hardwood resources, innovative manufacturing systems, a quality deployment model for specific process chains and concepts for technology transfer between research institutions and hardwood producers / processors has to be installed.

The conference series of hardwood research in Sopron, Hungary, already addressed the various assets and challenges of hardwood such as issues of hardwood research and utilization in Europe (first and second conference), the beauty of hardwood (third conference). Prof. Sándor Molnár and Dr. László Bejó did that time a pioneering work and established good reputation and scientific background for the conference edition in 2012.

We are delighted to present the proceedings of the 5th European Conference on Science and Technology on Hardwood, held in Sopron, Hungary, 2012, which has been organized in close cooperation with the University of Natural Resources and Applied Life Sciences, BOKU Vienna. This cooperation also reflects some cooperation in hardwood research of the two universities and we hope to present interesting topics of hardwood research and technology in the various sessions the industrial visit as well. We are grateful to all speakers, poster presenters and participants for this information transfer and for making this conference successful. We also hope that the readers of these proceedings will benefit from this documentation.

Alfred Teischinger & Róbert Németh

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Yield, process and cost analysis for the processing of small diameter hardwood

Jörn Rathke[1], Alfred Teischinger[2], Christian Hansmann[1]

[1] Address of first Wood K plus – Competence Centre for Wood Composites and Wood Chemistry, Altenberger Straße 69, A-4040 Linz, Austria

[2] Department of Material Sciences and Process Engineering, Institute of Wood Science and Technology, BOKU – University of Natural Resources and Life Sciences, Konrad Lorenzstraße 24, A-3430 Tulln an der Donau, Austria

Keywords: Small diameter hardwood, sawmill, yield, cost, technology assessment

ABSTRACT

The most effective production technology for the processing of small diameter hardwood has been discussed for a long time in research and industry. Currently these resources are mainly used for firewood. An increase of the added value is expected by using small diameter hardwoods for material applications. Higher prizes of the logs are of high importance for a sound forestry management and the biodiversity of the forests. Therefore the development of new products, alternative production technologies and new sales possibilities of this specific assortment is of high economic interest. One major factor in this process chain is the production cost in the sawmill. This cost varies, depending on the technology which is chosen.
In this study three different types of saw mill technologies are analyzed. First a bandsaw headrig, second a gang saw and finally a bandsaw line were compared. The results showed high variation of the cost depending on sawing technology and the production volume. The data showed that only lowest log price qualities could be paid for the small diameter timber due to high processing cost. The study shows that a cost-effective small diameter hardwood processing is only possible using frame saw and bandsaw systems for the species sycamore, oak and ash. A profitable processing of small diameter beech is not possible. In order to enhance yield, new technologies or yield limits for the minimal acceptance of board width have to be discussed.

INTRODUCTION

Climate change, as well as the forest management with a focus on natural juvenescence, has lead to significant increase of hardwood trees in the middle European forests. Due to this change, the amount of small diameter logs, especially beech and oak rises (KNAUF AND FRÜHWALD 2011). According to SEEGMÜLLER (2006) small diameter timber is defined as a log with a maximum diameter until 35cm (3a HKS diameter class).
The idea to find a better purpose than firewood for small diameter hardwood is not new. In the 1970s and 1980s a number of scientific studies have been performed in the U.S. which dealt with the usage and processing of small diameter hardwood (STUMBO 1981). In central Europe small diameter hardwood was only used in a limited range, as the sawing process was optimized for bigger diameters. Anyway a couple of studies were done on a project basis to analyze the process capability and market ability of small diameter hardwoods. ANTHES ET AL. (1993) determined the sales and market possibilities of small diameter hardwoods of beech and oak. EHLEBRACHT (1995) analyzed alternative processing technologies for the machining of small diameter beech and oak logs, which should result in a better market chance. In a couple of studies EHLEBRACHT (1997, 2000, 2001) determined machining technologies for small diameter hardwood, as well as ideas for a better processing of hardwood in general. Here for example product possibilities for finger jointed oak construction timber were analyzed (EHLEBRACHT AND BLEILE, 2000).
FISCHER ET AL. (1997) worked on the possibility to use small diameter hardwood for the production of poles in the parquet manufacturing. In this study the high sapwood content of oak resulted in a significant lower yield. This problematic is also described by CLAUDER AND FROMMHOLD (2009). Here a sapwood width of 3 to 4 cm was calculated which again had a significant effect on the yield. In the study of CLAUDER AND FROMMHOLD (2009) the processing of small diameter beech logs was problematic, due to a high amount of cracks. In contrast to that the processing of ash and sycamore resulted in a better yield (EHLEBRACHT AND BLEILE 2000).
BÜCKING ET AL. (2003) calculated performance data and process cost for the sawmilling process of small diameter beech logs. The study dealt with the machines gang saw, chipper sawline, circular saw line, and gang saw with an automated log feed. While chipper and circular sawline performed with the lowest production cost, the two techniques resulted in the lowest yield. In contrast to that, the two gang saw production lines resulted in the highest production cost, but parallel performed with the highest yield. This

study showed that the processing of small diameter hardwood is in general possible. Anyway the question remains how and with which technologies the processing of small diameter hardwood is cost effective and allows a positive result for both, forest and forest products industry.

Assuming this, the following questions are worked out in this study:

1. Which yield can be achieved when small diameter hardwood is processed?
2. What technologies and machine configurations are best suited for the processing of small diameter hardwood logs?
3. How much does the processing of small diameter hardwood cost?
4. What is the maximum log prize for the cost effective processing of small diameter hardwoods?

YIELD CALCULATION

In general an average yield for processing logs by means of a gang saw is calculated to be at 65% at a log diameter of 35 cm (FRONIUS 1989). In this study, four hardwood species (i.e. beech, oak, ash, sycamore) were analyzed on various characteristics as for instance the lumber yield. All together, 122 logs were selected from four forests with an average diameter of 26 cm. This counts for a total volume of 20.52 cubic meters. The logs were sawn with a band saw headrig, dried using kiln drying and resulted in 10.6 cubic meters of sawn small diameter hardwood lumber. The sorting was performed in accordance with the Austrian standard (ÖHHU). Due to the minimum width of 10 cm about 2.1 cubic meters had to be rejected (Assortment I). A second sorting trial allowed a minimum width of 8 cm (Assortment II).
The first assortment resulted in a total yield of 41 %. Especially the oak lumber resulted in very low numbers, which is based on the high sapwood content. In contrast to that the average yield of assortment II is at about 52% with higher differences concerning the used species.

TECHNOLOGY ASSESSMENT

Today the most common technologies for processing hardwood are headrig bandsaw, frame saw and bandsaw line (WILLISTON 1976, FRONIUS 1989, FRONIUS 1991, WAGENFÜHR AND SCHOLZ 2008). Circular sawlines are not taken into account in this trial due to a wider kerf and a high material output.

For a comparison of the three processing technologies (i.e. headrig bandsaw, frame saw and and saw line) a short description is given. The layout planning was performed in a first step by Esterer WD, Altötting/Reutlingen, Germany. Systematic boarders were defined to make a technology comparison possible. Therefore the machine planning was started directly before the first sawing machine and on the other side, before the sorting line for main product and byproduct starts. For the logs a length range from 2.5 m to 5.0 m and a diameter from 20 to 30 cm were predetermined. The lumber thickness should be in a range from 20 mm to 30 mm. For the three production technologies a different production capacity was planned, due to varying technologies. For the bandsaw headrig a production capacity of 12.000 cubic meters was planned, while for the gang saw setup a capacity of 30.000 cubic meters was planned. The bandsaw line was planned to produce 75.000 cubic meters.

The machine setup, as well as the material flow, is described in detail for the bandsaw line, vicarious for bandsaw headrig and frame saw, in detail as follows: The bandsaw line represents the highest production capacity compared to the two other concepts. This technology is today most often used for the processing of softwoods and offers a combination of small kerf and high flexibility. The layout is given in figure 1.

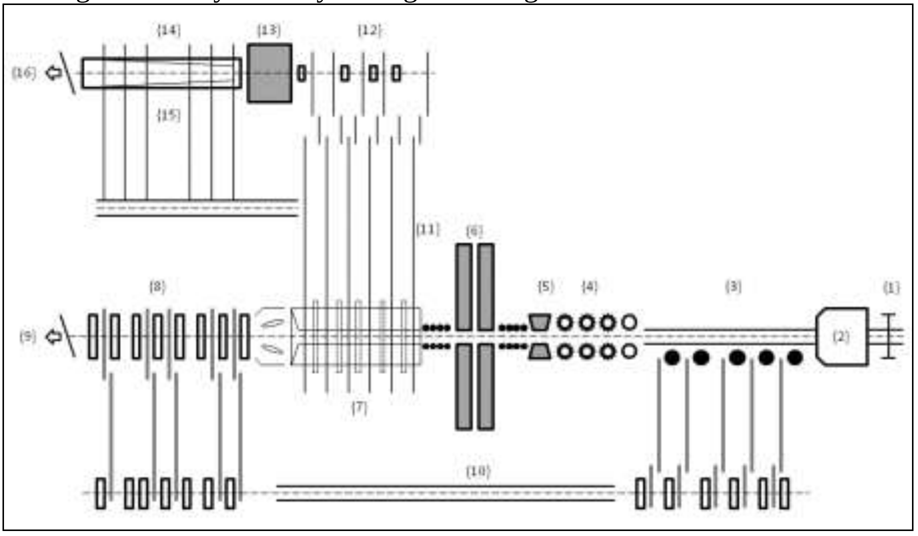

Figure 1: Machine concept of a band sawline (on the basis of Esterer WD); {1} 3D log measurement, {2} control cabin, {3} log haul, {4} log centering system, {5} profile chipper, {6} bandsaw line, {7} automatic side boards separation, {8} cross chain conveyor, main product sorting line, {10} cant running true, {11} cross chain conveyor to resaw, {12} board centering system, {13} edger and resaw system, {14} resaw product separation, {15} running true of resaw products, {16} by-product sorting line

The machine setup, given in figure 1, starts with a material flow from the right hand side. The logs are conveyed through a 3D measurement ring [1] and pass the control cabin [2]. The logs are conveyed using a log haul [3] and are clamped in the centering system [4]. The slabs are chipped of using profile chippers [5] which improve the following material flow. After that the bandsaw is placed [6] and the sawing process is performed. The byproducts are separated by means of an automated sideboard separation [7] and conveyed to the edger resaw by means of a cross chain conveyor [11]. The main product is transported after the side board separation to the main production sorting line [9] or by means of a cross chain conveyor [8] to the cant run through [10]. The edger resaw [13] allows a board orientation either in the middle axis or on the rough edge. After the resaw the splinter are separated [14] and the sawn product can be transported again [15] to the resaw or to the byproduct sorting line [16].
A descriptive comparison of the three sawing technologies is given in table 1. It is evident, that the bandsaw headrig offers the highest flexibility but parallel stands for the most expensive processing type.

Table 1: Descriptive comparison of the three analyzed sawing technologies

	bandsaw headrig	**frame saw**	**bandsaw line**
Thickness change	+	-	+
Diameter change	+	-	+
Accuracy	0	+	-
Production volume	-	0	+
Product change	+	-	+
Investment	0	+	0

The gang saw offers the highest sawing accuracy and allows the lowest investment cost. On the other hand the gang saw has a low flexibility in terms of the changing log diameters and varying board thicknesses. The bandsaw line offers a high material output with a good flexibility. The high investment cost and the bandsaw related cutting inaccuracy are the only negative aspects.

COST COMPARISON

To allow a cost comparison, the following passage deals with a determination of the production cost, depending on the three machine concepts. Based on the production cost, the maximum affordable log prize is determined by means of a profit margin calculation. Therefore static cost for operators log transport, log yard, storage, humidity-controlled storage, debarking, as well as further processing after the sawing as for instance steam treatment, kiln-drying and grading are added.

Table 2: Processing cost of small diameter hardwood logs in a sawmill

cost unit	bandsaw headrig	frame saw	bandsaw line
log yard [€/m³]	4.00 €/fm	4.00 €/fm	4.00 €/fm
storage and debarking [€/m³]	1.00 €/fm	1.00 €/fm	1.00 €/fm
process [€/m³]	10.18 €/fm	3.16 €/fm	1.82 €/fm
tools [€/m³]	2.00 €/fm	1.00 €/fm	1.50 €/fm
energy [€/m³]	1.44 €/fm	1.44 €/fm	1.44 €/fm
sorting [€/m³]	14.55 €/fm	7.89 €/fm	5.21 €/fm
personnel [€/m³]	1.94 €/fm	1.95 €/fm	0.99 €/fm
expendable materials [€/m³]	1.00 €/fm	1.00 €/fm	1.00 €/fm
total process cost [€/m³]	**36.09 €/fm**	**21.44 €/fm**	**16.96 €/fm**
log transportation [€/m³]	10.00 €/fm	10.00 €/fm	10.00 €/fm
total cost [€/m³]	**46.09 €/fm**	**31.44 €/fm**	**26.96 €/fm**

As shown in table 2, remarkable cost differences between the three processing layouts were found with the calculation model. The cost differences depend mainly on scale effects due to invest cost and the production volume.
Based on the calculated process cost (table 2), the maximum affordable log cost can be estimated by means of an inverse cost calculation. For the calculation of the lumber production cost the average process cost of 24.83 €/m³ (≈ 25 €/m³) was used with an additional 10 €/m³ for the log transport from the forest to the mill. The personnel cost was added to the corresponding subsection of the production.

In table 3 the maximum affordable log prize is calculated for each species. Generally and average yield of 65% is used in literature. In this trial the calculated yield, based on Austrian grading rules, was used and revealed 41% (Beech), 45% (Oak), 52% (Ash) and 67% (Sycamore).

Table 3: Determination of maximum affordable log prize, based on yield numbers gained from tests

Assortment I – yield:	**Beech 41%**	**Oak 45%**	**Ash 52%**	**Sycamore 67%**
lumber price [€/m³]	220	450	280	350
sales + logistic + personnel [€/m³]	30	30	30	30
storage + transport [€/m³]	15	15	15	15
grading + transport [€/m³]	20	20	20	20
kiln drying + transport [€/m³]	90	130	90	90
air drying + transport [€/m³]	-	20	-	-
steam treatment + transport [€/m³]	40	-	-	-
intermediate total [€/m³]	25	235	165	195
conversion [€/m³]	11	96	86	131
process cost [€/m³]	35	35	35	35
maximum log price [€/m³]	-24	61	51	96
maximum log quality [€/m³]	-	C	C	C

The usage of market data made a classification of the log prize into the quality categories A/B/C possible. Referring to the quality/prize determination beech reveals a negative prize and shows that no positive processing, based on the average processing cost is possible. Oak, ash and sycamore have a positive log prize and yield a quality category C depending on the price.

RESULTS AND DISCUSSION

Yield numbers of 65 % are given in literature (FRONIUS 1989) for the processing of small diameter timber. In this study different sawing technologies were compared. The bandsaw headrig performed with the highest flexibility but showed parallel the largest process cost with 46.09 €/m³ roundwood. In contrast to that the frame saw resulted in the most unflexible machine configuration but performed with low production cost and a comparatively low production cost (31.44 €/m³). The bandsaw line has the highest investment cost but shows due to the high material output the lowest production cost (26.96 €/m³).

It can be assumed that due to natural growth, small diameter hardwood yields only medium to poor roundwood qualities. Therefore the usage of frame saw and bandsaw line can be expected, depending on the roundwood volume which will be processed in the mill.

The calculation of the maximum log prize, by means of the inverse profit margin calculation shows a high variety across the analyzed species. For beech no profitable result can be calculated by means of the average processing cost. In contrast oak, ash and sycamore allow a positive result for the processing of small diameter hardwood.

CONCLUSION

The yield calculated in this study for small diameter hardwood differs highly from the numbers found in classic literature. The species oak, ash and sycamore allow a profitable processing, while beech does not reveal a positive result. According to the finding in this study, frame saw and bandsaw line are, depending on the production volume, the machine concept of choice for the processing of small diameter hardwood.

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The influence of different dimensions on the drying rate of oak

H. Pleschberger[1], R. Stingl[2], C. Hansmann[3]

[1] Wood K plus – Competence Center of Wood Composites and Wood Chemistry, Altenberger Straße 69, 4040 Linz, Austria, corresponding author: h.pleschberger@kplus-wood.at

[2] Institute of Wood Science and Technology – Department of Material Science and Process Engineering – University of Natural Resources and Life Science, Konrad Lorenzstrasse 24, 3430 Tulln, Austria, robert.stingl@boku.ac.at

[3] Wood K plus – Competence Center of Wood Composites and Wood Chemistry, Altenberger Straße 69, 4040 Linz, Austria, c.hansmann@kplus-wood.at

Keywords: oak, drying rate, dimension

ABSTRACT

The drying of oak (*Quercus spp*.) is due to the reduction of the drying time in accordance with quality requirements still in the interest of present research. The drying time of oak with regard to the dimension of the timber and the setting of the drying schedule is a particular point of interest. In this study boards with a thickness of 30 mm and poles with a thickness of 50 mm as well as 65 mm were compared in regard of their drying rates. Furthermore the drying schedules were changed concerning drying temperatures and equilibrium moisture contents. The drying time of the different dimensions and drying schedules were compared in the range from 16% to 9% final wood moisture content. The results have indicated a strong correlation of the drying time as well as the kiln operation in the investigated range of wood moisture to the different dimension of the timber.

INTRODUCTION

Oak is a difficult wood to dry, and often surface and checking, splitting, honeycomb, collapse, discolorations, etc. occur if the wood is subjected to a severe drying condition. Because of long time kiln residence, heavy oaks are usually air-dried first. Drying time for 1-inch oak will be ⅓ to ¼ of those required for 2-inch oak (BOIS 1978). The drying rate depends on the wood characteristics, the lumber thickness and the climate conditions. Drying time required increases rapidly with increase in lumber thickness. The climate and the season in which green lumber is exposed have major influence on the time required to air-dry lumber, temperature perhaps is the most influential factor. Green lumber stacked during the warm months will typically dry much faster than lumber exposed during the late fall and winter (PASTORET 2011).

Information about drying rates of kiln dried oak with different thicknesses in comparison is hardly available. In particular the drying behaviour of green compared to air-pre-dried heavy oak is missing.

EXPERIMENTAL METHOD

Oak wood (*Quercus spp*.) with different dimensions and initial moisture content were investigated in five different convection drying experiments as shown in Table 1. Two test series, "air-pre-dried_50 mm" and "air-pre-dried_65 mm", were air-dried protected from sun and rain before kiln drying. Air-pre-dried lumber showed much lower initial moisture contents compared to green lumber just before kiln drying (Table 1).

Table 1: Dimensions and initial moisture content of investigated drying schedules

Drying schedule	Thickness [mm]	length [m]	Initial moisture content [%]
Air-pre-dried_50 mm[a]	50	1.5	18.0[c]
Air-pre-dried_65 mm[a]	65	1.5	25.8[c]
Green_65 mm[b]	65	1.5	76.4[c]
Green_gentle-dried_30 mm[b]	30	1.5	57.5[c]
Green_severe-dried_30 mm[b]	30	1.5	66.2[c]

[a]predried in air, [b]green condition, [c]moisture values for kiln operation

Before drying, end coats were applied to prevent rapid drying of cross sectional areas in order to simulate drying behaviour of longer boards. Also the initial state of the wooden surface regarding cracks was documented. The drying experiments were carried out in a convection laboratory kiln drier with a computer-aided process control. The applied drying schedules with the characteristic values of drying temperature, equilibrium moisture content (EMC) and the drying time in the observation range from 16% to 9% targeted moisture content (MC) for each drying is presented in Table 2.

Table 2: Applied drying schedules with its characteristic values

Drying schedule	Temperature [°C]	EMC [%]	Drying time [h]
Air-pre-dried_50 mm[a]	65.8 - 82[c]	2 - 3.6[c]	143.67
Air-pre-dried_65 mm[a]	65.6 - 82[c]	2 - 3.7[c]	230.83
Green_65 mm[b]	65.8 - 82[c]	2 - 3.6[c]	272.25
Green_gentle-dried_30 mm[b]	39 - 46.7[c]	3.2 - 5.6[c]	661.17
Green_severe-dried_30 mm[b]	83 - 85[c]	2.8 - 3.7[c]	115.58

[a]predried in air, [b]green condition, [c]minimum and maximum temperature and equilibrium moisture content during drying from 16% to 9% moisture content.

RESULTS AND DISCUSSION

The challenge associated with drying heavy oak is definitely to minimize degrade during drying at appropriate drying time. Very cautious drying procedure, at low drying temperature and high EMC, results in uneconomic drying time as shown in Figure 1 by means of "green_gentle-dried_30 mm" drying schedule. However forced drying procedure results in stress development during drying and consequently in degraded of the material. According to BOIS (1978) thinner lumber dries with less degrade and drying time is considerably shorter for air-dried as well as kiln-dried wood.
Figure 1 shows the effect of different thicknesses on the drying time. The set points of temperature and EMC of each drying in the range of 16 - 9% MC is summarized in Table 2. Within this relatively small observation range considerably below the fibre saturation point, clear differences regarding to the drying time was found. "Air-pre-dried_65 mm" drying schedule shows obvious shorter drying time than "green_65 mm" drying schedule, while settings of the drying parameter were the same. Therefore an effect of the pre-drying in the air for following convection kiln drying can be assumed. "Air-pre-dried_50 mm" drying schedule shows more than ⅓ shorter drying time than "air-pre-dried_65 mm" from 16 to 9%, compared to only 15 mm higher thickness. On the other hand the "green_severe-dried_30 mm" drying schedule shows only 20% higher drying rate than the "air-pre-dried_50 mm" drying schedule. These results show that the drying rates change disproportionately with increasing or decreasing thicknesses of the dried material.
To indicate a correlation between the drying rate and the thickness of oak wood further drying experiments with different dimensioned oak is required.

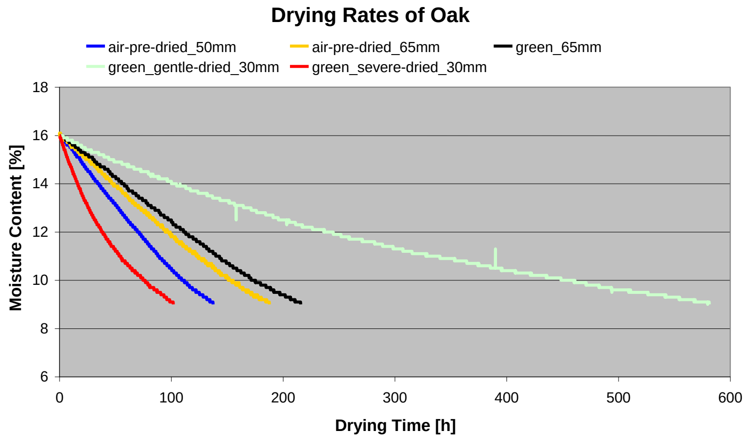

Figure 1: Drying rates of 30mm (green condition), 50mm (air-pre-dried condition) and 65mm (green and air-pre-dried condition) thick oak in the observation range from 16% to 9% targeted moisture content.

CONCLUSIONS

The rate at which pre-dried and green oak lumber dries in a technical convection kiln depends on the thickness. The thicker the oak lumber is the longer the drying time, but not linear. Air-dried lumber reaches a higher drying rate compared to green lumber with the same drying configuration within the range of 16 - 9% moisture content.

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Influence of the hydro-thermal treatment on chemical composition, physical and mechanical properties of ash-tree wood.

Juris Grinins[1], Vladimirs Biziks[2], Bruno Andersons[3], Ingeborga Andersone[4], Errj Sansonetti5

[1] Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str., Riga, Latvia, jurisgrinins@inbox.lv

[2] Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str., Riga, Latvia, orkaans79@inbox.lv

[3] Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str., Riga, Latvia, bruno.andersons@edi.lv

[4] Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str., Riga, Latvia, brunoan@edi.lv

[5] Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str., Riga, Latvia, harrysansonetti@hotmail.com

Keywords: Ash-tree, hydrothermal modification, chemical composition, mechanical properties

ABSTRACT

In the present study, hydrothermal modification of ash-tree wood was carried out in a WTT experimental laboratory device in a water vapour medium, under elevated pressure conditions. The optimal ranges of the treatment parameters were elucidated, which makes it possible to reach and improved durability against rot and stain fungi, without the destructive decreasing of the bending strength properties. Ash-tree boards were modified at 4 different temperatures - 140, 160, 170 and 180°C. Mass and density changes in the thermal treatment were determined. With increasing treatment temperature, density decreases and mass losses grow, which can be explained by the evaporation of more volatile components.

In the hydrothermal modification process, not only the chemical properties and structure of wood are changed, but also physical properties such as colour, mass, volume and mechanical strength. The heating of wood in the water vapour medium influences mainly the three basic components of wood - cellulose, hemicelluloses and lignin.

To study the chemical composition, extraction with acetone, cellulose determination according to the Kürschner-Hoffer method, lignin

determination according to the Klason method were performed. Wood element composition was determined. As optimum regimes for thermal modification of deciduous wood (aspen, birch, ash-tree), temperatures from 180 to 220°C are recommended. In this temperature range, changes in the chemical composition (destruction of hemicelluloses) inevitably lead to the worsening of mechanical properties. Therefore, to forecast the properties of the modified material, bending strength measurements and determination of Brinell hardness were carried out.

INTRODUCTION

Wood heat treatment induces chemical modifications of the main wood constituents. The thermal treatment not only removes water from wood but also causes a significant transformation in the chemical composition of wood. The degradation of wood components takes place through dehydration, hydrolysis, oxidation, decarboxylation and transglycosylation (DIROL AND GUYONNET 1993). One of the main components in wood - hemicelluloses are the most reactive components and are strongly degraded (SIVONEN ET AL. 2002, NUOPPONEN ET AL. 2004). Due to their relatively low molecular weight they degrade at lower temperature (160-220ºC) than the other components of the cell wall (FENGEL AND WEGENER 1989). The degradation starts by deacetylation, and the released acetic acid acts as a depolymerisation catalyst that further increases the polysaccharide decomposition. Acid catalysed degradation leads to the formation of formaldehyde, furfural and other aldehydes (TJEERDSMA ET AL. 1998).

Cellulose is less affected by heat treatments, probably because of its crystalline nature (BOURGOIS AND GUYONNET 1988). The ratio between amorphous and crystalline cellulose is changed (YILDIZ ET AL. 2006).

The lignin polymer network is modified (TJEERDSMA AND MILITZ 2005, NGUILA ET AL. 2006). Despite the increase in the percentage of lignin, there are also indications that lignin starts to degrade at the beginning of the treatment, but at a lower rate than polysaccharides (WINDEISEN ET AL. 2007).

Different compounds evolve in the complex reactions (CALLUM HILL 2006). A part of them are volatile and evaporate with the volatile extractives into the environment during the manufacturing process (HOFMANN ET AL. 2008). A significant part of the moisture content from wood turns to steam in the heating process, which condense on the cold surfaces of the manufacturing equipment, constituting with the mentioned volatile organic compounds – a strong aggressive and acidic fluid.

The total stock of deciduous trees in the Republic of Latvia is ~251 million m^3, from which approximately a half (56%) is birch, 22% is aspen, 20% is alder, and 2% is ash-tree. Ash-tree wood is heavy, tough and durable; hence, it belongs to hard deciduous wood species. In comparison with oak, ash-tree is more fast-growing; it reaches a height of 20 m in mixed forests. Ash-tree wood is used for producing joinery articles and furniture. It has very good mechanical properties, but low durability against rot, wood borers and different microorganisms, UV irradiation, humidity; therefore, to extend its applicability in outdoor conditions, it is necessary to improve the biodurability properties of wood. Worldwide, the modification of soft deciduous wood in a water vapour medium at elevated pressure is poorly investigated. In the recent years, studies have been initiated in Latvia on the use of soft deciduous wood for producing products with a higher added value, but practically, there are no studies on the thermal modification of hard deciduous wood (ash-tree, oak).

EXPERIMENTAL METHODS

Materials

Ash-tree boards without any visible defects were chosen for modification. Samples sizes were: length 1000 ± 2 mm, width 100 ± 0.5 mm, thickness 40 ± 0.5 mm. The average density of ash-tree wood at the absolute moisture content of 12% was 784 kg/m^3. Absolute moisture content of the wood before modification was 5-7%.

Thermal treatment

The thermal modification was carried out in a multifunctional wood modification pilot device (WTT). Ash-tree boards were thermally modified in the water vapour medium for 1 h at 4 different temperatures: 140°C, 160°C, 170°C and 180°C and for 3 h at 160°C. The material was placed in an autoclave, in which 0.45 ml of water was supplied per 1 g of oven dry wood. The thermal modification process can be divided in three stages. The first stage: temperature rising from room temperature to the maximum final temperature of the process. The second stage: holding of the maximum final temperature. The third stage: cooling. Pressure in the autoclave, depending on temperature, reached 0.5-0.8 MPa.

Methods

Chemical analyses were performed for both untreated wood and the modified samples. 8-12 g of air dry chips of each sample were extracted in a Soxhlet apparatus with acetone for 8-10 h for extractives determination. Cellulose was determined applying the Kürchner-Hoffer method; for lignin determination, the Klason 72% sulphuric acid method was applied (BROWNING 1967).

Element composition was performed using Vario MACRO CHNS (Elementar Analysensysteme GmbH) elementanalyser. Sulphanilamide was used as a standard substance for calibration of burning column.

Bending strength. For each treatment series, 25 parallel samples with the sizes 20 x 20 x 360 mm without visible faults were chosen, with fibers parallel to the longitudinal direction. The difference of densities for parallel samples was in the range of ± 10%. Samples were placed in a conditioning chamber at a temperature of 20 ± 2°C and the relative humidity of air 65 ± 2% until the constant mass was reached. Wood properties in bending were determined according to the requirements of the DIN 52186 (1978) standard. Bending strength of wood was determined, using a material strength testing device ZWICK Z100. Speeds of loading were appropriate for each group individually, so that to achieve the destruction maximum within 90 ± 10 sec.

Wood surface hardness according to Brinell. For untreated and thermally treated ash-tree wood, hardness was determined by the EN 1534 test method. Using the material hardness testing device, the ball semisphere (ball diameter 10 mm) was pressed into the wood with a constant strength of 1000 N. The semisphere impress hollow diameter was determined with the help of a reflecting light binocular microscope. Sample sizes were: 25 x 25 x 50 mm without visible faults, parallel to the annual ring direction. Those were conditioned for 4 weeks at a temperature of 20 ± 2°C and the relative humidity of air 65 ± 2%. The difference of densities for parallel samples was in the range of ± 10%. For each series, 20 parallel samples were chosen.

RESULTS AND DISCUSSION

Physical properties

Table 1: Changes in the physical parameters of ash-tree wood depending on the modification temperature.

Treatment temperature/time [°C/h]	Mass loss [%]	Density (W_{rel} = 12%) [kg/m^3]	Density loss (W_{rel} = 12%) [%]
Untreated	-	784	-
140/1	5.4	756	3.6
160/1	7.3	741	5.5
160/3	9.3	721	8.0
170/1	16.5	664	15.3
180/1	17.7	657	16.2

With increasing treatment temperature, density for ash-tree decreases and mass losses grow (Table 1). Relative mass losses embrace: water evaporation, evaporation of extractives, evaporation of the products of destruction of wood components, especially products of hemicelluloses destruction (KOCAEFE ET AL. 2008). It has been reported that the mass loss during the heat treatment could be a reliable and accurate marker to predict decay resistance of heat-treated wood (WELZBACHER ET AL. 2007).

Chemical composition

With increasing treatment temperature, the amounts of acetone soluble extractives grow 5-10 times (Table 2). The increase of extractives can be applied to hemicelluloses destruction into easier volatile compounds, which are then obtained in extraction (MANNINEN ET AL. 2002). With increasing temperature, relative amounts of cellulose and lignin in ash-tree wood also grow. It is observed that, varying the treatment parameters (temperature, holding time, pressure), the relative amount of crystalline cellulose grows (BHUIYAN AND HIRAI 2000). However, it is not known whether this growth is connected with the destruction of the amorphous region, or also crystallization processes, or both the processes simultaneously. With decreasing polysaccharides and increasing mass losses, as a result of the thermal treatment, the relative content of lignin grows. Chawla and Sharma published results suggesting that during the heating process crosslinking of polysaccharide chains could occur (CHAWLA AND SHARMA 1972). They also suggested that some of the thermal degradation products recombined during heating. Norimoto (NORIMOTO 1994) and

Dwianto (DWIANTO ET AL. 1998) also suggested the formation of interlinkages between wood polymers during the heat treatment of wood.

Table 2: Changes in the chemical composition of ash-tree wood depending on the modification temperature

Treatment temperature/ time [°C/h]	Acetone soluble extractives [%]	Cellulose [%]	Lignin [%]	Hemicelluloses [%]
Untreated	1.4	49.6	24.9	25.5
140/1	1.1	49.9	26.3	23.8
160/1	7.7	52.5	30.2	17.3
160/3	10.1	56.7	30.7	12.6
170/1	13.1	60.7	31.9	7.4
180/1	14.9	61.3	36.8	1.9

Hemicelluloses = 100 – (Cellulose + Lignin)

Element composition

Table 3: Element composition of modified ash-tree wood

Treatment temperature/ time [°C/h]	Elements [%]				O/C ratio
	N [±0.05]	C [±0.6]	H [±0.5]	O [±0.6]	
Untreated	0.21	49.2	6.2	44.4	0.90
140/1	0.19	50.2	6.3	43.3	0.86
160/1	0.22	51.6	6.2	42.0	0.81
160/3	0.24	52.2	6.1	41.5	0.79
170/1	0.25	53.4	6.1	40.3	0.75
180/1	0.24	55.0	6.0	38.8	0.70

O, % = 100 – (N, % + C, % + H, %)

Our results show that with increasing treatment temperature, total amount of carbon in ash-tree wood increases, but amount of oxygen decreases (Table 3). It results in decrease of wood’s O/C ratio. Amount of nitrogen and hydrogen remains almost unchanged. Other studies have also shown that heat treatment resulted in numerous dehydration reactions due to degradation of amorphous polysaccharides (SIVONEN ET AL. 2002, YILDIZ ET AL. 2006) jointly with the formation of carbonaceous materials within the wood structure leading to a strong decrease of wood’s O/C ratio (NGUILA ET AL. 2006).

Hardness according to Brinell

Table 4: Brinell hardness according to the EN 1534 test method

Treatment temperature/ time [°C/h]	Hardness according to Brinell [HB]	
	Tangential surface	Radial surface
Untreated	3.50 ± 0.27	3.20 ± 0.15
140/1	3.27 ± 0.13	3.45 ± 0.08
160/1	2.70 ± 0.16	2.45 ± 0.10
160/3	2.33 ± 0.16	2.32 ± 0.11
170/1	2.64 ± 0.15	2.11 ± 0.09
180/1	2.21 ± 0.09	1.97 ± 0.07

With increasing treatment intensity, both tangential (except 170°C) and radial (except 140°C) surface hardness for ash-tree decreases (Table 4). It is mentioned that thermal modification increases the wood hardness, but also the opposite effect is recorded, namely, the wood becomes softer (PONCSAK ET AL. 2006, GUNDUZ ET AL. 2009). It can be concluded that the tangential surface hardness is by 5-20% greater than that for radial surface, which is probably explained by the densification of the structure in the radial direction. The decrease in hardness is caused by the decrease in density, which develops mainly due to the destruction of hemicelluloses.

Bending strength

Table 5: Static bending strength and modulus of elasticity

Treatment temperature / time [°C/h]	Modulus of elasticity [N/mm^2]	Bending strength [N/mm^2]	Decrease of bending strength compared to control [%]
Untreated	11475 ± 1138	111 ± 17	0
140/1	11786 ± 1192	110 ± 19	1
160/1	13120 ± 1297	97 ± 23	13
160/3	12575 ± 1315	90 ± 26	19
170/1	11925 ± 1255	86 ± 23	23
180/1	11541 ± 1249	79 ± 21	29

Modulus of elasticity for ash-tree grows at the first treatment regimes (140°C and 160°C/1h), then decreases (Table 5). However, the same tendency was obtained by Kobujima and co-authors (KOBUYIMA ET AL. 2000). With increasing treatment temperature, bending strength decreases. Bending strength for unmodified wood and that modified at 140°C differs little. At 180°C, bending strength losses for ash-tree, in comparison with the case of the initial wood, reach 29%, which is a good indicator, because even up to 50% strength losses are reached for pine and eucalyptus at such temperatures (ESTEVES ET AL. 2007). The decrease in strength is explained by the thermal destruction of hemicelluloses, mainly xylan.

CONCLUSIONS

With increasing hydrothermal treatment temperature, density of ash-tree wood decreases and mass losses grow, reaching 17.7% and 16.2% at 180°C, respectively. Amount of acetone soluble extractives grow 5-10 times. Relative amount of cellulose increases 0.6 – 19.1% and amount of lignin increases 5.3 – 32.3% if modified material is compared with untreated sample. Loss of hemicelluloses is from 6.6% at 140°C to 92.5% at 180°C. Total amount of carbon in ash-tree wood increases, but amount of oxygen decreases and as a result wood’s O/C ratio decreases.

Surface hardness of modified material, both in tangential and radial direction decreases. Tangential surface hardness is higher by 5-20% than that for the radial surface. Modulus of elasticity is higher at the first treatment regimes (140°C and 160°C/1h) and with higher temperature (170 and 180°C) decreases. With increasing treatment temperature, bending strength decreases and at 180°C losses reach 29%.

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Influence of drying potential on moisture content gradient, drying stresses and strength of beech wood

Ž. Gorišek[1], A. Straže[1]

[1] University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology

Rožnadolina, C. VIII/34, SI 1000 Ljubljana Slovenia

zeljko.gorisek@bf.uni-lj.si

Keywords: wood drying, drying potential, moisture content gradient, drying stresses, mechanical properties, beech wood

ABSTRACT

Comparing drying schedules of beech wood with different drying gradient we can confirm that mild or sharp drying conditions significantly influence the drying time. A more precise analysis of drying kinetics showed that in all drying processes the drying rate above fiber saturation point (FSP) was comparable but it was significantly different below FSP. In accordance with drying intensity the occurrence of moisture content gradients was the highest in sharp drying conditions also reflecting in the development of very intense drying stresses. During the drying process there is also significant change of strength properties of wood. As expected, during first drying period mechanical properties remained unchanged and increase during drying below FSP. Analyze of each drying process showed that the increase of strength during drying with mild conditions was steeper then when we use sharper regime. Consequently the strength of wood at the end of process was higher using lower drying gradient. We assumed that the sharpness of drying conditions affect the permanent reduction of some mechanical properties of wood what have also negative impact on subsequent further processing or end use of wood.

INTRODUCTION

In a modern woodworking production the technical drying of wood is obligatory technological process by which we reduce the otherwise time-consuming removing of water from the timber. Unfortunately, all drying techniques are energy consuming; despite the use of modern technologies. After all, the time remains still important issue as the wood is the limiting factor in the efficiency of water transport in the wood itself. For choosing the optimal technical, technological and economical decision the evaluation and detail analyses of time, energy consumption and cost of drying process are required. Even than the decision is not always simple or the same for each case because of influencing the large number of variables (wood species, timber dimensions, initial and final moisture content, type and size of dryers, energy availability and its price, etc.) and because of higher and higher demand for achievement the corresponding final quality of dried material.

The high drying gradient and high temperature significantly accelerate the drying rate particular in diffusion regime unfortunately with spiteful (unpleasant) occurrence of drying stresses as a consequence of differential shrinkage through the cross section of dried timber (c.f. SIMPSON, 1991, KEEY ET AL., 2000, PERRÉ, 2007). Just after the surface layers dry below fiber saturation point an internal stress field is created inside the board such the tensile stress is appeared near the surface and compression stress at the core.

At this point, in the case of too fast drying of the surface, the differential shrinkage between the surface and the interior is very large and drying stresses may cause the surface checking (HANHIJÄRVI ET AL. 2003). However with the reduction of drying speed, the stresses are kept lower and cracking limit is not exceeded. The stresses can be reduced also by use of the viscoelastic and/or mechano-sorptive properties of wood (HANHIJÄRVI & HUNT, 1998, KOWALSKI, 2001, RANTA-MAUNUS, 1992. SALIN, 2003, SVENSSON & MARTENSSON, 1999 WO & MILOTA, 1994).

Depending on dying conditions the tensile stresses generated in the surface of the board induced also permanent deformation which is responsible for well-known phenomena as stress reversal or casehardening: compressive stresses are generated near the surface and tensile stresses in the core of the board (PERRÉ, 2007). The level of residual stress depends on many parameters (board orientation, species, thickness, drying conditions …), which provide most of the problems for drying optimization.

Sometimes the reverse stresses can induce internal cracking but in many cases the drying stresses remain built-in the wood and can cause defects after further processing or can just reduce the strength of wood.

With this study we investigated the influence of mild or sharp drying condition on drying gradient, on stress level and possible diminishing the strength of the material. We tried to confirm the hypotheses that drying with sharp conditions generated very large stresses which can also reduce the strength of dried wood.

MATERIAL AND METHODS

The experiment for examination the influence of drying potential on moisture content gradient, drying stresses and strength was carried out on 38 mm thick beech wood, dried with mild and sharp drying condition. The mild drying process was started with low temperature (25°C) and finished with 52 °C; the average drying gradient was 2,4. The started temperature at sharp drying condition was 40 °C and was finished temperature of 60 °C; the average drying gradient was 2,9.

Boards with no significant defects were dried in the experimental kiln dryer, capacity of 1 m^3. Drying conditions in the kiln was controlled with dry and wet bulb temperature through regulation system Vea. Every two hours dry and wet bulb temperature, mass of wood, energy consumption, as well as moisture content (MC) on 6 places were registered.

The accurate moisture content and moisture gradient were determinate by gravimetrical method (EN 13 183-1) on small samples taken from the boards in uniform intervals during the drying process (Fig. 1).

The drying rate was correlated with the model of the exponential function of natural growth (eq. 1) where *a* represent the maximum drying rate, *k* the drying rate at the end of drying and MC_c the moisture content of the quickest decrease of drying rate (GORIŠEK & STRAŽE. 2010).

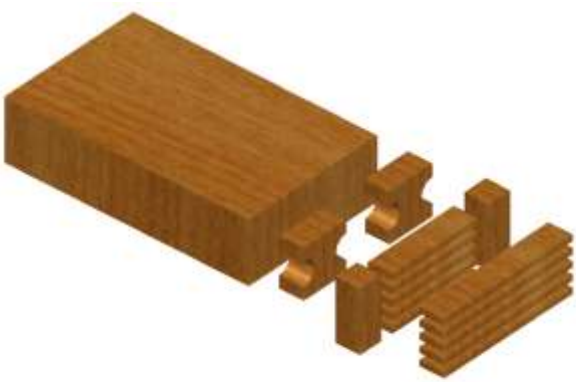


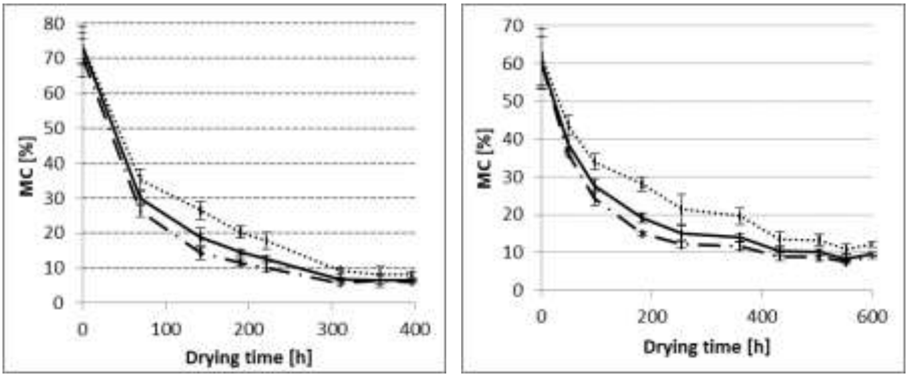
***Figure 1** Sampling for determination casehardening, moisture gradient and tensile strength.*

$$\frac{\Delta MC}{\Delta t} = a \cdot e^{\left(-e^{(-k\cdot(MC-MC_k))}\right)} \tag{1}$$

Parallel with samples for determination MC, we also took 20 mm thick samples, which we sliced to 5 layers and measure the curvature (gap) in each of it (SIST ENV 14464). The same slices we also use for modified standardised bending test (SIST EN 408) for determinate MOE, bending strength, proportional limit and strain at maximum stress. From similar wood pieces were made also the samples for establishing tensile strength (Fig. 1).
At the end of the drying process wood quality was evaluated regarding drying rate, time of drying, variability of moisture content, moisture content gradient, casehardening and occurrence of drying defects.

RESULTS

Comparing two drying processes of beech wood with different drying gradient we can confirm that mild or sharp drying conditions significantly influence the drying time (Fig. 2). A more precise analysis of drying kinetics showed that the drying rate during the first period was comparable in both drying processes. Parameter *a* (eq. 1), represented maximum drying rate, was in mild condition just slightly lower than it was in sharp process (Tab. 1). Drying rate rapidly dropped, when the outer layer had achieved the fibre saturation point and then exponentially decline until apparently steady state condition has been reached. In mild drying condition the constant rate period lasted longer. The quickest decrease of drying rate was detected at MC 39,2%, (MC_c = 39,2%%)(Fig. 3). During drying with sharp drying condition the constant rate period was shorter and so called diffusion barrier occurred at higher moisture content. For this condition the quickest drying rate calculated from eq.1 was achieved at MC 45,7 % (MC_c = 45,7%).

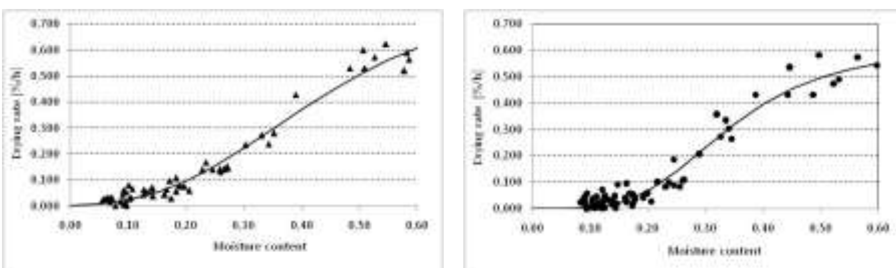


A B

Figure 2 ***Drying curve for A/ sharp and B/ mild drying regime forsurface layer (···), for core of the wood (– –· –) and for average moisture content (——).***

Table 1 ***Drying schedule, initial and final moisture content, maximal drying rate and moisture content of the quickest decrease of drying rate for sharp and mild drying processes for 38 mm thick beech wood (st.dev.)***

Schedule	Initial MC (u_i) [%]	Final MC(u_f) [%]	Max. drying rate [%/h]	MC_c [%]
SHARP	56,3 – 70,3	9,8 (1,16)	0,61 (0,063)	45,7 (2,54)
MILD	59,9 – 75,8	10,1 (1,14)	0,59 (0,029)	39,2 (0,95)



A B

Figure 3 ***Drying rate for A/ sharp and B/ mild drying regime fitted with Gompertz regression line (eq. 1).***

Significantly different drying rate between sharp and mild drying schedule was indicated during drying bellow fiber saturation point when the effect of higher temperature accelerated the process in sharp drying condition.
In accordance with drying intensity the occurrence of moisture content gradients was the highest in sharp drying conditions, reflecting also in the development of very intense drying stresses. It is indicative for both drying

schedules, that the moisture gradients were higher in radial oriented boards than in tangential (Fig. 4). Because of lower shrinkage in radial direction this effect is not so problematic, since generated stresses are not so pronounced. In all drying processes we observed the formation of the maximum moisture gradient at around MC 20 %, which means that in terms of generating drying stresses in this interval drying process reached a critical point.

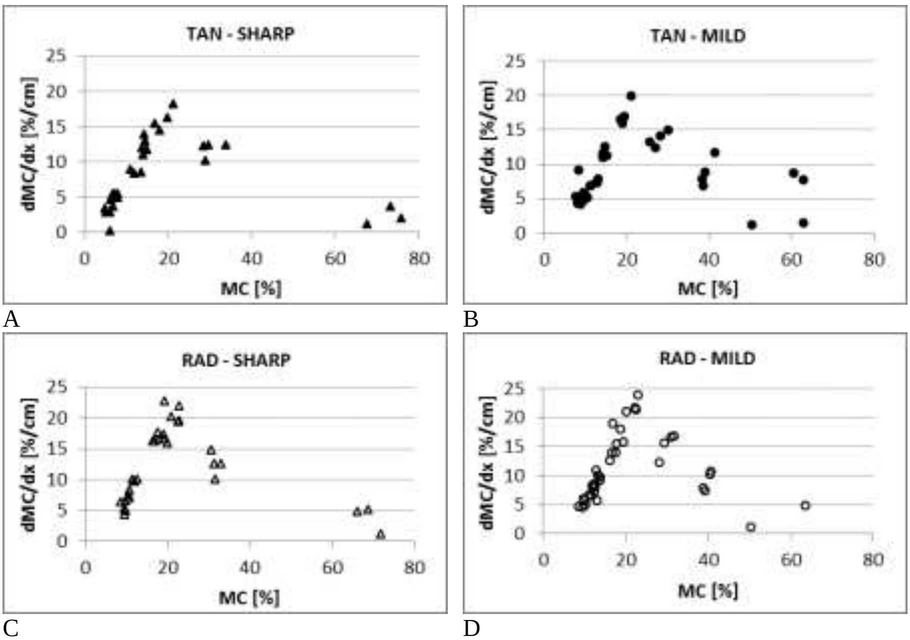


Figure 4 ***Moisture content gradients for sharp drying regime A/ for tangential oriented boars and B/ for radial oriented boars and mild one C/ for tangential oriented boars and D/ for radial oriented boars.***

Despite quite similar moisture gradient, reached the drying stresses during mild conditions significantly lower levels. The phenomena can be explained with relaxation during longer drying time (Fig. 5).

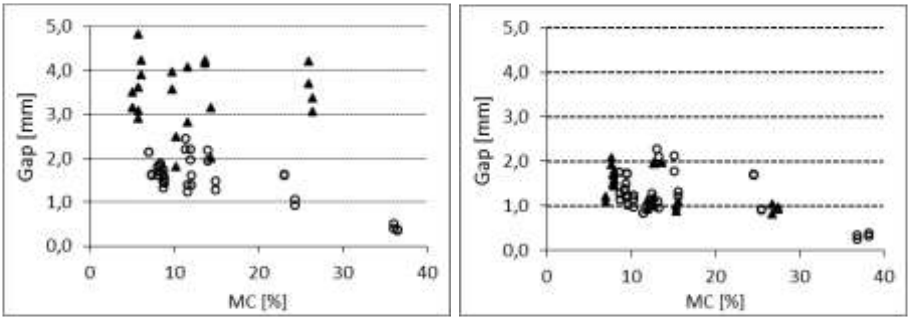


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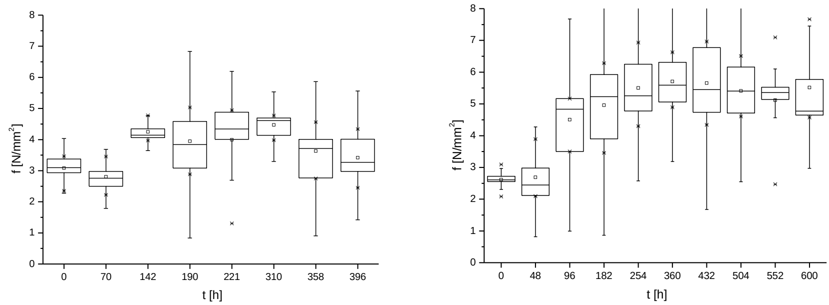
Figure 5 ***Dependence of gab from moisture content for A/ sharp and B/ mild drying regime.***

In the experiment the difference between the strength properties of wood dried by sharp and mild condition were insignificant. As expected, during first drying period, when the moisture content stayed above fiber saturation point, the mechanical properties remained unchanged. When the moisture content dropped below the fiber saturation point, the mechanical properties more or less increased.

Analyze of each drying process showed that the increase of strength during drying with mild conditions was steeper then when we use sharper regime (Fig 6 and Fig. 7). We also observed that towards the end of the drying process the strength of wood dried by severe condition slightly decreased; high drying stresses probably caused some micro cracks in the cell wall which may affect the overall reduction of strength.



A B

Figure 6 ***Dependence of tensile strength from drying time for A/ sharp and B/ mild drying regime.***

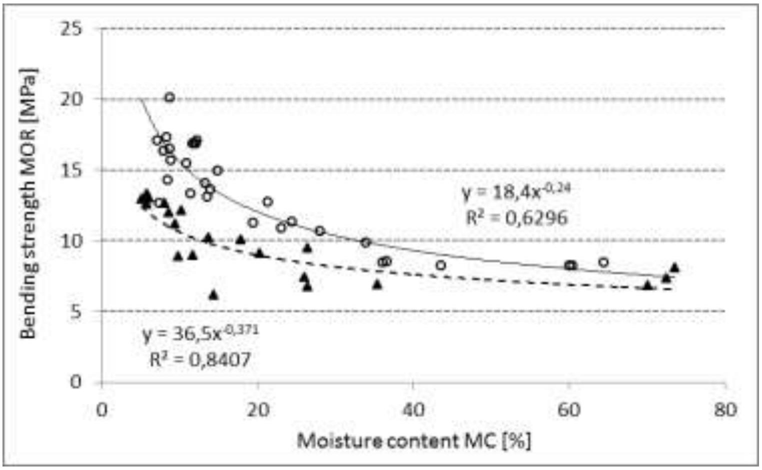


Figure 7 ***Influence of moisture content (MC) on bending strength of beech wood dried by sharp (- - -) and mild (-----) drying regime.***

Consequently the strength of wood at the end of process was higher when we use lower drying gradient. We assumed that the sharpness of drying conditions affect the permanent reduction of some mechanical properties of wood what have also negative impact on subsequent further processing or end use of wood.

CONCLUSIONS

In accordance with drying intensity the occurrence of moisture content gradients was the highest in sharp drying conditions also reflecting in the development of very intense drying stresses. Predictably, during first drying period mechanical properties remained unchanged and increase during drying below fiber saturation point. Analyze of eac h drying process showed that the increase of strength during drying with mild conditions was steeper then when we use sharper regime. Consequently the strength of wood at the end of process was higher using lower drying gradient. We assumed that the sharpness of drying conditions affect the permanent reduction of some mechanical properties of wood what have also negative impact on subsequent further processing or end use of wood.
We anticipated that faster and shorter drying time can be achieved by oscillating drying schedule (c.f. MILIĆ, 2010) and can also prevent against appearance of casehardening and reduction of mechanical properties of dried wood.

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EFFECT OF PRESSING PRESSURE ON INDICES OF FIBREBOARDS MANUFACTURED FROM WOOD OF HARD BROAD-LEAVED SPECIES

Julia Mihajlova[1], Viktor Savov[2]

10, Kliment Ohridski Blvd.
University of Forestry, Sofia, Faculty of Forest Industry
[1]jmihajlova@hotmail.com; [2]victor_savov@abv.bg

Key words: FBs, hard broad-leaved wood-based raw material, piezothermal treatment, thickness, density.

ABSTRACT

The main factor defining the performance of the hard thin FBs is the pressure applied in the process of piezothermal treatment. In order to manufacture a product designed by engineering, the pressing pressure should be with a specific value determined in advance. The latter is in correlation dependence on the tree species, the characteristics of the wood-fibre mass and of the wood-fibre carpet. Determining, out of these factors, is the resistance that the carpet shows under the applied external load, with it depending mainly on the characteristics of the mass and, to a determining degree, on the tree species used for the manufacture of the boards.

In this paper, an investigation on the effect of pressure during manufacture of thin FBs on the basis of beech and cerris oak wood is presented. Derived are the main dependences of the performance of FBs on the factors examined in case of application of the methods of regression analysis, with use of the least squares method. Established are the optimum values of pressure depending on the thickness of the boards and the design thickness set.

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INTRODUCTION

The manufacture of wood-fibre mass with fixed technological characteristic and the modes of piezothermal treatment of the carpet formed of this mass are the main elements on which the performance of FBs depends. Of greatest significance for the manufacture of boards with strictly fixed indices are the mode factors during hot pressing. The latter are determined with respect to the set input parameters of the process in conformity with the type of the wood-based raw material and the characteristics of the wood-fibre carpet.

In case of absence of limitations in the process of hot pressing, the thickness and the density of the boards depend exclusively on the compression ratio of the wood-fibre carpet. The determination of the value of the pressure applied during pressing is an extremely important technological index that depends on the wood-based raw material used and on the characteristics of the wood-fibre carpet.

In Bulgaria. there is a raw material potential for manufacture of FBs from wood of hard broad-leaved species. Because of the specificity of the development of this manufacture in the country to this day, the efforts have been concentrated mainly on the investigation on the effect of the mode factors during the manufacture of FBs after the wet method. Investigations on the characteristics of the manufacture after the dry method are limited and this necessitates concentration of the efforts in this respect.

STATE OF THE PROBLEM

In the last decades, intensive investigation on the relationship between the physical, mechanical and morphological properties of the wood fibres, on the one hand, and the strength characteristic of FBs, on the other hand, has been performed. Although the tensile strength of the individual fibres is very high, only part of it affects the structural configuration of FBs. As a result of the limited fibre length or because of the low bonding quality, the bonding zone between the fibres is of considerably lower strength, which leads to failure before reaching the maximum possible stresses in the fibres (Woodston, E.G.). This is presented graphically on Fig. 1 where L_s denotes the overlap length between two fibres, which may be considered proportional to the relative bonding area in the board. If L_s is shorter, then the bonding strength diminishes, and the failure during application of tensile load takes place in the bonding zone, and not in the wood fibres, which leads to decrease of the boards’ strength.

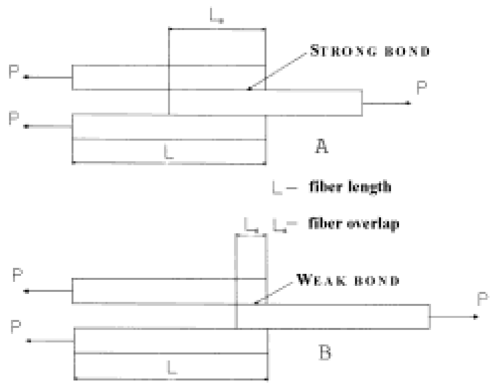

Figure 1: Fibre bonds under tensile stress
A – Conditions favouring fibre failure (maximum strength)
B – Conditions favouring bond failure (low strength)
L – fibre length; L_s – fibre overlap

From the presented above follows the conclusion that the FBs strength depends strongly on their density, which, at structural level, is explained with the successful transfer of stresses from the bonding zone of the wood fibres and the possibility for reaching maximum stresses.

The fibre length is also of great importance for the tensile strength of FBs. This fact is explained with the greater number of bonding zones in the board, which allows the tensile stress in the fibres to reach its limit value. The length of the fibrous elements affects the structure of the wood-fibre carpet and of the board. With fibres of greater length, a trend towards formation of a wood-fibre carpet with more open structure and higher thickness (bulk density), in comparison with a carpet formed of shorter length, is observed. The length of the fibres is also a factor through which their orientation in the carpet is controlled. With fibres of smaller length, it is very probable that a vertical, or z-component, emerges during the orientation in the board, unlike the orientation in the case of the longer fibres (Fig. 2).

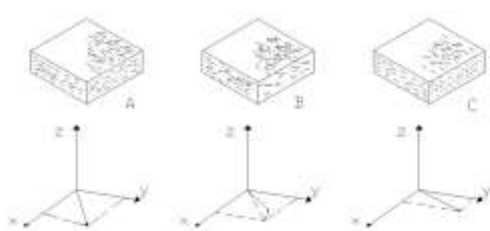

Figure 2: Orientation of fibres in fibreboard
A – Random orientation in plane of board, no vertical components;
B – Random orientation in plane of board, small vertical component;
C – Orientation in y-direction, small x-component, no vertical component.

The density in FBs (except for the soft FBs) is determined by the degree of compaction of the wood-fibre carpet. In case of higher wood density, higher bulk density of the carpet necessary for reaching the previously set density is produced, which leads to a lower compression ratio. The high compression ratio obtained due to the lower wood density ensures closer contact of the fibrous elements. On account of this, in the case of hard FBs manufactured after the dry method, there exists a reverse relationship between the wood density and the wood-fibre carpet, on the one hand, and the strength indices of the board, on the other hand, Fig. 3 (Woodston, E.G.).

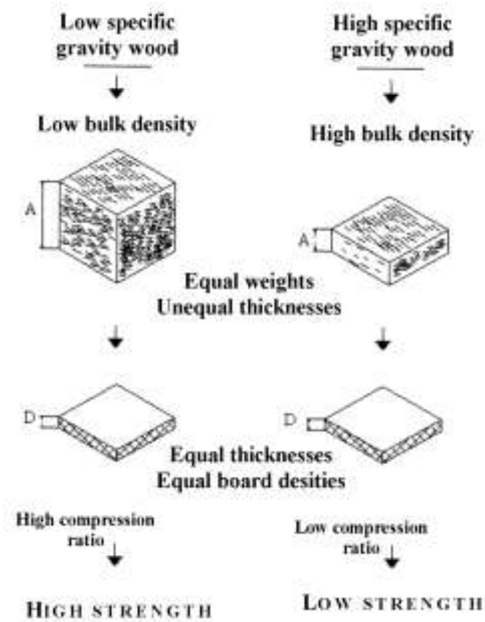

Figure 3: Manufacture of fibreboards of equal thickness and equal board density from low- and high-specific-gravity wood

The changes in the FBs dimensions as a result of the absorption or release of moisture are considerably influenced by the fibre length. The greater the length of the wood fibres, the smaller are the changes in the board dimensions.

From the presented above follows the conclusion that there is a number of technological difficulties in the manufacture of FBs after the dry method from wood of hard broad-leaved species.

In Bulgaria. there is a raw material potential for manufacture of FBs from wood of hard broad-leaved species, on account of which the main manufacturing facilities operate with such raw material. Because of the characteristics of this manufacture in the country, the efforts to this day have been concentrated on clarification of the main cause-and-effect relations in the case of the wet method of manufacture (Tsolov, V.).

The aim of this paper is to establish the effect of pressing pressure on the performance of FBs manufactured after the dry method.

INVESTIGATION METHODS

For the manufacture of laboratory fibreboards, wood-fibre mass obtained from common beech and cerris oak in the ratio of 2:1, with a bulk density of 32kg/m^3, at a degree of fibrillisation – 22 DS, was used.

In order to establish the effect of pressing pressure, the factor was examined within a variation range of 0.6 to 3.0MPa with a variation step of 0.4MPa.

The performance of FBs was determined pursuant to the current European norms.

To determine the effect of the bonding agent content on the performance of FBs, regression analysis was applied.

On the basis of experimental data obtained by means of measurements, the values of the approximating function for different values of the argument were determined. This problem is successfully solved by using the least squares method (Fig. 4), with regression equation of the type:

$$\hat{Y} = \sum_{i=0}^{k} b_i f(\tilde{x}) = b^T f(\tilde{x}) \qquad (1)$$

where: $b^T = (b_0, b_{1,} \ldots, b_k)$ is a (k + 1)-dimensional vector of the unknown coefficients in the equation;

$\hat{y}$ – the predicted value of the output quantity;

$f^T(\tilde{x}) = [f_0(\tilde{x}), \ldots, f_x(\tilde{x})]$ is a (k + 1)-dimensional function of the vector of input variables $\tilde{x}$.

being derived.

In the case of the least squares method, the polynomial of best root-mean-square approximation of given degree coincides with the interpolation polynomial.

As a criterion for approximation accuracy, the coefficient of determination is used:

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (y_i - \widehat{y})^2}{\sum_{i=1}^{N} (y_i - \bar{y})^2} \qquad (2)$$

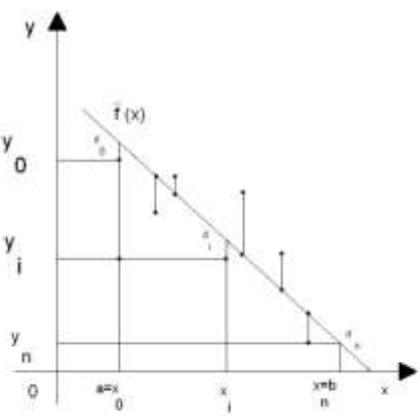

Figure 4: Root-mean-square approximation $\hat{f}(x)$

The check for significance of the coefficient of determination is performed by means of the *F*-criterion:

$$F_{calc} = \frac{R^2 (N - p)}{(1 - R^2).(p - 1)} \qquad (3)$$

where *N* is the number of the experimental series;

p – number of the coefficients of the model.

If:

$$F_{calc} > F_{kp}\left(\alpha; \nu_1 = p - 1; \nu_2 = N - p\right),$$

then the coefficient of determination is considered significant, at the given level of significance.

ANALYSIS OF EXPERIMENTAL DATA

The graphic presentation of the relationship between the density and thickness of FBs manufactured after the dry method and the maximum value of the pressing pressure is shown on Fig. 5. On the figure, the points represent the recorded experimental results, and the curve corresponds to the approximating function derived after the least squares method.

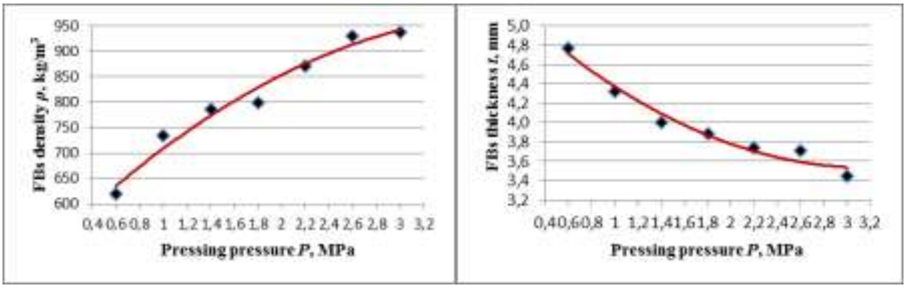

Figure 5: Variation of the density and thickness of FBs, in connection with the pressing pressure

The results for the density of FBs treated after the methods of regression analysis allow deriving of a functional dependence between the variation of the density and thickness of FBs:

$$\widehat{Y} = 829.2 + 153.4X - 40.62X^2 \qquad (4)$$

$$\widehat{Y} = 3.87 - 0.58X + 0.25X^2 \qquad (5)$$

The equations are characterised with a coefficient of determination respectively $R^2 = 0.97$ и $R^2 = 0.96$.

In case of use of hard broad-leaved tree species as wood-based raw material, with the increase of the pressing pressure within the range of 0.6 to 3.0MPa, the density of the hard FBs increases from 630 to 930kg/m^3, i.e. by about 300kg/m^3. The thickness of the manufactured boards at the set components decreases from 4.8 to 3.5mm, or by nearly 40%. The density increase is due to the higher compression as a result of the increased specific pressure and, therefore, is realised at the expense of the thickness of the boards at identical characteristics of the wood-fibre carpet.

The greatest variation of the two indices is recorded in case of pressure increase from 0.6 to 1.0MPa, and the smallest – in case of pressure increase from 2.6 to 3.0MPa. The dependence is of 2nd degree, with greater relative variation being observed in case of pressure increase to 2.0MPa whereupon the increase is relatively smaller. The set density of 900kg/m^3 is only reached at a pressure above 2.6MPa.

The variation of the water absorption and swelling of FBs at different levels of pressing pressure is presented on Fig. 6.

The equation of regression between pressing pressure and water absorption is:

$$\widehat{Y} = 187.20 - 59.12X + 5.41X^2 \quad (6)$$

The relationship between the pressing pressure in case of a range of variation from 0.6 to 3.0MPa and the swelling in thickness of FBs is described with a regression equation of the type:

$$\widehat{Y} = 28.27 - 10.67X + 3.56X^2 \quad (7)$$

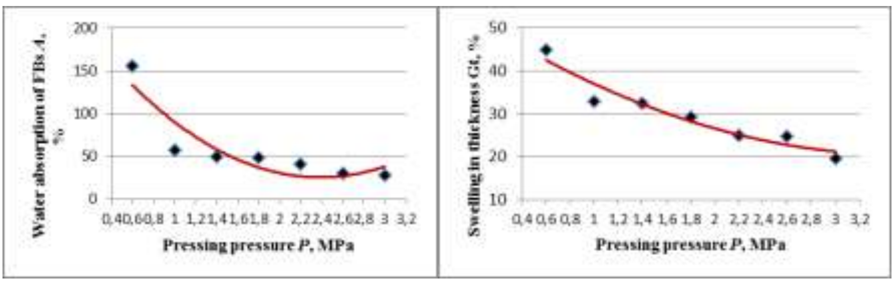

Figure 6: Variation of water absorption and swelling of FBs depending on the pressing pressure

Very big improvement, respectively decrease, of the water absorption index is observed in case of pressure increase from 0.6 to 1.0MPa, with the index decreasing from 150 to 60%. The dependence is of 2nd degree and greater relative improvement of the index in case of pressure increase to the value of 2.0MPa is observed.

The very deteriorated value of the index at a pressure of 0.6MPa could be explained with the low structural stability of the boards, due to the lower compression ration and mainly to the deteriorated heat exchange because of the direct release of the steam and gas mixtures during their formation. The latter impedes the formation of both cohesive bonds and adhesive ones.

The swelling in thickness is improved, with it decreasing with the increase of the pressing pressure. This trend is more clearly expressed up to 2.0MPa whereupon the improvement is smaller.

As a whole, the water absorption and swelling decrease with the increase of the pressing pressure. This may be explained with the plastic deformations that have occurred, which guarantee irreversibility of the bonds created in the boards.

The regression equation describing the dependence of the bending strength on the pressing pressure is of the type:

$$\widehat{Y} = 22.11 - 15.37X + 1.49X^2 \qquad (8)$$

The above equation is characterised with a coefficient of determination R^2 = 0.99 and, therefore, the equation adequately describes the examined relationships in the examined range of variation of pressing pressure.

The dependence between the bending strength and the pressing pressure is graphically presented on Fig. 7.

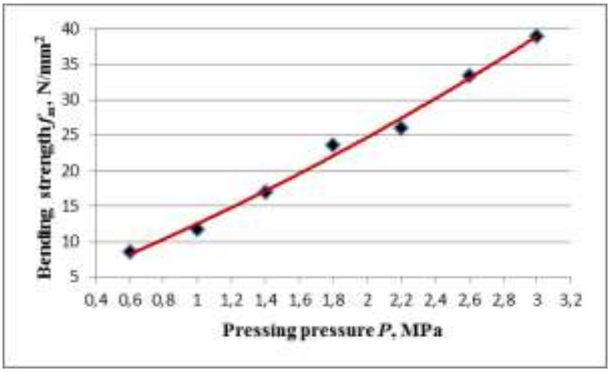

Figure 7: Variation of bending strength of FBs depending on the pressing pressure

The relationship between the bending strength and the pressing pressure approximates linear one. With the pressure increase, the bending strength increases considerably. Lowest value of 8N/mm^2 is recorded at a pressure of 0.6MPa. The index has highest value, of nearly 40MPa, at a pressure of 3.0MPa, with the laboratorially manufactured boards meeting the most strict requirements in the field with respect to this index, without additional modification of the manufacture mode being necessary. Although the trend is more poorly expressed, there is greater relative improvement of the index in case of pressure increase from 0.6 to 2.0MPa here, too.

As a result of the investigation performed on the effect of specific pressing pressure on the performance of FBs manufactured after the dry method from wood of hard broad-leaved tree species, the following more fundamental conclusions may be drawn:

1) The dependence between the pressing pressure and density of FBs is of direct nature. Highest density increase is observed in case of pressure increase from 0.6 to 1.0MPa, and smallest – in case of pressure increase from 2.6 to 3.0MPa;

2) The pressure increase leads to decrease of board thickness as a result of the higher compression ratio. The relationship between the thicknesses of the boards manufactured and the pressure is of quadratic nature, with greater decrease being observed in case of pressure increase to 2.0MPa;
3) The increase of the pressing pressure leads to reduction of the water absorption of FBs, with the relationship being expressed through the equation of 2^{nd} degree. Very big decrease, i.e. improvement of the index, is observed with the pressure increase from 0.6 to 1.0MPa;
4) The swelling in thickness is improved in case of pressure increase from 0.6 to 3.0MPa, with the biggest improvement being to 2.0MPa;
5) With the increase of the pressing pressure, the bending strength of FBs increases considerably, with them meeting to the most strict requirements for FBs within the above factor range examined.

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The effect of moisture content and drying temperature on the colour of Poplars and Robinia wood*

Ott Ágota[1], Takáts Péter[2], Németh Róbert[3]

University of West Hungary, Faculty of Wood Sciences, [1,2]Institute of Wood and Paper Technology, [3]Institute of Wood Science

H-9400 Sopron, Bajcsy-Zs. u. 4.

e-mail: [1]ottagi@fmk.nyme.hu; [2]patakats@fmk.nyme.hu; [3]nemethr@fmk.nyme.hu

ABSTRACT

The colour change of wood is a topic of numerous research activities worldwide. This paper deals with the colour change of Robinia (*Robinia pseudoacacia* L.) and two hybrid poplars, namely Pannónia Poplar (*Populus x euramericana Pannónia*) and I-214 Poplar (*Populus. x euramericana I-214*). For poplars the sapwood and the heartwood were investigated separately, for Robinia the narrow sapwood was neglected. The timbers were dried in a climate chamber by 4 different temperatures (20°C, 40°C, 60°C and 80°C), as the relative humidity was reduced in 5 steps (95%, 80%, 65%, 40% and 20%).
The colour coordinates L*, a* and b* were measured according to the CIELab system. Differences in terms of colour change between wood species and sapwood versus heartwood are discussed in the paper. The effect of wood’s moisture content and heat on the colour coordinates is published as well.

INTRODUCTION

In this research work the effect of drying at low and moderate temperatures on the colour co-ordinates for Robinia, Pannónia Poplar and I-214 Poplar was investigated. Robinia is one of the dominant species in the Hungarian plantation forestry and the wood working industry (Molnár and Bariska, 2002). Because of its frequent use and importance several studies dealing with the anatomical, physical and chemical properties were preformed

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worldwide (Adamopoulos and Voulgaridis 2002, Adamopoulos et al. 2005, Oltean et al. 2008). The unattractive greenish-yellowish colour of Robinia can be changed by steaming as well (Tolvaj et al. 2005, Tolvaj et al. 2006). The effect of moisture content and the drying temperature on the colour co-ordinates of Robinia wood was not investigated yet.

The utilisation of poplars is limited by the low natural durability and the moderate to low mechanical characteristics. Recently the wood of poplars is widely used in the panel industry and due to its light colour it is appreciated by the furniture industry as well (Alpár and Rácz 2006, Katona 2010, 2011). The effect of elevated drying temperature on different physical properties of poplar was published by Christiansen (1994). A complex study to enhance the colour and hydrophobicity of Pannónia Poplar was performed by Bak (2012). There is a lack of information in the literature according to the effect of lower temperatures and the moisture content on the colour of poplars.

The main goal of this research work was to investigate the effect of different drying temperatures and the moisture content on the colour co-ordinates of Robinia heartwood and Poplar sap and heartwood.

MATERIAL AND METHODS

Freshly cut Robinia and Poplar logs were purchased at the Forestry District in Kapuvár (Hungary). The logs were cut into boards, subsequently packed in foil and kept in a refrigerator to protect them against moisture loss and fungal attack.

5 different materials were tested: Robinia heartwood, Pannónia Poplar sap- and coloured heartwood, I-214 Poplar sap- and coloured heartwood.

Samples for colour measurements, sorption measurements and shrinking were prepared in different size and numbers. In this paper the results of colour measurements and the equilibrium moisture contents are discussed. 6-6 samples from each material with dimensions of 5mm thickness and 45mm x 120mm surface served for colour measurements, the surfaces were planed. The equilibrium moisture content was determined with 20 samples for each material having the dimensions of 20mm x 20mm x 5mm. The colour coordinates lightness (L*), red hue (a*) and yellow hue (b*) were determined by using a Konica Minolta 2600D device (D65 light source, 10° angle).

In order to avoid the contamination of Poplar’s wood surfaces by VOCs evaporating from Robinia wood, the Robinia samples were treated (dried) separately.

The test materials with freshly cut moisture contents were put into a climate chamber (Binder KBF 115) where the relative humidity was reduced stepwise from 95% to 20% (±1,5%), while the temperature was kept constant. Colour measurements were performed at the beginning of the drying and at the end of every relative moisture content step (fresh conditions, 95%, 80%, 65%, 40% and 20% relative humidity). After reaching the equilibrium (72 hours) the samples were dried at 103±2°C until constant mass. The simulated drying in the climate chamber was carried out at 4 different temperatures (20°C, 40°C, 60°C and 80°C). The treatments (drying schedules) are shown on Fig 1.

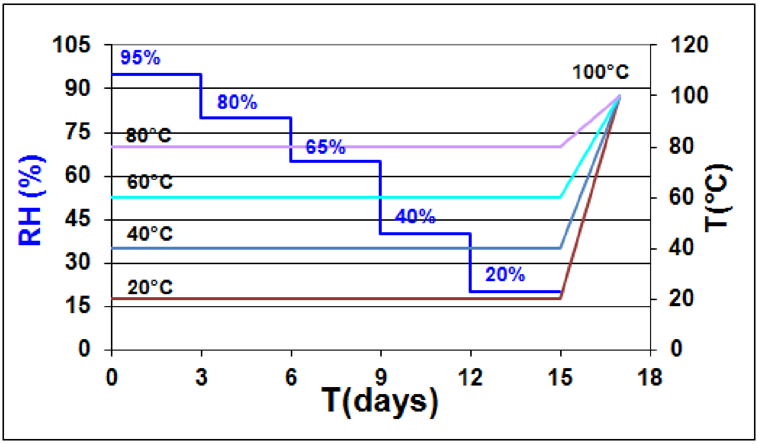

Fig 1. Treatment / Drying schedules

RESULTS AND DISCUSSION

The colour change of Robinia is shown on Fig 2. – Fig 4. The lightness values start at different levels, as there is a natural within-tree variability of the colour. The moisture content of wood decreases gradually. The decrease of lightness values is influenced by the moisture content at higher drying temperatures (60°C and 80°C) 7.45% and 20,65% respectively. Lower temperatures cause only a slight lightness change. As a consequence of the drying in an oven at 103°C the lightness of the wood falls significantly.
Red hue and yellow hue values of Robinia heartwood response differently. The red hue is influenced by the drying temperature by the higher temperatures (60°C and 80°C) only. The values increased by 18.22% and 128.57% respectively. The yellow hue showed similar changes to the lightness. Thus values decreased by 60°C and 80°C significantly, expressed in percentage 33.26% and 18.34% respectively.

Important additional information for colour measurements is the result that the colour co-ordinates (L*, a* and b*) are not influenced by the moisture content below the fibre saturation point (FSP), if the temperature is kept below 40°C.

Furthermore the moisture loss from green state down below the fibre saturation point resulted in increased lightness at 20°C and 40°C. Thus, if the temperature is kept below 40°C the lightness increases because of the evaporation of free water from the cell lumens and the change of the refraction coefficient. The same was reported by Németh, 1998. The opposite tendency can be observed by the red hue values in case of Robinia (Fig. 3), as the a* values are increasing as the wood dries from fresh state below the FSP. The yellow hue (Fig. 4) of Robinia wood changes with the initial moisture reduction at all investigated temperatures.

The fibre saturation point for Robinia and Poplar wood at different temperatures was reported by Németh et al (2009).

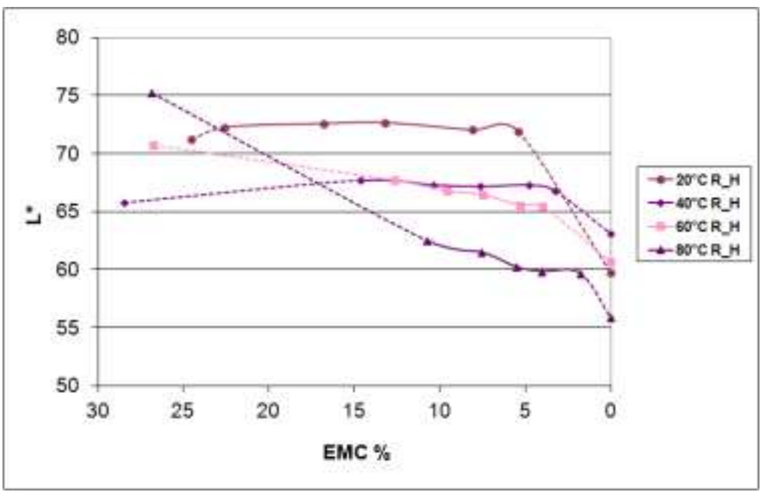

Fig. 2 Change of Lightness values by Robinia heartwood (R_H) at different drying temperatures and moisture contents

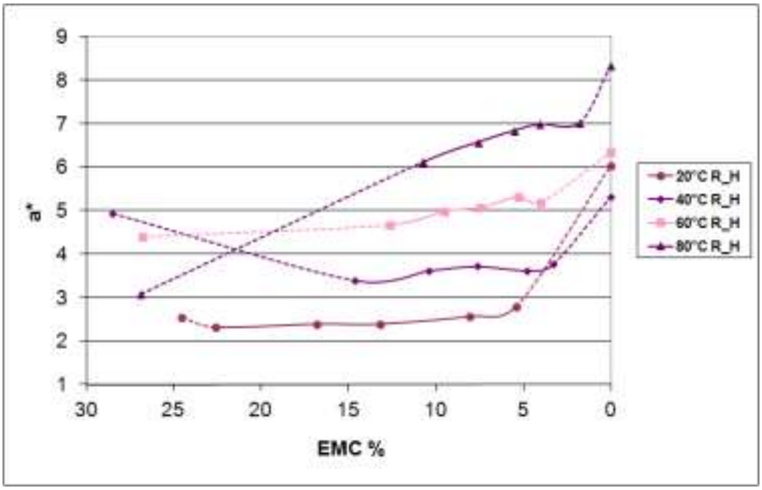

Fig. 3 Change of red hue values by Robinia heartwood (R_H) at different drying temperatures and moisture contents

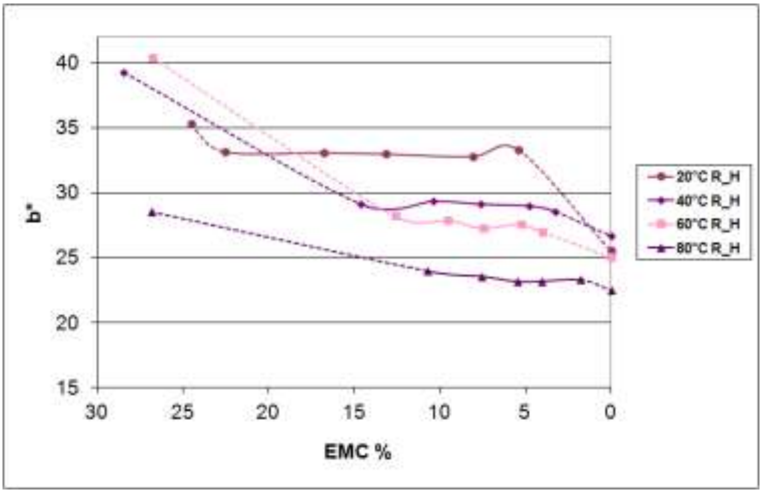

Fig. 4 Change of yellow hue values by Robinia heartwood (R_H) at different drying temperatures and moisture contents

The colour change of I-214 Poplar sap- and heartwood is shown on Fig 5. – Fig 7. The other investigated Poplar (Pannónia Poplar) shows similar results, therefore in this paper the results concerning the I-214 Poplar are discussed only. The initial moisture content of heartwood starts from the range between 213-254% (dry mass based), while the sapwood starts from 88-100%.

The initial lightness values in green conditions start at different levels (Fig. 5); as there is a natural within-tree variability of the colour. The moisture content of wood decreases rapidly, as the samples reaching EMC values lower than the FSP during the first 72h of the drying.

The lightness values are increasing with decreasing moisture content from the fresh state to FSP at all temperatures for heartwood, while there is only a slight change for sapwood. For example at 40°C the heartwood shows 13% lightness increase, while the sapwood's L* value decreases 0.2% only. The different behaviour can be explained by the darker colour of the heartwood.

The temperature is influencing the lightness only at 80°C, thus the lightness of Poplar is more stable against heat compared to Robinia, where 60°C resulted already in significant decrease of the lightness. This is valid for the Poplar coloured heartwood as well, thus the chromophore groups of Robinia are more sensitive to heat.

On Fig. 6. the red hue values are shown for Poplar sap- and heartwood. The heartwood's red colour co-ordinate is higher compared to the sapwood's a*. During drying the red hue values are changing with decreasing moisture content. At the beginning there were significant differences between the samples' a* values, this differences decreased during the moisture loss.

At the end of the drying processes the differences between sapwood and heartwood decreased, thus a board containing both parts (sap and heart) would appear more homogenous in terms of red hue. Important practical observation was made as the texture of the surface appeared more homogenous for the naked eye, as annual ring borders were hardly to detect on dry surfaces.

On Fig 7 the yellow hue values are shown. At 20°C and 40°C the b* values decreased significantly during the whole drying process, while at 60°C and 80°C the yellow hue values decreased first and showed increase during the drying. The original (fresh conditions) yellow co-ordinate could not be regained by the investigated samples. Similar to the red hue values the differences being present in fresh conditions between heart- and sapwood decreased.

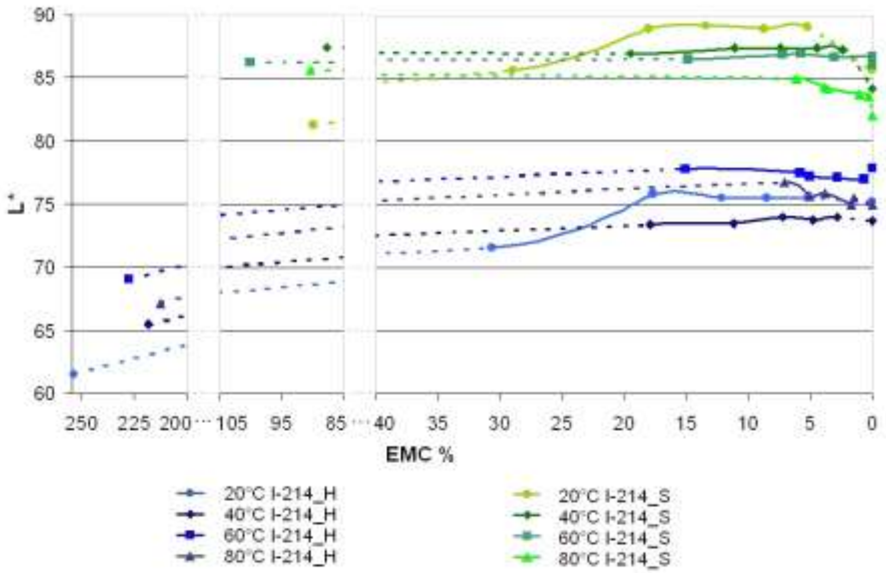

Fig. 5 Change of Lightness values by I-214 Poplar heart- (H) and sapwood (S) at different drying temperatures and moisture contents

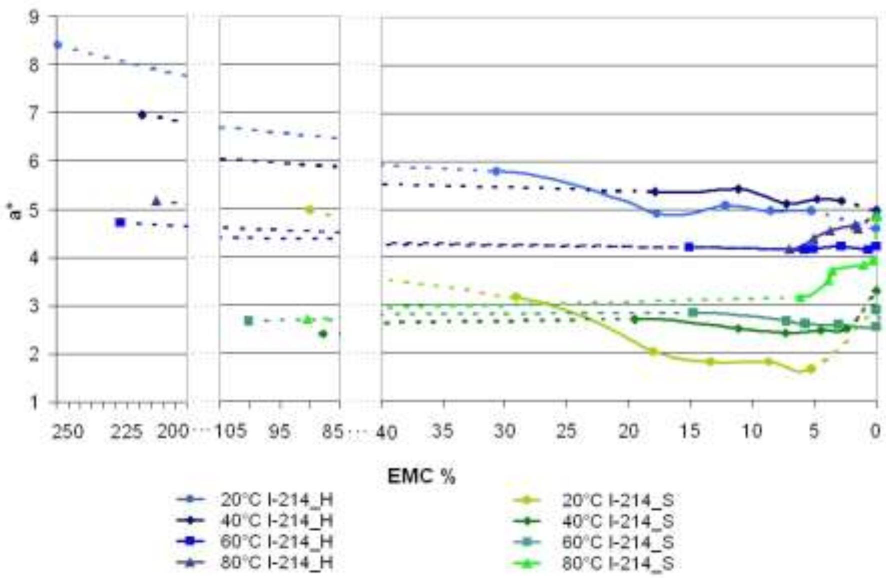

Fig. 6 Change of red hue values by I-214 Poplar heart- (H) and sapwood (S) at different drying temperatures and moisture contents

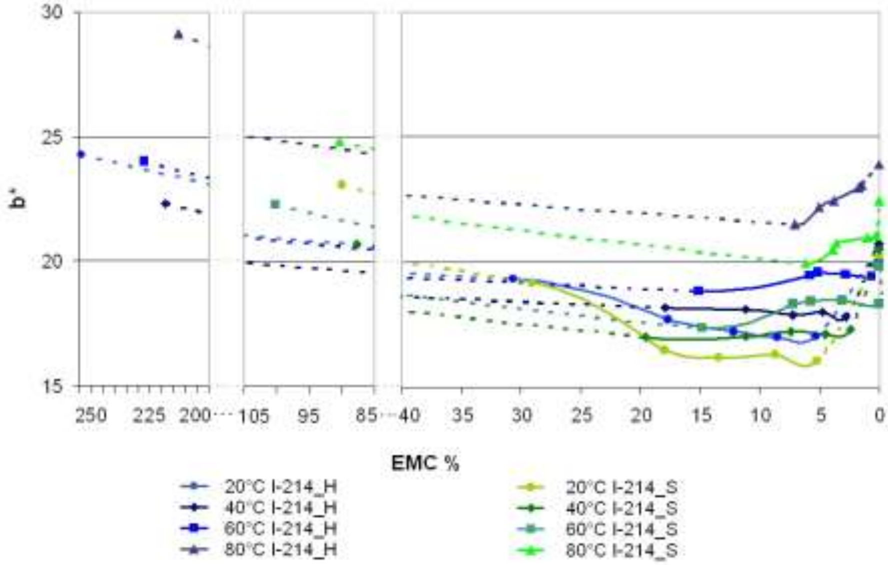

Fig. 7 Change of yellow hue values by I-214 Poplar heart- (H) and sapwood (S) at different drying temperatures and moisture contents

CONCLUSIONS

The colour co-ordinates (L*, a*, b*) of Robinia and I-214 Poplar woods were investigated in this research work. Freshly cut samples (over FSP) were dried in a climate chamber by lowering the relative humidity at constant temperatures. Simulated drying regimes were performed at four different temperatures (20°C, 40°C, 60°C and 80°C). The moisture content of the samples were measured (calculated) as well. The colour co-ordinates were measured at every relative humidity step. The results allow drawing conclusions upon the effect of the drying temperature and the moisture content on the colour of wood.

The colour of Robinia wood did not change significantly at 20°C in the moisture range below FSP. Elevated temperatures, over 40°C, resulted in reduction of lightness, increased redness and decreased yellowness. Tolvaj et al. 2004 measured the colour change of Robinia wood during steaming in the temperature range of 75°C and 135°C. Comparing our findings with those data it can be concluded that a 4 days long steaming process at 80°C causes the same lightness change ($\Delta L = 12$) as our drying process to 8% moisture content during 6 days. This 6 days consisting from 2 drying steps: 3 days

95% rel. humidity and additional 3 days 80% rel. humidity. For larger samples (boards) in practice the moisture content of wood would remain higher for longer period in a drying chamber. Thus, the period of steaming would last longer, assumingly resulting in more pronounced colour change.
The colour change of I-214 poplar is dominated by the loss of the free water over the FSP. In the range of bound water the colour changes only at 80°C significantly. The differences between heartwood and sapwood decreased as a consequence of moisture loss at all investigated temperatures, as the colour co-ordinates of heartwood shifted to towards the co-ordinates of sapwood. The texture of poplar wood became more homogenous after drying, as the annual ring borders, and the streakiness were hard to detectable. The last observation has practical importance where poplar is used on "visible" places, e.g. furniture fronts.
Comparing the reaction to the moisture loss and temperature of Poplar and Robinia wood we came to the conclusion that Robinia is more sensitive to heat. But because of Robinia's low green moisture content the possible absolute changes are lower as the wood dries from green condition.

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Process improvement on a log yard using double and single stage problem solving by means of Excel and Xpress

Jörn Rathke[1], Maria Huka[2], Manfred Gronalt[2]

[1] Institute of Wood Science and Technology, University of Natural Resources and Life Sciences, 3430 Tulln

[2] Institute of Production and Logistics, University of Natural Resources and Life Sciences, 1180 Vienna

Keywords: logistic, log yard, optimization, sawmill

ABSTRACT

This paper presents an optimization approach in order to minimize log yard round timber transport time for a medium sized hardwood sawmill. The log yard is the first processing step in a mill. Additionally, it serves as a stable source of raw material for the entire production process. The main factor for a stable production process is the continuous material flow from the forest to the sawmill, while the log yard serves as the first mill internal storage and sorting capacity. Thus, an optimal storage arrangement and the optimization of transportation time between ejectors, storage boxes and feeding carriages leads to higher productivity. The purpose of this paper is to develop an unified approach to optimize the log transportation time, storage capacity and yard crane deployment, simultaneously. Therefore, the optimization was performed in the three steps: definition of storage spaces per assortment, calculation of distances and finally the calculation of the optimum material flow by means of an heuristic model and a binary integer problem.

INTRODUCTION

This paper presents a logistic optimization concerning the log yard of a hardwood sawmill with an annual production capacity of 30,000 cubic meters. As main approaches to improve the profitability of a sawmill, most often new technologies and new products are seen. Both of them are in principle right but at times of souring markets these two strategies are questionable concerning the costs of their development and implementation. Another access is the logistic optimization of the process chain, the log yard at first instance. BRYAN (1996) describes mathematical models as a door opener for testing ideas and the creation of ideas without interruption of the business. Two basic models can be chosen in this case, simulation and optimization.

Plenty of examples can be found in the literature where simulation is used to optimize processes in the forest industry. MENDOZA ET AL. (1991) present one of the earliest papers dealing with the topic of hardwood sawmill optimization and RANDHAWA ET AL. (1994) show the topic of object orientation for sawmill simulation. GREIGERITSCH (2009) determined production planning processes for softwood sawmills including the optimization of the sorting line of the sawline. Hence, no direct solution for the log yard planning and optimization could be found in literature. The objective of this paper is to show how an easy to handle logistic optimization approach, concerning the log yard of an European middle size hardwood sawmill can be performed. Considering that the software of choice has to be easy to handle and unproblematic applicable with a commercial available computer system, Excel is used for the optimization of the model. It is assumed that Excel will not provide the optimal solution, so Xpress is used for comparison. The system is defined as successful if the improvement in time reduction is 10% less than the initial situation and the difference to the Xpress data is less than 3%.

MATERIAL AND METHOD

In a sawmill logs are sawn into several board dimensions during the initial production process. Generally, four different cutting machines are used for the initial breakdown. According to WILLISTON (1976), FRONIUS 1989), FRONIUS (1991) and WAGENFÜHR AND SCHOLZ (2008) these are circular saws, chippers, band-saws and frame-saws.

During the production, the characteristics of a log impact processing times, quality and yield of the produced boards. In general these log parameters can be defined by specie, grade and scale. Grade is the determination of the log quality which reflects the estimated yield of the lumber, while scale means the volume of a log which is measured in cubic meters.

Process description

The analyzed sawmill produces three main hardwood species: beech *(Fagus sylvatica)*, European oak *(Querqus robur/Querqus patrea)*, European Ash *(Fraxinus excelsior)* and a small amount of softwood. As beech production accounts for app. 75% of the total annual production, the log yard will be optimized for this raw material segment. Therefore, the assortment arrangement changes 3 to 8 times per year while the changes mainly depend on species and length changes. Before the sawing process logs are measured, cut to length, sorted and stored on the log yard. The material flow of the log yard is shown in Fig. 1.

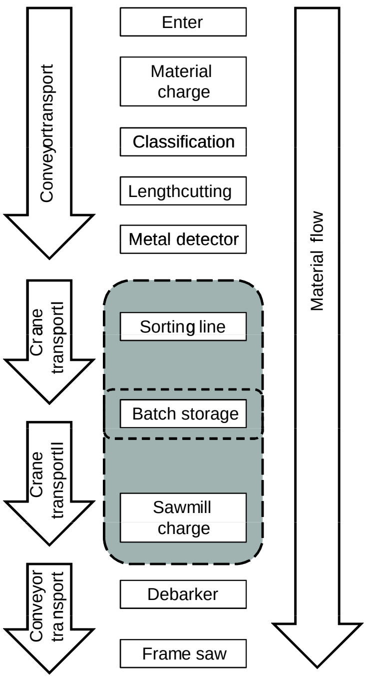

Figure 1: Material flow in log yard and sawmill

While the boxes represent the process, the arrows represent the material flow. The encircled boxes show the process parts, special regard is given to. The material transportation between the not encircled boxes is performed by conveyor bands or rolls with continuous movement. Clearly, the production rate at the sawmill must cope with the feeding rate of the logs and the yard crane productivity. The logs are transported by trucks from the forest to the mill. The further process is displayed in Fig. 2. Before being placed on the conveyor system {1} the logs are sorted by species and pre stored. In the system the logs are at first two dimensional measured by means of an opto-electronic measurement device. The combination of log shape and human quality grading identifies the optimum cut in length {2} which ranges in this case from 3.5 to 6 m in 0.5 m steps.

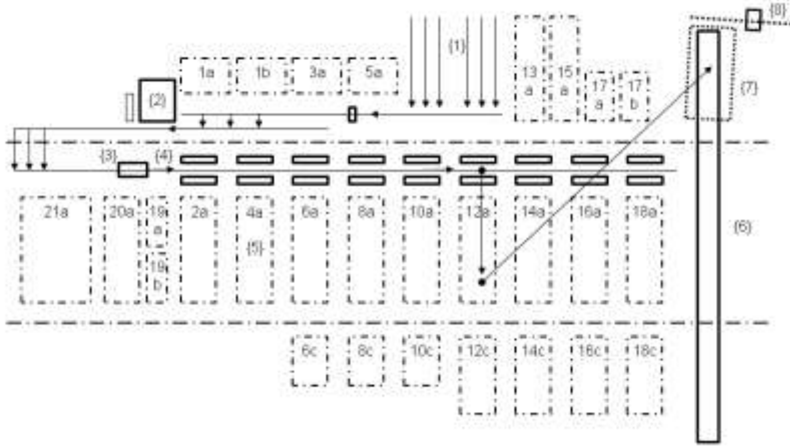

Figure 2: Optimized and new designed log yard

The metal detector {3} analyzes metallic enclosures when the log passes through its electric field. If metal is enclosed the field shifts, what can be measured. The position of the metal is marked by color and the log is ejected. Having passed the metal detector, the log is on the sorting line were the logs are ejected according to diameter and length {4}. The sorting line consists of a chain conveyor with mechanic ejectors, putting the logs into one of eighteen ejection boxes. If a certain box is full, a gantry crane {5} transports the logs into one of the assortment storing boxes. The crane moves with a speed of 80 m/min (crane) and 100 m/min (diagonal) respectively {6}. The ultimate load of the crane is according to machinery data at 8 tons. As the claw has a weight of 0.7 tons, the effective bearing load is at 7.3 tons. The capacity of transportation depends on the relative density of the beech logs, yielding about 1.0 ton per cubic meters in moist condition. Assuming this the log diameter and the log weight restrict the transportation capacity. In contrast to that the storing box capacity depends mainly on the log diameter.

In current status, storage boxes are designed to cover a high variability of assortments. When one

assortment is finished the logs are transported to the sawmill charging {7}. Straight before the sawing process logs are debarked. The debarking process directly before the sawing process offers a natural protection layer. Even more this process chain permits the distribution of clean logs to the saw as all contamination is removed in combination with the bark {8}. The level of a finished assortment is determined first visually depending on the filling degree of the storage box and second in correspondence with the gained measurement data of the volume determination.

Model formulation

The capacitated facility location problem (CFLP) is formulated as a linear programming model and a binary integer problem. It is assumed that the company operates one mill with a demand of D per assortment A leading to a required storing capacity CAP_s. This creates a count of transportation N_a. The following notation is used to specify the mathematical model.

Indices

A = Set of assortments (a = 1; …; 15)
E = Set of ejection boxes (e = 1; …; 18)
S = Set of storage boxes (a = 1; …; 28)

Initial the travel distances from the ejection box to the storage box and then to the feed were calculated and plotted in a matrix. As the crane can only move in axial (80 m/min) and transverse (100 m/min) direction, for each traveling step both distances are measured. The distance is then divided by the traveling speed, showing the real traveling time, where **VT** stands for vertical crane time and **DT** for the diagonal moves.

$$TT_{es} = \max_{e \in E, s \in S} \left\{ \frac{VT_{es}}{80}, \frac{DT_{es}}{100} \right\} \tag{1}$$

$$TT_s = \max_{s \in S} \left\{ \frac{VT_s}{80}, \frac{DT_s}{100} \right\} \tag{2}$$

Parameter

N_a Number of trips per assortment **a**, due to the diameter of the assortment and the demand per set assortment
TTT_{es} Total transportation time for every assortment from ejection box **e** to storage box **s** and to the material charge
TT_{es} Transportation time from eject box **e** to storage box **s**
TT_s Transportation time from storage box **s** to the material charge
CAP_s Capacity of storage box **s**
VOL_a Maximal volume of assortment **a**

Variables

x_{as} Binary assignment variable, 1 if assortment **a** is assigned to storage box **s**, 0 otherwise

y_{ae} Binary assignment variable, 1 if assortment **a** is assigned to ejection box **e**, 0 otherwise

z_{aes} Binary assignment variable, 1 if assortment **a** is assigned to eject box **e** and that in turn to storage box **s**, 0 otherwise

Double-stage model

This is a simplification of the single-stage model which is described later, on that account this idea is just described shortly. The first stage is to assign the assortment **a** to the storage boxes **s** considering the available storage volume and the logical assignment constraints. With the result of stage 1 the next instance is going to be solved. Therefore, the best assignment of assortment **a** to ejection box **e** is calculated. Hence, the transportation time is minimized in both steps.

Single-state model

When looking at the binary integer problem on the whole, the solution can be improved by introducing one binary variable $\mathbf{z_{aes}}$ which describes the assignment of every log assortment **a** to an ejection box **e** and storage box **s**.

$$\min_{a\in A, e\in E, s\in S} \quad N_a \times TTT_{es} \times z_{aes} \tag{3}$$

$$TTT_{es} = TT_{es} + TT_s \qquad \forall e \in E, s \in S \tag{4}$$

$$CAP_s \times z_{aes} \geq VOL_a \qquad \forall a \in A, s \in S \tag{5}$$

$$\sum_{e\in E, s\in S} z_{aes} = 1 \qquad \forall a \in A \tag{6}$$

$$\sum_{a\in A, s\in S} z_{aes} \leq 1 \qquad \forall e \in E \tag{7}$$

$$\sum_{a\in A, e\in E} z_{aes} \leq 1 \qquad \forall s \in S \tag{8}$$

Objective function (3) minimizes the total transportation time, which in turn is calculated with the first constraints (4). The next constraints (5) ensure a feasible solution of the assignment for every assortment **a** and storage box **s**. Constraints (6), (7) and (8) make sure that every assortment is assigned to exactly one ejection box and storage box and that on the other hand at most one ejection box and one storage box is used for an assortment.

Excel optimization process

The systematic used to solve this logistic problem is based on the transportation problem which is specified in VAHRENKAMP AND MATTFELD (2007). The aim of this study was to generate a system which offers an industry applicable solution to the problem of a logistic optimization. Both linear programming models (double-stage and single-stage) are two-layered. This means that parallel to the minimum transportation time a constraint, reflecting the box placement possibilities per assortment, is taken into account and is finally prioritized over the minimum transportation time. The combination with the lowest number is privileged.

Xpress optimization

To get the optimal material flow the problem is solved with Xpress, first with the double-stage approach and second, with a three indexed binary variable linear optimization model described earlier. After due consideration, it occurred that when looking at the whole assignment at once, a better solution could be gained. Therefore, when solving the single-stage approach the solution can be minimized compared to the double-stage approach.

RESULTS AND DISCUSSION

To evaluate the quality of the test results, the generated data is compared with a solution which is obtained by classic manual planning. The former way of assortment allocation worked on an ad-hoc basis. The storage boxes were filled, depending whether they were empty or not, the factor of transportation time was not implemented here. The yard throughput is assumed to be equal over all dimensions.

Table 1: Comparable solutions of the log yard and box assignment problem

Assortment	Original	Excel double-stage	Excel single-stage	Xpress double-stage	Xpress single-stage
1	1/-	1/-	1/-	1/-	1/-
2	2/-	2/-	2/-	2/-	2/-
3	3/-	3/-	3/-	3/-	3/-
4	12/12 a	17/16 c	4/6 a	14/18 c	12/16 c
5	8/8 a	11/18 c	7/12 c	8/12 c	8/12 c
6	2/2 a	9/17 b	17/17 b	17/17 b	17/17 b
7	16/16 a	18/18 a	14/13 a	16/16 a	16/16 a
8	10/10 a	10/14 c	6/8 a	10/14 c	10/14 c
9	4/4 a	8/12 c	10/12 a	4/8 c	4/6 a
10	17/17 a+c	16/16 a	12/14 a	18/18 a	18/18 a
11	9/10 c	7/10 a	5/10 c	12/16 c	14/18 c
12	6/6 a	6/10 c	11/16 c	5/8 a	5/8 a
13	13/13 a	13/15 a	13/15 a	15/13 a	15/13 a
14	18/18 a	14/14 a	18/18 a	9/12 a	9/12 a
15	11/12 c	5/8 a	9/14 c	7/10 a	6/10 c
16	15/15 a	15/13 a	15/13 a	13/15 a	13/15 a
17	14/14 a	12/12 a	16/16 a	11/14 a	11/14 a
18	7/8 c	4/8 c	8/10 a	6/10 c	7/10 a
Number of storage boxes	43	28	28	28	28
∑ dez.	532.876	487.904	478.671	470.107	468.979
∑ hh:mm	08:52	08:07	07:58	07:50	07:48
Saving	-	8.4%	10.2%	11.8%	12%

From the previous table it is evident, that the method of choice for an optimized log yard is the single-stage model, even though the double-stage model shows values, nearby. In the columns the ejector box and the storage box are given in dependence of the assortment. Ejector boxes 1, 2 and 3 contain oversize, undersize and metal infected logs. The single-stage models both perform the 10% time reduction if compared to the manual planning model. The two-stage models performed quite well. Anyway, only the Xpress version meets in this case the threshold of a 10% time reduction in comparison to the manual planning. Assuming this the Excel model meets the preconditioned target value of a deflection of less than 3%.

CONCLUSION

The Log Yard and Box Assignment Problem has been modeled in a new way which guarantees a production optimized and time transparent solution. The model is flexible enough to deal with variations of the production volume and intermittent blocked boxes. The solution methods of the problem are adapted to the variations, corresponding to the changes. From the test results it is evident, that the model facilitates with both, double- and single-stage algorithm, a solution superior than those achieved by annual planning. Even more the deviation of the optimization models of Excel and Xpress show low numbers, confirming the Excel model. Future work should be performed analyzing the gained data in comparison with real data. In practical application it is possible to confirm the exact generation of the optimization models. In this paper the model is based on feeding data and log storage yard spacing regulations meeting direct production data in contrast to theoretical approaches, which do not take advantage of structures in the problem data. Nevertheless, the model presented in this paper shows a valuable way of solving logistic problems in wood products industry.
Further work should be done on the optimization of the lumber yard. The lumber yard shows a high variety of different species, grades and even more important, a high variation in turnover frequency.

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Colour change of wood surfaces due to reactions with dispersion adhesives*

József Ábrahám[1], Szabolcs Komán[2], Zoltán Börcsök[3]

[1] University of West Hungary, Bajcsy-Zs. u. 4., H-9400 Sopron,

[1]abrahamj@fmk.nyme.hu

[2] komansz@fmk.nyme.hu

[3] borcsok.zoltan@fmk.nyme.hu@

Keywords: wood surface, colour change, glue, durability class

ABSTRACT

The bonding process is an important technology in the wood industry. The problems arise during bonding are in a wide palette range from the serious structural faults to the simple aesthetic problems. The aesthetic errors can also dramatically reduce the price of the product even if it has an ideal adhesive quality, so this is important to eliminate these errors. The discoloration of bonding (bonding plane) may caused the different bonding participants, materials in contact with one another, which can occur between:

1. adhesives and bonding materials
2. the glue and applicators
3. the bonding material and backhaul devices.

We studied the wood surface discolouration with the effects of different dispersion adhesives. Six adhesives were used, two of them were D3 (water resistance level), the others were D2. The most commonly used wood species in Hungary (oak, black locust, ash, beech, birch, Scots pine and spruce) were used.

The changes of the measured values in the CIELAB color coordinate system shows that each species responded differently depending on the type of adhesive used. In some cases, significant changes have caused the adhesives, especially the D3 type adhesive on wood surface containing a high amount of extracts.

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INTRODUCTION

The surface of wood often suffers some discolouration during industrial gluing technology. Depending on the extent and the measure of this phenomenon, customers often claim about this problem. The user of the glues often claim the glue producer as the detected discolouration would be caused by the low quality, and/or changing quality of the glue. According to our experience in many cases the detected discolouration is a consequence of the inappropriate gluing conditions (e.g. applicators, temperatures) and the different wood species.

In the wood discoloration examination the measurements of color changes was applied in the past two decades, in particular the study of photodegradation (TANEDA ET AL. 1989, TOLVAJ 1994/B, TOLVAJ AND FAIX 1995, CHANG AND CHANG 2001, AYADY ET AL. 2003, HANSMANN ET AL. 2006, OLTEAN ET AL. 2008, 2009, WANG AND REN 2008, SHARRATT ET AL. 2009, TOLVAJ AND MITSUI 2010).

During the discoloration caused by the reaction of the wood and the glue the extracted substances from the wood can react with components of the adhesive, which is observed soon after the bonding. Woods, containing other types of extract materials has other type of color change as the woods does not have extracts, or contains only small amounts of it. If the wood contains a high amount of extract material, the chemical processes of the color changes quickly take place. A number of studies made to study the effect of substances extracted from the wood on the photodegradation of wood (NÉMETH ET AL. 1992, CHANG ET AL. 2010). The conclusions said that the resulting compounds will protect the wood from further degradation. At woods without extract materials, soon begins the photodegradation of the lignin with less but continous color change speed.

EXPERIMENTAL METHODS

The goal of the investigation was to determine how to change the appearance of the surface the interactions of dispersion adhesives and wood (most commonly used in Hungary). The changes of the surface were examined with color measurement. The color compositions of the woods were determined with Minolta CM-2600 spectrocolorimeter. The data are given in the CIE L* a* b* color coordinate system. The results pertain to D_{65} light source, measuring 8 mm in diameter surfaces, 10° observation. 6 different PVAc glues were tested, durability class: Type D2 (nr 1, 2, 5, 6), Type D3 (No.3, No.4). The glues were applied in 250 μm thickness onto the surface of 7 different wood species: oak, black locust, ash, beech, birch, Scots pine and spruce. The wood were marked in 10 to 10 different locations before the measurements (before the adhesive coat) so the color measurement was always done in the same place. The color measurement was performed prior to adhesive application, 24 hours after application, when the adhesive layer is fully cured. The difference of the color (between the color of the wood and the changed color of the wood) was calculated with the average of measurements on 10 pre-designated places (Fig. 1).

Fig. 1. Discolouration of the wood surfuces

RESULTS AND DISCUSSION

There were differences between adhesive types and wood species too. Each color coordinates has different effect on the change of the color, so the three color coordinates has different contribution to the total color change.
The coordinate a* (red component) majority moved towards the positive range in case of the broadleaved species (Fig. 2), while in case of the pines a slight negative shift was typical. The change is usually below 1, but in case of the ash and the black locust with some types of glue, this was more than 2. The differences between the glue types the most clearly pronounced in the case of ash and black locust. In case of the black locust one of the D3 type glue (No.4) caused the far greater change than others. The other, No.3 D3 type adhesive has only a third effect as the No.4, despite the fact that the effect is more than double than the D2 type adhesives produced. In case of the ash the adhesives No.1 and No.2 give of twice as big the values as D3 types, but the other two D2 type is omitted from them. There isn’t a clear difference between the two types of glue in the change of a*, the changes are determined by the individual reactions between the different woods and adhesives.

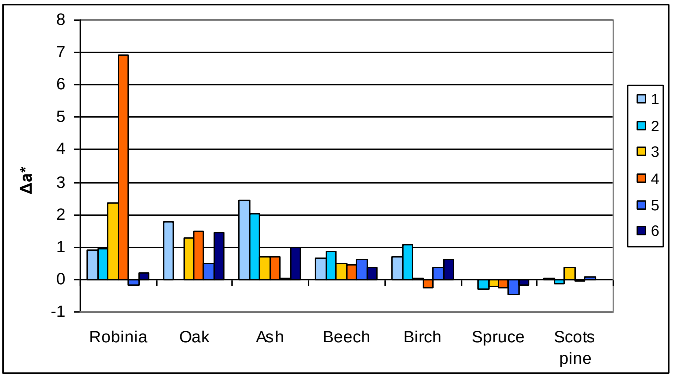

Fig. 2. Redness change of different wood surfaces

The b* coordinate in almost every case shifted towards the yellow color (Fig. 3). The values of the changes are the majority vary between 2 and 4. So the yellow color changes accordingly more significant than the red color change. In the b* changes the differences between adhesive water resistance level are also shown. In case of all species the D3 type adhesives caused major change. This is particularly important in case of the lack locust, where adhesive products classified in lower water resistance level, caused differences in b* color coordinates is a fragment than belong to the higher one. In case of the other species these differences are much smaller. Between the changes caused by the D2 type adhesives minor differences can be observed as two of them (No.2 and No.5) caused lower changes within each tree species than the others. There is no clear difference between the D3 type glues, with the exception of black locust where the adhesive No.4 cause greater color change.

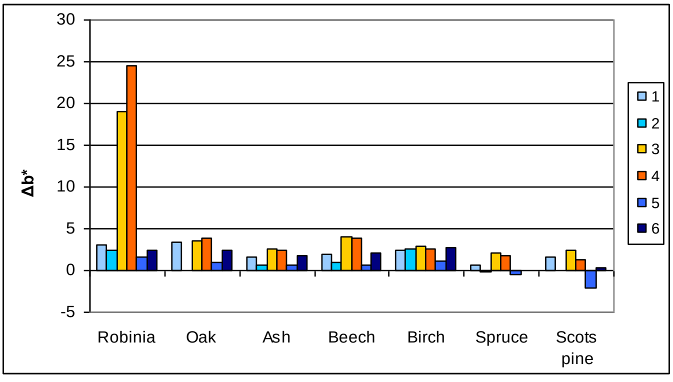

Fig. 3. Yellowness change of different wood surfaces

The change of L* in pines showed a clear shift towards the dark shades (Fig. 4). The role of the two adhesive types (D2 and D3) in the change of the light factors and varies in species, you can not formulate a general effect. In case of the black locust, the effect of the D3 type glues are not increase as much as in case of the other two color components. However, the adhesive No.4 has greater changes than the others. The effect of D3 type adhesives is stronger. The effect is greater in case of the oak and lower in case of the spruce. At the ash, especially at the birch and the beech, the D2 type glues caused higher L* values (changes). At Scots pine it is interesting that the L* coordinate – though only slightly, but – shifted to positive and negative directions in case of the same glue type.

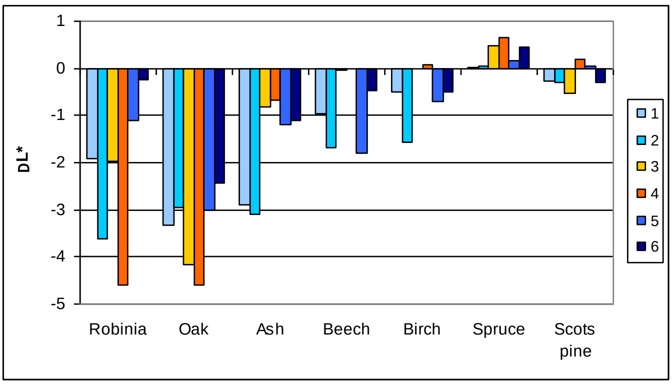

Fig. 4. Lightness change of different wood surfaces

24 hours after coating, the total color change (ΔE*) fall in different detectable ranges to the human eye (Fig. 5). In case of the pines most of the adhesives cause barely detectable (0.5-1.5) color change. In case of spruce the effect of the D3 type pass in the visible range (1.5 to 3), while in case of the Scots pine only the glue No.3 can do it. In case of the ash and birch the ΔE* values are in the noticeable range. The No.1 and No.2 of D2 type adhesives caused slightly larger changes on these two species than the D3 types. Tin case of the oak are even more significant color changes, as the values are in the visible (3-6) range and the two D3 glue approach the upper limit. In case of the black locust clearly the D3 type adhesives cause significant changes, as in the other color components were measured. The No.4 caused the highest discoloration. Until the color changes of the D2 type glues are in the noticeable (No.5, No.6) and well visible (No.1, No.2) range, while the color changes (ΔE*) of the D3 types are over the range of high difference (6-12).

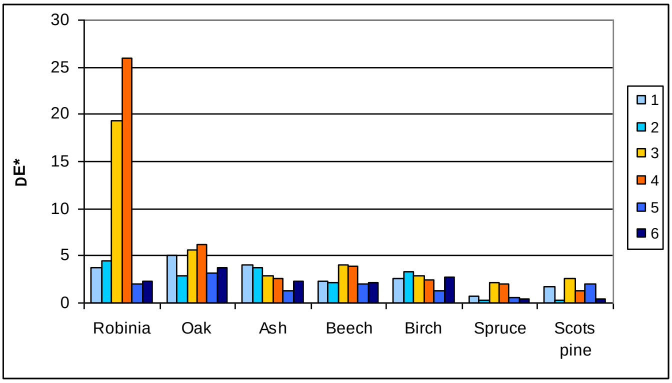

Fig. 5. Total color change of different wood surfaces

Looking at the change of color components, can be seen that these determine in different percentage the ΔE* in different species (Fig. 6). Overall, the red hue has the smallest effect, followed by the light changes. Mainly the change of the yellow component determined the amount of the color stimulation difference in case of most species and glues. This especially in case of the D3 type glues appears strong, with the exception of the oak, which was more determined by the darkening. In case of the D2 type adhesives there isn’t a color coordinate, which determine the overall color change independent from the species. Two of the four D2 type adhesive (No.2, No.5.) have similar proportion of the color components. In case of these two adhesives, at most of the broadleaved species the changes of the lightness are usually dominant. The other two D2 type adhesive are similar to the D3 type, as usually the yellow component has the highest proportion, but not so high extent.

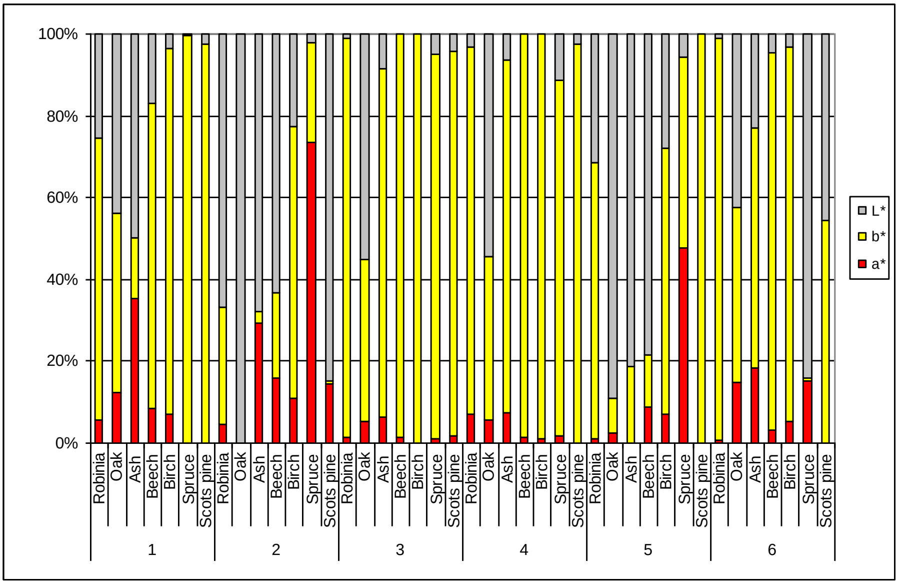

Fig. 6. The rate of the color components in total color change

CONCLUSIONS

There are significant differences between total color changes of surface of the selected seven different species 24 hours after the adhesive material application. In case of the pine all the three color coordinates have the smallest change. So regardless of the type of the glue the color change is not considerable according to the other species. Until there isn’t any difference in the changes of the a* between the water resistance types of the adhesives, while in the changes of the b* it is clear that the D3 type of glues cause greater change. In case of the changes of the L* coordinate depend on the species which type of adhesive caused the greater change. The more powerful effects of the D3 type glues can be observed in the change of ΔE*. This was the strongest at the black locust, which has a special material (dihydro-robinetin) and it causes the color change by reacting with one component of the D3 type adhesives.
Overall, the adhesives cause changes in the surface color of the wood. This change depends on the type of the adhesive and the species. In case of species which rich in extract components, the reaction of the components of the adhesives used to determining the degree of water resistance with wood surface can be more powerful. There can be difference between the surface

reactions of the same types of adhesives depending on components of the adhesive.

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Actual situation and future perspectives for supply and demand of hardwood in Germany

Björn Seintsch[1], Holger Weimar[1]

[1] Thünen Institute of Forest Based Sector Economics

Federal Research Institute for Rural Areas, Forestry and Fisheries

Leuschnerstrasse 91, D-21031 Hamburg, Germany

E-mails: bjoern.seintsch@vti.bund.de, holger.weimar@vti.bund.de

http://www.vti.bund.de/

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ABSTRACT

The forest area in Germany consists of 10.1 million hectares (stocked timberland). 43% of the forest area is covered by broadleaves and 57% by conifers. In contrast to this, hardwood accounts for only 20% of total removals and of domestic consumption. Focusing only at industrial roundwood in the German woodworking industry, the proportion of hardwood is even smaller (10%). The forest industry is very much dependent on coniferous roundwood. National forest inventory data show that the potential removals of softwood will be decreasing in the future, whereas significant logging potentials of hardwood are still unexploited. This discrepancy can be considered as one of the biggest challenges for the wood-based industry in the future. The industry will have to modify existing production processes and to develop new processes and products, in order to remain competitive on international markets.

INTRODUCTION

The forests in Germany are managed by about two million forest owners. 44% of the area belongs to private owners, 33% to national and federal states and 20% to corporations. These owners may have different objectives and sylvicultural concepts. However, a commonly shared concept can be described as an integrative approach to multifunctional forest management, which takes economic, ecological and social demands on the same area into account. In contrast, segregative approaches to forest management (i.e.

allocating the respective forestry functions to different areas) are rarely found (e. g. in national parks). The dominating management system in Germany is the high forest system, which is managed on relatively long rotations. The predominant aim is stem wood production, whereas the production of pulpwood and fuelwood is only subordinated. Converting coniferous forests to mixed and broadleaf forests has been an important objective in German forestry policy for the past 30 years. The main motivation is to increase the stability and biodiversity of forest stands, as well as their adaptation to climate change.

To date, the stocking area of 10.1 million hectares in Germany consists of 43% broadleaf trees and 57% coniferous trees. In the first age class (between 1 and 20 years) however, the share of broadleaf species already is 54% (OEHMICHEN ET AL. 2011). These proportions do not fit well to annual felling and domestic consumption in Germany. Hardwood accounts for only about 20% of total removals and of domestic consumption (OEHMICHEN ET AL. 2011, SEINTSCH 2011a, WEIMAR 2011). Focusing only at industrial roundwood in the German woodworking industry, the proportion of hardwood is even smaller (10%). On the contrary, 70% of the hardwood is used for energetic purposes (SEINTSCH 2011a; WEIMAR 2011). While it will not be possible to maintain the actual level of softwood fellings, especially with regard to spruce, there are significant unused potentials of hardwood (OEHMICHEN ET AL. 2011). This paper presents the actual situation and the prospective development of hardwood supply and demand, illustrates future perspectives, and presents possible adaption strategies for the woodworking industry.

CURRENT MARKET SITUATION

In the beginning of the century (2002 to 2007), domestic supply and demand of roundwood was constantly increasing. A significant drop occurred in 2008, which can be attributed to the effects of the financial and economic crisis (SEINTSCH 2011b). Since then the market is recovering again. However, actual market levels are still below the years 2006 and 2007 (see Fig. 1). Until the beginning of the crisis, numerous investments have been realized in the coniferous sawmilling industry (SÖRGEL ET AL. 2006, OCHS ET AL. 2007a). At that time, the forest based industry as a whole had increased their production and turnover substantially, benefiting from its international competitiveness and from receptive world markets (LÜCKGE ET AL. 2008, DIETER AND ENGLERT 2009).

A more detailed view on supply and demand of hardwood is provided regularly in our Institute. The estimations are using official statistics as well as additional information, especially regarding the demand of roundwood for energy. These calculations show that national fellings increased from 48.5 million m³ in 2002 to 68.4 million m³ in 2011 (Fig. 1).

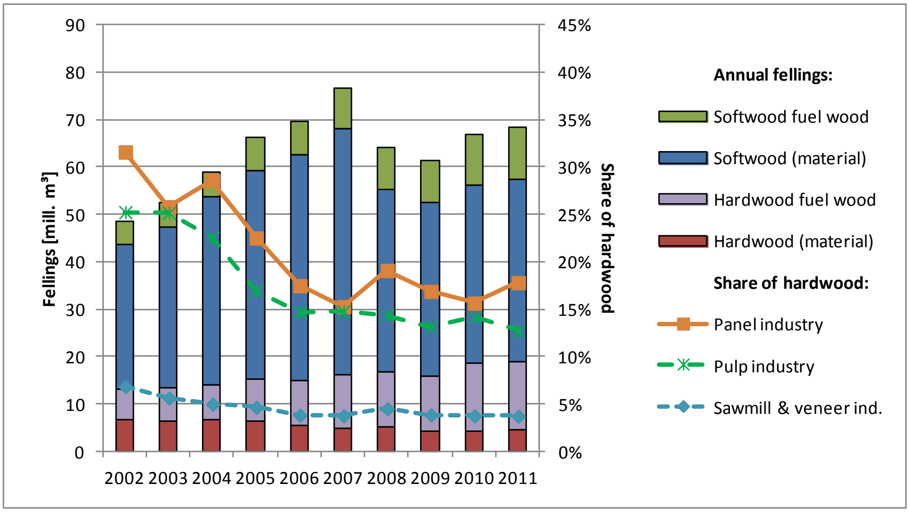

Figure 1: Estimations of annual fellings and shares of non-coniferous roundwood in specific woodworking industries

While the material utilisation of hardwood remained more or less static between 2002 and 2011, the consumption of hardwood for energetic purposes developed dynamically in this period. Especially the use of split logs in private households has doubled to 21.9 million m³, with hardwood sharing 57% of total consumption MANTAU (2012). Accordingly, the share of hardwood used as fuelwood in total fellings has increased. On the other hand, the share of hardwood used in the woodworking industry has decreased. Solely the veneer industry increased its share of hardwood in the last ten years from 72% to 86%.

FUTURE PERSPECTIVES

Various studies have been carried out to estimate the future demand for roundwood, and to compare it to timber harvesting potentials (e. g. MANTAU ET AL. 2007, OCHS ET AL. 2007a, b, c). In most of these studies, harvesting potentials were estimated by using the WEHAM model (i.e. a model of forest development and timber harvesting potential which uses the Federal Forest Inventory as a data base, and assumes that actual concepts of sustainable forest management will continue unchanged, specifically with regard to the maintenance of the current stocking volume). These studies show that a significant gap of coniferous wood supply can be expected, while the hardwood potential remains partially unused at the same time. In the last years, such supply gaps have been closed by increasing fellings of conifers (predominantly spruce), resulting in a decrease of the stocking volume in spruce stands. Between 2002 and 2008, the average annual fellings of spruce exceeded modelled timber harvesting potentials by 31%. It is unlikely that these high felling levels of spruce can be maintained in the upcoming years without severely violating the sustainability principle (OEHMICHEN ET AL. 2011).

In this respect it seems necessary to show future potentials of domestic hardwood supply. OEHMICHEN ET AL. (2011) provide estimates of hardwood supply based on WEHAM. Fig. 2 shows annual fellings for the period 2002 to 2008, and updated forecasts of the hardwood harvesting potentials for the periods 2009 to 2048.

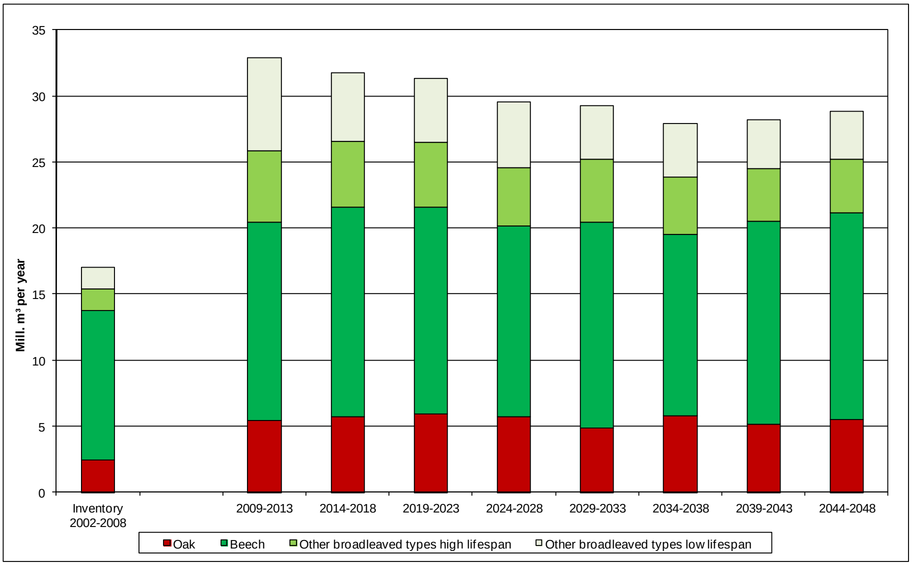

Figure 2: Annual hardwood fellings in the inventory period (2002-2008) and hardwood harvesting potential according to the WEHAM model (base scenario) (OEHMICHEN ET AL. 2011)

Fig.2 shows that assuming current harvest levels (period 2002-2008) will be continued in the future, only 57% of the potential hardwood volume which will be available until 2048 will be harvested. Hardwood is commonly subdivided into two main timber species groups: oak and beech. Beech as a timber species group comprises tree species groups: beech (only common beech), other broadleaved types with high lifespan (mainly ash, hornbeam and maple) and other broadleaved types with low lifespan (mainly alder, birch and poplar). Within these tree species groups beech is being used most intensely. Current fellings of beech amount to 74% of the future potentials. The other hardwood species are used much less intensively. The current harvesting level of oak species is 45% as compared to future potentials. For "other broadleaves with high lifespan" and "other broadleaves with low lifespan", the percentages are 37% and 36%, respectively. The latter two tree species groups cover 7% and 10% of the total forest area in Germany, respectively, which translates to 52% of the forest area covered by beech as a species group (OEHMICHEN ET AL. 2011). However, in this context it must be mentioned that the modeled timber harvesting potential is not a market forecast, since it is only based on standardized assumptions about forest development and management, but does not explicitly account for varying market conditions.

Future developments of the timber market have been analyzed within the second Forest Sector Outlook Study, EFSOS II (UN 2011). In EFSOS II, an econometric analysis provides scenario projections on production and consumption of forest products of the European countries between 2010 and 2030 (JONSSON in press). Tab. 1 shows the consumption of coniferous sawnwood, non-coniferous sawnwood, wood pulp and wood-based panels in Europe and in Germany. These products are subsumed under the term "wood-based products"; they have the main impact on the demand for industrial roundwood.

Table 1: Predicted changes in consumption of wood-based products compared to 2010 based on modelling results in EFSOS II (own calculation, JONSSON in press)

Product	Region	2015	2020	2025	2030
Coniferous Sawnwood	**Total Europe**	2,1%	4,4%	6,4%	9,3%
	Germany	0,5%	1,3%	1,6%	2,5%
Non-Coniferous Sawnwood	**Total Europe**	4,3%	9,0%	14,9%	22,2%
	Germany	-6,6%	-13,3%	-17,0%	-21,2%
Wood-based panels	**Total Europe**	5,6%	11,8%	17,2%	25,3%
	Germany	4,4%	9,1%	11,6%	14,8%
Wood Pulp	**Total Europe**	4,6%	11,1%	15,5%	20,6%
	Germany	0,0%	6,4%	10,3%	14,2%

As Table 1 shows, the demand for wood-based products will rise constantly in Europe as a whole as well as in Germany, except for non-coniferous sawnwood in Germany for which a decline is predicted. In general, the consumption in Europe will develop more dynamically than in Germany. The demand for raw material for the production of wood-based products could also affect the demand for hardwood. If the softwood potentials will be used completely, the industry will either have to increase the imports of softwood or the share of hardwood (however, the latter possibility is restricted by technological capabilities and material properties).

Nature protection regulations are another aspect which has to be taken into account when discussing future perspectives of hardwood utilisation. The National Strategy for Biological Diversity of the German federal government (BMU 2007) demands that 5 % of the forest area develop naturally by the year 2020. An associated implementation concept recommends that old beech forests in state forests be set aside, in order to reach an unused wooded area of about 0.55 million ha (BFN 2008). DIETER ET AL. (2008) estimate the corresponding loss of harvesting potential at 4.4 million m³ per year. According to the mentioned implementation concept, the total additional potential in the tree species group beech would already be assigned to natural protection.

Further possible harvesting restrictions are conceivable due to the implementation of the Habitats Directive (Council Directive 92/43/EEC). In Germany, 1.8 million hectares of wooded area have been allocated as Special Areas of Conservation. Within these areas, further restrictions for timber production will apply. Since the respective management plans are still being drafted, information about these restrictions is however not yet available at national level.

A further important aspect for the future role of wood is the recent promotion of renewable energies. Regulatory measures (e. g., the German RENEWABLE ENERGY SOURCES ACT) as well as rising energy prices affect the use of wood for energy purposes. The increased demand for fuelwood has set a price limit for pulp wood which could also exceed the ability to pay of material users (e. g. SEINTSCH 2011a).

Given the described developments, it seems not unlikely that forest enterprises will place more emphasis on the production of hardwood for energy usage than of industrial roundwood in the future. Actual calculations of the GERMAN TEST ENTERPRISE NETWORK FORESTRY show that the share of roundwood logs in total fellings has significantly decreased between 2002 and 2010, namely from 35% to 20% in the timber species group beech, and from 46% to 37% in the timber species group oak, respectively. At the same time, the corresponding share has remained quite constant with the softwood timber species groups spruce and pine (ca. 74% and ca. 50%, respectively).

As a consequence, it may be asked whether the production of high value hardwood logs in high forest systems can still be justified, given that this sylvicultural system is very costly, and that the demand for fuel wood may become even more eminent in the future (as indicated by the stable development of fuelwood demand in spite of the recent crisis). Due to the high demand for fuelwood, the economic situation of forest enterprises which are dominated by broadleaf forests has markedly improved in recent years. As an additional argument, marketing trends in individual hardwood products need not be taken into account when producing fuelwood, as quality standards for fuelwood are low.

POTENTIAL STRATEGIES

Based on the actual trends and future perspectives described above, we will subsequently illustrate potential adaption strategies for the wood-based industry as a whole, and for the utilization of hardwood as a raw material. Two main issues can be identified which describe the wide range of potential strategies. The first is a high dependence on coniferous industrial roundwood, the second is the development opportunity which is given by the unused potentials of hardwood.

With regard to the first issue, it seems necessary to develop a more efficient use of coniferous roundwood in products and production processes, in order to meet the foreseeable decrease in softwood supply. Another possibility is the acquisition of softwood which has been used for energetic purposes so far. This would however require that the wood industry improve their market position against the fuelwood sector.

A further option is to increase imports of coniferous roundwood. This option has indeed been followed in recent years: While Germany had been a net exporter of coniferous roundwood in the years 2002 to 2008 (with an export surplus of 1.2 to 2.5 million m³); it turned to a net importer position in 2011 (with an import surplus of 4.3 million m³). In contrast, the export surplus of hardwood decreased only slightly in the last decade (i.e. from 1.1 to 0.6 million m³). It remains an open question if these recent changes in German external trade will continue as a long term development. In particular, scenarios on the further development of wood supply and use in Europe (MANTAU ET AL. 2010) show that a demand surplus is probable also in the future, and that a strongly import oriented strategy thus might be risky.

In addition to this, DIETER AND SEINTSCH (2012) show the effects of 50% overseas-imports of coniferous roundwood on the product prices of the main branches of the wood-based industry (Fig. 3) in a scenario analysis

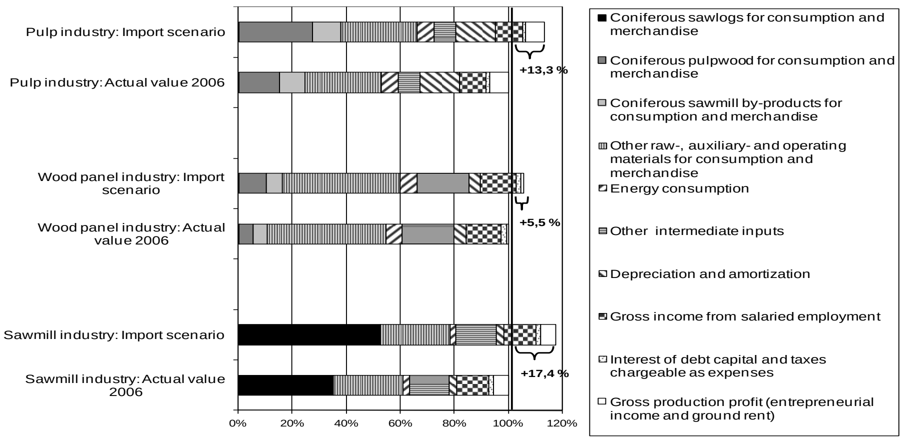

Figure 3: Share of selected cost elements of gross production of the industries in the year 2006 and percentage change in the import scenario (DIETER AND SEINTSCH 2012)

This analysis reveals that increased imports may come along with high additional costs. These would have to be compared with the additional costs induced by substituting coniferous roundwood by domestic hardwood, as well as with the necessary investment costs for product development, technology, and marketing.
The substitution of scarce softwood with domestic hardwood leads to the second main topic of potential strategies, the unused hardwood potentials. According to the product-market matrix proposed by ANSOFF (1957), a process-market matrix for the main growth strategies for hardwood can be defined: market penetration, market development, process development and diversification (Tab. 2).

Table 2: Process-market matrix (according to the product-market matrix by ANSOFF 1957)

	Existing markets	**New markets**
Existing processes	Market penetration	Market development
New processes	Process development	Diversification

The market penetration strategy focuses at products from existing processes in existing markets, hence at increased market shares (notably with new marketing concepts). However, it is not likely that high growth rates can be achieved with this strategy, unless the industry will be enabled to increase their share of hardwood (which could be the case e.g. in the wood-base panel industry, based on developments in technology and adhesives). A market development strategy, i.e. the placement of products from existing processes in new markets, could also lead to higher growth rates. However, it must be

admitted that most markets for traditional hardwood applications are already saturated due to the high linkage of international markets by trade.
For an increase of the hardwood utilisation in the wood-working industry it seems necessary to develop new processes and hence, new products. Especially new hardwood products for the building and construction sector could positively impact future growth. Diversification of the market requires new processes for new markets. Wood polymer composites could be mentioned here as a product group with high growth potentials (NOVA-INSTITUT 2012), as well as biorefinery processes which demand hardwood as a raw material.

CONCLUSIONS

What are the future perspectives for supply and demand of hardwood? The wood-based industry in Germany will have to find sustainable solutions for a decreasing domestic softwood supply. Currently it is not foreseeable whether this will lead to constantly high imports of coniferous roundwood or not. Forest enterprises recently have focused more on the energy market, following an increasing market demand for fuelwood. Under actual circumstances the wood-based industry may want to acquire at least some of these domestic quantities. Additionally, it seems necessary that the industry increase research and development in new and modified processes and products. This necessity arises not only from the competing demand on international markets, but also from domestic wood demand for energy utilisation. In case the industry will not react on this situation accordingly, a substantial decline of German production capacities can be predicted already.

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Research and utilization of domestic hardwood species in Finland

Juha Rikala[1], Marketta Sipi[2]

[1] Dr., University Lecturer, Department of Forest Sciences, P.O.Box 27, Latokartanonkaari 7, FI-00014 University of Helsinki, juha.rikala@helsinki.fi

[2] Dr., Professor, Department of Forest Sciences, P.O.Box 27, Latokartanonkaari 7, FI-00014 University of Helsinki, marketta.sipi@helsinki.fi

Keywords: research, utilization, hardwood, Finland

ABSTRACT

In Finland, the most important industrial hardwood species are silver birch (*Betula pendula*), downy birch (*B. pubescens*), aspen (*Populus tremula*), common alder (*Alnus glutinosa*), and grey alder (*A. incana*). In 2010, the Finnish forest industries used domestic hardwood logs and pulpwood about 7.7 million m^3. In addition, about 7 million m^3 of hardwood was imported, mainly from Russia.

In 2010, major part of hardwood (10.7 million m^3, including domestic and imported roundwood) was used in pulp and paper industries, mostly in chemical pulping (birch). Wood product industries, i.e., sawmilling and plywood industries used 0.16 and 0.78 million m^3 of domestic hardwood, respectively. Consumption of hardwood logs has been quite steady during the last decades, whereas consumption of pulpwood has varied more according to the markets of pulp and paper products.

The quality requirements set for hardwood logs are much stricter than those of pulpwood. In consequence, it has been problematic to find high quality hardwood for certain processes in wood product industry. This concerns all hardwood species. However, there are lots of challenges in sorting of hardwood logs as well as in the processing itself. According to studies carried out in the joinery industry, the most severe problems in the production are deformations (all species) and changes in colour in drying (birch), and variations in moisture content after drying (aspen). This stresses the importance of controlling the drying processes. It has been shown that some problems can be diminished or even avoided by using novel drying methods.

It has been estimated that hardwood species will benefit from the climate warming in Finland, which, in the long run, will probably also increase the use of hardwoods in forest industries. On the other hand, changing growing conditions may affect wood properties, and by that way, use of hardwoods. The above-mentioned issues emphasize the importance of versatile hardwood research in the future.

INTRODUCTION

Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) account for about 80% of the growing stock volume of 2284 million m^3 in Finland (FINNISH STATISTICAL YEARBOOK OF FORESTRY 2011). It is natural that the Finnish forest industry is very dependent on these two coniferous tree species, whose properties – straight stem, relatively slow growth, thin branches, and long fibres – make them suitable raw material for sawn timber products, as well for many paper products.

For a long time, hardwoods were considered as devalued tree species. For example, in the 1950s and 1960s, silver birch (*Betula pendula*) and downy birch (*B. pubescens*) were systematically cleared off to promote the growth of highly valued conifers. Some consequences of this regime still exist (e.g., lack of high quality birch logs). Birch, aspen (*Populus tremula*), black alder (*Alnus glutinosa*), and grey alder (*A. incana*) are also called as minority tree species.

High quality Finnish plywood has traditionally been made of (silver) birch. During the last decades, there has been increasing interest towards the industrial utilization of other domestic hardwoods, as well.

In this paper, we focus on use and challenges of domestic hardwoods in wood procurement and wood product industry, and refer to some research topics in this field. Nowadays, hardwoods are increasingly utilized in energy production, but it is not considered here.

HARDWOOD RESOURCES IN FINLAND

According to the latest National Forest Inventory (NFI11, FINNISH STATISTICAL YEARBOOK OF FORESTRY 2011), the growing stock volume of birch (*Betula sp.*) and other hardwood species is 385 million m^3 and 78 million m^3, respectively (table 1). Altogether, hardwood species account for about 20% of the total growing stock volume as follows: downy birch 12%, silver birch 4%, and other broadleaved 3%.

Table 1: Forest resources in Finland according to NFI11 (2009–2010)

Forest and scrub land [mill. ha]	Growing stock volume [mill. m^3]	Tree species	Growing stock volume [mill. m^3]	Annual growth [mill. m^3]
22.79	2284	Scots pine	1129	47.6
		Norway spruce	693	32.2
		Birch	385	19.5
		Other broadleaved	78	4.4

When considering the development of hardwood proportion of the growing stock, it seems evident that it is increasing. Especially downy birch has benefited from forest drainage (common in the 1950s and 1960s in Finland) and the change of silvicultural practices: nowadays birch is favoured in mixed stands. Furthermore, volume of birch is centred on young age classes.

Unfortunately, there are no detailed data available on resources of aspen or alder but they are classified as a group of “other broadleaved”.

USE OF HARDWOOD IN FOREST INDUSTRIES

Hardwood in pulp and paper industries

In 2010, Finnish forest industries used 10.7 million m^3 of domestic and imported hardwood for pulp and paper production (FINNISH STATISTICAL YEARBOOK OF FORESTRY 2011). Birch is the most important hardwood species for chemical pulping and paper products. The volume of imported birch roundwood has varied a lot during the last years. In 2011, about 3.3 million m^3 of birch pulpwood was imported from Russia, Latvia, and Estonia (Peltola 2012).

Some mills started to use aspen in mechanical pulping during the late 1990s in Finland. It has not, however, managed to maintain its role in pulp and paper making. Considering globally, fast growing hardwood species like eucalyptus and acacia are highly competing with birch and aspen in some paper grades.

Hardwood in wood products industry

In 2010, the main users for domestic hardwood were plywood and sawmilling industries where the roundwood volumes used were 0.78 and

0.16 million m^3, respectively (FINNISH STATISTICAL YEARBOOK OF FORESTRY 2011).

The Finnish plywood production was started about 100 years ago using birch as raw material. Since then birch has preserved its position in high quality plywood products, even though softwood (spruce) plywood is produced much more nowadays. In 2010, the production figures were 0.28 million m^3 for birch plywood and 0.7 million m^3 for spruce plywood (FINNISH STATISTICAL YEARBOOK OF FORESTRY 2011). A small volume of the best quality birch is used for veneers for special purposes such as furniture. About 90% of birch logs utilized in forest industries are used for plywood production. Small amounts of birch are also used in chipboard and fibreboard industries.

Figure 1: High quality plywood made of birch with different surface patterns for flooring

The annual production of birch sawn timber has varied from 50 000 to 70 000 m^3 during the last years. The production is quite small compared to that of coniferous sawn timber (about 10 million m^3 in 2010). Birch sawn timber is usually used for high quality products in joinery and furniture industry.
Aspen and alder sawn timber is produced in small-sized sawmills. According to a study carried out in 2010, aspen and alder roundwood was used 15 000 m^3 and 4000 m^3, respectively (Torvelainen 2011).

Further processing – planing and moulding – of hardwoods is obvious, but they have had a significant role also in heat treatment. Still 10 years ago, birch, aspen and alder accounted for almost 25% of the production of heat treated wood (ThermoWood®). Nowadays, their proportion is only some percents of the total volume. One has to bear in mind, however, that within this period of time the total production of heat treated wood has increased fifth-fold.

CHALLENGES IN USING DOMESTIC HARDWOODS IN WOOD PRODUCTS INDUSTRY – EXAMPLES OF FINNISH HARDWOOD RESEARCH

One of the main problems in utilizing domestic hardwood species is the lack of high quality raw material. This mainly comes from the earlier silvicultural regimes in which pine and spruce were strongly prioritized over hardwood species (e.g., birch). In all, hardwood resources are quite limited in Finland compared to many other European countries. The lack of timber-sized birch has partly been compensated by importing roundwood from Russia and the Baltic countries. The possibility of using smaller-sized roundwood from thinnings has also been studied. According to Kilpeläinen et al. (2011), silver birch from thinnings showed a high potential for sawmilling when suitable stands were selected carefully. One has to accept, however, that the saw log recovery is lower in thinnings than final fellings, and it can not be increased at the expense of silviculture.

A comprehensive study regarding downy birch in plywood production was carried out by Verkasalo (1997). The study showed that downy birch can be used as a raw material for plywood production, even though its quality properties are worse than those of silver birch. The disadvantages of downy birch are smaller dimensions of plywood logs and lower log recovery. Downy birch usually has some irregularities at the stem base, as well. The most important defects that lower the quality of birch in plywood production are knottiness, sweep, disturbance of grain, and decay.

Predicting the value of sawn timber according to external properties of stems or logs has been of high interest. Kärki (1999) studied the internal knottiness of grey alder. According to the results, the knot free section at the base of grey alder is short, and there is not a clear difference between a dry-knot section and fresh-knot section. This causes some problems in the classifying of saw logs. Improved grading rules are needed for better utilization of alder in Finland.

There are some problems in sawing certain hardwood species, e.g., aspen which contains silica sand in wood. However, the most challenging part of processing hardwoods is usually drying of sawn timber. According to

Kivistö et al. (1999), the most severe problems in conventional warm air drying are deformations (birch, aspen, alder) and changes in colour in drying (birch), and variations in moisture content after drying (aspen). Some promising drying technologies have been introduced to diminish the drying defects or even avoid them totally. High frequency vacuum (HFV) drying has turned out to be a very promising drying method. According to Sipi and Kivistö (2007), the advantages using HFV in drying of birch sawn timber are short drying time and minor end checking and colour changes. The increase of twist and variation in moisture content are the disadvantages. Aspen and alder are mainly used in decorative end uses such as paneling which means that high mechanical performance is of minor importance. However, Heräjärvi (2009) showed that some strength properties of aspen may be increased by press drying.

DISCUSSION AND CONCLUSIONS

Finnish hardwood research has focused especially on the following issues: availability of raw material, log (wood) properties, sorting and grading of raw material, and drying of sawn timber. Birch, aspen, and alder are utilized in many end uses in wood product industry. One of the main obstacles for their increasing utilization is the lack of high quality raw material. For example, fast-growing hybrid aspen (*Populus tremula* × *tremuloides*) should increase the availability of raw material in the coming decades, but the quality issues still need lots of research work.

It has been estimated that hardwood species will benefit from the climate warming in Finland, which, in the long run, will probably also increase the use of hardwoods in forest industries. On the other hand, changing growing conditions may affect wood properties, and by that way, use of hardwoods. One of the aims of current silvicultural regimes is to increase biodiversity in our forests. In all, ordinary consumers have a very positive attitude towards the use of domestic hardwoods. The above-mentioned issues emphasize the importance of versatile hardwood research also in the future.

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Production, Marketing and Utilization of Sweet chestnut (*Castanea sativa* Mill.) Wood in the Haardt region

Peter Rademacher[1], Simon Eichhorn[2] and František Hapla[2]

[1] Dr. Peter Rademacher, University of Applied Sciences for Sustainable Development Eberswalde, Faculty of Forest and Environment, peter.rademacher@hnee.de

[2] Prof. Dr. František Hapla and Simon Eichhorn, Burckhardt-Institute, Department of Wood Biology and Wood Products, University of Göttingen, Germany, fhapla@gwdg.de

Keywords: *Castanea sativa* Mill., forest management, round wood assortments, sawn-timber, uses

ABSTRACT

The European chestnut forests in the Haardt forest district comprise an area of about 1000 ha and are hence the largest European chestnut forests in the federal state of Rhineland Palatine. European chestnut is rejuvenated through coppice in this region. The silvicultural target is characterised by promotion of selected future trees as well as a target diameter of 50 to 60 cm at 1.3 m height. However, also smaller dimensions from thinnings can be marketed successfully. The wood is valued for its naturally high durability and is used as e.g. timbering for avalanche protection. Thus far, marketing strategy of grading the wood derived from thinnings into round wood for avalanche protection, wood for wood-based-panels and fuel wood has proven itself economically. Since 2010, however, fuel wood yielded higher prices in comparison than derived round wood assortments for wood-based-panels industry. Nevertheless, highest prices were paid for high-quality sawmill round wood.

Surveys in local carpentries showed that the wood of European chestnut and its properties are largely unknown. Obviously, the European chestnut is better known regionally as an orchard tree for edible chestnut and honey production than for its wood. An awareness that identifies the wood of the European chestnut with the region and the linked culture should be created to strengthen this future market. Moreover, the status of the European Sweet

chestnut, due to its special wood properties (e.g. naturally high durability of the heartwood), but also in regard to climate change, is going to gain significance.

Through well-directed grading of round wood the share of sawmill able assortments in the total cut can be increased and significant value can be added for the forest enterprise. In further examinations the influence of ring shakes on the yield of quality, defect-free sawn timber was calculated. The results showed that consistent grading of sawn timber can clearly increase the economic success of sawmills.

INTRODUCTION

The uses of Sweet Chestnut and its wood become more important in the future against the background of climate change. In this study, figures from 2004 to 2011 for European Sweet chestnut from the forest district Haardt were compiled and evaluated with regard to round wood yield, assortments and revenue. Furthermore, the use of Sweet chestnut wood in local carpentries were surveyed and documented. Finally, an evaluation of sawn timber quality on Sweet chestnut with ring shake could ensue. Therefore, a calculation of sawn timber yield after log cutting (ten selected sample trees from the forest district Haardt, age approx. 120 years) was performed.

MATERIAL AND METHODS

For this study, various data and information about European Sweet chestnut in the Haardt region were collected, measured and evaluated.

Economic Figures

The forest district Haardt (ANONYMUS 2009) provided the economic figures for Sweet chestnut of the years 2004 to 2011. They became available as Pivot-Tables in Microsoft Excel. The numbers relevant to the study were summed up, subdivided into single financial years and comprised: Total amount of logging (in m^3 of solid volume), achieved revenues (in €) and average prices of round wood assortments per solid m^3 (€/$m^3$of solid volume).

Written survey of carpentries

A study confirmed 144 small and medium enterprises in total for the region. Out of these, 30 enterprises were randomly selected. To obtain information on current regional use of Sweet chestnut, a written survey, combined with an accompanying interview, was carried out at established carpentries within the region. For this, a questionnaire, directly tailored to suit the questioned target group was created. It featured a structured survey used a fixed strategy in written form. The questioned person was to answer the questionnaire without help and additional explanation. Through the accompanying interview, occasional consultation ensued (ATTESLANDER, 1995). The questions were structured in the following topics: General, enterprise-specific information, processing of Sweet chestnut, sustainability of Sweet chestnut and acquisition of the wood used in the respective enterprise.

Sawn timber yield calculation

Furthermore, it was necessary to quantify the yield of high quality sawn timber when ring shake and/or other cracks in the wood are taken into account (FONTI ET AL., 2002 a; FONTI ET AL., 2002 b; FONTI AND SELL, 2002). In this case, 10 selected sample trees (no. 51-60) from a stand aged approximately 120 years were used for this investigation. The sample trees were felled and cut at DBH (1.3m height) and at 10m height. Thereafter, each sample tree log (of 8.7 m length) was halved into a tail log section and an upper log section in order to extract a 15 cm disc from the middle of the whole log. Then, as far as possible, the tail and the upper log sections of each sample tree were marked for bucking for sale purposes (Fig1.).

For the calculation of sawn timber yield, three parameters were required:
Round wood volume of the log sections bellow bark, volume losses due to sawing (V1) and volume losses due to ring-shake and/or other cracks in the wood of the log sections. In sawmill, all 20 log sections were cut into boards with a horizontal band-saw. For this, 20 % loss of volume (V1) due to saw kerfs (2,6 mm) and removing of the upper and lower slabs was subtracted. This empirical figure from sawmill applies to non-squared logs. Following this, the volume losses due to ring shake and/or other cracks in the sawn timber (V2) per log section were determined. For this, every single board was measured and the defect-free volume of sawn timber was calculated.

Figure 1: Tail and upper log of sample tree no. 52

RESULTS

Economic figures

The forest district Haardt’s Sweet chestnut areas, mainly located on private and community forest land, comprise an area of approximately 1000 ha. As Sweet chestnut, among others, only features as admixed species of the under- or medium storey, the following figures only apply to approximately 500 ha of managed Sweet chestnut stands in community forest. In the years 2004 to 2011, approximately 15000 m³ of solid round wood of various grades were distinguished. The distribution of round wood assortments is shown in Fig. 2.

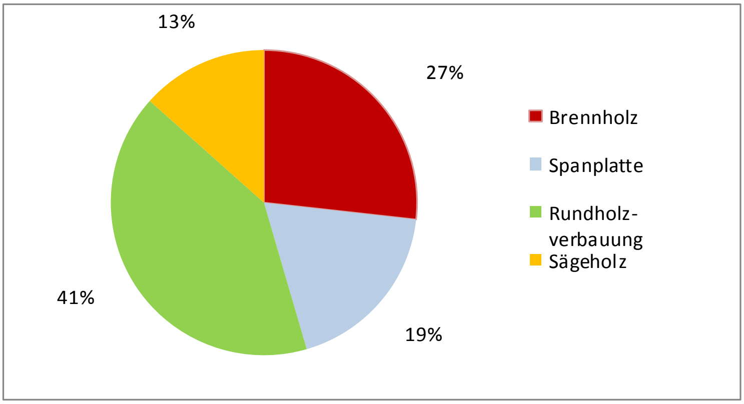

Figure 2: Total logging amount (%) of round wood assortments from 2004 till 2011 in the forest district Haardt (sawmill round wood – yellow; timber for avalanche protection – green; particle board industry wood-assortment – blue and fuel wood-assortment – red)

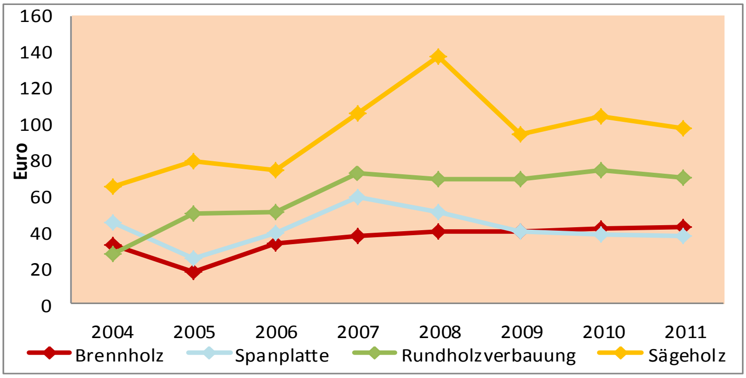

Figure 3: Obtained average prices (Euro/m³) for different round wood assortments from 2004 till 2011 in the forest district Haardt (sawmill round wood – yellow; timber for avalanche protection – green; particle board industry wood-assortment – blue and fuel wood-assortment – red)

In the analysed period of 2004 to 2011, the forest district of Haardt earned an average price for a solid m³ of Sweet chestnut sawmill round wood of approximately 99 €. The price per solid m³ for Sweet chestnut for timbering (avalanche protection) was on average 59 €/solid m³. The round wood of Sweet chestnut destined for wood based panel industry gained an average price of 43 €/solid m³. For the fuel wood-grade, 38 €/solid m³ could be earned (Fig.3). During the course of the analysed time period, the price of

Sweet chestnut increased steadily. Prices for sawmill round wood of Sweet Chestnut experienced the most definite increase (METTENDORF 2007).

Survey of the carpentries

Regarding the processing of Sweet chestnut, round about 75% of questioned enterprises stated the wood’s suitability for furniture making. Garden furniture, kitchen goods, window shutters and flooring were each named by less than 10% of the carpenters. Areas of use beyond carpentry were mentioned by only 7 of the participants. Barrel-making was named 5 times only. When asking for estimable attributes of Sweet chestnut wood, the easy and good processing attributes were most commonly praised. Further, the similarity in appearance to oak (Qercus spp.) and the special aesthetics of the wood were pointed out. Durability and good finishing properties were mentioned too.

As statements about negative attributes of Sweet chestnut wood, ring shake and wide cracks were mostly named, whereas the issue of ring shake in Sweet chestnut is not known to all questioned regional carpenters. Further, the high tannin content, an intensive chemical reaction to metal and high amount of off-cuts were criticized. In relation to the sustainability of Sweet chestnut, most enterprises judge the demand for its wood during the last ten years as consistently low. However, the Sweet chestnut is an important tree for tourism and culture due to its flower and edible chestnuts. Various reasons for low use of Sweet chestnut wood in spite of a region-wide distribution along the edge of the Haardt-Mountains were mentioned: High wood prices, lack of a trend and low sawn timber quality as well as lacking customer interest in this type of wood. If the wood products are, however, presented to the customers, they are largely enthusiastic about it.

Sawn timber yield calculation

Considering the sum of volumes of all log sections (100 %), the calculated percentage of volume loss due to ring shake and/or other cracks in the wood (19,5 %) and the volume loss through sawing (20 %) the yield calculation showed the following result, presented in Fig. 4. The average calculated yield of 60,5 % for high quality sawn timber refers to a total of 7,7 m^3 bellow bark of the 20 log sections.

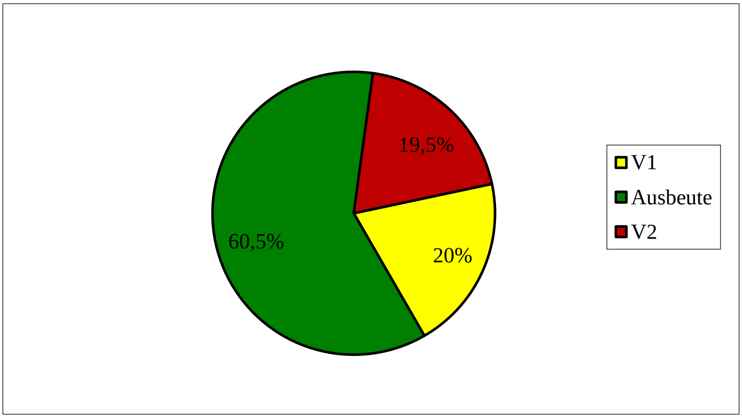

Figure 4: Relative distribution of sawn-timber yield (green) and losses due to cutting process (V1- yellow) and due to defects (ring shake and other cracks, V2-red).

Fig. 5 shows the calculated amounts in (m³) of wood losses V1 and V2 as well as the amounts of high quality sawn-timber yield in relation to total volumes of the 20 log sections. Sample tree no. 58, with the lowest log section volumes in comparison to other sample trees showed the highest V2-wood losses at 0,25 m³. The more strongly-dimensioned sample trees no. 53, 57 and 59 however showed relatively low V2-wood losses through ring shake and/or other cracks in the wood (Fig. 6).

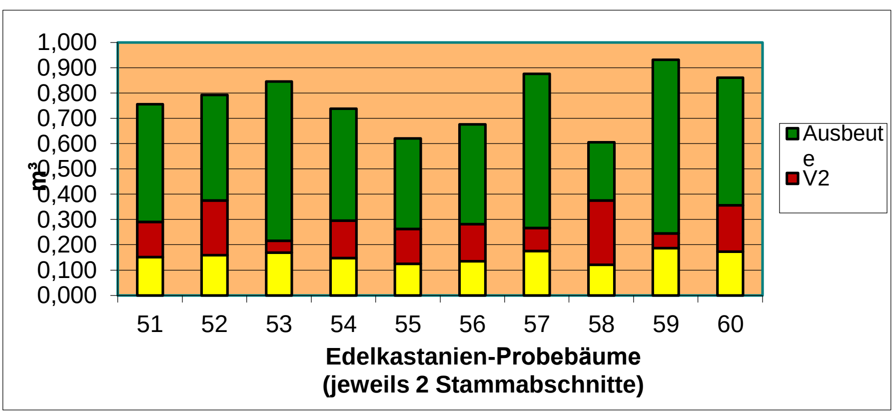

Figure 5: Sawn-timber yield calculation (m³) after cutting 20 Sweet chestnut logs (tree age ca. 120 years; forest district Haardt). Calculated wood losses (V1 and V2).

Figure 6: High quality sawn-timber: log no. 59u (left) and log no. 53u (right)

CONCLUSIONS

During an examination of the log cross sections before cutting and the board surfaces after cutting it was found that the occurrence of ring shake increased with increased height of the log in three of the ten sample trees. Through cutting of the log sections, a total of 139 boards with a thickness of 40 mm were produced. Of those, 39 boards did not show any ring shake and/or other cracks in the wood. Furthermore, 89 boards showed only cracks at the board end. Merely 11 boards were graded as off-cuts after sawing. They were almost exclusively “heart-boards” with pith. In total, more than 60 % of the produced sawn timber was of very good quality.

The good price development for sawmill round wood in the forest district of Haardt in the years 2007 to 2011 with an average revenue of 105 €/solid m³ shows clearly, that well-directed grading positively influences the operating profit. Through directed grading of the logs as well as of the sawn timber during processing, the share of high quality wood products can be clearly increased. Moreover, the significance of Sweet chestnut, due to its special wood properties, but also in the context of climate change, will increase in the future.

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Utilization of poplar instead of coniferous in light frame wall constructions*

Gábor Benke[1], Zoltán Pásztory[2]

[1] 4. Bajcsy Zs. Sopron, Hungary, University of West Hungary, e-mail benke.gabor@fmk.nyme.hu

[2] 4. Bajcsy Zs. Sopron, Hungary, University of West Hungary, e-mail pasztory@fmk.nyme.hu

Keywords: Light frame wood construction, spruce, poplar Populus Euramericana, thermal conductivity

ABSTRACT

The overall objective of the running project is to change coniferous wood element to poplar in the wall construction of light frame wood residential buildings.

Although not all coniferous element of wood wall is worth to be changed, but there are elements such as studs what are not bearing big forces and have lower exposure.

It was investigated some of the most important influencing factors determining the utilization of poplar elements in light frame wall constructions. The element chosen to be changed in the wall construction was examined in the following aspects: Durability; Mechanical properties; Thermo dynamical properties; Screw holding strength.

Nowadays one of the most important questions is the thermal resistance of the structure. The poplar studs have a lower thermal conductivity than that of the coniferous consequently the thermal resistance of complete wall is higher. The other main part of the project is to investigate the properties of the whole construction. According to our investigations the poplar seems to be an appropriate row material of light frame constructions.

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INTRODUCTION

In the northern hemisphere the most widespread raw material used in light frame wood construction is coniferous. There have already been numerous experiments to use Hungarian broad leaved wood species raw materials but these attempts have been suppressed by the existing coniferous-based construction techniques.

In the 1970's the Forestry Research Institute (FPI) already looked into the possible applications of broad leaved wood materials in glue laminated frame structures (Wittmann and Pluzsik, 1975). The two applicable species mentioned in their work are poplar and acacia. From a strength point of view, acacia is the most desirable; however poplars are more favorable in terms of figure and size properties. The raw material of the first building of this sort, using layered-cemented three-point arc framed was hybrid poplar. In addition, even presently, there are family houses at the Hungarian Great Plane with poplar-based roof structure.

Apart from these, numerous European and North American examples exist. There have been a number of experimental attempts on using broad leaved wooden materials for structural purposes. Hernandez et al. (1996) reported the construction of a vehicular bridge with a glue laminated structure of tulip tree. Another example is presented by the collaboration of the Swiss architecture company, Bernath and Widmer with other experts (Hermann Blumer, Michael Koller, Bergauer Holzbau GmbH, Heiri Bührer), who constructed a three-story youth hostel of oak logs in Schaffhausen province near Büttenhardt.

In summation, experts are constantly examining the possible usage of stratum raw materials, which could open new horizons in wood construction, beyond the conventional coniferous-based methods.

To create safe poplar structures, thorough examination of basic stress factors, like tensile compressive and bending strength followed by the different analysis of the full-sized specimen including the thermo-technical attributes. In the case of full structures where the overall performance depends on the interaction of the adjacent materials and their features, these thermo-technical and strength tests and durability comprise the basis of the examination.

This article focuses on introducing only on some of the important examined attributes, such as strength and thermodynamic differences between poplar and spruce. The authors are aware that deeper analysis of more features is necessary for the applicability but the article does not touch upon these due to space limitations.

MATERIAL AND METHODS

In Hungary, poplar cover 1.5 million ha, accounting for the 9.6%-a of the full forest area. Every year 1.3-1.5 million m^3 poplar raw materials is processed which comprises 23-25% of all wood cutting. To ensure good quality, poplar plantations have to be branch cut to 6 meter (Molnár and Bariska 2006).

The coniferous wood species ratio is very low in Hungarian forest contrast to the west- and north European situation. Because of this fact high amount of the construction wood is imported in building market. However Hungary has valuable broadleaved wood species such as poplar (*Populus Euramericana cv Pannonia*).

From the 1980's more and more hybrid poplar species have been genetically improved, cutting back the share of then-popular I 214 Italian poplar. Examining the plantation data of the poplar species in the 90's, the *Populus Euramericana* proves to have had the biggest market share (almost 50%) in the market (Tóth, 2006).

Fundamental differences can be observed among certain poplar clones in density, strength, and figure and also in durability. In the table 1 below the attributes of the most common poplar clones and the control variables are highlighted.

Table 1. – Mechanical properties of polar species (Tóth, 2006; Molnár, 1999)

Name	Density [kg/m³]	Mechanical properties [MPa]				Elastic modulus [MPa]	Hardness [MPa, Brinell]	
		shear	compressive	bending	tensile		butt	side
I-214	330	6,4	22,5	52	44,3	5330	21,9	8,3
Villafranca	350	6,9	32	64	46,2	5600	19,3	9,9
Triplo	360	-	26,6	57	64,1	-	22,8	7,7
BL-Costanzo	375	7,5	36,9	75,1	59,6	6160	25,4	11,3
Koltay	390	-	-	56	-	-	-	-
Kopecky	390	7,4	33	70,7	56,1	5620	20,6	12,5
Parvifol	400	-	32,9	66,3	75	7830	24,8	9,8
Agathe-F	405	6,9	29,6	58	44,5	5200	20,7	11,7
I-273	410	8,1	32,8	72,2	-	5690	28	13,9
Pannónia	410	8,3	32,6	67,4	56,2	6510	20,6	10,8
Robusta	419	8,1	30,2	66,9	74,4	7500	22,8	7,7
Unal	420	-	-	-	-	-	-	-
White poplar	450	7,8	38,3	67,5	82,3	8250	27	-
Black poplar	450	6	35	65	77	8800	30,5	-
Trembling poplar	450	6,8	32,5	56	75	7800	23	-
Spruce	470	6,7	50	78	90	11000	32	-
Scotch pine	520	10	56	80	104	12000	40	19

Among the mechanical properties density and strength have crucial importance. Bending strength plays a crucial role among strength features. *Populus Euramericana* was selected due to its excellence in these two defining parameters along with its figural properties, durability and quantity. Its Hungarian ratio is remarkably high; it is the most important poplar species of the plantation-type poplar growing (Tóth, 2006).

Due to the lower mechanical properties of poplar the dimensions of the cross section should expectedly be changed as the distance of studs from each other.

Mechanically the wall should not be significantly weaker than the original construction build with coniferous studs and top and bottom elements.

Mechanical properties

The utilization of the different wood species depends on their physical and mechanical properties. In general, the strength of poplar wood falls below that of coniferous, but for certain species the differences is not substantial. Examinations by The FKI show strong correlation between the mechanical properties of poplar and their volume mass. According to their findings, the poplar species whose absolute dry volume mass reaches (Wittmann és Pluzsik, 1975) or exceeds 400 kg/m^3 can effectively replace coniferous in strength-stressed structures and in structural units. Taking into account the literature and our test results, these apply to the *Populus Euramericana.* The FKI results also reveal that the density of wood highly depends on the soil of planting location and the volume of precipitation.

We conducted our tests on 50 *Populus Euramericana* specimens prepared in accordance with the standards based on the following strength groups:

- tensile strength (MSZ ISO 3345:1991)
- compressive strength (MSZ 6786-8:1977)
- shear strength (MSZ ISO 8905:1991)
- bending strength (MSZ 12865:1980)
- impact strength (MSZ 6786-7:1977)

Screw holding strength

There is no literature with exact information about the nail and screw holding strength of the Populus Euramericana but there is indication that their nail holding strength is 5-10% lower than that of pines (Csizmadia, 1969). Due to the number of species, the screw holding strength of the hybrid poplar should be measured experimentally, in parallel with pine test units. The last valid standard (MSZ EN 1382) gives an exact description of the examination that can be conducted with arbitrary nail and screw properties so that specific values can be assigned to the joints the most likely to be used.

Thermal conductivity

Our research also examined the conventional thermal conductivity of the Populus Euramericana compared that of the spruce, the most widely used wood species in light frame wood construction. Minimizing the thermal bridges is essential when designing the wall structure. There is a huge difference between the thermal conductivity of the wall frame and the insulation materials.

The frame in the wall structure are located every 62.5 cm. This wall structure relates back to the 125 cm table division. The usual 40-50 (45) mm thick studs create a substantial thermal bridge in the wall.

16.5% of the full wall surface comprises wood compared to insulation material (Pásztory et al.). The bigger the difference in thermal conductivity the bigger the thermal bridge effect in the structure. The thermal conductivity of the insulation material is 0,04 W/mK compared to 0,15 W/mK of the spruce studs.

In accordance, on one sixth of the surface the coniferous material determines the thermal conductivity while the rest of the surface is dominated by the properties of the insulation material in terms of thermal behavior.

If the spruce material is replaced by poplar, the thermal bridge effect changes by the difference between the spruce and poplar thermal conductivity.

Within the project scope, we also aim for constructing a test building that makes identifying every step of the necessary technological processes possible. Manufacturing the building blocks requires industrial usage of the new material, and assembling and joining the structures also differs from the spruce technology. Testing and measuring the real stress results become possible on the full-size structure, especially regarding the thermal behavior of the building. Determining the value of low energy need is also possible.

RESULTS

Mechanical properties

The test results have a strong correlation with density. In numerous cases, the density of Populus Euramericana reaches or even exceeds 400 kg/m^3. Using this material for studs in structural applications is also possible, thus it can replace spruce in certain structural units. Our test results are summarized in Table 2.

In structural materials bending strength is the most important property. According to our tests, the Populus Euramericana should be further examined as raw material for light frame wall construction as its key strength properties approach those of the spruce. It is important to examine which spruce parts can be replaced in the wall structure system, as well as how the dimension of these parts would change.

The strength test results of the Populus Euramericana show favorable values, in addition it is available in high quantities. It is reasonably priced and it is a raw material relatively easy to work with. Due to its low natural resistance, the Populus Euramericana needs proper protection as well.

Table 2. – Mechanical properties of Populus Euramericana

	Populus Euramericana $\sigma_h - u_{12\%}$ [N/mm^2]	Spruce $\sigma_h - u_{12\%}$ [N/mm^2]
Tensile strength	52,49	90
Compressive strength	38,51	50
Shear strength	5,24	6,7
Bending strength	57,04	78
Impact strength	3,65	4,6

Screw holding strength

Our screw holding strength analysis was conducted in accordance with the latest corresponding standards. Table 3 shows the test results of the Populus Euramericana test pieces – measurements included 1 from butt direction, 2-2 screw tests from radial and tangential direction.

Table 3. Result of screw holding strength tests of Populus Euramericana

Table 3. – Screw holding strength of Populus Euramericana

	Butt [N/mm]	Serial 1 [N/mm]	Serial 2 [N/mm]	Serial 3 [N/mm]	Serial 4 [N/mm]
Minimum	20,00	47,50	47,50	40,00	50,00
Maximum	62,50	92,50	90,00	95,00	102,50
Average	**45,70**	**63,80**	**63,60**	**65,40**	**66,26**
Scatter	8,84	12,31	11,92	11,52	9,86
Variance	78,07	151,59	142,13	132,74	97,25

Thermal conductivity

During the tests we prepared 15 test specimens per wood species whose corresponding thermal conductivity are shown in Table 4. The specimens had been air conditioned in a climate chamber on normal climate

(20°C and 65% relative humidity). To be able to compare them, the specimens were stored and measured the same way with the same methods.

Table 4. – Thermal conductivity of Populus Euramericana and spruce specimens

Specimen id.	Thermal conductivity [W/mK]	Density [g/cm^3]	Specimen id.	Thermal conductivity [W/mK]	Density [g/cm^3]
Poplar 1	0,099	0,319	Spruce 1	0,087	0,397
Poplar 2	0,105	0,335	Spruce 2	0,091	0,409
Poplar 3	0,106	0,343	Spruce 3	0,090	0,417
Poplar 4	0,105	0,357	Spruce 4	0,092	0,401
Poplar 5	0,101	0,346	Spruce 5	0,095	0,428
Poplar 6	0,100	0,340	Spruce 6	0,092	0,405
Poplar 7	0,112	0,414	Spruce 7	0,091	0,406
Poplar 8	0,098	0,410	Spruce 8	0,110	0,491
Poplar 9	0,117	0,406	Spruce 9	0,128	0,515
Poplar 10	0,113	0,420	Spruce 10	0,126	0,516
Poplar 11	0,099	0,405	Spruce 11	n.a.	0,517
Poplar 12	0,108	0,406	Spruce 12	0,124	0,503
Poplar 13	0,106	0,407	Spruce 13	0,124	0,519
Poplar 14	0,105	0,409	Spruce 14	0,128	0,529
Poplar 15	n.a.	0,410	Spruce 15	0,125	0,532
Poplar 16	0,096	0,421	Spruce 16	0,122	0,519
Poplar 17	0,099	0,422	Spruce 17	0,117	0,514
Poplar 18	0,098	0,412	Spruce 18	0,119	0,511
Poplar 19	0,097	0,419	Spruce 19	0,117	0,505
Poplar 20	0,103	0,416	Spruce 20	0,114	0,497
Average	**0,104**	**0,391**	**Average**	**0,110**	**0,477**

The data clearly indicates that the thermal conductivity values of the poplar are more favorable. Comparing our test results with the literature we arrive to an even more desirable conclusion: according to our measurements the difference between the two wood species in terms of thermal coefficient is nearly 6%. During the design process when using spruce the usual values vary between 0,13-0,15 W/mK, in contrast our measurement showed only 0,110 W/mK. The moisture percentage could also have contributed to this difference.
The need for technological change compared to spruce techniques is going to be an important topic to examine during the research, as well as finding out whether the extra technology input is proportional to the benefits derived from using poplar instead of spruce.

CONCLUSION

Mechanical properties

All of the mechanical properties of poplar showing weaker results than coniferous can be compensate with higher dimension or higher processing technologies, however the thermal conductivity is better in case of poplar.

Screw holding strength

According to the preliminary test results, the screw holding strength of the poplar raw material approximates that of the spruce. Special attention should be taken to the number, size and location of the joints in the important corner units. The point of view this aspect the Populus Euramericana could be substitute the spruce.

Thermal conductivity

Examination of the thermal coefficients revealed that the Populus Euramericana shows better properties leading to decreased thermal bridge effect in wall structures constructed of poplar rib frame. In the wall construction the poplar causes lower heat bridge effect thus the heat loss of the whole structure is lower. In case of a successful project the poplar could be the rival of the widely used coniferous row material of wood residential buildings

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THE TRENDS IN FOREST STANDS SPECIES COMPOSITION IN THE REPUBLIC OF POLAND, AND THE VOLUME OF HARDWOOD TIMBER HARVEST

Dr inż. Grzegorz Jednoralski, Dr inż. Hubert Lachowicz

Poland, Department of Forest Utilization, Forestry Faculty of the Warsaw University of Life Sciences-SGGW in Warsaw

jednoralski@wp.pl , hubert.lachowicz@wl.sggw.p

Key words: stand species composition, wood harvest, hardwoods

ABSTRACT

This paper presents the dynamic trends in the forest stands species composition in Poland. It is outlined that the continuous increase in the share of hardwood species has been result, among others, of the forest policy of the state. This trend has been uninterruptedly maintained since 1945 when Poland has established its present day borders. Since, the share of hardwood species has risen from the initial 13% to 29.2% in the year 2010. The most recently published results of the large-area forest inventory in Poland show that the highest shares in the category of broadleaves (in terms of area) is currently due to the following species (in diminishing order): oak, birch, beech, alder, poplars and hornbeam. All the remaining hardwoods: ash, elm, lime, maple, sycamore, willow, rowan tree, cherry, locust have altogether participated in merely 2.1% to the whole forested area in Poland. If so, they should be considered rare (niche) species, locally important for the specialized production of veneer, wall panels and floor materials. The continuously growing since 1945 proportion of the hardwoods in the species structure of Poland's forests clearly suggests their growing importance in the wood processing industry in the near future.

Another topic discussed in the paper is the volume of broadleaved species harvest in Poland. The trends of hardwoods harvest are discussed concerning the State Forests that is, the most important and absolutely dominant so far wood raw material supplier (about 95% of the domestic market). The analyses have been based on the recent detailed SILP (Information System of the State Forests) data representative for the period 2004 – 2008. The original data were subject to statistical analyses. The actual level of particular species harvest is influential for the assessment of their importance for the wood processing industry. The most important

hardwoods in Poland are (in the diminishing order): birch, beech, oak, alder and poplars.

INTRODUCTION

The ownership structure of forests in Poland is unlike in the majority of European countries. As much as 77.5% of country's total forest area is under the direct management of the State Forests Enterprise (PGL LP). State Forests Enterprise are thus the largest wood raw material supplier for the domestic market, contributing in about 95% to the total volume of wood harvested in the country. It results from the above that the remaining 22.5% of country's total forest area supplies the market with 5% of wood raw material. Those are: privately owned forests (18.5% of total forest area), national parks (2% of total forest area), and forests belonging to other owners (2% of total forest area) (GUS 2011).

The State Forests Enterprise PGL is a sound self-financing enterprise, and the main player on the wood market in Poland (Anonim 1991). Beginning with the year 1997, the Information System of State Forests (SILP) has been operational in SF. Within the framework of the System all sort of information is collected, archivized and analyzed concerning every aspect of activity of the State Forests. The access to the database is, of course, limited but after one gets relevant permits, interesting data may be generated from the system that can further be used for different analyses and trends simulations which, in turn, allow for prognose-making eg the potential volume of woody raw material harvest in particular species. Unfortunately, no equally detailed databases exist for the other forest administrators; in order to obtain relevant information on last mentioned it is necessary to obtain less detailed general data from local (commune) governments or base on assessment data extracted from the large-area forest inventory in Poland; the latter's firs results were published in 2010 (Inwentaryzacja 2010). Prior to year 1997, the volume of forest resources was assessed with the use of yield tables - and thus the obtained results were very heavily biased.

The activities undertaken beginning with the year 1997, in order to increase the country's forest cover index and especially so – the accomplishment of two documents: the Forest Act of 1991 and the State Forest Policy from 1997, have resulted in a permanent growth of the share of hardwoods in Poland's forests; noteworthy, it is not only the area, but also the standing volume, that has been on a continuous increase (Anonim 1997). These trends lead in turn to the increased level of harvest volume of broadleaved species as we observed today, and will - most probably – result in an even more accelerated increase of harvest volume in the future. The observed increase in the harvest volume of hardwoods directly produces an elevated interest in the wood of those species and their enhanced importance for the wood processing market.

The potential for further development of the wood processing industry in Poland is limited by the supply of wood raw material harvested in Poland's forests. The import of wood raw material does not seem to be a promising solution for a longer time. It does not give the sufficient basis for the development plans. It seems that the wood processing industry in Poland is able to react positively for increased supply of any sort of wood raw material, including also that coming from the broadleaved species (Jednoralski, Paschalis 2000).

AIM AND METHODS

The paper is aimed at presentation of:

1. Stand species dynamics as observed in the period 1945 – 2010;
2. The volume of hardwood harvest in Poland in 2004 – 2008 at the background of softwood species harvest; in this aspect, the elementary statistical measures have been applied (standard deviation and variability coefficient).

The present paper has been outlined with the use of a number of source data, first of all State Forests' own reports were utilized, the results of large-scale survey of country's forests belonging to all owners. Status for the period 2006 – 2010; Leśnictwo 2011: a study of the Chief Statistical Office; as well as selected SILP databases dealing with the harvest volume of particular forest forming woody species in the years 2004 – 2008.

DYNAMICS OF POLAND'S FORESTS STAND SPECIES COMPOSITION

Poland has been existing in its today shape since the year 1945. This gives an opportunity to follow the dynamics in the size of forest cover. In the year 1945 the total forest area in Poland was equal 6470 thousand ha, out of which as much as 5629 thousand ha (87%) were covered by conifers, while hardwoods participated in only 841 thousand ha (13%). Beginning with that time, the total area of forest in Poland has been maintained on a continuous increase, reaching in the year 2010 the level of 9089 thousand ha; out of this, 6424 thousand ha (70.8%) were under coniferous stands, and the remaining

2665 thousand ha (29.2%) were under broadleaves. It can be concluded from the data that considering the period 1945 – 2010, the forest area covered by coniferous species has grown by about 14% while that under broadleaves has risen by as much as 217%. This exceptionally dynamic process of stand species composition alteration and the rapid growth of hardwoods proportion as observed from more than two decades now, is part of the country's forest policy. The country-wide process of reconstruction of coniferous monocultures (mainly: Scots pine) into the mixed broadleaved-coniferous forests will bring a decrease in portion of the coniferous species for the benefit of broadleaves. All these will also influence sooner or later the structure of wood raw material harvest. The changes in area covered by particular species or groups of species are presented in the below table. Even though the data are not fully comparable (differences in calculation methods and grouping species as took part within the period) they illustrate clearly enough the direction of change in the species composition of Polish forests.

Table 1. Shares of the more important hardwood species in Poland's forest in the years 1945 and 2010 (all data in per cent of total forest area)

Species in 1945	**Per cent of total forest area in 1945**	**Per cent of total forest area in 2010**	**Species in 2010**
oak, ash, maple, elm	4.1	7.0	Oak
beech	3.3	5.6	Beech
birch, locust	2.2	7.3	Birch
alder	2.8	5.3	Alder
aspen, lime, willow	0.3	0.8	aspen, poplars
hornbeam	0.3	1.2	Hornbeam
hardwoods total	13.0	29.2	hardwoods Total

It can be clearly concluded from table 1 that within the last 65 years the highest has been the growth of role of birch and oak, then that of beech and alder. Somewhat less dynamic has been the increase in portion of aspen and hornbeam. In the table no data are given concerning those broadleaved species that occupy very small acreage: they altogether constitute merely 2.3% of the 2010 forest area and were not included in the table (no detailed data available).

It has to be emphasized that no forest stands are included in the survey (due to methodological solutions in the „Large-area Inventory of Forest Condition in Poland Regardless the Ownership- Inwentaryzacji wielkoobszarowej stanu lasów kraju wszystkich form własności”) in Poland if they occur on grounds classified as non-forest grounds. To include an afforested area (both following the artificial or spontaneous forest emergence) as „forest” it is necessary that the ground of interest has been prior re-classified as forest ground in land use official documents records. If so one may come to a conclusion that the real acreage of first of all first forest generation young birch stands, and to some extent also – alder and aspen stands is underestimated (Tarasiuk, Jednoralski 2004).

A more comprehensive analysis of the potential role of broadleaved woody species in Polish forests enables the comparison of the area covered by particular forest forming woody species, their average age and average standing volume [m^3/ha] as well as, the gross total standing volume of each of them [m^3].

Table 2. Average age, standing volume per hectare and gross total volume of all hardwood species in Poland. Source: (Inwentaryzacja… 2010)

Species	Average age (years)	Average standing volume [m^3/ha]	Gross total standing volume [milions m^3]	Share of hardwood species in the gross total standing volume [%]
beech	66	310	156.1	6.8
oak	55	222	138.6	6.0
hornbeam	54	229	24.6	1.1
birch	42	170	113.5	4.9
alder	46	242	115.9	5.0
aspen	39	207	13.7	0.6
poplar	44	252	2.3	0.1
other hardwoods	53	229	43.0	1.9
hardwoods total	52	230	607.6	26.4

The broadleaved woody species in Poland are characterized by somewhat smaller values of the average standing volume per hectare 230 [m^3/ha] as compared with the conifers 264 [m^3/ha]. Despite the continuously growing hardwoods area, their present share in Poland’s forest total area is still below the level of their natural potential as assessed upon the structure of forest sites fertility and humidity (Raport 2010).

THE VOLUME OF HARDWOODS HARVEST IN POLAND AT THE BACKGROUND OF SOFTWOODS

The tables below present summary data concerning the wood raw material harvest in Poland. It can be concluded that the mean annual harvest of hardwoods has been at the level exceeding slightly 8 million m^3. The year-by-year variation has been rather slight in the period (variation coefficient equal 3.77%). The volume of softwoods harvest in the period of interest was on the average three times as large, reaching the level of nearly 24 million m^3/year, and being a little more variable (variation coefficient V=5.34%).

Table 3. The amount of timber harvest in the State Forests in Poland in the period 2004-2008 (m^3)

SPECIES	2004	2005	2006	2007	2008	Sum in period 2004-2008
Locust	67128.95	65112.45	61399.56	66247.87	74367.56	334256.39
Beech	1893488.03	1733669.18	1728941,11	1707664,25	1717815.11	8781577.68
Birch	3065159.92	2554142.81	2617954.86	2440515.96	2487999.84	13165773.39
Oak	1376152.80	1390604.72	1669659.12	1513009.84	1604039.37	7553465.85
Douglas fir	12415.51	11418.83	11618.54	16200.12	12792.49	64445.49
Hornbeam	249737.59	246248.59	239377.12	219622.49	247795.48	1202781.27
Silver fir	279878.96	305188.39	360719.74	441350.87	442869.88	1830007.84
Ash	136555.32	147591.61	187575.25	238234.66	273689.18	983646.02
Sycamore	67020.37	60870.61	64520,24	58675.82	58590.77	309677.81
Maple	25387.01	26277.70	27207.76	23497.37	28164.04	130533.88
Hazelnut	3143.50	3275.88	3181.13	3147.88	2326.66	15075.05
Lime	72808.81	71179.08	66102.92	61114.35	67303.14	338508.30
Larch	236400.99	253914.91	324959.33	339335.99	300405.12	1455016.34
Alder	965781.47	911245.51	984173.75	817718.02	864152.35	4543071.10
Walnut	66.87	13.86	42.07	13.49	67.27	203.56
Aspen	396382.95	364908.85	391662.30	364461.51	374530.90	1891946.51
Other s-w	376780.28	275280.03	237352.77	206613.53	190872.70	1286899.31
Other h-w	132111.97	141678.58	128592.12	109597.10	124962.46	636942.23
Scots pine	19841562.59	18536249.88	18539293.26	20332290.77	19186883.50	96436280.00
N. spruce	3122366.78	2964536.63	3293601.37	4542833.40	4218656.22	18141994.40
Poplar	141323.81	156131.27	146084.26	121639.83	115569.07	680748.24
Willow	12721.98	14819.10	13685.01	11523.74	10413.19	63163.02
Elm	8833.52	9798.05	9990.36	9034.04	11033.00	48688.97
Total	32483209.98	30244156.52	31107693.95	33644342.90	32415299.30	159894702.65
Softwoods	23869405.1	22346588.7	22767545	25878624.7	24352479.9	119214643.4
Hardwoods	8613804.87	7897567.85	8340148.94	7765718.22	8062819.39	40680059.27

The broadleaved forest forming woody species are represented in Poland by a significantly larger number as compared with conifers. Considering the volume of harvest, it is birch that prevails definitely; then it comes beech, oak and alder; further – in a decreasing order - aspen, hornbeam and ash. The relatively high level of ash wood raw material harvest may have been one result of the species dieback as observed in the last decade, and associated with it the increased intensity of so called sanitary cut volume. This opinion is supported by the very high year-by-year variation (V>26%). Even higher values of the variation coefficient are observed only for the harvest volume of least significant species, those are usually harvested in small amounts and as such – subject to significant changes in particular years. As an excellent example of the thesis, walnut may serve: its mean annual harvest volume reaches 40 m^3 but the variation coefficient is as large as nearly 60%.

Table 4. Average annual volume of timber harvest (m^3) in period 2004-2008, with elementary descriptive statistics (standard deviation and variability coefficient)

SPECIES	Mean/yr	Standard deviation	Coefficient of variability V (%)
Locust	66851.28	4235.10	6.34
Beech	1756315.54	69177.66	3.94
Birch	2633154.68	224179.41	8.51
Oak	1510693.17	115335.51	7.63
Douglas fir	12889.10	1730.46	13.43
Hornbeam	240556.25	11033.76	4.59
Silver fir	366001.57	67423.29	18.42
Ash	196729.20	52468.53	26.67
Sycamore	61935.56	3331.17	5.38
Maple	26106.78	1600.05	6.13
Hazelnut	3015.01	347.46	11.52
Lime	67701.66	4105.68	6.06
Larch	291003.27	39835.70	13.69
Alder	908614.22	62005.22	6.82
Walnut	40.71	23.89	58.68
Aspen	378389.30	13345.69	3.53
Other s-w	257379.86	66299.90	25.76
Other h-w	127388.45	10491.77	8.24
Scots pine	19287256.00	711742.45	3.69
N. spruce	3628398.88	631421.44	17.40
Poplar	136149.65	15223.85	11.18
Willow	12632.60	1552.53	12.29
Elm	9737.79	782.04	8.03
Total	31978940.53	1182100.49	3.70
Softwoods	23842928.68	1248990.40	5.24
Hardwoods	8136011.85	306361.93	3.77

In the entire period under study the harvest of hardwoods has been maintained at a relatively equal volume level.

In Poland wood harvest plans are outlined for 10-year periods by a specialized agenda (Biuro Urządzania Lasu i Geodezji Leśnej – Forest Management and Forest Geodesy Office) for each forest district. The administration (chief forest officer in charge) of a forest district is in a sense forced to obey the plan's statements so that the harvest volume be similar year by year, in order to keep the finances of their FD at a good condition. The 10-year total harvest volume is, as a rule, obligatory; it only may be exceeded in case of a disaster (storm-wind etc.).

The large area forest inventory in the year 2010 (Inwentaryzacja 2010) has proven that the actual wood volume of Poland's forest is significantly higher comparing with the earlier estimations. The actually higher level of forest resources gives the rationale for the Forest Management and Forest Geodesy Office staff to plan new higher values of harvest volume, but those are not always accepted both by forest administration itself, and by different environmentalist organizations

(NGO-s). Despite the above mentioned constrains, the planned volume of wood harvest in the State Forests grow from year to year in order to avoid the danger of wood raw material depreciation. The annual average wood volume increment assessed in the last few years to some 10 m^3/ha means that no more than 50% of the annual wood volume realized increment is harvested (Raport 2011).

CONCLUSION

1. The total forest area in Poland has been on the continuous increase in the period 1945 to 2010: form the initial 6470 thousand hectares in 1945 to 9089 thousand hectares in 2010.
2. This increase of the total Poland's forest area has been first of all, due to the growing acreage of hardwood species: from the initial 842 thousand hectares (13 %) in 1945, to the present 2665 thousand hectares (29.2%) in 2010.
3. The most important hardwood species (in terms of the average annual harvest volume) for the wood processing industry are (in the decreasing order): birch, beech, oak, and alder.
4. Of moderate importance in terms of harvest volume are the following: aspen, hornbeam, poplars, and ash.
5. All other hardwoods are harvested at the level below 100 thousand m^3 a year, and they should be subject to local markets analysis rather.
6. It should be expected that the harvest volume of all forest forming woody species will be gradually growing in the future, and the trend will be especially evident in the case of hardwoods: because of the high rate of standing volume annual increment on one hand, and the high average age of Poland's forest stands on the other.

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Discoloration of Heat Treated Sliced Veneers*

Levente DÉNES[1], Elemér M. LÁNG[2]

[1] University of West Hungary, Faculty of Wood Sciences, Hungary,
dali@fmk.nyme.hu

2West Virginia University, Division of Forestry and Natural Sciences
elang@fmk.nyme.hu

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ABSTRACT

This paper outlines an investigation pertaining to color changes of hardwood veneers exposed to elevated temperature. The effects of convection and contact type heat applications on the different species were separately evaluated. The experimental analyses included two-factor, three-level randomized block designs, where the factors were the temperature and the duration of the exposure. Examined species included: Yellow-poplar (*Liriodendron tulipifera*) and red oak (*Quercus rubra*). Two way analysis of variance (ANOVA) indicated major overall effects with significant interactions between the factors for all species/heat-treatment combinations. However, pair wise comparisons (Tukey tests) revealed lack of significant differences within factors for certain levels. The gained information might be useful for adjusting drying or pressing time/temperature relations.

INTRODUCTION

Veneers, during the various manufacturing and application processes are frequently exposed to thermal distress. Softening (steaming and hot water bathing) of logs/flitches, drying and hot pressing of veneers are the major sources of thermal exposures during the processing of these thin wooden plates. It is well known, that the heat application significantly alters the mechanical and physical properties; which includes changes in color as well.

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The natural tint of wood varies between light yellow and dark brown. This color range and the earlywood latewood differences in color or pattern provide emotive comfort for the observer. The majority of manufacturing processes change the perceived color of solid wood; however it should be noted that ageing is the major cause for discoloration of outdoor and indoor wooden structures. In many instances the unfavorable color maybe altered on purpose. These modifications include bleaching, staining and steaming, just mentioning a few.

The color changes of wood exposed to heat must have been observed since ancient times; although the scientific analyses of the phenomena may have started just at the beginning of the 20th century. One of the earliest surveys on the discoloration of hardwoods was reported by Kollmann et al. (1951). They documented that the redness of beach (*Fagus sp.*) and maple (*Acer sp.*) may be altered if the temperature is above 50 ºC and the relative humidity exceeds 65%. Since then, color changes during the kiln-drying or steaming processes have been of the main research interests. These efforts resulted in several reports and publications (Kozlik 1962, Brauner and Conaway 1964, Kozlik 1967, etc.).

Over the past couple of decades the quantity and quality of research works, dealing with the hue or discoloration of solid wood, increased noticeably. The advances in measuring techniques and instrumentation made the identification of colors easier. The majority of these studies dealt with different aspects of photo-degradation. Usually the color changes during natural or accelerated ageing were the focal points of these investigations. On the other hand, limited number of publications addressed the modification of veneer colors from technological point of view.

A research paper of Yixing et al. (1994) dealt with the color changes of wood substances grown in China. The applied convection type heat treatment ranged between 90 ˚C to 120 ˚C with 10 degrees of increments. Durations of the exposure were 5 and 10 hours that resulted severe darkening for all the examined specimens. Mitsui et al. (2001, 2004) investigated the effect of heat treatment, combined with light irradiation, on the discoloration of different species. They concluded that the heat treatments intensify color changes if coupled with light irradiation. The photo-degradation of solid wood, exposed to subzero temperature, was analyzed by Mitsui and Tsuchikawa (2005). Their results implied that under identical treatments, the color change of cooled wood was less extensive compared to specimens kept at room temperature. This corresponds to the general theory that the chemical decomposition of lignin and hemicelluloses are the major sources of dark discoloration of wood under thermal exposure. White and Dietenberger (2001) pointed out that such thermal degradation of cell wall constituents may start at or around 65˚C depending upon the environmental relative humidity, duration of the treatment, etc.

Thompson et al. (2005) provided a comprehensive study discussing the temperature and exposure time effects on red alder (*Alnus rubra*) veneer cants in connection with discoloration. The applied range of temperature was 30 to 90 ˚C, while the treatment time varied between 8 to 72 hours. They reported significant two-way interaction effects of temperature and exposure time that influenced redness and lightness of the examined specimens.

Tolvaj and Nemeth (2008) measured the darkening effect of steaming on black locust (*Robinia pseudoacacia* L.) Besides the time and temperature effects, they identified significant correlation between lightness and hue angle after treatments. Most recently two research papers published by Tolvaj et al. (2009, 2010) dealt with the color homogenization effect of steaming on beach (*Fagus silvatica* L.) and black locust (*Robinia pseudoacacia* L.)

It does appear that veneer discoloration during the drying process and/or during applications by hot pressing is a fairly researched phenomenon. Consequently, our research efforts with the objectives as stated below may be warranted.

Objectives

The work presented here aimed at to investigate the effect of different heat transfer methods on the color changes of hardwood veneers. Specific objectives included:

- To explore the differences between convection and conduction (contact) heat applications in terms of discoloration of the veneers;
- To investigate the characteristic color changes of ring porous and diffuse porous hardwoods;
- To identify the effects of different temperatures and exposure durations on the color alterations of the species.
- To obtain statistically reliable data of discolorations that may be used to adjust time/temperature specifications for oven drying or for veneering by hot pressing operations.

MATERIALS AND METHODS

The examined veneers included 2.5 mm thick rotary cut (peeled) Yellow-poplar (*Liriodendron tulipifera*) and approximately 0.8 mm thick, sliced, Northern red oak (*Quercus rubra* L.) leafs. These raw materials originated from local manufacturing facilities of West Virginia, U.S.A. Specimens were cut to about 15 cm x 15 cm in-plane dimensions. Veneers prior to treatments were kept in controlled environment, (i.e. 65% relative humidity and 21 ˚C temperature) to achieve approximately 12 % moisture content. The samples were exposed to heat treatments after six days of conditioning. Stacked specimens on spacers were treated in a convection oven. The contact heat applications happened by the use of a laboratory sized, single daylight press with platens' dimensions of ~70 x 70 cm. The applied contact pressure was minimal ($<10\ N/m^2$).

The randomized complete block design of experiments included two factors (temperature and time) with three levels for each by species and by heat application methods. Accordingly, convection and conduction treatments and the veneer types were analyzed separately. The desire for significant color change and yet realistic technological parameters (time/temperature) were the selection criteria for the levels of the factors. Tables 1 and 2 specify the experimental design configurations that applied to both species, where the summary statistics are also compiled. On each four replications three measurements were performed. Additionally, each group of factors by levels underwent color assessment prior to treatments to establish robust data base for control purposes. To ensure consistency of the evaluations, three circular pencil-marks located the assessment areas on each specimen. The L*, a* and b* coordinates were measured with a Konica-Minolta Chroma Meter, CR-400/410. SigmaStat® commercial statistical software helped to analyze the obtained data. Statistical procedures included, summary statistics, two-way ANOVA and pair wise comparisons. All analyses were performed at 95% significance level, i.e. $\alpha = 0.05$.

RESULTS AND DISCUSSION

Table 1. Summary statistics of the measured color coordinates (L*, a*, b*) of Red Oak decorative veneers.

Oak								
Lightness (L*) *Control mean:71.7; std:2.2*								
Convection (oven)					***Conduction (press)***			
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	59.1 *(1.6)*	45.8 *(4.9)*	34.9 *(1.5)*	***3***	60.5 *(1.2)*	50.3 *(0.7)*	42.0 *(1.0)*
	20	53.0 *(1.1)*	45.6 *(1.5)*	31.8 *(1.2)*	***6***	62.8 *(0.3)*	52.5 *(1.4)*	42.0 *(1.0)*
	30	50.7 *(1.7)*	41.6 *(0.6)*	31.1 *(1.7)*	***9***	63.7 (*0.5*	46.1 *(1.4)*	30.4 *(1.2)*
Redness (a*) *Control mean:6.5; std:1.1*								
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	7.9 *(0.1)*	7.9 *(0.1)*	6.1 *(0.4)*	***3***	8.0 *(0.2)*	7.7 *(0.4)*	6.7 *(0.05)*
	20	8.7 *(0.3)*	7.8 *(0.2)*	5.5 *(0.4)*	***6***	8.1 *(0.3)*	7.8 *(0.3)*	7.6 *(0.1)*
	30	8.4 *(0.1)*	7.6 *(0.1)*	5.4 *(0.5)*	***9***	8.5 *(0.1)*	7.4 *(0.1)*	4.7 *(0.4)*
Yellowness (b*) *Control mean:22.2; std:0.9*								
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	20.4 *(0.4)*	15.0 *(3.1)*	8.8 *(1.0)*	***3***	20.5 *(0.5)*	16.9 *(0.5)*	13.0 *(0.5)*
	20	18.7 *(0.4)*	15.7 *(0.7)*	7.5 *(1.3)*	***6***	20.5 *(0.2)*	18.1 *(0.6)*	17.0 *(0.9)*
	30	17.6 *(0.6)*	13.5 *(0.9)*	7.5 *(1.8)*	***9***	20.7 *(0.1)*	16.7 *(0.6)*	6.7 *(0.9)*

**- Cells contain the average of 12 replicated measurements with standard deviations in parenthesis.*

Table 2. Summary statistics of the measured color coordinates (L*, a*, b*) of Yellow-poplar structural veneers.

Yellow-poplar[*]								
Lightness (L*) *Control mean: 68.6; std:5.7*								
		Convection (oven)			***Conduction (press)***			
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	60.3 *(8.3)*	46.8 *(4.7)*	39.0 (5.4)	**3**	68.0 *(7.1)*	56.7 *(6.2)*	53.4 *(7.3)*
	20	65.8 *(1.7)*	39.9 *(2.5)*	32.4 *(1.2)*	**6**	64.9 *(10.5)*	57.3 *(5.1)*	60.1 *(2.0)*
	30	54.1 *(2.7)*	32.2 *(8.8)*	26.7 *(1.6)*	**9**	68.1 *(3.6)*	49.5 *(3.3)*	37.0 *(3.6)*
Redness (a*) *Control mean:3.5; std:1.4*								
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	3.4 *(1.5)*	5.2 *(1.4)*	5.7 *(1.2)*	**3**	4.6 *(1.6)*	5.7 *(1.6)*	5.7 *(1.4)*
	20	3.2 *(1.3)*	5.9 *(0.2)*	5.5 *(0.8)*	**6**	2.7 *(1.1)*	5.4 *(1.9)*	5.2 *(0.9)*
	30	5.2 *(2.1)*	6.6 *(0.6)*	3.2 *(0.9)*	**9**	2.0 *(2.0)*	5.9 *(1.4)*	6.0 *(0.8)*
Yellowness (b*) *Control mean:23.3; std:1.6*								
Factor **A** Temperature (˚C)		**180**	**200**	**220**		**180**	**200**	**220**
Factor **B** Time (min.)	**10**	21.0 *(3.3)*	15.9 *(2.3)*	12.7 *(3.4)*	**3**	23.8 *(1.8)*	22.3 *(2.7)*	18.7*(2.4)*
	20	24.1 *(0.7)*	12.9 (1.3)	8.6 *(1.4)*	**6**	22.4 *(3.5)*	21.4 *(3.2)*	20.6 *(1.2)*
	30	20.3 *(1.6)*	16.3 *(4.1)*	3.4 *(1.7)*	**9**	22.2 *(1.4)*	19.3 *(1.7)*	11.2 *(2.8)*

**- Cells contain the average of 12 replicated measurements with standard deviations in parenthesis.*

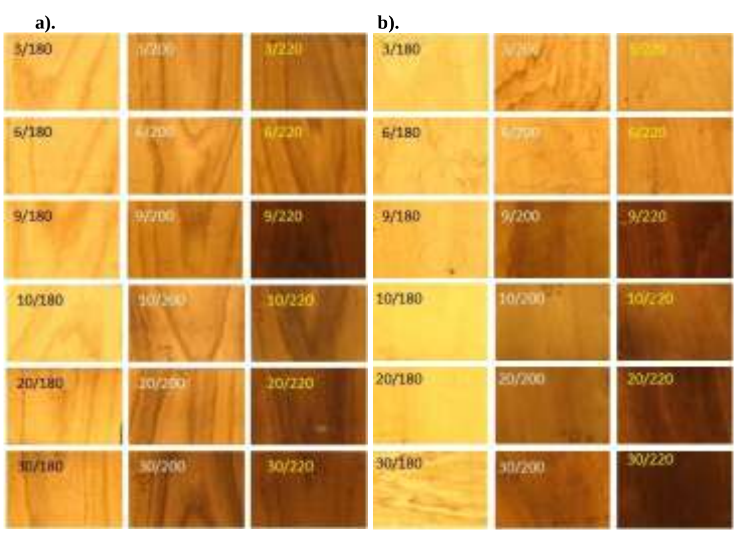

Figure 1. Color changes of Red Oak after conduction (oven) heat treatments (a), and of Yellow-poplar after conduction (press) heat treatments (b).

As illustrated on Figures 1 both the convection and contact type heat treatments created notable changes in color for both species. One can realize that the oven treatment caused significantly deeper darkness compared to the conduction type heat applications by the press. It should be noted however, that these images may not represent the exact hues of the treated specimens, because of their possible alteration during the digitalization processes. Nevertheless, their use for comparison purposes is certainly justified.

After analyzing the summary statistics of the measured color coordinates we observed decreasing standard deviations of lightness (L*) and redness (a*) parameters along with the increasing temperature (Tables 1 and 2). Regardless of treatment type and species at the two higher levels of factor B (time) the spread of data usually decreased. This statistical veracity implies the equalizing effects of the elongated heat treatment on darkness. Data of yellowness (b*) exhibited erratic variances, thus no trend could be observed.

The two way Analysis of Variance procedures on the assessed color coordinates indicated statistically significant factorial and interaction effects. Table 3 shows a typical ANOVA results for L* on oven treated Yellow-poplar; while Table 4 provides information on the yellowness (b*) for red oak exposed to contact heat treatments.

Table 3. Results of ANOVA for Yellow-poplar; heat treated by convection (oven). Dependent variable: lightness (L*)

Source of Variation	*DF*	*SS*	*MS*	*F*	*P*
Treatment (A)	3	14570.631	4856.877	166.196	<0.001
Time (B)	2	188.178	94.089	3.220	0.047
Treatment (A) x Time (B)	6	776.316	129.386	4.427	<0.001
Residual	60	1753.427	29.224		
Total	71	17126.518	241.219		

Normality Test: *Passed* *(P > 0.050)*
Equal Variance Test: *Failed* *(P = 0.021)*

Table 4. Result of ANOVA for Red Oak; heat treated by conduction (press). Dependent variable: yellowness (b*).

Source of Variation	*DF*	*SS*	*MS*	*F*	*P*
Treatment (A)	3	969.475	323.158	572.069	<0.001
Time (B)	2	67.627	33.814	59.859	<0.001
Treatment (A) x Time (B)	6	194.803	32.467	57.475	<0.001
Residual	60	33.894	0.565		
Total	71	1225.833	17.265		

Normality Test: *Passed* *(P > 0.050)*
Equal Variance Test: *Passed* *(P = 0.063)*

The overall and the interaction effects may be studied on Figure 2 for oven treated Yellow-poplar specimens. These response surfaces provide general overviews of the color parameters’ changes due to the thermal exposures. The lightness (L*) and yellowness (b*) dropped significantly with strong factorial interactions. Redness (a*) increased slightly with the severity of treatment and duration, however for time/temperature combinations of 30/220, redness dropped below the original level. We observed similar trends for the other three heat application/species combinations, although the magnitude or percentages of the changes differed. Note that the control data of the three-dimensional mesh diagrams are the overall average measurements. However, the meshes show slightly increasing or decreasing values in the X-Z and Y-Z planes. These divergences came from the interpolation of mesh data. Because the control values had usually the highest variance, no corrections were made to mask the problem. It might be considered as the natural variability of the original hues.

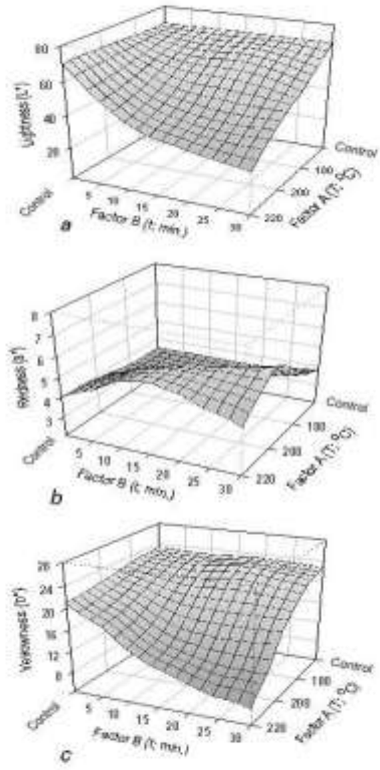

Figure 2. Response surfaces to convection (oven) treatments of the three color coordinates of Yellow-poplar: a – Ligthness (L*) b – redness (a*); c – yellowness (b*).

The effect of treatments on Red Oak

Figures 3 graphically depict the analyses of the contact (press) heat treated, oak specimens. Box-plot diagram denote the spread of the observed measurements as a function of factor A (temperature) at the indicated level of factor B (time). Further information may be obtained by examining data in Table 1. One can note that the decrease of lightness was almost linear up to the level of 200 ˚C of factor A. At temperature of 220 ˚C, the maximum values of factor B (9 and 30 min.) caused significant drops in lightness under both convection and conduction type treatments. Pair wise comparisons did not revealed differences between 6/180 and 9/180 press treatment combinations for red oak. Similarly, there was no significant difference between treatments of 3/220 and 6/220 combinations. However, after 9 min. heat application by convection at 220 ˚C, the lightness decreased significantly compared to the other levels of factor B at the same temperature (Figure 3a). Figure 3b shows the decreasing standard deviations at 3 min. level of factor B, indicating some equalizing effect on darkness. The oven treatment of red oak in terms of lightness was similar, but for all levels of factor B at 220˚C resulted in L* < 40 values. This fact numerically confirms the visual observation that the oven treatment causes more characteristic darkness than press treatment does. Though, one should be alert to the different levels of B factor (time) of the different treatments.

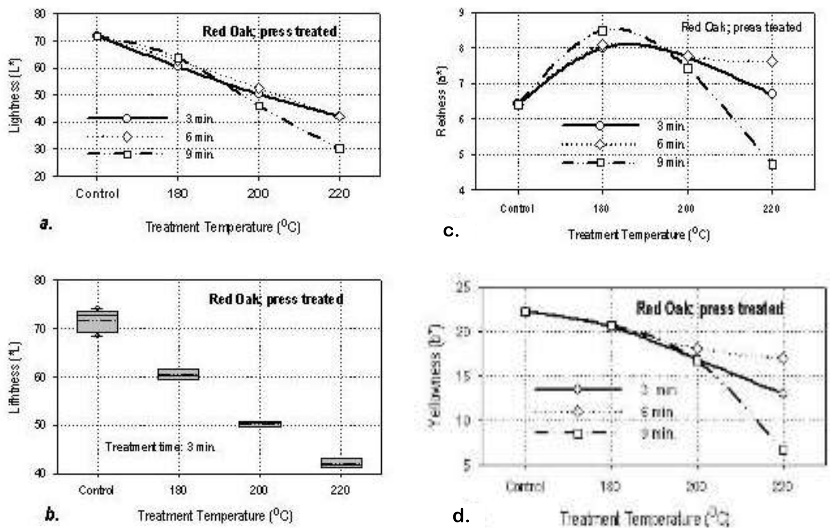

Figure 3. The results of conduction (press) treatments of Red Oak: a. – factorial effects on the lightness (L*), b. – variances at the indicated level of factor B (time), c. - factorial effects on the redness (a*), d. - factorial effects on the yellowness (b*).

The redness changes of oak showed different pattern (Figure 3c). An increase of a* was dominant up to 180 ˚C for both convection and conduction type heat applications. Treatments between 200-220 ˚C at 9 min. level of factor B again resulted in radical drop of a* below the average control values. The redness of oven treated oak samples, also dropped below the control value regardless of the duration of treatment. Besides, the standard deviations of the measured redness data consistently lessened along with the severity of treatments.

The yellow component of the hue of red oak (b*) decreased steadily for all treatment combinations as the level of A factors increased. Standard deviations of the observed yellowness indicated the lack of equalization effects of treatments on this color coordinate (Figure 3d).

Similarly to lightness and redness at the higher ends of factors B and A (i.e. 9/220) provided the sternest changes in yellowness under contact (press) treatment. The convection treatment had almost linear effects on yellowness and all levels of factor B caused the decrease of b* to less than 10 (Table 1)

These observations may indicate that generally the convection type heat application causes more radical changes of the measurable color coordinates for oak than the contact treatment. However, above 200 ˚C at 9 min. contact heat exposure may have severe darkening effect. It should be noted again that the B parameters (exposure time) differed for the two treatments because of technological considerations.

The effect of treatments on Yellow-poplar

The lightness change of oven treated Yellow-poplar was very comparable to the changes of convection treated red oak. However, the decreasing variance of the L* values manifested just above 20 min. treatment time (Table 2). Likewise for red oak, press treatment of Yellow-poplar resulted less overall lightness change. Decrease of the standard deviations of L* values was observed only at 6 and 9 min. levels of factor B. Similarly to red oak, the 9/220 factor combination caused equivalent lightness drop to that of all levels of factor B of oven treatments.

Redness of Yellow-poplar responded to the treatments somewhat erratically. No statistically significant differences could be detected among the control, 10/180 and 20/180 factor combinations during convection treatment. The further increase of temperature resulted in increase in redness. The 30 min. level of factor B produced significantly steeper increase up to 200 ˚C followed by steep decrease below the average control value of a*. There was no statistically significant difference between the 10/220 and 20/220 treatment combinations. Press treatment of poplar specimens showed similar responses of a* values but interestingly the steady linear increase between control and 200 ˚C happened at 3 min. treatment time without significant drop at 220 ˚C Additionally, no noteworthy changes in spread of a* values were observed along with the increasing treatment temperatures for all levels of factor B including both type of treatments.

Generally the convection treatment of Yellow-poplar decreased the yellowness more drastically that the press treatments did. Opposite trends in standard deviations were detected. The spread of b* data usually increased with increasing treatment temperature. For both the oven and press treatments, the 30/220 and 9/220 combinations caused the largest decrease of b*values.

SUMMARY

The work presented here investigated the effects of heat treatments on the discoloration of structural and decorative veneers. The treatment factors were selected to cover the time/temperature ranges of convection drying and veneering by hot pressing. After the analyses of results the following inferences may be drawn.

The convection heat treatments caused somewhat stronger discoloration regardless of the examined species. The decrease of L* and b* coordinates were more prominent during the oven treatments compared to the changes obtained by conduction heat applications. It does appear that the 200-220 ˚C temperature zone and the maximum levels of B factors (time) dominate the darkness for both of oak and poplar.

The redness color coordinates by species did not revealed significant differences between the types of heat applications up to 200 ˚C for oak. In terms of redness, Yellow-poplar demonstrated inconsistent responses to the treatments with opposite trends compared to red oak. This phenomenon needs further investigation.

The consistent changes and similar values of lightness (L*) and yellowness (b*) at a given time/temperature combination indicate that the exposure time has less significant effects on these parameters than temperature has during convection type heat applications. On the other hand, the L* and b* color coordinates are very responsive to the levels of time factor during press treatments over 180 ˚C.

The major difference between the two species is that the red color saturation of oak increases up to ~190 ˚C. Further increase of treatment temperature reduces the redness depending on the duration of exposure. This trend for poplar is just the opposite. For all the treatment combinations, except 30/220, the redness remained above the control level at 220 C˚

In technological aspects, pressing operations below 180 ˚C do not significantly alter the hue of the examined species; although read oak may manifest some reddish discoloration. Convection type heat applications longer than 10 minutes within the examined temperature range may result in undesirable darkening and/or it can obscure the grain pattern characteristics.

ACKNOWLEDGEMENTS

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The protective effectiveness of dry heat treatment on Turkey oak against fugal decay*

Horváth Norbert[1], Csupor Károly[2]

University of West Hungary, Faculty of Wood Sciences, Institute of Wood Sciences, Sopron, Hungary

[1]hnorbert@fmk.nyme.hu, [2] csupor@fmk.nyme.hu

Keywords: heat treatment, *Quercus cerris* L., wood protection, *Daedalea quercina*, fungal decay

ABSTRACT

Dry heat treatment as a wood modification process is known to significantly improve the dimension stability and to decrease the mass loss caused by brown-, white rot fungi on wide range of wood species.

The primary aim of the presented study was to clear up the effect of dry thermal treatment on wood properties of Turkey oak (*Quercus cerris* L.), with special emphasis on wood resistance to fungal decay. The research work was organised by the Institute of Wood Sciences of the University of West Hungary in Sopron. The thermal treatments were carried out in an electric oven under atmospheric air conditions. The temperature of the treatments ranged between 180-200°C and was combined with a wide range of durations. In our project the most important physical and mechanical wood properties were analysed using the European Norms. In this paper we only publish the effect of dry heat treatment on the mass loss caused by Oak mazegill (*Daedalea quercina*) on Turkey oak. Based on our results, the fungal decay resistance can be enhanced by dry heat treatment not only in case of sapwood, but heartwood as well.

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INTRODUCTION

Turkey oak is an east-Mediterranean species, native to South-Eastern Europe, the southern part of Central Europe (south of the Brno-Zvolen-Sighetul-Marmartiei line) and Asia Minor. Turkey oak has a high industrial importance in Hungary. Unlike grand oaks, Turkey oak develops wide, light-grey (sometimes yellowish) sapwood, distinctly different from the dark reddish-brownish heartwood in colour (MOLNÁR AND BARISKA 2002).

Five natural durability ratings against wood-destroying fungi are defined in EN 350 European Standard. The classes relate to heartwood only are numbered 1-5 (1-very durable, 2- durable, 3-moderately durable, 4-slightly durable, 5-not durable). Sapwood must always be considered as "not durable" against wood degrading agents. Turkey oak with its wide sapwood is less durable than grand oaks. Therefore the effect of dry heat treatment had a special importance in our research work. This research was part of a GOP 3.1.1 project called "Chemical free wood protection". It has been set-up in co-operation with the Institute of Wood Sciences (University of West Hungary), Sokon Ltd. and Apostol és Társai Ltd. The objective of a part-study of our project was to determine the effect of the dry heat treatment on the most important wood properties of Turkey oak (*Quercus cerris* L.) with a special emphasis on the protective effectiveness against Oak mazegill (*Daedalea quercina*).

Heat treatments as alternative wood protection processes have been developed and optimized in various countries for a considerable time. STAMM ET AL. (1946) reported on the first systematic attempts to increase resistance to wood-destroying fungi in a hot metal bath. BURO (1954, 1955) studied the heat treatment of wood in different atmospheres. Investigation often focused on the drying characteristics (SCHNEIDER 1973) and the chemical aspects of heat-treated wood (SANDERMANN and AUGUSTIN 1963; KOLLMANN and FENGEL 1965; TOPF 1971; TJEERDSMA ET AL.1998) as well as changes in dimensional stability (KOLLMANN and SCHNEIDER 1963) and strength (SCHNEIDER 1971, RUSCHE 1973). The well known moisture / heat / pressure (FWD) process by BURMESTER (1973) was further developed by GIEBELER (1983). There have been continuing researches to improve wood properties by thermal treatment for some years some other European countries. The production of TMT (thermally modified timber) in Europe is more than 300.000 m^3 in 2012 (IHD 2012). According the findings of the last decades it could be summarized, that the heat treatment is able to increase the dimensional stability, the resistance to fungal decay, though also has negative effects on the wood's characteristics. Due to the degradation of wood components the brittleness and the formation of cracks in particular

could be increased. The heat-related brown hue has low UV resistance which could also be problematic during practical use.
In this paper we publish the effect of dry heat treatment on the mass loss of Turkey oak caused by Oak mazegill (*Daedalea quercina*).

EXPERIMENTAL METHODS

During our research were used logs from one certain production site. The so called juvenile wood was not totally removed, but it was minimized by removing the first 5-10 annual rings. The native and to be treated samples were cut out from the same board before the tests. According to the preliminary tests, the temperature of treatments was limited to 200°C and the heat transmitter agent was dry, normal atmospheric air, without blowing steam. The schedules were based on the Finnish ThermoWood-schedule combined with 5-, 10- and 15-hour-long treatment period after reaching the 180 °C and 200 °C reaction temperatures. From statistical aspect, the number of samples was 25 pcs and evaluation of data was made in SPSS program. During the analysis of variance (ANOVA) we used a level of significance of 0,05.
The resistance to fungal decay of the modified timbers was tested in laboratorial conditions according to the standard EN 113. The special aim of this method is to determining the protective effectiveness against wood destroying basidiomycetes. During our research the tests were completed according to this standard, but in some cases we had to depart from it. In case of Turkey oak, we grafted mycelia of oak mazegill (*Daedalea quercina*) to the soils. Though oak mazegill is not listed in the standard EN 113, but it can be also found in the class of Basidiomycetes, and causes brown rot on wood. It attacks not only stubs in the forest, but the heartwood of freshly felled logs as well. In turkey oak forests it is not so frequent, but it attacks often the built-in timber of turkey oak. We set the sizes of samples according to the volume of the project, so we had to decrease those as compared to the prescribed sizes of the standard’s. So the dimensions of samples were 20×20×6 mm (tangential × radial × along the grain).

Figure 1: Placing samples into Kolle-flasks in grafting cabin

Samples were dried in an electrical oven at 103 ± 2 °C and their mass was measured with an accuracy of 0,01 g. Placing of samples has to be done in sterile environment (Fig.1.)

After placing of samples the Kolle-flasks closed by a sterilized paper cork were put in a thermostat, which assured constant 23 °C inner temperature for the growing of the fungi. The standard test lasts 16 weeks, which was also reduced due to the decrease of the sample size and the wood weight placed in one flask. So the test duration was 12 weeks, after which it was still able to measure the samples, without crumbling. The rate of fungal decay, practically the rate of oven dry mass loss was determined by comparing to the initial oven dry mass of the samples. After 12 weeks incubation the samples were measured with careful removal of mycelia and repeated oven drying. The rate of fungal decay can be calculated by the formula as Eq. 1 shows.

$$m_{ol} = \frac{m_{obefore} - m_{oafter}}{m_{obefore}} \cdot 100 \qquad (1)$$

where:

m_{ol}	mass loss, the rate of fungal decay, [%]
$m_{o\,before}$	oven dry initial mass, [g]
$m_{o\,after}$	oven dry mass after the incubation, [g]

The less the rate of decay, the more durable is the wood to the enzymatic decay of the fungus.

RESULTS AND DISCUSSION

In case of investigation of dry heat treatments at 180°C the average mass loss of untreated samples caused by oak mazegill was 24,76 %. It was established, that the longer schedule at 180°C we used, the lover mass loss was able to be reached. The Figure 2 shows the average mass loss of Turkey oak sapwood. After the schedule with 5-hour-long period at 180°C the samples showed significant decrease (data signed red) on mass loss compared to the native's. The 2nd schedule with 10 hours at 180°C had also significant effect on mass loss. In this case the average mass loss of the sapwood samples was less than half of the native's value. The schedule 3rd with 15 hours at 180°C didn't cause significant change compared to the 2nd schedule.

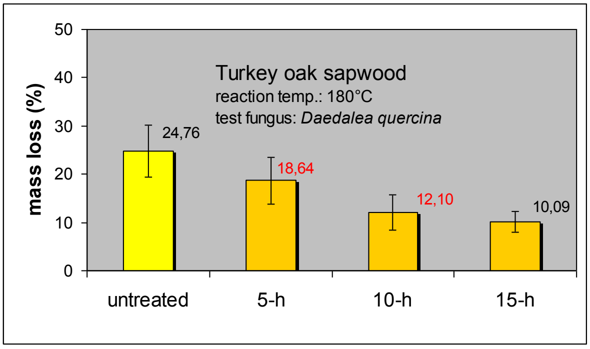

Figure 2: Average mass loss of heat treated (at 180°C) and native Turkey oak sapwood caused by oak mazegill after 12-week-long incubation

The results of investigation at 200°C can be seen on Figure 3. The average mass loss of untreated group was 26,72 %. After the 1st schedule with 5-hour-long period at 200°C the samples showed very significant decrease on mass loss compared to the native's value. The average mass loss after the 1st schedule was 5,5%. The 2nd schedule with 10 hours at 200°C had not significant effect on mass loss compared to the 1st one. In case of the 3rd schedule with 15-hour-long period at 200°C the samples showed 2,22% average mass loss, witch meant significant effect compared to the 1st schedule.

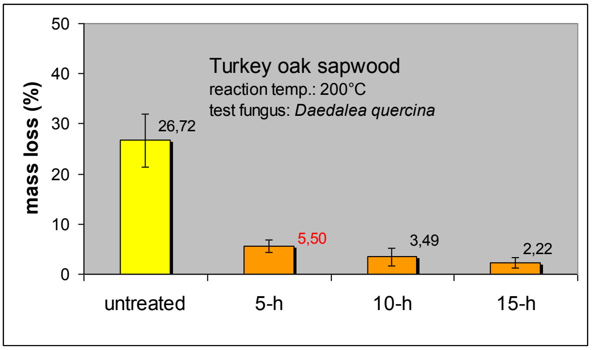

Figure 3: Average mass loss of heat treated (at 200°C) and native Turkey oak sapwood caused by oak mazegill

In group of treatments at 180 °C the native heartwood samples had an average mass loss of 11,60 %, witch was significantly lower than the sapwood's data (Fig. 4.). The same effect can be observed in case of native heartwood of group of treatments at 200°C on Fig. 5, witch could be explained by the different chemical ingredients of heartwood having more resistance against enzymatic decomposition caused by oak mazegill.

The samples treated by the schedule with 5-hour-long period at 180°C showed with their average mass loss of 9,95% no significant difference in comparison to the native's value. Increasing of the treating period of the 1st schedule had in all case significant effectiveness on decreasing the mass loss (Fig. 4.). The value (4,98%) reached by the schedule with 15 hours at 180°C was lower than the half of untreated heartwood's.

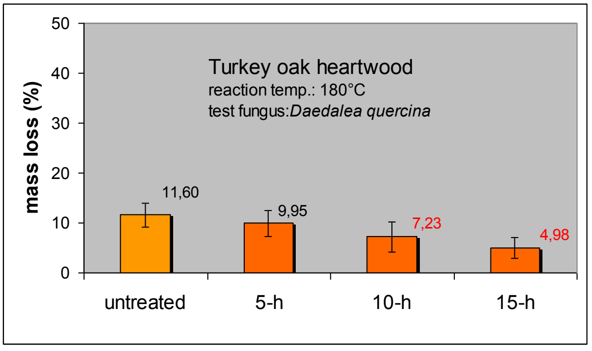

Figure 4: Average mass loss of heat treated (at 180°C) and native Turkey oak heartwood caused by oak mazegill

The effect of schedules including a treatment period at 200°C was found significant in all cases of our tests. The 1st treatment with a 5-hour-long period at 200°C was able to reach a value of mass loss of 2,19 %. Increasing of the treatment period was unnecessary in case of turkey oak heartwood.

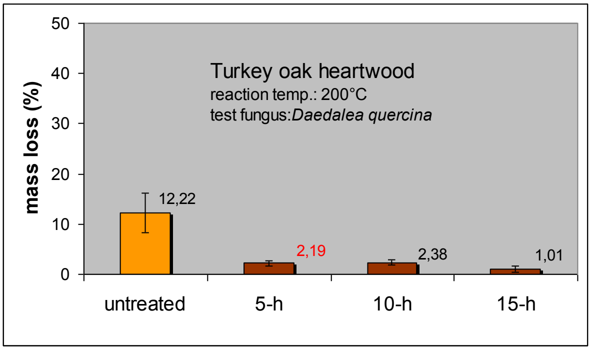

Figure 5: Average mass loss of heat treated (at 200°C) and native Turkey oak heartwood caused by oak mazegill

CONCLUSIONS

According to our investigations we can establish that the dry heat treatment is able to decrease the mass loss caused by enzymatic attack of oak mazegill on Turkey oak. The schedule including 10-hour-long period at 180°C was found suitable to reduce the mass loss of sapwood from 24,76 % to 12,1 %, although increasing of the treatment period to 15 hours didn't show significant effect on mass loss. In case of the schedule with 15-hour-long period at 200°C the sapwood samples sowed 2,22 % average mass loss in opposite to the native's 26,72 %. It was established that the native heartwood has a significant resistance against oak mazegill in comparison to native sapwood. The average mass loss of the untreated samples of heartwood was cca 12%. The schedule including 15-hour-long period at 180°C was found suitable to reduce the mass loss of heartwood from 11,06 % to 4,98 %. Because of a treatment with 5-hour-long period at 200°C was able to reach a value of mass loss of cca 2%, so the increasing of the treatment period was unnecessary in case of turkey oak heartwood.

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EN 350-2.: Durability of wood and wood-based products

EN 113.: Wood preservatives. Test method for determining the protective effectiveness against wood destroying basidiomycetes. Determination of the toxic values

The effect of dry heat treatment on physical properties of *Acacia mangium* and *Acacia auriculiformis* from Vietnam*

András Molnár[1], Norbert Horváth[2], Róbert Taschner[3]

[1] University of West Hungary, Faculty of Wood Sciences, Innovation Centre
H-9400 Sopron, Bajcsy-Zs. u. 4.,
molnar.andras@fmk.nyme.hu

[2] University of West Hungary, Faculty of Wood Sciences, Institute of Wood Sciences
H-9400 Sopron, Bajcsy-Zs. U. 4.,
hnorbert@fmk.nyme.hu

[3] University of West Hungary, Faculty of Wood Sciences, Institute of Wood Sciences
H-9400 Sopron, Bajcsy-Zs. U. 4.,
taschner.robert@fmk.nyme.hu

Keywords: Dry heat treatment, *Acacia mangium*, *Acacia auriculiformis*, swelling , EMC, density, colour

ABSTRACT

Acacia mangium and *Acacia auriculiformis* are among the most important plantation trees in South-east Asia and particularly in Vietnam. Up till now their wood has been used mainly as pulpwood, but they are suitable for the purposes of timber and furniture industry as well. The aim of our research was to test the effect of dry thermal treatment on these woods to give a base to extend their industrial use. *Acacia mangium* and *Acacia auriculiformis* samples were transported to our laboratory from Hoa Binh province of Vietnam.

The treatment was performed with a schedule at 180° C degrees and 15 hours duration. After the treatment we measured the density, shrinkage, equilibrium moisture content, and compared to those of the samples of untreated wood. Also we measured the change of the colour properties. The colour changes were measured according to the CIELab measuring system by a Konica-Minolta CM-2600d spectrophotometer equipment.

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Changing of physical properties was as follows: Normal density decreased considerably in case of *Acacia mangium* and more significantly in case of *Acacia auriculiformis*. Swelling properties of both wood decreased significantly in all the three wood anatomical directions, therefore anti swelling efficiency increased significantly in case of both species. Equilibrium moisture content at normal climatic conditions (20°C, 65% RH) of both species decreased significantly.
As an effect of the thermal treatment, the Lightness (L*) values decreased in case of *Acacia mangium* and *Acacia auriculiformis* as well. The green-red (a*) component increased by significantly in case of both species (the colour turned to red direction). The blue-yellow (b*) component also increased in case of both species (the colour turned to yellowish direction).

INTRODUCTION

Forests of the Socialist Republic of Vietnam suffered serious damages during the second half of the twentieth century, as a consequence of the war with USA, overexploitation and other reasons. The government started huge afforestation program to establish forest plantations. *Acacia mangium* and *Acacia auriculiformis* are among the mostly planted species of the plantations. In 2009, more than 25% of the 2920 ha forest plantations in the country were *Acacias*. 91% of the logged wood is fuelwood, pulpwood and other industrial wood, only 9% is sawlog and veneer log (FAOSTAT). The wood processing and furniture industry at the same time has a tremendous demand of raw material. The wood of *Acacia* species in Australia and other countries is also used for furniture manufacturing. In the future more and more *Acacia* wood is expected to be used for furniture production purposes. Determining exact properties of Vietnamese *Acacia* wood and exploring its modification possibilities is an important issue. In the recent years several researches dealt with physical and mechanical properties, as well as workability of *Acacia* species, mostly in tropical countries. Thailandese researchers proved the suitability of local *A. mangium* for construction purposes. (Ouypornprasert et al. 2005) C. Tenorio et al. based and improved the industrial kiln drying of the wood of *A. mangium* plantations.
Our experiments aimed to test the main physical properties of *Acacia mangium* and *Acacia auriculiformis*. After finishing the tests with natural wood, we carried out a dry thermal treatment and measured the physical properties again. In the recent years a number of researches were carried out in the subject of thermal modification of wooden materials. It was proven, that equilibrium moisture content decreases, dimensional stability increases as an effect of thermal treatment in case of European hardwoods, like turkey

oak, beech and poplar. (Horváth N. 2008). Besides, colour of treated wood changes, lightness decreases, while red and yellowish components increases. As a comparison to the test results of *Acacias*, we used the respective figures of *Populus ×euramericana Pannonia* from the dissertation of Horváth N. (2008).

EXPERIMENTAL METHODS

Selection and preparation of samples

The wood samples were selected from 7-year-old trees of *A. mangium* and *A.auriculiformis* plantations from Hoa Binh province of Vietnam. The trees were cut to boards and kept together in Boules form and were transported to Hungary. Thus the original place of the boards was clearly seen. For the test of physical tests the samples were selected form the middle boards as it is shown in the Fig. 1.

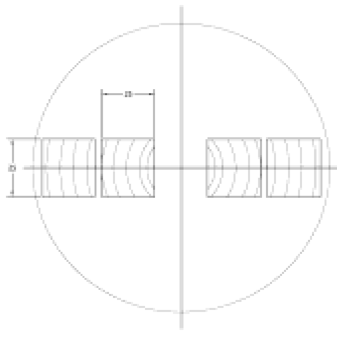

Figure 1: Selection of the samples from the tree

In case of all tests, the number of specimens were 25.

Schedule and heat treatment

Heat treatment was carried out in a 0,4 m^3 volume, insulated chamber, in atmospheric condition. Maximal temperature of treatment was 180°C for 15 hours duration. Initial moisture content of the samples was between 12%. ±2%.

Determination of equilibrium moisture content

The untreated and the treated samples were acclimatized under laboratory conditions in a Binder type equipment. Relative air humidity was 65% and temperature was 20°C (normal climate) The size of the samples were 20x20 mm in radial and tangential direction and 30 mm along grain according to MSZ 6786-2. Digital scales with 0,01 mm accuracy were applied for measuring. Equilibrium moisture content can be determined from the ovendry weight and the weight at the normal climate, which is measured after reaching the constant weight:

$$u = \frac{m_x - m_o}{m_o} \cdot 100 \qquad (1)$$

where: u net moisture content, %
m_x wet weight, g
m_o ovendry weight, g

Determination of density

Samples for the determination of density were acclimatized at 65% relative air humidity and 20°C temperature: The sizes of the samples were 20x20 mm in radial and tangential direction and 30 mm in grain direction according to MSZ 6786-3. Sizes of the samples was measured by a slide calliper with 0,01 mm accuracy. Digital scales with 0,01 mm accuracy were applied for measuring the weight. Density of the samples was calculated with the formula as follows:

$$\rho = \frac{m}{l \cdot r \cdot t} \cdot 10^6 [\mathrm{kg/m^3}] \qquad (2)$$

where: ρ density of the acclimatized sample
m weight of the acclimatized sample, g
l size of the sample in grain direction, mm
r size of the sample in radial direction, mm
t size of the sample in tangential direction, mm

Determination of dimensional stability

Terminology of the dimensional stability is in connection with the dimension change caused by the change of moisture content of the wood. Changing of water content bound in the wood structure results the swelling or shrinkage of wood. Changing of water content above saturation point doesn’t cause dimension change. The measurement of swelling is different in the three anatomical directions. It is the biggest in tangential direction, followed by radial and grain direction. Specimen blocks were placed in water till attaining full green volume. In this water saturated condition, the radial tangential and grain dimensions were marked and measured with a slide calliper with an accuracy of 0,01 mm . The blocks were then air dried for four days and oven dried at 105°C for further four days. The oven-dried blocks were then weighed and the dimensions were measured again along the points marked earlier using the same slide calliper. The ovendry to green swelling in radial and tangential directions of the same blocks was determined, expressed as a percentage of the saturated dimension to its ovendry dimension. The formulas used were

$$sw_{t,r,l}=\frac{x_{sat}-x_0}{x_0} \qquad sw_V=\frac{V_{sat}-V_0}{V_0} \qquad a_{sw}=\frac{sw_t}{sw_r} \qquad (3, 4, 5)$$

where: $sw_{t,r,l}$ linear swelling of the test specimen, % in t- tangential, r- radial, l- grain direction

sw_V volumetric swelling, %

x_{sat} dimension of the test block in the given anatomical direction, at/above saturation point, mm

x_o dimension of the test block in the given anatomical direction, at ovendry condition, mm

V_{sat} volume of test block at/above saturation point, mm3-ben

V_o ovendry volume of the test block, mm3 $V=x_r \times x_t * x_l$ in both cases

a_{sw} swelling anisotropy of wood

As the wood gets to ovendry condition during heat treatment, it was possible to measure the swelling caused by re-moisturizing and its corresponding parameters. Such parameters are swelling anisotropy (a_{sw}), which is determined as the quotient of maximal tangential swelling sw_t) and maximal radial swelling (sw_r).

Improvement of anti swelling efficiency (ASE_{sw}) is a result of decreased swelling and shrinkage as an effect of treatment. ASE anti-swelling efficiency is calculated by using the formula as follows, in all anatomical directions:

$$ASE_{sw} = \frac{sw_{control} - sw_{treated}}{sw_{control}} \quad (6)$$

where: ASE_{sw} anti-swelling efficiency (+increase, -/decrease)
sw- in case of swelling
$sw_{control}$ swelling of untreated wood in the given anatomical direction, %
$sw_{treated}$ swelling of treated wood in the given anatomical direction, %

Colour measuring

Colour measuring was done by a KONICA-MINOLTA CM 2600d type colour spectrum measuring machine, with a 8 mm diameter opening. Measuring was controlled by a SpectraMagic NX computer software, using CIELab measuring system (Fig. 2.). In the CIELab system every colour is assigned to a point in a coordinate system.

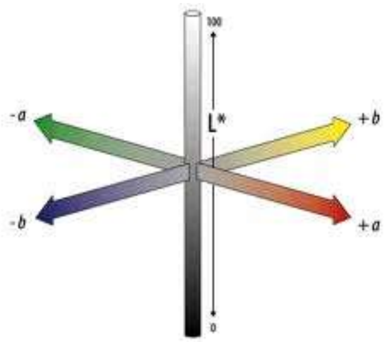

Figure 2. CIELab colour space system

Axes of the system are:
L*: positive direction is lightness, negative direction is darkness
a*: positive direction is red colour component, negative direction is green colour component
b*: positive direction is yellow colour component negative direction is blue colour component
Axes are perpendicular to each other.
Before the heat treatment sample blocks were acclimatized at normal air conditions (65% rel. h, 20°C temp.). Then they were marked and cut to two

pieces. One of the pieces was treated, the other one was the control block. This way the texture was the same in both pieces, the measured difference was clearly the effect of heat treatment.
Colour difference of the samples can be determined by counting the total colour difference parameter, which can be calculated from the colour coordinates using the formula below:

$$\sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (6)$$

Where :

	ΔE	total colour difference of the samples
	ΔL^*	difference in lightness of treated and control samples ($L^*_{treated}$ -$L^*_{control}$)
	Δa^*	difference in red colour component of treated and control samples ($a^*_{treated}$ –$a^*_{control}$)
	Δb^*	difference in yellow colour component of treated and control samples ($b^*_{treated}$ -$b^*_{control}$)

When evaluating the total colour difference of samples the results are categorized into 5 groups. If ΔE is between 0-1, there is no difference
If ΔE is between 2-4, the difference is low
If ΔE is between 4-5, the difference is significant
If ΔE is above 5, the difference is very significant

RESULTS AND DISCUSSION

Change of equilibrium moisture content

After the treatment the equilibrium moisture content of the samples decreased significantly. The reason of the result can be explained by the decrease of the –OH groups in the wood and the spherical effect of the swelling. Diminishing of –OH groups in the wood components results the decreasing of the number of hydrogen-bridges of the water molecules, which determines the water bound in the cell walls.

Table 1: Change of equilibrium moisture content

U_{norm}	Untreated	Treated	Difference	Change [%]
Acacia mangium	12,26%	7,87%	-4,39%P	-35,81%
Acacia auriculiformis	12,17%	8,32%	-3,85%P	-31,64%
Populus eu. Pannónia	12,26%	9,59%	-2,67%P	-21,78%

Change of density

As an effect of thermal treatment chemical changes occur in the wood structure. Some components of the wood disappear as a result degradation. It causes the decreasing of the weight of the samples. At the same time, the matrix structure of the wood also changes. Both changes have an effect of the density. The two effects are opposite to each other.

Results of the tests were as follows:

Table 2: Change of density [kg/m^3]

Density	**Untreated**	**Treated**	**Difference**	**Change [%]**
Acacia mangium	496	473	-23	-4,64%
Acacia auriculiformis	569	465	-104	-18,28%
Populus eu. Pannónia	411	412	1	0,24%

Density of both *Acacia* species decreased. The degree of density change was -4,64% in case of the *A. mangium*, and -18,28% in case of *A. auriculiformis*.

As compared to the density change of the poplar, the rate of change of *Acacias* is much higher, as the respective data of the poplar is nearly 0.

Change of dimensional stability

<u>Maximal swelling before and after heat treatment</u>

The Table nr. 3. shows the values of maximal swelling in case of the untreated and the treated samples. The maximal swelling was measured as a quotient of the difference of the sizes of blocks above fibre-saturation point and sizes of ovendry blocks, divided by ovendry sizes. The value is given in percentage. We measured maximal swelling in case of all the three anatomical directions and calculated the volumetric swelling as well. Heat treatment decreased the values of swelling significantly in case of both species in all anatomical directions.

Table 3: Change of maximal swelling

Swelling	Species	Maximal swelling		Difference	Change [%]
		Untreated	**Treated**		
	Acacia mangium	7,47%	6,96%	-0,51%P	-6,83%
	Acacia auriculiformis	9,32%	6,38%	-2,94%P	-31,55%
ST	*Populus eu.* Pannónia	11,44%	7,93%	-3,51%P	-30,68%
	Acacia mangium	3,87%	3,25%	-0,62%P	-16,02%
	Acacia auriculiformis	3,28%	2,87%	-0,41%P	-12,50%
SR	*Populus eu.* Pannónia	4,60%	3,70%	-0,90%P	-19,57%
	Acacia mangium	0,95%	0,3%	-0,65%P	-68,42%
	Acacia auriculiformis	0,72%	0,32%	-0,40%P	-55,56%
SL	*Populus eu.* Pannónia	-.	-	-	-
	Acacia mangium	12,70%	10,80%	-1,90%P	-14,96%
	Acacia auriculiformis	13,72%	9,78%	-3,94%P	-28,72%
SV	*Populus eu.* Pannónia	-	-	-	-

Dimensional stability

The figure of dimensional stability shows the maximal difference of swelling of the treated material in the percentage of the same of the untreated material. Positive value means the increasing, negative value means the decreasing of dimensional stability.

Dimensional stability was calculated in all anatomical directions of both species. The values are summarized in the Table nr. 4. As a comparison, the relating figure of the poplar is shown. The values of dimensional stability show improvement in all anatomical directions in case of both species, similarly to the respective data of poplar.

Table 4: Dimensional stability

Characteristic	Species	Values
ASEt	*Acacia mangium*	3,76%
	Acacia auriculiformis	24,43%
	Populus eu. Pannónia	30,71%
ASE_r	*Acacia mangium*	14,30%
	Acacia auriculiformis	12,00%
	Populus eu. Pannónia	19,57%
ASE_l	*Acacia mangium*	64,14%
	Acacia auriculiformis	46,28%
	Populus eu. Pannónia	-
ASE_V	*Acacia mangium*	7,75%
	Acacia auriculiformis	22,51%
	Populus eu. Pannónia	-

<u>Swelling anisotropy</u>

Swelling anisotropy means the rate of maximal swelling in tangential and radial anatomical direction. Swelling anisotropy decreased significantly in case of *A. auriculiformis*, similarly to the respective data of poplar, however slightly increased in case of *A. mangium*.

Table 5: Change of swelling anisotropy

Species	Swelling anisotropy		Difference	Change [%]
	Untreated	Treated		
Acacia mangium	1,93	2,14	0,21	11%
Acacia auriculiformis	2,84	2,22	-0,62	-22%
Populus eu. Pannónia	2,54	1,98	-0,56	-22%

Change of colour

<u>Lightness</u>

All measurements were carried out on the heartwood of the samples. Original colour of *A. mangium* is rather light, L*value is cca 72, while *A. auriculiformis* is much darker, L* value is nearly 60. Lightness, the vertical coordinate of the CIELab colour space system decreased significantly in case of both tested material. The rate of decrease was very similar, 22,8% and 21,6% in case of *A. mangium* and *A. auriculiformis* respectively. These values were nearly the double of the relating value of the poplar.

Table 6: Change of lightness(L*)

Species	**L*(D65)**		**Difference**	**Change [%]**
	Original	**Treated**		
Acacia mangium	71,81	55,31	-16,50	-22,8%
Acacia auriculiformis	59,49	46,71	-12,78	-21,6%
Populus eu. Pannónia	84	76,24	-7,76	-9,2%

Red colour component

The values of red colour component (a*) were 6,42 and 7,66 of the untreated samples of *A. mangium* and *A. auriculiformis* respectively. As an effect of the thermal treatment, the values increased by 72,7% and 40,9%. Both materials turned to a reddish colour. As compared to the respective values of poplar, the direction of change is similar, however the rate of change is slightly smaller and considerably smaller in case of *A. mangium* and *A. auriculiformis*.

Table 7: Change of red colour component (a*)

Species	**a*(D65)**		**Difference**	**Change %**
	Original	**Treated**		
Acacia mangium	6,42	10,71	4,28	72,7%
Acacia auriculiformis	7,66	10,68	3,02	40,9%
Populus eu. Pannónia	3,63	6,51	2,88	79,3%

Yellow colour component

The value of red colour component (a*) were 22,49 and 24,47 of the untreated samples of *A. mangium* and *A. auriculiformis* respectively. As an effect of the thermal treatment, the values increased by 37,8% and 16,4%. Both materials turned to a yellowish colour. As compared to the respective values of poplar, the direction of change is similar. The percentage of change in case of poplar is between the two species of *Acacia*.

Table 8: Change of yellow colour component (b*)

Species	**B*(D65)**		**Difference**	**Change [%]**
	Original	**Treated**		
Acacia mangium	22,49	30,97	8,48	37,8%
Acacia auriculiformis	24,47	29,63	5,16	16,4%
Populus eu. Pannónia	18,42	21,83	3,41	18,5%

Total colour difference

The calculated total colour difference proves, that the colour change is very significant in case of both tested material. The total colour difference was higher in case of *A. mangium*, but the relating value of *A. auriculiformis* was also much higher, than that of the poplar.

Table 9: Total colour difference (b*)

Species	**Total colour difference ΔE**
Acacia mangium	19,03
Acacia auriculiformis	14,11
Populus eu. Pannónia	8,95

CONCLUSIONS

By completing the experiments of thermal treatment of *Acacia mangium* and *Acacia auriculiformis*, we proved that the change of physical properties of these tropical hardwoods is generally similar to the same of moderately hard European hardwoods. (The test results were compared to the same figures of *Populus* × *euramericana* Pannónia.)

Equilibrium moisture content decreased significantly in case of both species, especially in case of *A. auriculiformis*. Density decreased considerably, which shows, that degradation of the wood structure starts at the temperature of the applied thermal treatment (180°C). Anti swelling efficiency increased considerably as an effect of the heat treatment. This property is important when processing the wood.

Change of colour components was also similar to that of the European hardwoods and especially poplar: value of lightness decreased, while value of red and yellow components increased. This property can be well used in the industrial processing of *Acacias*, as favourable darker coloured wood can be gained by thermal treatment.

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Glulam beams made of Hungarian raw materials*

Mátyás Schlosser[1], Norbert Horváth[2], László Bejó[3]

[1] PhD student, Institute of Wood and Paper Technology, Faculty of Wood Sciences, University of West Hungary, 4 Bajcsy-Zs. st., Sopron, HUNGARY.
schlosser@fmk.nyme.hu

[2] Scientific Associate, Institute of Wood Science, Faculty of Wood Sciences, University of West Hungary, 4 Bajcsy-Zs. st., Sopron, HUNGARY.
hnorbert@fmk.nyme.hu

[3] Associate Professor, Institute of Wood and Paper Technology, Faculty of Wood Sciences, University of West Hungary, 4 Bajcsy-Zs. st., Sopron, HUNGARY.
lbejo@fmk.nyme.hu

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ABSTRACT

A research team was established at the Faculty of Wood Sciences in September 2011, in order to foster the production of glued-laminated beams based on Hungarian raw materials. The goal is to support the production of straight, and, later, curved beams through creating, testing and evaluating model beams and prototypes. Historic examples found in the literatures should first be reviewed. Because of the general lack of construction wood, many studies were conducted in the 1960's and 70's for replacing conifers with poplar raw materials, e.g. in the Wood Research Institute in Budapest. The physical and mechanical properties of various hybrid poplars were investigated. The 'Robusta' hybrid, and occasionally the 'Marilandica' and 'Serotina' varieties, were found to be applicable for construction purposes to carry medium loads, with some technical conditions (wood protection). Other tests showed that a basic criterion for using poplars is that their density should exceed 400 kg/m^3, because density and strength values correlate closely. This is the criterion for wood to satisfy the standards concerning construction materials (like EN 338 and EN 1194). The apex of contemporary research was designing and constructing an 800 m^2 hall built of poplar raw material, with a novel, three-hinged truss structure. Built in

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Velence, Hungary in 1974, the hall is still in use today, and has a surprisingly sturdy wood structure. This proves that poplar has great potential as a structural wood, and justifies further investigation of the available hybrid poplars (e.g. plantation ‘Pannonia’ poplar.)

INTRODUCTION

Glued constructional wood was first introduced by master carpenter and entrepreneur Otto Hertzer who was granted a patent in 1906 for his invention of a constructional element made up of several lamellae glued together. He applied pressure to create a permanent bond between the lamellae. Hetzer’s technology was further improved in the second half of the 20th century, and today laminated beams of homogeneous quality, as long as 50 m, with heights in excess of 3 m may be created. A further advantage is that beams may be curved in one or two directions, or even twisted around their own axes. Products are manufactured precisely in a plant, and thus construction times of buildings (houses, halls and bridges) made of glued elements are considerably shorter than those of traditional construction techniques, which offers a competitive edge. In terms of environment protection, there is hardly another building material that can meet the ever more stringent requirements, which will make wood even more attractive in the future.

HUNGARIAN WOOD SPECIES SUITABLE FOR GLULAM BEAM MANUFACTURE

None of the wood species are completely excluded from constructional use, but economic factors and structural design requirements limit the range of practically applicable species (Wittmann 2000). Of the many wood properties, mechanical and physical characteristics are especially relevant.

When producing wood beams, reliable glueline strength calls for consistent wood quality. In this respect, coniferous species with their homogeneous structure are most suitable, and therefore are most commonly used. Growth characteristics, physical and mechanical properties and workability are also vital, these also put softwoods in a preferred position. On the other hand, aesthetic requirements, high strength and durability may necessitate the use of high density hardwoods, even considering the higher costs.

In Hungary, the following species are typically used:

- softwoods: spruce, silver fir, Douglas fir, Scots pine, and, for special purposes, larch.
- hardwoods: oak, occasionally black locust, as well as beach, poplar and alder with appropriate wood preservation.

Arguments for hardwoods include high strength, in case of oak and black locust, and good dimensional characteristics and favourable price, for poplar. The construction industry, as well as door and window manufacturers almost exclusively use softwood, mostly in the form of sawn lumber (Zoller and Molnar, 1974). In terms of softwood, Hungary is entirely dependent on import. There were several research projects aimed at technical development that takes the species mix of Hungarian forests into consideration. These projects proved that poplars can usually be used instead of softwoods as raw materials for glued-laminated beams (Erdelyi et al, 1976). Compared to other hardwood species, poplar grows fast, and the age of harvest is low (15-30 years). In forest management it is considered economically important because of the high yield of industrial wood.

A member of the salicaceae family, the poplar genus includes many species. Earlier, poplars used to be divided into two groups in Hungary, including domestic poplars (silver, grey, black poplar, and quaking aspen) and noble poplars that included hybrid species. This classification is not valid any more, because, in addition to the Marilandica, Serotina and Robusta varieties, more than 10 other hybrids are being cultivated today (Molnar 2004). Different poplar species and hybrids may have widely variable density, so mechanical properties vary as well. Three different groups can be distinguished based on density (Table 1.)

Table 1: Classification of poplar species and hybrids

Group	Density	Hybrid
Very low density	< 360 kg/m^3	I-214, Villafranca, etc.
Low density	360 – 400 kg/m^3	Kopecky, Sudar, etc.
Moderately low density	> 400 kg/m^3	Robusta, Marilandica, Pannonia, etc.

The macroscopic identification of domestic and noble poplars are effectively impossible based on a small section. Still, their characteristics are very different, and this may cause many problems during utilisation. This fact often discourages wood industry professionals from using poplar. One way to overcome this problem is by attaching a certificate of origin to each shipment. Also, due to the uniform density of late and earlywood, no serrulate notching of the cutting edge occurs, as is the case when cutting softwood. Poplars are not resistant to fungal and insect attack, but pressure

treatment is effective both with oil- and water-based preservatives. Preservative uptake is 180 kg/m^3 when using oil-based preservatives, and approx. 5 kg/m3 is required when using a aqueous solution (Hadnagy 1968).
Erdelyi and Wittmann were the first to study the physical and mechanical characteristics of poplar comprehensively, in 1969. They collected samples from various locations in the country, including Baja, Szolnok, Nyirseg and Sarvar, to study their properties. They carried out the strength measurement of the robusta, marilandica and serotina varieties, as well as the I-214 hybrid, at 15% moisture content. Their data show that the physical and mechanical properties of the same hybrids can be different when grown at different locations. This proves that, in addition to genetics, site characteristics influence physical and mechanical properties significantly (Erdelyi and Wittmann 1969).
Their study also proved that, even though, traditionally, poplar was traditionally deemed unsuitable for uses that call for high strength, the properties of the robusta poplar are outstanding, and approach the strength values of some softwood species. However, differences between the strength properties of the four varieties are so significant that they limit their practical application. I-214, especially, yielded such low values that this hybrid may not be used in load-bearing applications. With medium loads, when fulfilling some technical criteria (wood protection), particularly the robusta variety, but also the marilandica and serotina hybrids may be suitable (Erdelyi and Wittmann 1969).

Table 2: Mechanical characteristics

Characteristic	Unit	Marilandica*	Marilandica**	Pannonia**	Pannonia***
Density	kg/m^3	396	425	406	411.3
Compression strength	N/mm^2	28.8	22.6	32.6	38.8
Bending strength	N/mm^2	54.4	60.8	67.4	63.5
Shear strength along the grain	N/mm^2	7.7	7.6	8.3	
Brinell hardness	N/mm^2	27.1	30.9	20.6	
Bending MOE	N/mm^2	7651.8	7800	6510	7695.8

Erdelyi and Wittmann 1969, **Molnar 2004, * Horvath 2008,* u_{ave}*=12,26%*

Based on the results of Erdelyi and Wittmann, as well as those of Molnar and Horvath, there is sometimes a significant difference between the results of the same hybrids grown at different sites. Non-destructive testing techniques would be useful for the strength grading these hardwoods.
The robusta, marilandica and serotina varieties are the primary species used to be considered for structural use, not only because they fulfilled the strength and density criteria, but because of their availability in the necessary quantities and in adequate length and cross sectional dimensions. Today, however, Pannonia poplar may be the best choice. Since growing this

material has been permitted since 1980, almost 40% of all poplar propagation material was made up of this species in 1991, and 30-32 year-old-stands may exist today.

GLUED-LAMINATED BEAM PRODUCTION TECHNOLOGY

The production technology of glued laminated beams consist of the following processes:

- raw material preparation
- cross-cutting
- end jointing
- planing the lamellae
- adhesive application
- pressing
- finishing

During raw material preparation, low quality materials that are unsuitable for lamella manufacture are rejected, and do not get dried. The remaining lumber is classified according to width. Drying lumber with nearly uniform width together ensures that the raw material is available for a given beam width.

Cross cutting is based on the quality and shape of the raw material in order to provide full-size, defect-free blanks. This seriously impacts both the cost of production and final product quality. After cross-cutting, rip sawing may be included (usually with a double blade edging saw). The lumber is sawn 10-15 mm wider than its final size to allow for subsequent planing losses. After cutting, the moisture content should be verified.

10 to 20 mm long finger joints are used for end jointing according to the relevant standards. An automated combined finger jointing machine moulds the end of the blanks, applied the adhesive and performs the longitudinal pressing of the meshing finger jointed ends. Choosing the right type of adhesive is very important. Resorcinol adhesives used to be used for this, but nowadays some of the more modern adhesives like polyurethane based construction grade adhesives and emulsion polymers are most widespread. The applied pressure should also be chosen carefully. Based on earlier studies, the applied load depends on the wood species and the dimensions of the finger joints. Table 3 shows the recommended minimum values.

Table 3: Recommended minimum pressing forces (Kajli et al., 1975)

Finger length (mm)	Pressing force N/mm^2 *	
	poplar	black locust
7.5	12–19	16–25
10	8–12	11–16
20	5–7	6.5–9
50	2.5–3	3.5– 4.5

**Based on the cross-sectional area of the jointed lumber*

The planing of the lamellae occurs after the finger joint strength reaches the required level. Lamellae are planed in a single step, with a multi-head moulder.

Adhesive may be applied to both side using rollers, or to one side only, using a curtain coater. The recommended mode of application depends on the type of adhesive used. The adhesive should be used within its gel time. E.g., in case of resorcinol glues, at a 20 °C temperature, pot life was approx. 3–4 hours.

After the adhesive application, the bundle containing the appropriate nr. of lamellae according to the beam dimensions, are placed in presses that can provide the necessary pressure. This varies between 0.5–1.5 N/mm^2, depending on the species. There are many pressing setups, from simple horizontal screw presses to vertical hydraulic presses with automated feeding. In addition to the appropriate level of pressure, uniform pressure distribution is ensured through the use of shims and pressure distributing bars. At the beginning of the pressing cycle, lateral presses are used to adjust the lateral faces of the lamellae. Clamping starts in the middle of the beam, and proceeds outward towards the two ends. During pressing, some of the adhesive gets pressed out of the gluelines, and the wood suffers a permanent viscoelastic deformation. This leads to a drop in the applied pressure over time, so, in case of mechanical clamping, the presses need tightening after 15 minutes. Temperatures and pressing times vary according to the type of adhesive used, and some adhesives require several weeks to reach their final strength (Kajli et al. 1975).

A MULTIFUNCTIONAL HALL BUILT OF POPLAR WOOD

The load-bearing structure of the first poplar glulam beam-supported building was manufactured at the Wood Research Institute in Budapest, commissioned by the National Technical Development Committee in 1975. This was also the first building with a three-hinged truss structure in the country (Wittmann and Pluzsik 1975).

The structure was built mostly of glued-laminated (robusta) poplar raw material. The base girder is an exception; it was manufactured of black locust, another Hungarian species. The laminate structure is very important when using hardwood species. This should consist of at least 4 laminates in order to prevent subsequent warpage. A great advantage of lamination, especially when using hardwood, is the elimination of wood defects. This improves strength and fire resistance, as well.

The curved „shoulders” of the three-hinged arches are appended to support the sheathing.

Principal dimensions:
- span: 18 m
- distance between arches: 6 m
- shoulder height: 4 m
- top hinge height: 7.5 m
- floor space: 800 m^2

The interior height of the building is 3.9–7.4 m in-between, and about 0.2–1.5 m lower underneath the arches. The structural elements of the framework are jointed with steel connectors. Poplar has low resistance against degradation, and was treated with a preservative (Pharmol HSL 1019) and a transparent finish (Pharmol PVK 1085). The outside sheathing consists of wood-frame panels made of glued-laminated poplar.

The primary joists are made of glued-laminated arches with shoulder appendages, 120 mm in width and variable in height (0.64 m at the base, 1.54 m at the middle of the curve, and .36 m at the top hinge.) The distance between the lower hinge and the shoulder is 4 m, the height of the top hinge is 7.5 m. The vertical column on the outside of the joist allows the connection of sheathing. The purlins are 100 mm in width and 320 mm in height, and are 6 m long to match the distance between the joists. The two ends of the purlins have a 20 cm high rabbet, so that only 12 cm of the material sits on top of the joist, and 20 cm rests on the side. Thus, they also provide lateral support for the joists. On the two ends of the building, purlins protrude over the façade to support the rim. (Wittmann and Pluzsik, 1973).

According to the technical description, the hall (Fig. 1) was designed as a multi-functional building. The large, unbroken, enclosed internal space is uninterrupted by any internal support element, and thus it is suitable for the purposes of storage, industrial hall or even as a sports hall. Throughout the years it was used for all three of these purposes (most recently as a winter tennis court), and it performed well in all capacities. The fact that, even after 40 years, there is no evidence of damage to the joists, the building still stands and is structurally sound, bears witness to the to the quality of construction. During a 2012 visit, the building was found in excellent conditions, no deterioration was evident when compared to its original state.

Figure 1: Glued-laminated structure made of poplar

SUMMARY AND CONCLUSIONS

A thorough review of the Hungarian literature revealed that some poplar hybrids are suitable for structural use. The necessary production technology is well known and established. The use of the Pannonia variety, not included in earlier studies, as a construction material necessitates further studies. In case of positive results, Pannonia poplar can be included in the list of hardwoods applicable for structural purposes. A more detailed examination of the hall designed and built using poplar glued-laminated joists in the ‘70s by the Wood Research Institute in Budapest, and preserved in a good condition, may provide further important learnings as well.

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