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for Wood Science and
Engineering (WSE)

Wood science and engineering –
a key factor on the transition to
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This is the 12th Meeting of the Nordic-Baltic community, involved in the NORTHERN EUROPEAN NETWORK FOR WOOD SCIENCE AND ENGINEERING (WSE) studies.

The basis of this meeting, which has become already traditional, is the decision taken by the SNS-Nordic Forest Research Cooperation Committee in 2004 to back the Nordic-Baltic network for scientists involved in wood science and engineering research. Currently, the network involves 10 partner countries.

The previous meetings starting from 2005 were held in Honne (N), Stockholm (SE), Helsinki (FI), Riga (LV), Copenhagen (DK), Tallinn (EST), Oslo (N), Kaunas (LT), Hannover (DE), Edinburgh (UK) and Poznan (PL).

The importance of this meeting is undeniable, especially for young researchers. Essential contributions are the exchange of know-how and experience, dissemination of results, and the potentialities to establish new contacts and further co-operation projects.

The meeting will cover the following themes:

• Wood physics and mechanics
• Engineered wood products & composites
• Wood protection and modification, durability
• Application of wood based materials
• Wood engineering

A separate session is dedicated to the evaluation of the role of forestry and timber industry in the Nordic bio-economy (new tendencies, markets). The bio-refinery concept potential in the rational utilisation of wood (new products) is assessed. Great attention is paid to the development of engineered wood products.

The task of all researchers involved in the wood field is the transfer from fundamental research to applied research; development of technologies, innovations and promotion of the transfer to the optimal utilisation of wood.

These network activities will certainly reach the target – to support and contribute to the Nordic research cooperation.

We are really glad to welcome you at the 12th Meeting in Riga, and we express our gratitude for the contributions in ensuring the high scientific level of this event.

Riga, September 2016
Bruno Andersons
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FOREST SECTOR – THE CORNERSTONE OF LATVIA’S (BIO) ECONOMY

Klauss, K.¹

ABSTRACT

With forests covering more than half of the country’s territory, Latvia is one of the most forested EU member states, and it is so natural, that forest sector is very important in Latvian economy.

Apart of being the most common natural resource, forest and forestry has a huge impact to all Latvian population, especially to those in rural areas, giving work and business opportunities to communities living outside of the central cities and towns.

THERE IS NO LATVIA WITHOUT FORESTS

The amount of forestland is constantly expanding, both naturally and thanks to afforestation of infertile land and other land that is not used for agriculture. More important, however, is another indicator – the volume of timber in the forest is increasing three times more than the area of forestland. This proves that the forest area in Latvia is not expanding because of bushes that are not counted as part of the area of forest. On the contrary, forestry work in Latvia has been very targeted. An average of approximately 12 million m³ of round wood have been harvested each year in Latvia’s forests during the past decade. That is less than the annual increment, and so forestry in Latvia can be described as sustainable.

In historical terms, the intensive use of Latvia’s forests for economic purposes began comparatively later than in many other European countries, and that has allowed us to preserve extensive biological diversity. Limitations on economic activity apply to 13,7% of Latvia’s forests at this time, and most of this territory is owned by the state. 683 especially protected environmental territories have been set aside to protect nature. Many are included in the unified and pan-European NATURA 2000 network of protected territories.

The Latvian state owns around one-half of the country’s forests, while most of the rest of the forest belongs to approximately 150 000 private owners. Nearly everywhere, people are free to hike through the forest and to pick mushrooms or berries. The number of places for recreation is increasing every year in Latvia’s forests, and the territories in which recreation is one of the main goals of forest management represent 8% of all forestland in Latvia.

¹ Latvian Forest Industry Federation, kristaps.klauss@latvianwood.lv
WOOD PROCESSING

Forest sector’s share of Latvia’s manufacturing is about 27%, and the value of products turned out by the sector reached more than 2 billion EUR. Forest sector is also providing around 20% of overall product exports and forest sector share in National GDP is around 5%. Currently more than 70% of forest sector output is exported.

In recent years, in order to remain competitive, companies operating in the wood-working industry have been obliged to give serious consideration to developing new competitive products, as it was recognized that manufacturing inexpensive products from expensive raw materials was not cost-effective.

The last few years have seen the replacement of equipment, technologies, and products in the woodworking industry, aiming for more complete utilization of various tree species and small-dimension saw-logs. Small and medium-sized companies, which predominate in the forestry sector, mainly manufacture niche products (garden, finishing, packaging, joinery products, etc.), while the larger enterprises focus on the production of higher value-added products (load-bearing products, impregnated products, construction materials).

Primary wood processing is generally based on modern technologies meeting the requirements of the global market, both in terms of productivity and product quality. As a result, primary wood processing has built a stable foundation both for exports and the development of further processing, as well as for the production of higher value-added products.

WOOD ENERGY

Apart of timber production, the wood energy subsector is very developed in Latvia. Despite being a small country, Latvia is one of European leaders of wood-pellet production, even though there is little local demand for them.

Because of Latvia’s climate and traditions, thermal-energy generation traditionally forms the largest proportion – almost 70% - of the national energy balance, and wood products have always been an important domestic fuel in Latvia, with a fuel-balance proportion of around one third.
ROLE OF WOOD-BASED BIOREFINING IN THE EUROPEAN BIOECONOMY

Niemelä, K.¹

ABSTRACT

The role of wood-based biorefining in the European bioeconomy is briefly discussed, with some comments on the current and future trends. At the moment, the European forest industry and other relevant sectors are actively searching for new processes and products for sustainable use of forest resources. This is achieved, for example, by converting pulp mills to more advanced pulp mill biorefineries (bioproduct mills), by developing novel value-added applications to the cellulosic fibres, and by more efficient ways to re-use recovered wood and fibres.

Keywords: Bioeconomy, biorefining, forest industry, bioproducts.

INTRODUCTION

Wood-based biorefining – sustainable processing of wood to a spectrum of marketable products – represents a bio-resource vision in bioeconomy (cf. Bugge et al. 2016). In other words, there is a strong focus on processing and upgrading of the biological raw materials, as well as on the establishment of the corresponding new value chains. This vision can also include the cascading use of the raw materials; as covered in a recent comprehensive report by Vis et al. (2016). The present contribution discusses selected topics on the current and potential roles of wood-based biorefining in Europe, with a clear focus on the operations integrated into pulp and papermaking processes. For further information and additional examples on the current academic and industrial topics of interest, the readers may look at a recent book edited by Christopher (2013) and two freely available proceeding books from Nordic Wood Biorefinery Conferences (NWBC 2012 and 2015).

ABOUT RECENT, CURRENT AND FUTURE TRENDS

Different industrial processes have been used in the past for the manufacture of various chemicals and chemical fractions from wood, using approaches characteristic of modern biorefinery concepts. However, many of them were far from sustainable processes, thus heavily exploiting available wood resources, also leaving high amounts of waste materials. Well-known early examples include the production of

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potash, charcoal and different tars or related products. Later (c. 1800-1930), huge amounts of wood were used for the production of chemicals such as acetic acid, methanol, acetone and oxalic acid, before synthetic methods for them were invented. By the middle or end of the 20th century, a large number of pulping by-products became important chemicals, biofuels and materials from forest industry. The long list of products include ethanol, methanol, other alcohols, torula yeast, pekilo protein, xylose (for xylitol), furfural, acetic acid, p-cymene, turpentine and its fractions, tall oil (including phytosterols), kraft lignin, lignosulphonates, vanillin, and many others. Innovative nature of the developed recovery processes is revealed by the fact that low-concentration chemicals such as ammonia and dimethyl sulphide were occasionally also isolated from the pulp mill streams.

Today, the interest in pulping by-products continues strong as the industry is aiming at more advanced pulp mill biorefineries and bioproduct mills. This is indicated by several recent realised or announced new separation (and application) projects, as well as by new pulping capacities (recently realised, under construction, or under planning). At the same time, there is increasing interest in the production of specialty fibres or cellulosic materials, for more value-adding applications (e.g. textiles, chemicals, advanced packages, composites) than traditional pulp and paper products (although their demand in Europe is predicted to stay nearly constant in near future, as shown in Fig. 1).

![Fig. 1. World demand for paper and paperboard (from Pöyry).](image)

New types of pulping by-products of interest, as well as the main or secondary products from different stand-alone biorefinery operations, seem to be focused on utilisation of both of lignin and cellulose/hemicellulose fractions. A huge number
of process concepts have been proposed or designed for the production of lignocellulosic sugars as platform chemicals (especially as biopolymer raw materials, cf. Koutinas et al. 2014), but their industrial scale production can be expected to remain rather limited in near future. The use of different technical lignins (including hydrolysis lignin from bioethanol processes) for numerous chemical and material applications has also attracted a lot of (new) interest during the past couple of decades; new lignin-based products will inevitably enter the markets during the coming years.

The increasing interest in the use of recovered materials (both wood and fibres) for value-added applications is evident. As illustrated in Fig. 2, the level of post-consumer wood use varies a lot in Europe. In different countries, there are varying activities taken to increase both the recovery rates and new uses for the recovered wood. In a similar way, alternative uses (e.g. textiles, bioethanol, and chemicals) are being developed for the recovered fibres.

![Fig. 2. Percentage post-consumer wood used for material and energy applications in Europe (from Vis et al. 2016).](image)

In general, the European and many national and regional bioeconomy strategies and initiatives favour the sustainable use of forest resources as raw materials in bioeconomy (Bioökonomierat 2016; see also Scarlat et al. 2015, de Besi and McCormick 2015). The strategies emphasise the need for strong collaboration (nationally and internationally) between the research institutions and industrial players to facilitate technological innovations. In this, the small companies (SMEs and spin-offs) also have important roles.

For the research efforts, availability of suitable research infrastructures with open access policy is getting more and more important. A 2-year EU project Erifore,
European Research Infrastructure for circular forest bioeconomy, was started between 13 partners in the beginning of 2016 to address this question. The planned work will review current state-of-the-art of infrastructures for the forest biomass, processing, separation, purification and conversion to products involving all the stakeholders in surveying the main drivers, technology trends and development needs of the infrastructure. The collected and analysed data will be utilized for the conceptual analysis and design study aiming for future ESFRI collaboration project. The suggested future European research infrastructure will facilitate the development towards enhanced utilisation of renewable raw materials and renewal of established European process industry.

The current status and future visions of the European and international wood-based biorefining will be the topic of the 7th Nordic Wood Biorefinery Conference, to be held in Stockholm on March 28–30, 2017 (NWBC 2017).

REFERENCES

DRIVERS AND BARRIERS FOR AN INCREASED USE OF BIO-BASED BUILDING MATERIALS IN SWEDEN

Markström, E.¹, Bystedt, A.², Fredriksson, M.³ & Sandberg, D.⁴

ABSTRACT

To limit the climate impact of buildings, low carbon materials such as bio-based materials could be used. This study intends to contribute to the understanding of drivers and barriers for an increased use of bio-based building materials in apartment buildings. For this purpose, semi-structured interviews with Swedish architects, contractors and developers were conducted. The results indicate weak drivers for selecting bio-based materials at present and that the key barriers are insufficient incentives, lack of knowledge and experience, bad examples, issues regarding performance, and construction-related culture and habits. Important future drivers could be green building certificates and other environmental standards and regulations, evidence that the materials keep a certain quality over time, and educational support from municipalities.

Keywords: Construction industry, stakeholder perception, green building, diffusion of innovations

INTRODUCTION

Currently, there is a housing shortage in many Swedish cities and as a result investments in new apartment buildings have started to increase. The climate impact of the buildings depends to a great extent on the amount of energy used during operation and on the environmental performance of that energy (Rossi et al. 2012). However, since the energy-efficiency of buildings has improved and there is an ongoing shift towards a more sustainable energy mix, the production phase is starting to become a more significant feature of a building’s climate impact (Blengini and Carlo 2010). Material substitution to include a larger share of bio-based materials has been shown to decrease the climate impact (Thormark 2006, Rossi et al. 2012).

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⁴ Professor, Department of Engineering Science and Mathematics, Luleå University of Technology, Forskargatan 1, 931 87 Skellefteå, Sweden, Tel.: +46(0)70 431 90 62, Email: dick.sandberg@ltu.se
Thus, it is of interest to consider ways to increase the proportion of bio-based materials used in buildings.

Drivers and barriers for using structural timber in multi-storey constructions in Europe have been reported in earlier studies (see Hurmekoski et al. 2015 for an overview) as well as drivers and barriers in UK for low carbon building materials (Giesekam et al. 2016), and for recycled materials (Chick and Micklethwaite 2004). The present study intends to contribute to a deeper understanding of drivers and barriers for an increased use of bio-based building materials in Sweden by adopting a broad perspective, including the perception of architects, contractors and developers regarding bio-based materials in general. Further, the present study builds upon an earlier interview study with Swedish architects and contractors by Markström et al. (2016).

**MATERIAL AND METHODS**

The methodological approach follows that in Markström et al. (2016) and rests on the Theory of Planned Behaviour (Ajzen 1985) and on Innovation Theories (Rogers 2003). A qualitative approach with semi-structured interviews was used. Swedish architects, contractors and developers were selected for the interviews since they have been identified to have a large impact on the selection respectively of façade materials, structural materials, and the interiors (Markström et al. 2016). Purposive sampling was used in the selection of respondents. The study targeted larger firms and also aimed at a geographical spread. Thus, the firms were selected based on size and geographical location. Within these firms respondents were selected based on their experience of residential buildings. In total 12 interviews were held (Table 1). During the sampling, attention was also given to the respondent’s years of experience, gender, and background in order to get a spread among these parameters to better capture different viewpoints and information (Yin 2011).

<table>
<thead>
<tr>
<th>Category</th>
<th>Years of experience</th>
<th>Gender</th>
<th>Number of interviews</th>
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<td>10-20</td>
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<tr>
<td>Architect</td>
<td>1</td>
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<tr>
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<td>Developer</td>
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</table>

Four of the interviews were held face-to-face at the respondent’s office and the rest were conducted via telephone. The duration of the interviews was between 30 and 75 minutes. All the interviews, but one, were recorded and then transcribed. Each transcription was summarized and sent to the respondent for correction in order to strengthen the validity, as suggested in the literature (Yin 2011). In two cases, the respondent made minor changes to the text.
During the analysis, the five phases commonly used in qualitative research were followed (Yin 2011). Sentences and phrases from the interviews were given labels and then they were sorted in categories. The data under each category was compared and interpreted, first for all respondents individually and then collectively, after which conclusions could be drawn. Before the disassembling, all the transcriptions and the summaries were read through several times.

RESULTS

Barriers

When selecting materials, cost and durability (proof of quality over time) are considered to be important criterions in addition to functional requirements concerning e.g. fire and moisture. Regarding cost, the developers mainly think of the purchase price and the cost of installation whereas the developers consider the life cycle cost where the need of maintenance is of importance. The architects also consider the need of maintenance as important, but from an aesthetical point of view. The time horizon regarding durability varies for the actors; the developers want the materials to sustain the warranty period with marginal (about 10-15 years horizon), the developers want materials that sustain 30-100 years or more – depending on application – with no or minimal maintenance, and the architects has a time horizon somewhere in between the other two groups. When there are uncertainties regarding the quality of a material, the actors are reluctant to select it. Developers are worried about an increased burden in maintenance and that the potential initial environmental gains with a bio-based material will be lost if the service life proves to be short. Contractors see the risk of an extra cost and bad reputation if the material fails within the warranty period. Other important criterions are delivery time, supply security, and assembly period for the contractors. How the customers perceive the materials and that the materials are well proven are considered important by the developers and the architects consider aesthetics as important.

Thus, it is a barrier that bio-based materials in general is considered to be new and not tested, less durable than other groups of materials, and that bio-based alternatives with improved durability often are considered to be too costly. Another barrier is that bio-based materials are associated with a risk of mould and moisture damage which contributes to the selection of e.g. plasterboard and steel joists over wooden alternatives. The perceived difficulty with fulfilling fire requirements, the perceived high cost of fulfilling the fire requirements, and the perceived negative impact on human health and the environment of the chemicals needed for fire protection are also barriers for an increased use of bio-based materials.

Existence and spread of bad examples also hamper the probability of selection of bio-based materials since it contributes to a conservative and reluctant attitude to introduce both bio-based and new materials. Among the architects and contractors, external wall insulation systems were mentioned frequently as bad examples
whereas the developers brought up examples of less successful timber buildings and troubles with cellulose insulation. Some have had bad experience with bio-based sheet materials, thermally treated wood, and wood-plastic composites as well. There is also a lack of knowledge among building engineers and architects of which bio-based alternatives that are available, and how and where to use them. Small profit margins among contractors also contribute to the reluctance of using other materials than the commonly used and since there are plenty of building projects, they do not need to be that innovative in order to get work. Another barrier is that bio-based materials are marketed to a less extent than other materials.

Regarding timber façades, the need of maintenance and the risk of fire are seen as major barriers by the developers. Regarding the maintenance the barriers are; the cost, shortage of painters, the environmental impact, and worries about differences in appearance when using timber cladding in balconies e.g. if the residents do not use the same methods to maintain the cladding and/or do maintenance with different intervals.

Two major barriers for timber construction are difficulties in fulfilling requirements regarding fire safety and acoustics. The developers also perceive that in comparison with concrete, it is more difficult to obtain a construction that is tight when using timber which results in a decreased energy performance. Settlements and crack formation is also seen as barriers to select structural timber by this group since cracks are perceived to impair the visual impression. Further, the service life of timber is perceived to be too short by the developers. Another barrier is that the contractors has interests in other materials and want to streamline the use of the current system where concrete is used.

In some cities there are a shortage of construction workers with knowledge and experience of timber construction. Thus, some developers do not get any tender with timber frames. Stakeholder organizations that lobby against timber construction (uses risk of fire as a main argument) and insurance companies that do not insure buildings with timber frames or timber claddings (due to the risk of fire and the resulting water damage from a fire fighting operation) hinder an increased use of timber. The municipalities are perceived to have insufficient knowledge of timber construction and inconsistent terms regarding buildings which are seen as barriers. The local plan which regulates the height of buildings sometimes constitutes a barrier for timber construction.

**Drivers**

In general the respondents perceive no or low incentives to use bio-based building materials. Incentives seen by some respondents are: green building certification systems, the local strategies for timber construction that exists in some municipalities, political pressure to decrease the environmental impact, faster drying times when using timber compared with concrete, social benefits (timber has a calming effect and makes the residents feel good), that timber provides a warmth, and that
solid timber feels genuine and lavish. Another driver is that there is a lack of labour in the larger cities and to minimize the time on the construction site, work is relocated to smaller cities and other countries. In those cases it is perceived convenient to use prefabricated timber modules.

The incentives to select bio-based building materials would increase if those materials were highly valued in green building assessment schemes, demands and regulations regarding e.g. climate impact of materials were put in place, the customer demand for bio-based materials or more environmental friendly homes increased, and that the developers with rental apartments could access the residents’ potential willingness to pay for such a home. Improved properties of the products regarding moisture sensitivity, maintenance, durability, fire resistance, and acoustics would also increase the incentives to select bio-based alternatives. As an example, properly coated finger joint timber claddings in longer lengths than the ones available at present were requested in order to decrease the need for maintenance and increase the durability. Proof that the materials keep a certain quality over time is also important to increase the incentives to select bio-based materials.

Proof of cost effectiveness, price in the same range as the materials commonly used, and cheaper land prices when building with a certain proportion of timber were also identified as potential future drivers as well as knowledge of the relative advantages of using bio-based alternatives (both the advantages for the customers and the project), increased knowledge of which bio-based alternatives that exists and of how and where to use them, better access to information about bio-based materials, and an increased discussion about these materials in positive terms. One instrument to increase the knowledge that is requested is municipality support for education in timber construction.

**DISCUSSION**

A major part of the currently perceived drivers to select bio-based materials is derived from the general perception that those materials are more environmental friendly than other groups of materials in the perspective cradle-to-gate. When talking about the whole life cycle, the respondents are uncertain if bio-based materials are the best alternative due to transport distances, need for maintenance, and perceived shorter service life. The respondents also find it confusing that the concrete industry and the wood and timber industry calculate the environmental impacts somewhat different. Thus, it is of importance to continue the work with life cycle assessments on building materials and to spread these results and knowledge of how to interpret them among building professionals.

A further indication that good environmental performance is regarded as important by the sector is that the concrete industry has started to change their recipes in order to decrease their environmental impact. These changes has led to longer drying times at low temperatures which some developers has found troublesome.
At present, short construction periods are of great importance and the short drying times for timber could thus become a stronger driver in the future.

Although green building certification systems is highlighted as a promising future driver by the majority of the respondents there are indications of some trends that need attention. There is an indication of an increased interest in these systems among contractors and some of the developers. However, the contractors and some of the architects perceive that the certifications results in an inferior and more expensive product. Among developers that have worked with the systems for some years, the interest has gone cold due to the cost and the workload. However, these actors stated that most of their buildings would pass the second level in the most commonly used green building certification system in Sweden but they do not bother to certify them because they do not see a benefit by doing so.

The shortage of builders with knowledge about timber construction is a major barrier that must be addressed. At present researchers at Linnaeus University are trying to get manufacturers of detached timber houses to engage in multifamily houses as well and some developers are pushing smaller contractors to invest in learning timber construction in order to gain competitive advantages over larger firms. The lack of knowledge is also an explanation to some of the unsuccessful attempts of using bio-based materials. One example mentioned were bio-based insulation that had been used in an incorrect way.

Moreover, there is a need to evaluate how well the local strategies for timber construction have worked out so far and what can be done in order to strengthen them. Even though some perceive these strategies as drivers to select timber, some perceive them to hinder the use of timber since they do not focus on the main barriers for an increased use. There are also mixed opinions regarding introduction of regulations on the environmental impact of materials, were a few of the respondents are negative. In order to know how such legislation would be received and how to best design them, more actors must be asked. A lifecycle perspective is, however, perceived to be important in this context.

CONCLUSIONS

This study has contributed to the understanding of drivers and barriers for an increased use of bio-based materials in apartment buildings. This was done by semi-structured interviews with Swedish architects, contractors, and developers. The result indicates that the major drivers perceived by the respondents could be connected to the environmental performance of bio-based materials, fast construction, and the positive feelings that timber provides. Barriers identified are lack of knowledge, issues regarding performance (maintenance/durability, fire safety, acoustics, moisture, crack formation, cost), existence and spread of bad examples, insufficient incentives, insurance companies, local plans, and construction-related culture and habits. To increase the incentives, further development of green
building certificates, implementation of environmental standards and regulations regarding the environmental impact of materials, evidence that the materials keep a certain quality over time, and educational support from municipalities are seen as promising. Further studies must be done in order to know if it is possible to generalize the results to a wider population.

REFERENCES


CUSTOMER REQUIREMENTS ON SOLID WOOD MATERIAL; A BIRCH ROUNDWOOD CASE-STUDY

Nilsson, J.¹ & Johansson, J.²

ABSTRACT

Today a majority of the pre-commercial thinning (PCT) cut birch stems in Sweden are retained on the site for biodegradation, since their market value is lower than the cost of harvesting. Some stems are removed as firewood. The uses of the PCT material can be difficult to find, and the costly PCT is carried out in expectation of greater returns later in the forest rotation. There is a growing body of literature that recognizes the possibility of using a low-value wooden material for furniture and interior purposes. While some research has been carried out on character-marked wood, there have been few investigations on the utilization of small-dimensioned roundwood. However, proper utilization of this material requires appropriate matching of the material attributes with the end user’s expectations on furniture or joinery products. The aim of this work is to understand challenges and possibilities for the utilization of small-dimensioned roundwood birch in furniture and joinery products. The study synthesizes the literature on customers’ demands on hardwood and important material properties. A case-study approach was used to evaluate how a bench, made out of small-dimensioned roundwood birch, can meet the requirements from customers and manufacturing industries. The results demonstrate that opportunities exist within the customer segment appealed by naturalistic furniture design. Proposals are made for future research needed for successful use of small-dimensioned roundwood birch for furniture applications.

Keywords: Betula, customer requirements, furniture material

INTRODUCTION

A specific material may have superior properties but if with low or no commercial availability it will not be possible to use (Karana, Hekkert et al. 2008, Neyses and Sandberg 2015). Birch is the third most common tree species in Sweden (Skogsdata, 2016). Even though birch from a consumer perspective is appreciated in interiors applications such as furniture and joinery, the largest volumes are still utilized for energy or pulp production (Nylinder and Woxblom 2005). In 2010, Swedish

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sawmills’ yearly consumption of birch was only estimated to 80 000 cubic meters solid volume excl. bark (Palm, Karlsson et al. 2011). The industrial use of birch sawn wood in Sweden includes furniture, interior panels/claddings, floors, turned products, plywood, pulp and paper and energy (Lousticinen 2000, Nylinder 2001). However, furniture products are the wood products that today contribute with the highest added value to the raw material (Nylinder and Woxblom 2005, Johansson 2013). Those products are followed by joinery.

One reason for the small volumes of birch utilized for high-value furniture production may be that the wood species rarely is grown with the aim of being raw-material for the sawmill. Most of the Swedish birch resource is found in mixed stands dominated by conifers (Hynynen, Niemistö et al. 2010). In pre-commercial thinning, most birch trees are removed to reduce competition with the commercially valued conifers (Savill 1997). As a result, birch constitutes 12 % of the standing forest volume in Sweden in the range class of all diameters at breast height. In the range 0-9 cm, birch stands for 33 % out of the total volume of 239 million cubic meters standing volume (forest cubic meter) (Nilsson, Cory et al. 2014). For sound silviculture, different timber assortment plays an important role and PCT is also important as a forest management tool (Savill 1997).

Increased demand for cheap material for furniture production has led to the exploration of alternative sources of raw material, either under-utilized species, or lower grades or smaller dimensions. Nicholls and Bumgardner (2015) provide a thorough review of solid wood manufacturing and marketing of low-grade and character-marked hardwoods. According to their classification, low-grade lumber can be used for industrial products (e.g. pallets and railways ties), for value added products as dimension parts for traditional ones such as furniture, and as more novel products making use of the special attributes of character-marks. Many authors investigated the utilization potential of small-diameter stems, with sizes ranging from 10 cm up to around 15 cm (Choong and Tesora 1974, Hakkila, Leikola et al. 1979, Ranta-Maunus 1999, Bumgardner, Hansen et al. 2000, Bumgardner, Bowe et al. 2013, Nilsson and Johansson 2015). A study by Kilpeläinen, Lindblad et al. (2011) showed that simulations with end-use based timber assortment could estimate harvesting recoveries, and that a careful selection of birch thinning stands could provide a substantial amount of raw material for the mechanical wood processing industry (Kilpeläinen, Lindblad et al. 2011).

Today a majority of the pre-commercial thinning PCT cut birch stems are retained on the harvest site for biodegradation, since their market value is lower than the cost of harvesting (Holmström 2015). Some are removed as firewood (Hynynen, Niemistö et al. 2010). The uses of the PCT material can be difficult to find, and the PCT is carried out in the expectation of greater returns later in the forest rotation (Savill 1997, Bumgardner, Hansen et al. 2000). Additional opportunities can come from small-dimensioned roundwood birch, an area which is not researched and rather unexplored. An opportunity could then be to use this material in special
applications for furniture or joinery. A proper utilization of this material requires, however, knowledge of the material properties as well as understanding of the potential customers’ needs. The aim of this work is to understand challenges and possibilities for the utilization of small-dimensioned roundwood birch in furniture and joinery products. The study synthesizes literature on customers’ demands on hardwood and important material properties. A case-study approach was used to evaluate how a bench, made out of small-dimensioned roundwood birch, can meet the requirements from customers and manufacturing industries.

CUSTOMER REQUIREMENTS ON HARDWOOD COMPONENTS FOR FURNITURE

The main aspect of the wood material selection is related to user satisfaction created through aesthetics and the overall perception of the product. Understanding customer requirements and knowing how product criteria affect the satisfaction of customers, leads to a customer-driven design, achieving satisfied customers and securing future market shares. The materials used in the production play a significant role in creating the conception of the quality of the product (Johansson 2008).

Both the processing industry and the end customer wants a material free from cracks. They also require accuracy in dimension and geometry and that the material has controlled movements with changing humidity. Strength and hardness within the material are two other important factors (Johansson 2008, Johansson 2013).

A major difference between material demands from hardwoods and softwoods is the focus on appearance in hardwoods compared to that of strength properties in softwoods. Above-ground durability is crucial for hardwood for exterior applications. Processing industry also puts requirements on the wood materials workability, meaning possibility for surface treatment, constructional solutions, fittings and adhesives that can be used (Dahlgren, Wistrand et al. 1999).

MATERIAL PROPERTIES

Properties in juvenile wood are expected to be different to that of mature wood (Rowell 2012). A small-dimensioned roundwood component with the pith in the center should thus be handled with caution. Such a material was tested for constructional applications (Ranta-Maunus 1999). Due to the round form, it was expected that bending strength would increase compared to that of sawn wood. Multiple regression analysis verified that the 5th percentile value of bending strength of roundwood was double the value of sawn spruce.

Karana, Hekkert et al. (2008) emphasize the crucial role of ICM, intangible characteristic of materials. They conclude that product designers through their material selection impose perceived values and cultural meanings, trend issues, associa-
tions and emotions in the produced object. Also, the environmental profile of the material must be known (Mangonon 1999). It is pointed out that for marketing purposes, a design following environmental considerations can be appropriate for customers with high environmental consciousness. But depending on the market segment, compliance with environmental considerations can be seen as a must-be requirement for the material. That wood is a direct and unchanged product of nature with undeniable attraction. The importance of wood, leather, and wool testify to the aesthetic and psychological value of natural materials (Hoadley 2000). Jonsson (2005) studied the competitiveness of wood in material substitution for floor covering materials. Wood was compared to laminate and carpet, and again the tactical qualities of wood appeared to be connected to high customer satisfaction. It was suggested that when assessing customer needs in material substitution in an end-consumer context, one should allow analysis on the rather abstract level of customer benefits. Also, the function of the intangible characteristics of the original material needs to be fulfilled.

Rice, Kozak et al. (2007) studied how people’s psychological health and wellbeing can be connected to wood used in appearance applications. Wood evoked descriptors as “warm”, “comfortable”, “relaxing”, “natural” and “inviting”. Their findings suggest that marketing, including the potential psychological benefits of wood products, help the producers to differentiate themselves. If the natural aspect of interior wood could have the same psychological benefits as nature or elements of nature was investigated in a literature review by Nyrud and Bringslimark (2010). They found that the tactile sensation of wood evoked less stress response compared to other non-natural materials. They argued that even if emotive responses towards wood were measurable, more research is needed to draw conclusion of positive psychological effects of interior wood.

Wood is potentially a renewable material if sourced from a forest that is sustainably managed and replanted. Environmental properties of wood material would include wood origin, forest certification, processing, possibility for recycling and eventually disposal (Mangonon 1999). In combination with life-cycle analyses of a product, the carbon footprint is frequently mentioned. If kept in the solid wood state, the CO$_2$ is stored in the product until recycled. If the tree remains in the forest when harvested, the biodegradation process transfer carbon from the stem to soil carbon stocks (Lundmark, Bergh et al. 2016).

DISCUSSION AND CONCLUSION

Small dimensioned birch occurs in great abundance in Sweden. Character marked wood appeals to a customer segment that has environmental concerns. Similar with character marked wood there can be possibilities of using the intangible characteristics of the birch roundwood material, such as the shape and knot distribution. The results from the literature review demonstrate that opportunities exist
within the customer segment appealed by naturalistic furniture design, instead of going into markets that already have low tolerances to deviation in knottiness, color, and textural effects. An important area of inquiry has to be the properties of the small-dimensioned roundwood birch but also investigation of in situ mechanical performance of a solid pith-centered piece. Due to a strong statistical relationship between wood density and mechanical properties, the wood density variation pattern in the horizontal direction (pith to bark) in *B. pendula* and *B. pubescens* would be an area of interest when researching the potential of utilizing small-dimensioned roundwood birch. If provided, material properties data for small-dimensioned roundwood birch would likely encourage product development with such material. Material characteristics do not only include the typical engineering parameters but also the intangible and environmental, therefore also these characteristics should be researched for the small-dimensioned roundwood birch material. The new assortment of raw material should require new process flows in the processing industry to be profitable.

**REFERENCES**


THE ROLE OF BIOBASED BUILDING MATERIALS IN THE CLIMATE IMPACT MITIGATION OF CONSTRUCTION

Peñaloza, D. ¹

ABSTRACT

European industry, including the building sector, is aiming to shift to a “Bioeconomy”, relying on forest products to decrease their climate impacts while boosting economic growth. Life Cycle Assessment (LCA) is a tool used to analyze the environmental impacts of design alternatives of buildings, where biobased alternatives are often favored when a comparison with non-biobased alternatives is made. LCA of biobased products has methodological complexities that are not addressed traditionally in LCA studies such as biogenic carbon dioxide sequestration, storage and emission, timing of emission and impact characterization factors, storage in long-lived products, changes in forest carbon stocks, and land-use baseline in the forest. The aim of this work is to discuss these complexities, and how they affect LCA of biobased materials and comparative studies. Case studies of different constructions are analyzed using the Dynamic LCA method under different methodological setups to study the effects of assumptions where these complexities are accounted for. Results show that these methodological complexities have a significant influence in the outcome of an LCA, and therefore should not be overlooked. Different methodological setups can influence the outcome of an analysis, being the choice of time horizon and end-of-life scenario the most influential assumptions. Despite the difference made by these assumptions, results still favor biobased building materials in a significant majority of the studied setups, but the gap between biobased and non-biobased increases, especially in those where the time of biogenic carbon is storage in products is maximized. Recommendations based on the results are also given.

Keywords: Life cycle assessment; Forest products; Timber buildings; Timber bridges; Climate impact assessment

INTRODUCTION

Climate change is a serious threat to humanity, and urgent mitigation is needed to avoid irreversible damage (Field et al., 2014). The construction sector, as well as other industrial sectors, considers biobased products (BBP) as an alternative to mitigate their climate impacts in the long term (Lundmark et al., 2014). Life cy-

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cle assessment (LCA) is a tool that is widely-used to evaluate climate impacts of different design alternatives for constructions, and so give input for decision-making for climate impact mitigation. Nevertheless, there are particular aspects of life cycle climate impact assessment of BBP that are traditionally excluded in LCA practice but can have significant influence in the outcome of a study (Røyne et al., 2016).

Most non-traditional aspects in climate impact assessment of BBP are related to biogenic carbon dioxide ($CO_2$) exchanges across their life cycle, their timing and their effects in the forest carbon balance (Helin et al., 2013). $CO_2$ is usually assumed to be climate neutral, but this assumption has been challenged by demonstrating the effect of adding $CO_2$ in the inventory for LCA of bioenergy (Wiloso et al., 2016). Storing $CO_2$ in products for a period of time has a positive effect in mitigation of the radiative forcing that causes climate change (Brandão et al., 2013). Moreover, more consistency is needed concerning the time horizon of the metrics used for climate impact assessment of BBP since these exchanges may occur in the future, extending their impacts beyond the typically used GWP100 (Levasseur et al., 2010). The importance of the land use baseline choice in LCA has been discussed recently (Brander, 2015), a choice that could affect the climate assessment of BBM since a baseline is needed to account for forest phenomena. Soimakallio et al. (2015) have categorised four different approaches to this choice. Finally, the effects of biomass harvesting practices in forest carbon stocks have been also demonstrated (Liska et al., 2014).

The aim of this article is to discuss how the non-traditional aspects of climate impact assessment of BBP can affect LC results and the outcome of studies where comparisons with non-BBP. For this, case studies with different characteristics are analysed using the Dynamic LCA method, studying the effects of modifying five key variables.

**METHODS**

The first case study used in this article is a hypothetical building, for which three different designs with equivalent function (in m$^2$ of living area) have been used; one in concrete, one with a CLT structure but mineral-based insulation and coverings, and one with a CLT structure and biobased insulation and coverings, as well as sprinklers to comply with fire safety. All three designs have a concrete slab foundation. The designs only include structural elements, as well as internal and external coverings and windows; excluding details, pipes, HVAC installation and equipment, internal doors, elevator and electric system, which are assumed to be similar for all designs and non-relevant for the aim of the study. The buildings have a 50-year service life, are prefabricated, comply with passive house standards and are assumed to use 100% renewable operational energy. The end-of-life scenario used is 100% incineration for energy recovery (for BBM) and 70% recycling and 30% disposal (for non-BBM).
The other case study is a road bridge with two designs with equivalent function (in m² of functional road area); with glulam and concrete slabs. Both designs have the same asphalt sheets and insulation, but differ on the remaining components. The foundations and groundworks are excluded and both have different maintenance activities due to their different material composition. Their service life is 80 years, they are prefabricated, and their end-of-life scenario is similar to the one assumed for the buildings. All the calculations for both case studies have a cradle-to-grave scope; including manufacturing of materials, transports to factory, prefabrication of elements, transports to site, use and maintenance, demolition and disposal.

Dynamic LCA is a climate impact assessment method proposed by Levasseur et al. (2010), where every biogenic and non-biogenic greenhouse gas (GHG) exchange between the studied system and the atmosphere is assessed according to when in time it occurs. While in traditional LCA practice all characterisation factors have a 100-year time horizon (GWP100), in dynamic LCA one time horizon is chosen that is coherent with the time boundaries of the study. Whatever the time horizon selected, the climate impact of any GHG exchange (emission or uptake) is higher if it occurs shortly after the studied period starts, while it is lower if it occurs a long time afterwards. Since the BCO₂ stored in BBP is taken up first and emitted at the end-of-life, the uptake has a higher impact than the emission, which is how Dynamic LCA can be used to assess the climate benefits of BCO₂ storage in long-lived products (Levasseur et al., 2012). To model the BCO₂ uptake during forest growth, literature values for forest growth carbon exchanges have been used (Kilpeläinen et al., 2013). Forest productivity data and product inventory data for standing wood input were used to estimate the amount of BCO₂ taken up at the forest to produce the materials for the constructions.

Five key variables related to climate impact assessment of BBM and non-traditional aspects have been identified. The effects of modifying these variables in the climate impact result of BBM and in a comparison with non-BBM benchmarks have been studied using the case studies described. Table 1 presents an outline of how these variables are tested in this article. The results are calculated using three time horizons; 20 years, 100 years and 300 years. The first two variables correspond to design-related aspects such as the mass content of BBM in the design and the length of the service life of the building case study. The third variable is the assumed end-of-life scenario; instead of incinerating the materials and emitting the BCO₂ back the atmosphere, the materials will be recycled, keeping them stored in products. The choice of land-use baseline is the fourth variable, and the “business as usual” and “natural regeneration” categories proposed by Soimakallio et al. (2015) have been tested. Finally, as pointed out by Levasseur et al. (2012), modelling forest growth brings up the question whether it occurs before the materials are manufactured (previous to harvesting) or afterwards (as a consequence of replanting after harvesting). This is the fifth variable studied; assuming the forest growth occurs before and after harvesting, and including a third result where all the uptake occurs in year zero.
Table 1. Outline of the five variables studied in this article and how they are tested

<table>
<thead>
<tr>
<th>Key variables</th>
<th>Case study used</th>
<th>Baseline setting</th>
<th>Alternative settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BBM content of the design</td>
<td>Building</td>
<td>50% of BBM in weight</td>
<td>69% of BBM in weight</td>
</tr>
<tr>
<td>2. Length of service life</td>
<td>Building</td>
<td>50yr service life</td>
<td>70yr service life</td>
</tr>
<tr>
<td>3. End-of-life scenario</td>
<td>Building</td>
<td>100% incineration</td>
<td>70% recycling</td>
</tr>
<tr>
<td>4. Land use baseline for forest growth</td>
<td>Building</td>
<td>Business as usual</td>
<td>Natural regeneration</td>
</tr>
<tr>
<td>5. Timing of forest uptake</td>
<td>Bridge</td>
<td>Forest growth before harvest</td>
<td>Forest growth after harvest and equilibrium</td>
</tr>
</tbody>
</table>

RESULTS

The results for the calculations outlined in Table 1 are displayed in Fig. 1.

Fig. 1. Results for the calculations described in Table 1. The figures correspond to (a) Assumption 1 (BBM content); (b) Assumption 2 (length of service life); (c) Assumption 3 (End-of-life scenario); (d) Assumption 4 (Land use baseline at forest) and (e) Assumption 5 (Timing of forest CO₂ uptake). All the y-axis results correspond to Cumulative climate impact (W*m²) per functional unit. TH=Time Horizon.
DISCUSSION

The results demonstrate that all the studied variables have a significant influence in the outcome of the assessment. An overall observation from Fig. 1 is that the choice of time horizon seems to have a heavy influence in the results, and that more consistent outcomes are achieved with a 300-year time horizon concerning the comparison with non-BBM alternatives. This might be because the BCO₂ exchanges of all the studied systems occur during long periods of time since the BCO₂ is stored in long-lived structures. Therefore, it seems that only long-term time horizons can capture all the impacts from BBM in long-lived products.

Regarding the variables that depend on the design of the construction such as BBM content and service life, it seems that only the BBM content has meaningful long-term (300yr) effects in the results. Fig. 1(a) shows that increasing the BBM content in a building by 20% results in 25% lower long-term climate impact, while as seen in Fig. 1(b), extending the service life by 20 years would only signify a 3% reduction. The results in Fig. 1(c) for the end-of-life scenario present a significant difference. This is because by recycling a share of the BBM into new products, most of the BCO₂ in stored would not be emitted back, and since the positive impacts from the BCO₂ uptake during forest growth have already taken place, these will not be compensated. This might be unrealistic, as the benefits from recycling should be attributed to the secondary product according to most existing standards. This issue should be handled in future applications of dynamic LCA for BBM.

As can be observed in the results in Fig. 1(d), adopting a “Natural regeneration” baseline had the opposite effect to the previous assumptions, as it increased the long-term result by 10%. This is because a forest that is left to regenerate naturally takes up more BCO₂ than a forest that is harvested as usual. It can be argued that a natural regeneration scenario is unrealistic, and that not extracting forest products would mean that fossil or mineral products with significantly higher impacts would be needed to supply those functions. This is why this choice should be made carefully, but practitioners should be aware of its relevance and the importance of communicating clearly how it has been done. The choice of time horizon seems to be particularly relevant if combined with the choice for timing of the forest BCO₂ uptake, as Fig. 1(e) suggests. The three alternatives analysed give highly different outcomes if a 20-year time horizon is used (190% difference in result), or even the traditional 100-year time horizon (80% difference in result). Nevertheless, the difference in the result of the construction between accounting for the forest uptake before or after is only 20% if a 300-year time horizon us used. Moreover, the “equilibrium” assumption seems like a feasible middle point for this methodological choice.
CONCLUSIONS

Climate impact assessment of construction projects with BBM content can be heavily affected by design aspects such as BBM content; by system modelling assumptions such as service life, end-of-life scenario, timing of the forest BCO₂ uptake and land-use baseline for the forest; and by impact assessment choices such as the time horizon of the characterisation factors. The choice of time horizon is of particular importance given that the incidence of all the other variables becomes less relevant for long-term time horizons, thus obtaining more consistent outcomes. Even though the effects of these choices, the comparison with non-BBM alternatives still favours constructions with BBM content, and in most of the cases the gap between them increased with long-term time horizons, and especially if BCO₂ is stored in products for longer periods.

Some recommendations can be given based on the results obtained. First, in order to reduce the climate impact of a construction project, it is more effective to increase its content of BBM than to extend its service life. For future practice of climate impact assessment of BBM, it is recommended that long-term time horizons are used if the study aims to account for the BCO₂ exchanges and their timing, or BCO₂ storage. Moreover, it is recommended that practitioners are clear about their choice of land-use baseline in the forest, and consider the importance of this choice when carrying out any study that accounts for BCO₂. Finally, it is recommended that future research is focused on methods refining so the climate impact benefits from extending the storage period of BCO₂ in products through recycling are properly allocated among life cycles.

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PROPOSED CHANGES TO MACHINE STRENGTH GRADING OF STRUCTURAL TIMBER IN EUROPE

Ridley-Ellis, D.¹

ABSTRACT

In Europe, machine strength grading of sawn timber for construction is governed by the harmonized European Standard EN 14081-2. A substantially changed revision of this standard has recently undergone Enquiry along with an accompanying proposed amendment to EN 14081-3. These standards have a direct, and significant, influence on grading yields, and the safety of structural timber. This paper briefly examines the new proposals and the motivation behind the changes. It also explores some of the implications of the proposed procedures, putting forward some possible improvements for discussion. The proposed fixed settings for Norway spruce are examined for spruce grown in the British Isles.

Keywords: strength grading, structural timber, standards, machine grading

INTRODUCTION

The European system for grading structural timber is set out by the harmonized standard EN 14081 (CEN 2016a) and provides a means to sort rectangular cross-section timber into categories based on three grade determining properties: strength, stiffness and density. There are two parallel systems for grading: visual and machine. Regardless of the method of grading, the approach is concerned with the collective (“characteristic”) properties of the timber assigned to a grade and so grading is not aimed at predicting the properties of individual pieces per se. A more complete explanation of the current European method can be found in Ridley-Ellis et al. (2016).

Machine grading is governed by EN 14081 parts 2 and 3 (CEN 2012a,b) and can currently be carried out with predetermined machine settings (“machine control”) or by continuous testing of output (“output control”). Machine control grading relies on settings developed in advance from the results of a substantial destructive testing program. This way a producer can grade timber without requirement for further testing, and it is the method used for almost all machine graded timber produced in Europe. Output control requires the producer to regularly test samples of graded timber and, if necessary, adjust the grading machine settings to ensure

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grading proceeds safely and efficiently. Output control is used by some mills in Europe, but is not at all common.

For machine control settings, reports must be submitted for examination by European Committee for Standardization committee TC124/WG2/TG1 (TG1) to be thoroughly examined before the settings are approved for use. This is done not just to check that the standard procedures are followed correctly, but to uncover issues that affect correct grading that were not anticipated when the standards were written. Several of these issues have arisen over the years and TG1 compiles a set of additional rules that must also be followed. For output control, safety is supposed to be ensured by the factory production control requirements of the standard, including the regular testing. Industrial experience is limited in Europe but research (e.g. Deublein et al. 2010) has shown that the current procedures cannot always adjust quickly enough to shifts in resource quality.

Indeed, it is the variability in timber quality that forms the current main concern for timber grading in Europe. It was long known that timber varies from country to country, which is why grading settings are linked to growth areas defined by national borders, but the extent of variation within countries can also be large, as was revealed by the Gradewood project (Ranta-Maunus et al. 2011). Geographic variation is linked to shifts in resource quality in a sawmill, as timber is drawn from different areas during production. It can also mean that certain mills, drawing timber from poorer areas, might not be safely grading timber with machine control settings established on timber from a wider area that is, overall, of better quality. This is one of the primary reasons that proposed revisions of EN 14081 parts 2 and 3 (CEN 2016b,c) have been prepared and sent to Enquiry. The new approach was developed through the Gradewood Transition Project but is now in the hands of CEN TC124/WG2 which is undertaking the form standardization work. The main motivations to the revision of the standards are:

1. To try and bring the standards to the point where they are useable, and understandable, without the need to apply the additional rules set by TG1 and the background knowledge of that group of grading experts.
2. To create a grading system that is better able to cope with shifts in resource quality due to geographic variation in wood properties.
3. To permit better use of new and emerging technology.
4. To simply the system where possible.

THE REQUIREMENTS OF MACHINE STRENGTH GRADING

Any method of machine grading has to address the following (among other things):

1. A method of establishing an indicating property model (or models)
2. A method of determining settings
3. A method of checking settings (and adjusting settings if necessary)
Establishing an indicating property (IP) model

Grading machines make non-destructive measurements on the timber that have some ability to predict the three grade determining properties (strength, stiffness and density). The method by which that relationship is established is not particularly restricted, except that the standard specifies the minimum amount of testing. The current standard requires that the sampling be representative of the timber to be graded, but does not give explanation of what “representative” means in this context. The new draft (CEN 2016b) contains an informative annex on this topic, based on guidance drawn up by TG1.

The current standard employs a cost matrix method intended to ensure that the IP model is a suitably good predictor. This procedure is less important in the new draft, having only an informative role. Instead it is the overarching requirement that the graded timber meets the required properties which governs whether an IP model is good enough. In practice it may not be necessary to have a strong IP model. For example, when grading timber to a single grade that has nearly 100% yield the machine does not need to be able to correctly judge the properties of the majority of the timber – it only needs to be able to detect the very worst pieces in order to reject them. The removal of the cost matrix requirements will improve grading settings where the intention was not to achieve the highest possible grades, but rather to reduce rejects.

A method of determining settings

The overarching requirement is that graded timber needs to meet the characteristic properties that define the grade to which it is assigned. The current standard achieves this by using the whole dataset to calculate the settings thresholds that satisfy the grade requirements. This is subject to a number of additional checks intended to confirm that the different growth regions sampled are suitably similar to be combined into a common settings area. In essence these checks need to confirm two separate things:

That the IP model is similarly good at predicting the grade determining properties for the different growth regions. The potential for difference varies by type of IP.

That the means and standard deviations of grade determining properties in the different growth regions are similar. This is related to the fact that grading is about the collective properties of populations, not of individual pieces – and this is the main challenge arising from variability within the resource.

The current standard is known to be inadequate for this check, especially when sampling includes many subsamples (the subsample check is less potent, the more subsamples there are). For this reason TG1 formulated an additional “country check”. This amounts to confirmation that the characteristic values of the grades, within the countries that make up the whole sample, separately satisfy require-
ments of the strength class (within an allowed tolerance). Related to this is the additional requirement that sampling must include timber from all countries within the settings area.

The new draft incorporates a completely new check: the “bandwidth method”. This divides the dataset into five bands, based on the IP, and checks that timber from the different countries is evenly distributed over those bands, and that each of the countries included has similar levels of grade determining properties within those bands. This check is certainly more robust than the one in the current standard, but it still suffers from the shortcoming that the check is carried out on the basis of national borders. Variation is allowed within a country that would not be allowed across a border. This is problematic because forests, and the timber trade crosses borders, and because it treats small countries the same as large countries. However, this is addressed, to some degree, with the inclusion of a number of “standardised areas” which treat several countries as one unit. The properties check calls up EN 16358 (CEN 2016d) for confidence limits and this effectively means that about 400 specimens are actually needed per country (rather than the stated 150 minimum) in order that there are enough specimens to use the non-parametric method (see below).

A method of checking settings

The current standard does not have a formal method for verifying settings for machine control. The new draft addresses this issue for settings calculation by dividing the dataset into a learning set and a verification set. However, since it is not specified how the IP model and initial thresholds are calculated, this would, in practice, effectively amount to simply dividing the dataset into two parts and checking that both parts comply with properties requirements.

The latest revision EN 384 (CEN 2016f) uses EN 16358 for calculation of confidence limits on characteristic properties, but this does not change the calculation much for the current EN 14081-2. However, under the new draft it is required in a number of places without specifying whether the parametric or non-parametric method is used. When grading is effective, the assumption of normal (or lognormal) distribution for the parametric method is violated and this can potentially be an unsafe method. The verification part of the new draft makes a similar assumption of normality and so is also potentially unsafe (for a lower grade in combination) when the grading is effective (and potentially over conservative for the upper grade). This check needs to be replaced with a non-parametric method.

The new draft introduces a new ability: adjusting settings, during production, based on recent IP values measured by the machine. This is potentially a very effective method of dealing with resource variability, especially for machines with powerful IPs. The proposed method requires that the IP model be based on linear regression (although it does not explicitly state this in the draft) which does rule out use with some kinds of IP.
Output control was almost removed entirely but now is included in the standard in a much simpler form. It does, however, ask for 0.2% of the graded population to be destructively tested, which is a huge testing burden on the producer that is not justified by the actual need for information to monitor the process. A grading machine running at 175 pieces per minute means 21 tests are required per hour and after just two 8 hour shifts, the testing would have already exceeded the minimum required for machine control settings. A more appropriate testing requirement would be 0.1% limited by a sensible maximum requirement per grading machine per hour. Furthermore, the testing should concentrate on the properties that are grade limiting, and information from IP records should be able to be utilised where the IP is a good predictor of the actual properties (as it may be for stiffness and density).

**Fixed settings**

With the objective of providing simplicity, the new draft includes some fixed settings for use grading European Norway spruce (*Picea abies*) and fir (*Abies alba*) grown in Europe without further justification. These settings are for grading machines that operate on the basis of longitudinal resonance (a method that is very repeatable between different machines). Two sets of settings are provided: for an IP based on measured frequency alone, and for an IP based on measured frequency and measured density.

These settings are based on data from spruce and fir grown in mainland Europe but they would, in principle, allowed to be used on Norway spruce grown in the British Isles. This species is currently a minor part (~10%) of the species combination “British spruce” which is mostly Sitka spruce (*Picea sitchensis*). These species are known to have similar properties when grown in the British Isles, and so it is reasonable to ask the question as to whether these fixed settings work for UK grown spruce. The following analysis uses data from two approved grading reports (Ridley-Ellis 2014a,b) consisting of 863 pieces of British spruce ranging in cross section from 22x47mm to 75x150mm.

The fixed settings are provided for C18 and C24, either alone or in combination. The requirements for the characteristic properties are shown in Table 1. The 0.95 factor on bending stiffness within EN 384 is applied, and the bending strength target is shown with and without the $k_v$ factor. This factor is not allowed to be used for portable machines, but there is no restriction on the fixed settings for in-line machines only.

<table>
<thead>
<tr>
<th>C24</th>
<th>24 (21.4)</th>
<th>10.45</th>
<th>350</th>
</tr>
</thead>
<tbody>
<tr>
<td>C18</td>
<td>18 (16.1)</td>
<td>8.55</td>
<td>320</td>
</tr>
</tbody>
</table>

* requirement when the $k_v$ factor is applied, shown in parentheses

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**Table 1: Required characteristic properties (CEN 2016e)**

<table>
<thead>
<tr>
<th>5%ile bending strength*</th>
<th>Mean bending stiffness</th>
<th>5%ile density</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/mm²</td>
<td>kN/mm²</td>
<td>kg/m³</td>
</tr>
<tr>
<td>C24</td>
<td>24 (21.4)</td>
<td>10.45</td>
</tr>
<tr>
<td>C18</td>
<td>18 (16.1)</td>
<td>8.55</td>
</tr>
</tbody>
</table>
The achieved characteristic properties are summarised in Table 2. Here it is possible to see large difference in percentiles between the parametric and non-parametric methods in EN 14358. For the IP based on frequency, the strength and density meet the requirements for C24 if no confidence limit is applied and a larger dataset may show that the settings are OK. For the IP based on frequency and density the setting for C24 on its own fails to meet the stiffness requirement, although not by much. British Norway spruce is thought to be slightly stiffer than Sitka so the settings may be OK applied only to Norway spruce. It is not possible to calculate a C18/C24 combination on this dataset with the current standard, but comparable settings for IP of frequency give yield of 83% for C18, and for IP of frequency and density give yields of 90% for C18 and 11% for C24. These fixed settings for C24 give better yield.

**SUMMARY**

The new proposal for machine grading has some very good features, but there needs to be a practically useable form of output control, perhaps using more of the features of the adaptive settings approach to reduce the requirement for testing. For machine control there needs to be a common approach for verification of settings across the procedures and this needs to be based on a non-parametric approach to ensure safety and efficiency.
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BARRIERS AND INCENTIVES FOR THE MARKET DIFFUSION OF LIGNIN BASED PRODUCTS

Lettner, M.¹, Hesser, F.¹, Zins, F.², Smith, L.² & Stern, T.³

ABSTRACT

Lignin – nature’s most abundant aromatic polymer – plays a key role in the vision of future knowledge-based bioeconomy. The pulp and paper industry is one of the largest users of lignocellulosic biomass. Pulp and paper mills often function as biorefineries, which process biomass into a spectrum of marketable products and energy. About one third of the incoming wood in a pulp mill consists of lignin, which is almost completely dissolved during the pulping process. About 50 million tons of lignins are generated each year, but only about 2% are used for purposes other than energy production.

Increasing oil prices and the demand for more sustainable new products are key-drivers of the bioeconomy. Lignin, which is an underutilized by-product, in terms of material use has the potential to serve as a valuable source for sustainable biobased products, for example as phenolic substitute in phenol-formaldehyde (PF) resins or as a component in composites.

This study aims at showing the barriers and incentives for market diffusion of lignin based products, using different methods for the two applications. A Perception-Gap Analysis was conducted, which exposed gaps between the wood-based panel industry and researchers working on lignin based PF-resins, in terms of expectation and importance of relevant factors. Identifying such gaps between these areas provides an important basis for further research and recommendations for action, in order to help increase the market potential of lignin based products. In case of lignin as possible thermoplastic component for composite materials, a combination of a Delphi-Analysis and an Analytical Hierarchy Process (AHP) was conducted to identify influencing factors on market diffusion, as well as barriers that hinder use.

This research approach not only opens the possibility of showing possible market diffusion pathways for different applications, but also to identify factors which are influencing the success rate of the new products.

Keywords: Lignin, Biobased Products, Market Diffusion

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ABSTRACT

Forest in Latvia take up 3 383 million hectares of land, or 52% of the country’s territory. The amount of forestland, moreover, is constantly expanding. An average of approximately 12 million m$^3$ of round wood has been harvested each year in Latvia forest during the past decade. That is less than the annual increment, and so forestry in Latvia can be described as sustainable. Forestry, wood processing and furniture manufacturing represented 5.2% of GPD in 2014, while exports amounted to EUR 2 billion – 19% of all exports. Round timber consumption opportunities and long-term provision of raw materials woodworking sector development is very important. The study was conducted in 2015, during which surveyed (by telephone) 453 wood processing enterprises, of which the answers provided 65.5% of respondents. Of all the companies surveyed, 87% positioned themselves in the market as the primary wood processing companies.

Forecast show that by 2020 an assortment of wood demand will increase, which will definitely contribute to round timber processing volumes. During the period from 2006 to 2014, round wood recycling rate has increased from 6.8 million cubic meters in 2006 to 8.4 million cubic meters in 2014, which was due not only to wood processing capacity increase, but also wood products demand and exports rise in Latvian and foreign markets. The survey results show that the large wood processing companies make up only 7% of the surveyed companies, but recycle 72% of the total sawlogs of the amount. Latvian processing companies capacity mainly focuses on softwood. In 2014 the softwood of the total processing volume represents an average of 67%.

**Keywords:** sustainable timber use, demand and supply, Latvia

INTRODUCTION

The base of wood processing industry is primary wood processing enterprises where round wood supplied from forests is converted to further processed products – sawn timber, veneer sheets, construction timber, timber particles in different size and other products, which are used in further downstream sector for creation of additional value (Krumins et al., 2012). Central Statistical Bureau of Latvia
gathers general data about the wood processing industry, but specific information about primary wood processing companies like geographical distribution, round wood processing volumes, division of processing volumes between softwoods and hardwoods and assortment of produced materials is not being collected. This specific information is an important prerequisite for analysis of timber resource flow in Latvia and evaluation of round wood utilization sustainability (Krumins et al., 2012). The economic activity in the state forest is carried out according to sustainable forest management principles (Tunkele and Marcins., 2010). Our research had the main task. It was to survey primary wood processing companies in Latvia and gather information about their round wood processing volumes, how their processing volumes are divided between softwoods and hardwoods and assortment of produced materials.

After “Forest and Wood Products Research and Development Institute” Forest Information Center forecasts point to a variety of wood demand growth until 2020, which suggests that the processing of round timber volume coming years set to rise (Lise et al., ..., 2015). Latvian placed large softwood sawmills rated production capacity exceeds the available resources. As a result, enterprises are forced to import resources from neighboring countries. The whole situation can be assessed positively for the Latvian economy, but it increases the resource delivery risks related to the round wood trade regulatory policy decisions.

### Table 1. Wood assortment indicative of peak demand forecast for 2014-2020, million m³.

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<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawlogs (incl.products of primary processing)</td>
<td>5,40</td>
<td>6,00</td>
<td>6,50</td>
<td>7,00</td>
<td>7,50</td>
<td>8,00</td>
<td>8,00</td>
</tr>
<tr>
<td>Puplwood (export)</td>
<td>3,15</td>
<td>2,90</td>
<td>2,80</td>
<td>2,70</td>
<td>2,70</td>
<td>2,70</td>
<td>2,70</td>
</tr>
<tr>
<td>Technological wood</td>
<td>1,83</td>
<td>2,00</td>
<td>2,21</td>
<td>2,42</td>
<td>2,42</td>
<td>2,42</td>
<td>2,42</td>
</tr>
<tr>
<td>Firewood</td>
<td>3,95</td>
<td>4,17</td>
<td>4,37</td>
<td>4,37</td>
<td>4,51</td>
<td>4,51</td>
<td>4,51</td>
</tr>
<tr>
<td>Timber demand</td>
<td>14,33</td>
<td>15,07</td>
<td>15,88</td>
<td>16,49</td>
<td>17,13</td>
<td>17,63</td>
<td>17,63</td>
</tr>
</tbody>
</table>

### MATERIAL AND METHODS

The research work was carried out in the autumn 2015 within the frame of the project „Substantiation of deciduous trees cultivation and rational utilization, new products and technologies” in Forest faculty of Latvia University of Agriculture. To reach the aim of the research, a questionnaire of primary woodworking companies was carried out. Information about enterprises was taken from the database of surveys made in years 2013 and 2014 when similar research by the Latvia University of Agriculture and the Latvian Forest Industry Federation was carried out. Additionally, contact information from public data bases available on the internet (www.1188.lv, www.zl.lv, www.viss.lv, www.lursoft.lv) was used. Survey
was carried out over the phone call to every potential primary wood processing enterprise. In total, 453 enterprises were questioned and answers were received by 65.5% of respondents. From all respondents, 87% of respondents acknowledged themselves as primary wood processing enterprises on the market. Data obtained during the questionnaire were analyzed in dynamics for years 2006 to 2014. For deeper analysis of primary wood processing companies, they were divided into groups according to their round wood processing volumes: large (above 50’001 m$^3$ annually), middle (10’001-50’000 m$^3$ annually), small (1’001-10’000 m$^3$ annually) and micro (below 1’000 m$^3$ annually) enterprises. Additionally, companies were divided by tree species they process – softwood, hardwood or both.

**RESULTS AND DISCUSSION**

During the time period of 2006 to 2014 round wood processing volumes in Latvia decreased form 6.8 million m$^3$ in year 2006 to 8.4 million m$^3$ in 2014 (Figure 1). After recovery of the demand for wood products in global markets in 2009 and 2010 and thanks for additional volumes of supplied round wood timber from state forest, total round wood processing volumes in 2010 returned to the level they were before crisis and reached 6.8 million m$^3$. In 2012 and 2014 this level just increased to 7.3 and 8.4 million m$^3$, where in 2014 achieved the largest processing volume.

![Fig. 1. Total round wood processing volumes of surveyed enterprises and by processed tree species during years 2006 to 2014, mill.m$^3$.](image)

Over the past years substantial increase in the amount of processing associated with investments in the amount of increase in primary wood processing enterprises, increase production capacity. In some case, enterprises are able to during those periods even ready to double output. Large enterprises in 2014 counted only for 7% from the total number of primary wood processing enterprises, but processed 72% from annual round volume (Figure 2).
Comparing with year 2012, large enterprises had increased their share in round wood processing by 2%. Middle enterprises in 2014 counted for 27% from total number of enterprises, but processed 20% from annual round wood volume. In 2012, the share of middle enterprises in total number of enterprises was 22% and they consumed 19% from total round wood. Small enterprises counted for 44% from total number of enterprises and processed only 8% from annual round wood volume. Compared with 2012, when these shares respectively were 54% from total number of enterprises and 11% from annual round wood volume. Just 22% from total number of enterprises were micro primary wood processing companies, but they processed less than 1% from annual round wood volume.

Processing volumes of primary wood processing companies in Latvia are mainly focused on the use of softwood timber and in 2014, softwoods made 67% from all processed round wood. At the moment it marked a trend that enterprises are starting to recycle more hardwoods and large part of large enterprises in the production are increasingly used hardwood raw materials to increase output volumes (Figure 3).
Deeper analysis of processed tree species according to the size of enterprises shows that 59% of large enterprises, 37% of middle enterprises and 30% of small and micro enterprises work only with softwoods. Micro wood processing companies are most elastic in terms of tree species they process as 81% of them can work with both tree species - softwoods and hardwoods (Figure 3). At the moment it marked a trend that an availability of wood resources is important for all business groups, the enterprises more used both tree species that to increased production capacity.

Primary wood processing enterprises were asked to identify what is their production end-product – does their production process finish with wood pre-treatment products like sawn wood, packaging boards, log-house logs, veneer, plywood, plate materials, firewood or do they manufacture also subsequent processing products like furniture, glued beams, wood pallets, doors and windows, carpentry and joinery production (Kurmins et al., 2012). Approximately 42% of large enterprises admitted that they do also subsequent production. Largest proportion of subsequent processing product producers were observed in the middle (37%) and small (26%) enterprise group where every second enterprise preformed deeper processing of timber, thus making larger added value to every round wood cubic meter processed. In the micro enterprise group, 42% of companies were producing subsequent timber products. Comparing with year 2010, large enterprises had increased their share in end-product production by 9%, but middle and small decreased their share – by 14% and 21%. Analysis of usage of products produced by primary wood processing enterprises reveals that 42% of enterprises process round wood in products used afterwards in building and construction, 19% of enterprises produce source material for packaging (container production), but only 14% of enterprises produce half-finished materials for furniture industry (Table 2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Construction materials</th>
<th>Furniture production</th>
<th>Container production</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>63%</td>
<td>25%</td>
<td>60%</td>
<td>4%</td>
</tr>
<tr>
<td>2014</td>
<td>42%</td>
<td>14%</td>
<td>19%</td>
<td>14%</td>
</tr>
</tbody>
</table>

According with growth in the finished product sector is promoted the finished product assortment expansion in the primary wood processing enterprises.

**CONCLUSIONS**

- According to the forecast it shows that by 2020 an assortment of timber demand will increase, which will definitely contribute to round timber processing volumes.
• During the time period of 2006 to 2014 round wood processing volumes in Latvia decreased from 6.8 million m³ in year 2006 to 8.4 million m³ in 2014, which was due not only to wood processors productive capacity building, but also of wood products demand and export growth in Latvian and foreign markets.

• Large enterprises in 2014 counted only for 7% from the total number of primary wood processing enterprises, but processed 72% from annual round volume. Middle enterprises counted for 27% from total number of enterprises, but processed 20% from annual round wood volume. Small enterprises counted for 44% from total number of enterprises and processed only 8% from annual round wood volume. Just 22% from total number of enterprises were micro primary wood processing companies, but they processed less than 1% from annual round wood volume.

• Processing volumes of primary wood processing companies in Latvia are mainly focused on the use of softwood timber and in 2014 softwoods made 67% from all processed round wood. At the moment it marked a trend that enterprises are starting to recycle more hardwoods.

• Analysis of usage of products produced by primary wood processing enterprises reveals that 42% of enterprises process round wood in products used afterwards in building and construction, 19% of enterprises produce source material for packaging (container production), but only 14% of enterprises produce half-finished materials for furniture industry.

REFERENCES


ABSTRACT

How can the ever-increasing human understanding of material properties and behaviours be used in an applied manner to design and construct innovative and pioneering structures? How can the scientific understanding of a material’s properties be used as an active force driving the structural formation of its physical implementation? How can the unique data of a specific material inform an architecture harnessing that material’s distinct properties?

The COW project aims to investigate and develop new tools and methods for achieving precisely this within the confined research space of timber structures. An innovative parametric tool that uses genetic algorithms to search for optimal geometries within a fitness landscape defined by existing site conditions and other data specific to an architecture scheme (including but not restricted to the properties of different timber-based building systems), as well as a wide range of project-specific desires, COW is a practical tool for optimising timber structures in accordance with a collection of pre-defined objectives.

The most successful attempts to define relations between such material data and its implied structural geometries, in order to turn them into architectural strategies, can be found in quite recent trajectories within architecture theory: the parametric systems that have allowed for a veritable revolution within the field’s digital realms, exemplified most (in)famously by architect Patrik Schumacher’s 2008 manifesto, Parametricism as Style.

COW uses existing site data and a wide range of project-specific desires to go beyond Schumacher’s rather broadly defined style. Instead, it uses evolutionary logics as a productive strategy for achieving optimal compromises between a scheme’s different driving forces. This position paper discusses how the COW system is situated within contemporary architectural theory and practice in general, and shows how it can begin to be used to promote timber architecture in the urban context.

Keywords: timber architecture, multi-objective optimisation, COW, genetic algorithms, material performance

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INTRODUCTION

This position paper/research essay presents an opinion while referring to experiments that test the ideas propounded herein. The argument is simple: our built environment could benefit from design processes based on evolutionary logics, a consideration somewhat neglected by the proponents of architectural “parametricism.” The experiments are the author’s first non-expert attempts at developing a design tool that seeks to ameliorate this situation. As such, they are bound to be ignorant, simplistic, and flawed, but the reader is well advised to suspend disbelief in the particulars in order to perceive the universals. It is arguably “better to be vaguely right than exactly wrong”(1).

While practicing architects and engineers have been slow to allow genetic algorithms (GA) guide their workflows (probably due to a poor understanding of the methods and benefits involved, as well as the absence of easy-to-use tools to help guide the process(2)), such methodologies have been widely adopted within the academic community – in particular following the release of the Galapagos evolutionary solver as part of the Grasshopper graphical algorithm editor(3) and the 2011 unveiling of the perhaps more commercially focused Dynamo software.(4) Both use genetic algorithms to let designers explore a series of iterations within a user-defined search space, producing and evaluating geometries by cycling through pre-specified parameters.

Such parameters – values like the radius of a circle or the tangent of a curve – made architect and theorist Patrik Schumacher hail the neologism “parametricism” (a “contemporary architectural style that has achieved pervasive hegemony within the contemporary architectural avant-garde”) as “the great new style after modernism.”(5) To Schumacher’s credit, such perhaps hyperbolic early statements were developed in his 2010 study, The Autopoiesis of Architecture.(6) Schumacher’s argument attempts to apply the social systems theory of German sociologist Niklas Luhmann to architecture, and makes a very serious attempt to provide a grand theory of architecture and its “self-constructing” autonomy (the “autopoiesis,” of the title).(7)

While Schumacher convincingly argues the case for the possibility of changing the values held by the parameters of his parametricism. it is not clear how exactly he reckons that possibility should be deployed in order to cater to the vast array of desires – from budget-focused clients to zoning laws – that make up the internal logics of any architecture scheme. Schumacher seems predominantly interested in promoting potential formal exuberances: “Avant-garde architecture produces manifestos: paradigmatic expositions of a new style’s unique potential, not buildings that are balanced to function in all respects. There can be neither verification, nor final refutation merely on the basis of its built results.”(8) But shouldn’t avant-garde architecture provide exactly such a balancing act, one that makes “all” (the preconceived) aspects perform optimally.
MOO and COW

More design variables typically influence an architectural design than the human brain can process. Real-life design projects are bound by several different aspects that need to be reflected within the final result. Such driving forces are often in conflict with each other, resulting in many different solutions where trade-offs can be made in order to obtain desired results. Combining the multitude of variables in different ways results in different designs, and as the amount of variables increases, the search space of possible solutions increases exponentially. The traditional way to approach this situation is to crop the search space and only explore a handful of options, but even so it is hard to substantiate the best-performing iteration. Design variables are also nonlinear – they influence to different extents different aspects of the design. The use of artificial evolutionary processes move the discussion beyond a fascination with bottom-up design approaches(9) towards a debate about what operative logics might generate the highest performance throughout the resulting structure.

Controlling a parametrically designed geometry with genetic algorithms generates many different solutions, and multi-objective optimisation (MOO) methods allow the designer to evaluate as many positions within the search space as time and computational power allows. An automated MOO-driven workflow aids the decision-making process and makes it possible to explore a wide design space of competing objectives, balancing for instance programmatic requirements with aesthetic objectives and structural criteria.(10) COW is envisaged as an easy-to-use framework for MOO analysis of Grasshopper definitions that employ genetic algorithms as a meta-heuristic technique to simulate evolution and create a fitness landscape of possible combinations of design variables.
EXPERIMENTS

The initial experiment aimed to explore a massing study – the unique architectural undertaking that often constitutes the first phase of the design process(11) – for a pavilion on the KTH campus within an evolutionary MOO-based framework. The site boundary, a rectangular footprint of 50 x 80 meters, was extracted by the Elk plugin, which generates topographies using open-source data. While alternative evolutionary solvers (such as Octopus and Goat) will be investigated in the near future, the built-in Galapagos solver was used to carry out the experiments below.

Experiment A: indicative framework

Four points travel along x and y coordinates, forming a first genome(12). Four corresponding rectangles, the lengths of their sides (2-18m) controlled as a second genome, are allowed to rotate 360° about their origin point (a third genome). The fourth genome is their extrusion height (3-18m). The resulting building volumes are combined into a brep object, the volume and area of which are analysed through mass addition and fed into a simple subtraction (A-B) component to create a single number that Galapagos then maximises its fitness calculation for (Fig. 1.).

Allowing the solver to run for 1000 generations (~90 minutes), with the Galapagos Editor’s Options menu set to default values (no runtime limit; max. stagnant 50, population 50, initial boost 2, maintain 5%, inbreeding +75%; annealing solver set to 100%, cooling of 0.95, drift rate 25%), produced five solutions within the top 10% of genomes (fitness values 19865.2547-20150.7525).

A few obvious definition weaknesses were easily identified. Some were simple to remedy: the maximum lengths of the building volumes needed to correspond to the offset between the site boundary and the offset building volume boundary, as the volumes were rotating beyond the site boundary (though this could be kept as a feature if we wanted the pavilion to “connect” to the existing building fabric on the site). The value for the side lengths was thus lowered from 18 to 10.

An additional four volumes were added to create more diversified results. The definition was modified to allow for the volumes to shift in the z direction. For the sake of computational speed, expressions were added to narrow the domains of the sliders controlling this shift and those feeding angle values to the rotation component. The eight volumes were also divided into two groups of four, and each group assigned a different maximum extrusion distance (9 and 18 meters respectively). A mistake in the settings meant no box could become less than 6 meters tall; this was brought back to its intended value of 3 meters. Other potential improvements that can be considered in the future include making several hard-coded parts of the Grasshopper definition truly parametric, and adding a site-specific simulation plug-in (for instance DIVA).

One particular issue concerned how to save the Galapagos output. While all the
information accumulated throughout the solver run is stored in memory, to the best knowledge of this author it is impossible to export it without using a third-party solution. At the end of the solver run, one iteration is selected, but in the process of closing down the solver, the previous generations vanish. The third-party cluster Galapagos Listener(13) allows the user to record all of the variable values and fitness values for each of the optimisation iterations, and was added to the definition.

**Experiment B: cost/hybrid materiality/ LCA component**

The computer was left overnight to compute the second experiment, which ran for 50 generations; a testament to the painfully slow GA design process. Again five solutions fell within the top 10% of genomes (with fitness values ranging between 2122.319056 and 2439.581081). The massive reduction in solver pace, despite the calibrations implemented to lessen the computational strain, was due to the addition of a rudimentary version of a life cycle analysis (LCA) component that made the Galapagos solver incorporate material properties as genes and produce an optimised hybrid (timber/steel) structure, effectively allowing the massing volume to be designed based on preconceived notions of materiality, financial restraints, and environmental performance.

The factors controlling the LCA component were embodied energy, cost, and material life span. As only massing is being considered, no allowance was made in the model for fenestration, though this could of course easily be added in later versions. For reasons of computational efficiency only two materials (timber and steel) were used as genes. A single value was derived for each material by multiplying cost with embodied energy and then dividing the product by the relative material life span (the building’s life span divided by the material life span). This number was used as a penalty in the fitness function: above a specified value (in this case set to 1500),(14) it was multiplied by 1000000, effectively putting that genome (design iteration) at the bottom of the stack of solutions.

Material alternatives, budgetary restraints, and sustainability principles thus combine into thresholds or framing devices that govern the outcome already at the massing study stage. While this method is unquestionably very crude in its current form, this simple experiment shows the potential to develop a much more valid, fine-tuned, and efficient LCA component for the Cow system. The final solution obtained is shown in Fig. 3. and Fig. 4. It has an area of 1431.36m2 and a volume of 2064.99m3. Its hybrid materiality is composed of 80% wood and 20% steel.

**CONCLUSIONS & DISCUSSION**

In the introductory reservation, the experiments illustrated above were described as ignorant, simplistic, and flawed. They certainly are: as has been pointed out, every part of this preliminary definition needs to be improved upon. What these initial investigations demonstrate rather clearly, however, is the possibility to con-
trol even the earliest stages of the architectural design process from a preconceived understanding of parameters (such as financial and environmental targets) crucial to the success of the project.

Proponents of parametricism would perhaps inscribe MOO and the COW system’s logic into their own and argue it is just another facet of the parametric framework. But there is a vast difference between broadly declaring that a “style” of architecture based on (any kind of) parameters is a pioneering concept and proposing that a particular operative logic for how those parameters might be controlled could open up radically new possibilities for our future built environments. In 1948, Nobel laureate Herbert A. Simon concluded that whereas “economic man maximizes – selects the best alternative from among all those available to him, his cousin, administrative man, satisfices – looks for a course of action that is satisfactory or ‘good enough’”.(15) In this context, advocates of early-day parametricism appear to be working within the realm of economic man, whereas those working with MOO systems such as COW design in the administrative realm. The first approach produces a manifesto, the second a modus vivendi. Both procedures are reversible, recursively self referential, and continuously differentiated, but only the latter offers a productive strategy for achieving optimal compromises between vast ranges of architectural desires.

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3. The brainchild of developer David Rutten, Grasshopper is a plug-in for Rhinoceros, a commercial 3D computer graphics and computer-aided design (CAD) application software developed by Robert McNeel & Associates. The first version launched in September 2007.
4. Dynamo, created by Ian Keough (Solution Architect at Vela systems), is an add-in for Autodesk Revit, a building information modeling (BIM) software for architects, structural engineers, MEP engineers, designers and contractors. The first beta version launched in 2011.


12. In Evolutionary Computing, variables are genes and genomes specific values for each and every gene. A good introduction to evolutionary solving with Galapagos is given in Rutten, D. 2010. Evolutionary Principles applied to Problem Solving. [Online] Available at: www.grasshopper3d.com/profiles/blogs/evolutionary-principles


14. This value was calculated empirically from the results given by the settings shown in Fig. 2. The lowest possible value (for a building made from 100% timber) was 22.5, the highest (for a building made from 100% steel) was 6939.759036. Using 1500 as our cut-off point returns only results that are in or better performing than the 80% timber to 20% steel range.

INFLUENCE OF SURROUNDING ON THE WOOD MOISTURE CONTENT

Bridziulaitytė, V.¹ & Juodeikiënë, I.²

ABSTRACT

Wood is a hygroscopic material and its moisture content varies in dependence of surrounding. Major influence on moisture content of wood has relative humidity of surrounding, while temperature effect is less significant. In this work wood moisture changes in dependence on air conditions have been investigated.

Samples were cut from the pine wood. Pine trunk was divided in the four zones: I zone was near the stump, II zone was 3.2-3.7 m from the stump, III zone was located 6.3-6.8 m from the stump and the IV zone was in the distance of 9.5-10 m from the stump. In perpendicular direction wood was divided in the three zones: heartwood, in-between from heartwood to sapwood and sapwood. From the each group 12 samples were prepared. Half samples were kept outdoors in the meteorological boxes and the rest part of samples was placed indoors. Specimens dimensions in radial, tangential and longitudinal directions were respectively 35, 50 and 270 mm, initial moisture content of samples was about 9-10%. Average conventional wood density was 385-414 kg/m³. Samples weight and air parameters were fixed once a week.

It was found that wood sorption properties depend on the sample place in the trunk. For indoor placed samples from sapwood moisture variation was 0.19-0.21% and for outdoors it was from 0.75 up to 0.86%. Samples prepared from the core it was 0.15-0.17% for indoors placed samples and 0.6-0.72% for outdoors ones. The highest moisture content was found for the IV zone timber, i.e. 7.7-8.4% for indoors placed samples and 15.6-15.9% for outdoors placed samples. The lowest moisture content was found in zone I (14.8-15.4%) and zone III (7.7-7.9%). The highest variation amplitude of moisture was found for the sapwood (1.2-1.3% indoors, outdoors 5.3-5.8%), the lowest for the core wood (from 4.1 up to 4.8 % and from 1.0 up to 1.2% respectively for indoors and outdoors). It was found that intensity of moisture changes for outdoors placed samples was four times higher than those of placed indoors.

Keywords: Pine wood, moisture content, heartwood, sapwood

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CONDENSED TANNINS RICH GREY ALDER BARK EXTRACT POTENTIAL AS A RAW MATERIAL FOR WOOD ADHESIVE PRODUCTION

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ABSTRACT

Condensed tannin rich extract (CTE) isolated from grey alder bark is considered as potential as green adhesive for particleboards production. The adhesive potential and quality of particleboards made on the basis of pine sawdust and tannin derived adhesives (from 10 to 20% on dry sawdust mass) were evaluated by the static bending (bending strength and modulus of elasticity in bending (MOE)). Mechanical properties of particleboards prepared using CTE as an adhesive meet the demands of European standard (EN 312 (2010) for interior fittings used in dry medium.

Keywords: bark; deciduous trees; condensed tannins; green adhesive; particleboards

INTRODUCTION

Environmental needs and growth of interest in full/party substitution of fossil derived phenols by phenols of natural origin enhance actuality of novel sources of natural phenol. Simultaneously increasing industrial requirements to the quality of wood adhesives promote in some case the necessity of natural phenol modification for satisfaction of specific needs of wood materials, connected with area of application. Approximately 71.000.000 m³ of wood based panel were produced this in 2012, simultaneously increased the consumption of adhesive, which are typically produced from oil. Traditionally, the wood panels (particle boards, fibreboards,  

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plywood, oriented strand boards etc.) are manufactured using by-product (wood chips, sawmill shavings or sawdust) together with a formaldehyde based synthetic resin. Phenol resins even nowadays, 100 years after their invention, are in high demand, and the formaldehyde glues as to the consumed amount occupy one of the first places among other glues. The growing informative concerning concern about the harmfulness of formaldehyde emission for the human promote search of renewable resources that could be used as a feedstock for adhesive production. The search for natural adhesives has recently been focused on the use of tannin. Our investigation have shown that partly substitution of fossil derived phenols in synthesis of phenol-formaldehyde with condensed tannins rich extract contribute to the reduction of formaldehyde emissions from wood panel material [1].

The barks from deciduous and coniferous trees are plentiful, at its represent up to 15% of the total weight of tree stems in the case of adult trees. Currently, the wood bark from logging and wood mechanical processing are mainly used as an energy source, particularly in sawmills or as compost or decorative landscape mulching products for use in horticulture. The bark of the most deciduous tree species may be a perspective feedstock for production of polyphenol compounds; including condensed tannins (CT). Valorization of bark polyphenols is an important task nowadays. Content of CT can reach 40% on the dry bark (wattle, quebracho). The most valuable properties of condensed tannin are their tanning activity and capability to replace the fossil phenol in the production of phenyl-formaldehyde resins. At present barks of deciduous tropical trees, wattle (*Acacia mearnsii*) and quebracho (*Schinopsis balansae*) are most widely used for production of tanning agent and adhesives. Screening of composition of bark made by authors for deciduous trees, grown in Latvia and widely spread in Europe, have shown that judging by the yield of condensed tannins and their structures some of them also could be considered as a feedstock for commercial tannin production. In particularly high amount (12% on bark dry mass) of condensed tannins in bark of alder species (*Alnus incana* and *Alnus glutinosa*) allows to consider them as prospective feedstock for tannin production [2].

The analytical characteristic of condensed tannin isolated from grey alder bark, their modification with PEI and testing of both products as an adhesive for the particleboard (pine sawdust) were the tasks of present work

**MATERIAL AND METHODS**

**Isolation and characterization of CTE from grey alder bark**

Grey alder bark (*Alnus incana*) was collected from the forest in East-South part of Latvia. Condensed tannin was extracted as describe in [2] using solvent with increasing polarity: hexane, ethyl acetate and finally aqueous ethanol (4:6 v/v). The ethanol was removed under vacuum and the remaining aqueous solution was frozen and freeze-dried. CT content in the tannin extract was measured by Porter
Obtaining of CTE based adhesive

The CT based adhesive was prepared by mixing of aqueous CT extract solution (20% w/v in water) with 50% (w/v) aqueous polyethylenimine (PEI) solution (optimal mass ratio 2:1, w/w) purchased from Sigma-Aldrich. The resulting adhesives were mixed for 5 minutes at room temperature then used for particleboard formation. Thermogravimetric analysis of CTE and CTE-PEI were carried out using a Mettler Toledo model TGA/SDTA 851. Samples were heated from room temperature (~25°C) up to 200°C at the rate of 10°C/min. in an inert atmosphere.

Preparation of particleboards

Particleboards of 350 mm x 350 mm x 10 mm dimension were prepared using pine (Pinus Sylvestris) sawdust at 2 Mpa pressure, 150°C press temperature and 15 minutes press time. From 10 to 20 % (w/w based on dry sawdust) of adhesive was added. All particleboards were evaluated by the statistic bending (bending strength and modulus of elasticity in bending - MOE) according to the relevant international standard European Norm EN 310. Mechanical properties of the particleboards were studied on a Zwick/Z100 universal machine.

RESULTS AND DISCUSSIONS

It was found that the major components (42% on extract dry mass) of the tannin extract isolated from grey alder bark are condensed tannins (proanthocyanidins). Molecular mass of CTE was about 0.5 kDa. It was found using 13C-NMR and GC results that extract from grey alder bark also contain a certain amount of carbohydrates (24 % on extracts dry mass). The modified adhesive for particleboard manufacture was prepared on the basis of CTE and polyethyleneimine (PEI), which is widely used in pulp and paper industry. The interaction between of CTE and PEI was proved using DTG analysis (Fig.1).

The main condensation processes of CTE and PEI take place up to 150°C, increasing in temperature do not lead to degradation of modified product (Fig.1., curve 2). The evaluation results of CTE and modified CTE potential as a raw material for wood adhesive production represented in Table 1. The mechanical properties (bending strength and modulus of elasticity in bending - MOE) have shown that the both adhesives could be useful for particleboard production.
Fig.1. DTG date for CTE (1) and CTE-PEI (2)

Table 1. Mechanical properties of particleboards

<table>
<thead>
<tr>
<th>Particleboard (PB) samples</th>
<th>Bending strength, N/mm²</th>
<th>MOE, N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawdust + 10% CTE/PEI (mass ratio 2/1, w/w)</td>
<td>5.01±1,10</td>
<td>699±232</td>
</tr>
<tr>
<td>Sawdust + 20% CTE/PEI (mass ratio 2/1, w/w)</td>
<td>16.9±0,02</td>
<td>1904±297</td>
</tr>
<tr>
<td>Sawdust + 10% CTE aqueous solution</td>
<td>5.28±1,36</td>
<td>819±180</td>
</tr>
<tr>
<td>Sawdust + 20% CTE aqueous solution</td>
<td>13.21±3,15</td>
<td>1305±293</td>
</tr>
<tr>
<td>Standard requirements for PB (EN 312:2010) dry medium (P2) [4]</td>
<td>11</td>
<td>1800</td>
</tr>
</tbody>
</table>

The test of module of elasticity of bending revealed that particleboard, acquired using adhesives on a basis of modified PACE (PACE-PEI), and its characteristics fit standard LVS EN 312 requirements, which are set for use in internal conditions.
CONCLUSIONS

Adhesives containing CTE (condensed tannin rich extract) and CTE modified with PEI can be used for production of particleboards for interior fittings used in dry medium (P2) according to European norms EN 312 (2010).

It is foreseen to evaluate internal bond and swelling in thickness for particleboard obtained using modified CTE adhesive in order to confirm the possibility of their using for particleboard production.

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HEMP – ALTERNATIVE TO WOOD PRODUCTS

Jonaitienė, V. ¹, Norvydas, V.², Stuogė, I.³ & Jankauskienė, S.⁴

ABSTRACT

Hemp cultivation - a viable agricultural activity that meets the environmental principles. Hemp (Cannabis sativa L.) is environmentally friendly and helpful; it is especially suitable for use in crop rotation, not exhausting the soil, reducing its pollution by weeds. Lithuania legalized hemp cultivation in 2014. The experience in hemp growing and processing is rather poor. Hemp cultivation and processing in Lithuania is very relevant in growing processing sections, such as: textile, paper, and others. There is a possibility of hemp appliance in production of textile, furniture, and building construction products taking into account its eco-friendliness, harmony and increasing production in Lithuania.

The effective manufacturing, including cultivation and processing, is required for the successful development of the sector. Hemp wood, according to the characteristics of incandescent, comparable to oak wood. The bio-based industry can make use of crops grown for material substitution (e.g. hemp for insulation instead of glass fibre, straw for furniture production, car door panels made from hemp or flax plants, bio-plastic) or for energy (e.g. using biomass instead of fossil fuels).

Hemp demand will increase, due to an increased use of renewable and biodegradable nature resources in processed products. The possibility of using cannabis in Lithuania is visible in the construction and furniture production and for the manufacturing of other products.

Keywords: Hemp, wood, products, bio composites

INTRODUCTION

Hemp is one of the oldest cultivated crops. Hemp is an annual plant, valued for grown fibers and seeds. Hemp (Lat. Cannabis) is flowering plants (Magnoliophyta) tribe, belonging to hemp (Cannabaceae) family. This is one of the oldest cultivated plants.

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Many products can be produced from hemp seeds and stalks. The fiber from the stalk is used in traditional and technical textiles, for construction and insulation materials, for production of furniture, paper, fuel, litter for animals and other products. The possibilities of hemp use are very broad and can be applied in each country. Hemp fiber has one of the best mechanical properties when compared with other natural fibers (Smith-Heisters S, 2008).

True hems are the plants with amazing vitality and ability not only to kill and displace other tiny crops or weeds, but to improve soil characteristics also.

The aim of this research is to analyse the possibilities and perspectives of hemp as alternative to wood products.

DISCUSSION

Hemp is one of the few cultures in Europe, which is grown not in organic farms, but without the use of chemicals (Carus 2013). The plant can be used for land cultivation since hemp is growing rapidly (Piotrowski, 2011). Hemp is capable of returning the polluted abandoned fields to agricultural production cultivation, as they have the properties absorbing heavy metals.

Building blocks from cannabis have A1 non-combustibility class, they are produced not only using cannabis boon, but chopped fibers also. These blocks can be called 100 percent organic, because only lime and other natural supplements are used as a binding agent. Cannabis has no non-recyclable parts, it is fully recyclable.

Hemp shives are also used for particle board production. Hemp particle board production compared to chipboard panels in Europe is a niche. Lithuanian furniture manufacturers have a high level of technological bases. Woodworking, furniture from natural wood panels production equipment is ideal for manufacturing products from hemp. Appear in the Lithuanian market environment friendly bio composite material from natural hemp fibre reinforced plastic, which can replace the furniture used wood particle boards and other packaged materials. The new technology enables the production of lighter hollow frames, thereby reducing the amount of waste (Wood-Plastic..., 2014). Two types of materials are produced from hemp stems that can be used in industry: hemp boon is obtained after crushing hemp woody core of the stem and hemp fiber, obtained from the separation of the stem fiber. Cannabis stem, depending on the species, contains approximately 20-40% of fiber which is on the surface of the stem and 60 to 80% of wood (boon).

Hemp areas increased rapidly in Lithuania in 2011-2014 (Fig.1). Their growing areas were very small till legalization, but now they are increasing each year. By 3.8 times larger crops areas were declared in 2014 than in 2013. Industrial hemp was grown on 54 hectares in 2011, and already 1,063 hectares of hemp crops were de-
clared in 2014, where 755 hectares were grown for hempseed and 308 ha for hemp fiber. Therefore, the cultivation of hemp in Lithuania was oriented to seed yield in 2014 as 71 percent of all industrial hemp crops were accounted for seed crops.

![Graph showing hemp area (ha) in Lithuania in 2011-2014](image)

**Fig. 1.** Hemp area (ha) in Lithuania in 2011-2014

The hemp stalks, pellets from the chaff, dust, due to higher biomass than of many other plants and good incandescent properties are supposed to be used as fuel. Currently, the supply and demand of hemp production is still developing in Lithuania. The introduction of existing products (hempseed oil, hemp salt, clothes from hemp, etc.) and the process of the search for the markets, new product manufacturing, processing perspectives, expanding areas for crops are going on.

Lithuania Hemp allowed growing only from 2014, still not sufficient to supply a wider use, because the country is not yet in hemp fiber processing factories. Lithuania has already started to produce building blocks of cannabis and has already built houses using hemp fiber (about 100 sq. Meters of construction of a house requires about 1 hectare of cannabis). Organic hemp blocks - an alternative construction material made from hemp shives and binder can change light concrete blocks used in the construction of buildings.

Giving the increasing demand for timber there is a need to increase its resources. The world’s most practiced method for obtaining massive wood are plantation forests. Plantation forest are grown, the growth rate of productivity and characterized species (Hummel, 1989). Lithuania as plantations suitable tree species recognized nettle, flax, hemp, hybrid aspen, miscanthus. Short rotation plantation forest plantations - a viable alternative activities to agriculture unoccupied areas. Hemp, forest and other materials productivity is shown in figure 2.
Fig. 2. Productivity (t/ha) of various materials

The figure shows that hemp is very similar performance and productivity of the forest. The highest productivity 15.9 t/ha is characterized by miscanthus plant, it is twice more as hemp and forest. Hybrid aspen wood is soft and is only suitable for small range of products (pulpwood, slab wood). Miscanthus plant advantage is extensive use of biomass. Hemp cultivation becomes relevant because the increasing use of renewable raw materials of agricultural demand on limited fossil resources, global warming and the increasing competition for arable land. Hemp biomass productivity is very high, 2-2.5 times higher than that obtained from the same area of the forest. Cannabis incandescent properties is equivalent timber oak, its combustion products do not pollute the environment, compared to other biomass appropriate parts of the crop (canola, wheat straw) combustion releases the maximum amount of energy (18500 kJ) and leave at least - 1.2% ash (Johnson, 2013).

Shives are the woody residue left over after processing of stalks (hemp, nettle, flax or other fibrous crop) on target for fibre extraction. This agricultural waste could be well used as a renewable source for composites, combustion or other forms of bioenergy (Balčiūnas et al. 2013; Mankowski and Kolodziej 2008). Plantation forest plantations are associated with the creation of new jobs in agriculture and rural areas, the abandoned lands of economic efficiency increases, arable and the maintenance people in rural areas.

CONCLUSIONS

The demand for hems and their products is still developing in Lithuania. Currently, oil producers are limited to small quantities. Cannabis cultivation and processing are very important in order to increase the use of renewable resources for thermal energy generation in Lithuania, because they have good heat characteristics and can be applied to biofuel production. The largest plantation forest plantations
market - the pulp and papers industry, the development prospects of relatively high, as new technologies allow to compete in the market without significant environmental pollution. The possibility of using cannabis in Lithuania is visible in the construction and furniture production and for the manufacturing of other products.

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EFFECT OF THE WOOD SPECIES ON THE WOOD MILLING TOOL WEAR

Keturakis, G.¹ & Bendikienė, R.²

ABSTRACT

The report presents the study of the performance of high-speed tools steel (HS) wear when milling various wood species. The tests were done using wood samples prepared of oak, birch and pine grown in Lithuania. The samples were milled along the grain in the wood cutting stand. The wood samples were milled at two different cutting and two different feeding speeds. The main characteristic to describe the wear of milling tool were chosen to be the cutting edge radius, were determined by the method of lead prints, using the optical microscope and digital microscopy camera. The average values of the cutting edge radius were determined in the fixed intervals of cutting path. The measurements were done five times in each interval of path. The received results allowed deriving the average values.

Keywords: wood, wood milling, tool wear

INTRODUCTION

The wood milling tools undergo wear during the cutting process under the effect of force, temperature, electrical and chemical factors (Porankiewicz et al. 2005; Porankiewicz et al. 2008; Darmawan et al. 2012; Horman et al. 2014; Winkelmann et al. 2009). Under the influence of these factors the mass of the tools decreases and the geometrical parameters change (Porankiewicz 2006; Porankiewicz 2008). When the tool undergoes wear and gets blunt, its effectiveness decreases, and such a tool becomes unsuitable for work after some time (Porankiewicz 2006; Porankiewicz 2008).

The experiments show that the wear of the cutting tool depends on the actual cutting path or work time, composition of the material from which the cutter is made, peculiarities of the cutting regime and properties of the wood being processed (Ābele and Miončinskas 2012; Darmawan et al. 2011; Pamfilov et al. 2014). According to the wear dynamics, the wear process of the cutting tool is divided into three stages: initial, monotonic and emergency (Zotov and Pamfilov 1991; Moiseev 1981).

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The wear of the tool tip is the most intensive in the first stage (Darmawan et al. 2012; Porankiewicz 2006; Porankiewicz 2008; Darmawan et al. 2011; Zotov and Pamfilov 1991). The initial wear of the tool makes 40-60 % of all wear of the tool, while its duration is 5-10 % of all working duration (Zotov and Pamfilov 1991). The main reason of intensive wear is the crumbling and chipping of the top of cutting edge. Remaining metal burrs and other grinding defects also have negative impact (Zotov and Pamfilov 1991; Pamfilov et al. 2014). Angular tool parameters are also significant: cutting angle, sharpness angle, rake angle, and clearance angle. The following are considered to be microgeometrical parameters of the cutting edge: cutting edge radius, recession of the cutting edge and width of cutting edge (Moiseev 1981; Zotov and Pamfilov 1991).

The main reason of the monotonic wear is the mechanical wear of the cutting elements. The cutting edge of the tool gets hot while cutting up to the temperature 700–850°C (Zotov and Pamfilov 1991). High temperature causes changes in the metal structure. Undesirable electric and chemical processes begin in the cutting area: oxidation, electrostatic discharges, and electrochemical corrosion (Porankiewicz 2006; Porankiewicz 2008; Darmawan et al. 2011; Zotov and Pamfilov 1991; Moiseev 1981). These changes significantly reduce the strength of the cutting edge. The dynamics of the cutting edge wear in various areas of the cutting edge can vary very much. It depends on the maintenance conditions of the tool, geometrical parameters of its cutting edge and properties of the material being processed (Zotov and Pamfilov 1991; Moiseev 1981).

In the stage of the emergency wear the changes in the mass of cutting tool and microgeometry of cutting edge reach the highest values (Moiseev 1981; Zotov and Pamfilov 1991; Porankiewicz 1993). Due to these reasons the cutting force and cutting power increase. When the cutting edge radius comes close to the value of 30 μm, the cutter is considered to be blunt and has to be reground (Moiseev 1981). Thus the emergency wear is rarely encountered in practice; it is more experimental stage of the tool’s wear (Zotov and Pamfilov 1991; Moiseev 1981).

The purpose of this research is to determine the influence of the wood species and cutting path on the wear of milling tool, when the wood samples are milled along the grain at different cutting and feed speeds.

MATERIAL AND METHODS

The testing samples were made of wood of pine, birch and oak grown in Lithuania (Table 1). The samples were prepared for testing, with length of 1000 mm, width 100 mm, and thickness 45 mm. The average temperature in the testing room was 18 ± 2°C, while relative air humidity was 60 ± 5%.
Table 1. Physical characteristics of wood

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Moisture content $\omega$, %</th>
<th>Number of annual rings per 1 cm</th>
<th>Density, kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak ($Quercus$)</td>
<td>9…10</td>
<td>5.07…5.25</td>
<td>618…696</td>
</tr>
<tr>
<td>Birch ($Betula$)</td>
<td>8…9</td>
<td>3.64…6.04</td>
<td>520…609</td>
</tr>
<tr>
<td>Pine ($Pinus sylvestris$)</td>
<td>8…10</td>
<td>4.21…6.21</td>
<td>415…504</td>
</tr>
</tbody>
</table>

The high-speed steel (HS 18–0–1) milling knives were used for the tests (Table 2). The chemical composition of the steel HS 18–0–1 (EN ISO 4957:2003) is presented in Table 3. Before the tests, all the knives were sharpened in the same conditions and then the blades were converged.

Table 2. Specifications of milling tool

<table>
<thead>
<tr>
<th>Steel</th>
<th>HS 18–0–1</th>
<th>Dimensions of milling blade, mm</th>
<th>60×30×3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>67.6 HRC</td>
<td>Sharpness angle $\beta$</td>
<td>40°</td>
</tr>
</tbody>
</table>

The tests were done in the stand for wood cutting, which was made in the base of thickness planer (SR3-6). The samples were processed, according to the scheme of the longitudinal milling, when the directions of the cutting speed $v_c$ and feed speed $v_f$ vectors are opposite. The conditions of milling test are presented in the Table 4. Two knives were fastened in the cylindrical head of the knives, but only one took part in the cutting process. The second was used for balancing compensation.

Table 3. Chemical composition of HS 18–0–1 steel

<table>
<thead>
<tr>
<th>Chemical composition of the steel, %</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>V</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.73 – 0.83</td>
<td>$\leq$ 0.50</td>
<td>$\leq$ 0.40</td>
<td>3.50 – 4.50</td>
<td>0.90 – 1.20</td>
<td>17.2 – 18.7</td>
</tr>
</tbody>
</table>

The thickness of the shaving $a$, mm was changed indirectly, through the feeding per cutter $f = 1.0$ and 2.00 mm. The samples were processed at two cutting speeds $v_c = 22$ and 40 m/s.

The main characteristics describing the wear of milling tool was selected to be the cutting edge radius $r$. The factual values of edge radius were determined using the method of lead prints and optical microscope (Nikon Eclipse E200) with digital video camera (Lumenera Infinity 1).

Table 4. Milling test conditions

<table>
<thead>
<tr>
<th>Cutting speed $v_c$, m/s</th>
<th>22; 40</th>
<th>Width of milling $b$, mm</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed speed $v_f$, m/min</td>
<td>4; 8; 16</td>
<td>Cutting circle diameter $D$, mm</td>
<td>103</td>
</tr>
<tr>
<td>Feeding per cutter $f$, mm</td>
<td>1.0; 2.0</td>
<td>Number of cutting edge $z$, unit.</td>
<td>1</td>
</tr>
<tr>
<td>Depth of milling $h$, mm</td>
<td>2</td>
<td>Cutting angle $\delta$, degree</td>
<td>60</td>
</tr>
</tbody>
</table>
The values of the cutting edge radius were determined in the following intervals of cutting path $L$: 0; 50; 100; 150; 200; 400; 800 and 1600 m. The measurements were done five times in each interval of the path. The received results were processed and measured using the personal computer and software (Infinity Analyze Release 5.0.2). The error of radius measurement accuracy was $\pm 2 \, \mu \text{m}$. The received results were processed using the methods of mathematical statistics.

**RESULTS AND DISCUSSION**

While analyzing the received results on tool’s wear (Fig. 1), it was realized that the tool gets worn the most intensively in the first wear stage until the limit of cutting path $L = 400$ m. In the first stage of wear the species of wood does not have any significant influence on the wear intensiveness. The difference between the average values of the cutting edge radius in case of milling oak and birch samples was from 4 to 8 % while between oak and pine was from 7 to 15 %. In this stage the wear of tool is expressed by mechanical crumbling of cutting edge. When the cutting path reaches the distance of 400 m, the tool’s wear gradually passes to the stage of monotonous wear. In this stage the intensiveness of increase of cutting edge radius is reduced. The tool gets worn evenly, and the microgeometry of cutting edge changes because of temperature and electrochemical corrosion. The tool’s wear was observed until the section of 1600 m of cutting path.

When the influence of the wood species on tool’s wear was analyzed, it was noticed that the tool gets worn more intensively when oak is milled, although the density of oak’s wood is bigger if compared to the birch and pine wood (Table 1). However, the exception was also noticed: when the feeding per cutter $f$ is 1.0 mm, and the cutting speed $v_c$ grows from 22 to 40 m/s, the tool’s wear is smaller if compared to the milling results of oak, birch and pine wood. When the cutting speed increases, the bulk part of the shaving loses contact with the processed surface due to the oak and birch wood tendency to split under the influence of smaller cutting forces. The shaving is formed more easily; the real length of cutter’s contact with the wood gets reduced when compared to the milling of pine that tends to split less.

While analyzing the influence of feeding per cutter on the cutting edge radius, it was determined that when the feeding per cutter $f$ grows from 1.0 to 2.0 mm, the intensiveness of the tool’s wear gets more. When the feeding per cutter $f$ is 2.0 mm, the most intensive wear of the tool takes place when the oak is milled. When the pine wood is milled, the tool gets worn from 2 to 4 % less. When the birch wood is milled difference was from 3 to 5 %.

The received results are interesting for interpretation of the postulates of classical wood cutting theory. With increase of feeding per cutter, the shaving’s length gets bigger a bit, as well as theoretical contact of cutting edge with wood. The intensiveness of tool wear should grow, but the thickness of shaving also increases, and
the tendency of dry wood to split in case of against feed milling results in reduction of real friction contact and wear of cutting edge.

CONCLUSIONS

The wear of the milling knives is the most intensive in the initial cutting stage up to 400 m of the path. It is determined that in this stage the wear of knives is caused by the crumbling of cutting edge.

When the milling knife reaches the 400 m limit of the cutting path, the stage of monotonic wear begins. The increase of the cutting edge radius gets smaller and the wear process gets stabilized.

When the feeding per cutter is higher, the resistance of milling knives to wear decreases. It is determined that if the average thickness of the shave increases, the cutting force for the cutting edge increases as well. The wear of the cutting edge by crumbling gets more intensive.
When the cutting speed is increased from 22 to 40 m/s, the wear of the tools, decreases on average by 2 % when pine is milled, by 7 % when birch and by 10 % when oak.

The tool wears more intensively when oak is milled. When birch wood is milled, the tool’s wear is reduced from 4 to 8 %. When pine wood is milled, the tool’s wear is reduced from 7 to 15 %.

REFERENCES

CNC MACHINING OF HALFTONE AND LITHOPHANE IMAGES INTO WOOD-BASED PANELS

Kiiman, K.¹, Luga, Ü.² & Kers, J.³

ABSTRACT

CNC machining of images into wood-based materials allows production of high value products to be used as decorative elements in interior design.

The aim of the current research was to develop the processes of CNC-machining of halftone and 3D lithophane images into wood-based panels.

Firstly halftone images were machined into wood-based materials with the use of a special freeware named Halftoner V1.4 (by Jason Dorie). The output of this program being a G-code it had to be converted into*.ply file format to allow the insertion of the toolpaths into Weeke CNC machine. For that purpose necessary converter was written in Visual Basic programming language. Halftone technique was used for reproducing images in two different styles – in a line and in a dot style. Tests showed that the dot style is four times more time consuming. Nevertheless the dot style proved to work with several materials when the line style only produced satisfactory results for melamine faced MDF.

Secondly the lithophane technique was used to produce 3D photograph effect by CNC machining lines with different width, spacing and depth into plywood. To convert images to lithophanes Vectric’s PhotoVCarve program was used. Desired material chosen for testing was plywood and thus the use of plastics and solid surface materials (Corian) was set aside. After tests with different plywoods the 4 mm thick II/III quality birch plywood was selected for further testing. Back lit light was used to make CNC milled lithophane image visible, where thicker areas let less light trough thus representing darker tones of the original image and thinner areas in contrast let more light through hence portraying the lighter tones.

As a result processes of CNC machining of halftone and lithophane images were worked out, yielding in creation of several successful test pieces. The results of the research are applicable for customizing the developed processes for other specific CNC machines besides the used Weeke CNC as well.

Keywords: lithophane, halftone, CNC

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INTRODUCTION

CNC machining images into wood-based panels allows these materials to be used as decorative elements that can be used for decorations as paintings and photos or used in pieces of furniture for producing high value products.

Halftone is a technique for reproducing images where continuous tones are represented as dots, varying either in size, in shape or in spacing, thus generating a gradient like effect. Halftone can also be used to refer specifically to the image that is produced by this process. (London, 2012). In this study the term halftone is representing a wood-based panel with holes with different diameter, depth and spacing in it. If this panel (Fig.1.) is viewed from a right distance, our brains will merge all the holes together to give us the impression that what we are seeing is a smooth image.

![Fig. 1. CNC machined halftone image of Tallinn University of Technology’s Chair of Woodworking faculty members (a) and magnification of the same image (b)](image)

Lithophanes are 3D photographs that when viewed in normal lighting look a little dull and lifeless. But when back lit transform into stunning 3D pictures with depth and detail that cannot be seen in a flat 2D photograph (3D lithophanes ...).

Lithophanes originate from a process developed back in the mid 1800’s for mass producing 3D pictures in porcelain. A 3D design was hand engraved into a thin sheet of bees wax that was placed over a lighted candle to show the effect of light passing through the wax. This master design was then used to make a mold for casting designs in porcelain. Varying levels of light to pass through the porcelain depending upon the thickness. (3D lithophanes ...).

More recently lithophanes have been made with the use of CNC machines and 3D printing. This has massively reduced the cost of making custom lithophanes from photographs. (Lithophane).

The aim of the current study was to develop the process of CNC-machining of halftone and 3D lithophane images into wood-based panel materials.
MATERIALS AND METHODS

Halftones

The machine used in this work for CNC reproducing images was Tallinn University of Technology’s CNC Machining Center Weeke Optimat BHC 280. 7.5.1. To produce halftone images a 60 degree V-shaped router bit tool was used. The program used for converting chosen images into halftone and subsequently into CNC toolpaths described as a G-code was freeware named Halftoner V1.4 (by Jason Dorie).

The output of this program was G-code and as unfortunately the used CNC machine could not directly read this code therefore an additional converting program was used. As the research in order to find the suitable converter was unsuccessful thus a special made converter program that can transform G-code into *.ply file written in Visual Basic programming language was used. The *.ply file being the default file type for Weeke WoodWop program for describing toolpaths.

As the main aim of this work was to work out the process of CNC machine halftone images several materials were used from which melamine faced MDF and chipboard and HPL laminated MDF were chosen for further testing.

Litophanes

To machine lithophane images with CNC machining Center Weeke Optimat a ball-nose router bit with a radius of 1.6mm was used. For converting images to lithophanes Vectric’s PhotoVCarve program was chosen. Luckily it had a integrated postprocessor for generating *.ply file and no extra converter was needed. Desired material chosen for testing was plywood and thus the use of plastics and solid surface materials (Corian) was set aside. After preliminary tests with different plywoods the 4 mm thick II/III quality birch plywood was selected for further testing.

RESULTS AND DISCUSSION

The comparison of CNC machining experimental results of halftone and lithophane images is represented in Table 1. Halftone images can be made in two styles – in line and dot style. As these two styles turned out to be very different in process parameters then they are also addressed separately in the comparison table. Important parameter for manufacturing halftone and lithophane images is CNC machining time.
Table 1. Comparison of CNC machined halftone and lithophane images

<table>
<thead>
<tr>
<th>Image type</th>
<th>Suitable materials</th>
<th>Main problems</th>
<th>Machining time example</th>
<th>Esthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halftone images</td>
<td><strong>Line style</strong>&lt;br&gt; Melamine faced MDF</td>
<td>Breakage of the material surface layer</td>
<td><strong>15 min</strong>&lt;br&gt;187x280mm image $\rightarrow 35 \text{ cm}^2/\text{min}$&lt;br&gt;(See image a on Fig. 2.)</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td><strong>Dot style</strong>&lt;br&gt; Melamine faced MDF and chipboard and HPL laminated MDF</td>
<td>High time consumption, dyeing holes (dots) for higher contrast</td>
<td><strong>65 min</strong>&lt;br&gt;187x280mm image $\rightarrow 8 \text{ cm}^2/\text{min}$&lt;br&gt;(See image b on Fig. 2.)</td>
<td>Good</td>
</tr>
<tr>
<td>Lithophane Images</td>
<td>Birch plywoods produced using melamine formaldehyde and urea formaldehyde adhesives</td>
<td>Needs special lightning to display the image</td>
<td><strong>130 min</strong>&lt;br&gt;540x691mm image $\rightarrow 29 \text{ cm}^2/\text{min}$&lt;br&gt;(See image on Fig. 3.)</td>
<td>Very good</td>
</tr>
</tbody>
</table>

When examining the suitable materials for different CNC machined image types then it can be said that the most sensitive was the process of making halftone line style images – only melamine faced MDF (Fig. 2.) was suitable for carving out halftone images with satisfactory quality. For comparison it may be pointed out that all the materials tested for halftone dot style yielded in successful outcomes.

**Fig. 2.** Successful CNC machined line style (a) and dot style (b) halftone image on melamine faced MDF
For machining lithophane images the material used was plywood. The main factor for evaluation of plywood suitability for lithophane carving was the adhesive layer used between the birch veneers. The tests showed that phenol-formaldehyde glue based plywoods are not suitable for this application. The tested UPM Grada plywood with thermoplastic film based adhesive layer was also not suitable. The visual inspection showed that the cohesive strength in the UPM Grada’s special thermoplastic adhesive film layer is weaker than the cohesive strength for traditional adhesives resulting in unwanted peeling of the surface layer of carved plywood. Tests done with plywood’s based on melamine and urea formaldehyde adhesive layer between the veneer turned out to be successful (Fig. 3.).

Fig. 3. Lithophanes from II/III quality birch plywood – (a) from the machined side without a backlit, (c) with a backlit and (b) with a backlit from the opposite side

As it comes to the main setbacks of these three different technologies the hardest task is to avoid the breakage of the material surface layer for the halftone line style. Many tests were done to overcome that but without any success.

On the contrary the halftone dot style is not sensitive to material properties but has four times longer machining time (8 cm²/min) making this technology time wise undesirable. From this point of view the lithophane machining process seems to be the most preferable with widely available suitable materials and machining time almost as fast as for halftone line style images (35 cm²/min vs. 29 cm²/min). Despite the good sides it has the problem of needing a special backlight for displaying the images which is limitation of the possible areas of use.

There is no objective method available to evaluate the aesthetics of the outputs of these three different image reproducing technologies. As a result the following assessment may be considered as author’s personal opinion. As the lithophane image has the highest quality it is aesthetically most pleasing. The halftone dot style is second method because of its harder to grasp pattern if compared to halftone line style.
CONCLUSION

CNC machined halftone images can be successfully manufactured using freeware program Halftoner V1.4. There are two possible styles to produce halftones – line and dot style. The tests showed that dot style is four times more time consuming. Nevertheless the dot style proved to work with several materials when the line style produced satisfactory results only when melamine faced MDF was used.

Vetric’s program PhotoVCarve allows easy production of lithophane images using plywood. Although successful results were only achieved when melamine and urea formaldehyde adhesive based plywoods were used.

REFERENCES


AIR PERMEABILITY PROPERTIES OF CROSS LAMINATED TIMBER

Luciani, G.¹, Horta, R.², Kallakas, H.³ & Kers, J⁴.

ABSTRACT

The air-tightness of the building components (wall, ceiling and roof) is essential in many aspects as indoor climate, noise, energy balance and structural defects.

Inadequate air-tightness has as consequences low thermal protection, low surface temperature, damage to the structure, mould, draughts and increasing energy demand.

A CLT (cross laminated panel) panel, during the service, is exposed to different conditions. It is product with 10-12% Moisture content (MC), but during the construction can absorb building moisture and domestic ventilation can dry out CLT. The fluctuation of MC in CLT is connected with the changing in shape of the panels (swelling and shrinkage) and consequently the stresses in the panels.

Air-permeability test has been conducted in laboratory according to the standard EN EVS 12114/2000. The test machinery consists of the following parts: air compressor, air flow regulator, measuring the air flow with integrated flow adjustment valve, manometer, air filter with air pressure difference regulator, flow pipes, metal frame box.

Different pressures were applied in different steps (n.7) as reported in the standard.

This paper explains an air permeability test performed on spruce samples (n. 21 dimensions 110*110*6 mm³ MC 9.2%) in different configurations (n.3 single samples, n.3 with two lamellas glued together in crosswise direction) and with different holes (n.3 with 2 mm diameter and n.3 with 6 mm diameter) to simulate the cracks. It has been possible to see how the air flow rate changes from the samples without holes to those with holes.

In the cases of single samples and the 2 layers glued, test showed the completely tightly of them. For the drilled samples, how the flow rate doesn’t increase in proportion to the hole’s surface (2.5 for the flow instead of 9 for the holes) and the ratio between the flow and the hole is higher for the smaller holes (0.53 and 0.13). For further studies it was proposed to study a 5 layers CLT panel across the edges.

Keywords: Cross laminated timber, cracks formation, water vapour resistance

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FEASIBILITY STUDIES OF THE BIOOIL SUGARS AND ANHYDROSUGARS CONVERSION

Meile, K.¹, Zhurinsh, A.², Dobele, G.³ & Jurkøane, V.⁴

ABSTRACT

The conversion of biomass and its wastes to valuable products by termochemical route is of high interest but at the current moment it is far from practical realization. There are multiple problems to be solved, starting with pyrolysis process realization and up to the separation of individual products from complex reaction mixtures, especially if raw wood is used as a raw material. There are many researches devoted to obtaining levoglucosenone (LGO) from cellulose and cellulose containing materials - phosphoric acid is most often used for this purpose, though different acid catalysts can be applied as well. Biooils after levoglucosenone obtaining contain sugars and anhydrosugars which can also be converted to other valuable chemicals, for example, LGO. Main interest for LGO is its use as a raw material for biologically active compound building blocks synthesis. The present work is aimed at direct conversion of sugars and anhydrosugars fraction present in the biooil into LGO using traditional phosphoric acid as catalyst. Munktell microcrystalline cellulose, glucose and levoglucosan were used as model compounds for analytical pyrolysis. Samples were prepared by mixing these substances with 3%, 5% and 10% phosphoric acid water solution, dried and pyrolysed. Increasing phosphoric acid concentration to 10 w% increased relative amount of the LGO, and correspondingly side reactions products, such as water, CO₂, acetic acid, furfural and its derivatives, and levulinic acid, but also decreased the amount of 1,4:3,6-dianhydro-α-D-glucopyranose, 2-hydroxymethyl-5-hydroxy-2,3dihydro-(4H)-pyran-4-one and levoglucosan. Surprisingly, levoglucosan could not be converted to LGO completely. Comparing to levoglucosan relative amounts of pyrolysis products were 1.5 times higher for Munktell microcrystalline cellulose and practically the same in the case of glucose.

Keywords: biooil, pyrolysis, levoglucosenone, anhydrosugars.

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INTRODUCTION

Levoglucosenone (LGO) is an important 1,6-anhydrosugar with high added value, which can be produced by the fast pyrolysis of natural cellulose containing raw materials. Because of its specific structural characteristics, LGO can be used for the synthesis of pharmaceuticals, pesticides, particular carbohydrate polymers, epoxide resins, urethanes, acrylates, as well as rare sugars (Witczak, 2001). Therefore, it has a potential to be used as a replacement of fossil resources in the synthesis of different products (Sherwood, 2014), and to approach the goal of a bio-based economy.

Pyrolysis is the thermal processing of wood or other feedstock in the absence of molecular oxygen, and in the last few decades it has become particularly interesting in context with the production of value-added products (Meier, 2013). It can be applied to various feedstock, besides pyrolysis requires rather low capital investment and is easy to scale up for industrial processes (Li, 2013). In the fast pyrolysis process usually dry woody materials with moisture content not exceeding 8-10% are used and for this reason dry woodworking wastes can be excellent raw material, finding their use as utilization as fuel for energy producing more attractive and economical.

Apart from the pyrolysis parameters, such as heating rate and temperature or the vapor residence time in the reactor (Lin, 2013), a catalyst can have an important impact on the qualitative and quantitative composition of the pyrolysis products. Some examples of catalysts, which can be used to increase the yield of LGO are mineral acids and their salts (Wei, 2014; Kudo 2013).

Previous studies (Dobele, 2003) have resulted with the development of technologies for the production of individual 1,6-anhydrosugars (levoglucosan and levoglucosenone) from lignocellulose. Phosphoric acid has been reported as an acceptable catalyst for the conversion process, however the yield of the reaction was not optimal, and a high number of by-products was obtained. It was found that two of the most prominent by-products were levoglucosan and 1,4:3,6-dianhydro-α-D-glucopyranose, which decreased the yield of LGO. In order to determine the precise mechanism of the formation of LGO with levoglucosan as an intermediate product, it is necessary to perform an investigation of the catalytic impact of phosphoric acid on levoglucosan. The results of such an investigation could be used to develop a new selective method of producing LGO with a high yield.

MATERIAL AND METHODS

Materials

All chemicals were purchased from Sigma-Aldrich and used without further purification.
Analytical pyrolysis

Glucose, Munktell microcrystalline cellulose and levoglucosan were used as model compounds for analytical pyrolysis. The samples were prepared by mixing with 3%, 5% or 10% phosphoric acid solution in water, then they were dried under the vacuum at 20 °C to avoid decomposition and subjected to analytical pyrolysis. The Py-GC/MS analysis was performed using a Frontier Lab Micro Double-shot Pyrolyser Py-2020iD (pyrolysis temperature 500 °C, heating rate 600 °C/s), directly coupled with a Shimadzu GC/MS-QP-2010 gas chromatograph with a capillary column RTX-1701 (60 m × 0.25 mm) with 0.25 µm stationary phase film (injector temperature 250 °C, ion source 250 °C with EI of 70 eV, the MS scan range m/z 15–350, carrier gas helium at a flow rate of 1 mL/min and a split ratio of 1:30). The weight of the sample probe was 1.00-2.00 mg. The oven programme was 1 min isothermal at 60 °C, then a linear temperature increase of 6 °C/min to 270 °C, and finally 10 min at 270 °C. The apparatus was modified by the installation of the splitter of the carrier gas flow Vitreous Silica Outled Splitter (VSOS) in order to perform analysis, simultaneously using FID and MS detectors. As a result of the modification, the volatile products released during pyrolysis can be identified (MS detector) and quantified (FID detector) simultaneously. The mass spectrometer was operated in the electron impact mode using the electron energy of 70 eV. The identification of individual compounds was performed on the basis of a GC/MS chromatogram using the Library MS NIST 147.L113, whereas the relative area of the peaks of individual compounds was calculated using the Shimadzu software on the basis of GC/FID data. The summary molar areas of the relevant peaks were normalised to 100%, the data for five repetitive pyrolysis experiments were averaged and relative error of measurement was less than ± 5%.

RESULTS AND DISCUSSION

The analytical pyrolysis results showed that different anhydrosugars (Fig. 1) were formed during the pyrolysis process. The most notable products were not only LGO, but also levoglucosan and 1,4:3,6-dianhydro-α-D-glucopyranose.

The general trend was that with the increase of the concentration of the catalyst – phosphoric acid, the total area of the peaks in the analytical pyrolysis GC-MS chromatograms decreased. Table 1 shows the results of the analytical pyrolysis. Higher concentration of phosphoric acid resulted in an increase of acids (formic, acetic, propionic and especially levulinic acid). Similarly, there was an increase in the yield of furfural. The yield of LGO from levoglucosan was comparable to that obtained from glucose. Still it was only about 70-80% of the yield, if microcrystalline cellulose was used. It was surprising that levoglucosan could not be converted completely to LGO and other products at the given pyrolysis conditions and the detected relative amounts in pyrolysis products were two times more than for Munktell microcrystalline cellulose, but practically the same as for glucose.
On the whole, the observed trend in the LGO yields was as follows: Munktell microcrystalline cellulose > glucose > levoglucosan. Increasing the concentration of phosphoric acid decreased the yield of 1,4:3,6-dianhydro-α-D-glucopyranose, 1,6-anhydro-β-D-glucofuranose and levoglucosan.

Fig. 1. The formation of anhydrosugars during the decomposition of cellulose under the influence of phosphoric acid: 1 – section of cellulose, 2 – levoglucosan, 3 – levoglucosenone, 4 – 1,4:3,6-dianhydro-α-D-glucopyranose

Table 1. The main products of analytical pyrolysis depending on the raw material (levoglucosan, glucose or Munktell microcrystalline cellulose) and phosphoric acid concentration (3%, 5% or 10%), rel.%

<table>
<thead>
<tr>
<th>Product compound</th>
<th>Levoglucosan</th>
<th>Glucose</th>
<th>Munktell cellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Formic acid</td>
<td>0.68</td>
<td>1.09</td>
<td>2.93</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.70</td>
<td>0.63</td>
<td>0.33</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>0.27</td>
<td>0.57</td>
<td>1.50</td>
</tr>
<tr>
<td>Furfural</td>
<td>4.77</td>
<td>6.13</td>
<td>8.32</td>
</tr>
<tr>
<td>Levalinic acid</td>
<td>1.76</td>
<td>2.92</td>
<td>7.37</td>
</tr>
<tr>
<td>Levoglucosenone</td>
<td>35.65</td>
<td>43.86</td>
<td>43.74</td>
</tr>
<tr>
<td>1,4:3,6-dianhydro-α-D-glikopyranose</td>
<td>6.88</td>
<td>7.34</td>
<td>7.11</td>
</tr>
<tr>
<td>2-hydroxymethyl-5-hydroxy-2,3-dihydro-(4H)-pyran-4-one</td>
<td>3.69</td>
<td>3.19</td>
<td>1.38</td>
</tr>
<tr>
<td>Levoglucosan</td>
<td>29.82</td>
<td>17.48</td>
<td>8.82</td>
</tr>
<tr>
<td>1,6-anhydro-β-D-glucofuranose</td>
<td>2.29</td>
<td>1.27</td>
<td>0.31</td>
</tr>
<tr>
<td>Water, CO₂, methanol</td>
<td>32.86</td>
<td>38.43</td>
<td>42.20</td>
</tr>
</tbody>
</table>
CONCLUSIONS

Increasing the concentration of phosphoric acid increased the yield of LGO, furfural and organic acids (especially levulinic acid), but decreased the yield of other anhydrosugars. The highest yields of LGO were obtained from Munktell micro-crystalline cellulose, the yields from glucose and levoglucosan were comparable.

ACKNOWLEDGEMENTS

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REFERENCES

MEASURING THE ELECTRICAL CONDUCTIVITY OF WOOD AT LOW MOISTURE CONTENTS

Otten, K.A.¹, Brischke, C.¹ & Meyer, C.¹

ABSTRACT

The performance of porous and hygroscopic building materials is closely connected to its sorption properties and ability to get wet. Weight, mechanical, acoustic, and thermal properties as well as the resistance to discoloring and decay causing organisms is affected by moisture. For various reasons and purposes it is therefore recommendable to monitor the moisture content of building components continuously. Several methods are available for this purpose such as load cells, capacitive or tomography techniques. The most common and most easily applicable methods are electrical resistance measurements. They can be applied to wood and wood-based materials as well as to mineral products such as mortar and brick. However, resistivity measurements require material specific characteristics and a temperature compensation since both parameters have a remarkable effect on electrical conductivity.

This study aimed on developing a model to determine the moisture content at any temperature for different building materials such as untreated and modified wood as well as untreated and hydrophobized mortar. Therefore, the electrical resistance was measured with a data logging device in the giga-ohm range to obtain values at low moisture contents. The results showed that this model enables measurements within a wide range of moisture contents and suited with an acceptably high accuracy by using the appropriate resistance characteristic for each building material.

Keywords: Electrical resistance, giga ohm range, moisture monitoring, resistance characteristics

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FORMULATION OF AN ALKYD EMULSION SUITABLE AS A WOOD PAINT

Sansonetti, E.¹, Andersone, I.¹ & Andersons, B.¹

ABSTRACT

In this research, the stages and the attempts made to obtain a stable emulsion of alkyd resin and linseed oil in water are discussed. The starting point of this new formulation is a solventborne alkyd paint for wood, in which the solvent white spirit is replaced with water, in order to reduce the volatile organic compounds (VOC) emissions. The modification of the formulation requires further adjustments: to have the alkyd dissolved in water, thus forming an oil/water emulsion, suitable surfactants and other additives must be added to the formulation to ensure stability and to obtain the desired properties. Additives are required to modify the properties of the resin, such as viscosity or surface tension, or to improve specific properties throughout the life-cycle of a paint, such as processing properties in manufacture, in-can stability, application properties, drying properties and final film performance. In this framework, attempts have been made also to find the proper sequence of the addition of components in the emulsion, a very important aspect for paint formulators.

Keywords: wood paint, waterborne, alkyd emulsion, additive

INTRODUCTION

Historically, solventborne chemistries dominate wood paints technologies, and still nowadays in the paints market, solventborne formulations have a predominant position, although alternative solutions are gaining place. The function of organic solvents in paints relates to certain properties it brings: it facilitates the paint’s application, its drying, and the formation of a regular film. During the application and drying, solvents evaporate. However, when these solvents evaporate into the atmosphere, they have a negative, toxic impact on the environment. In the last 20 years, due to the environmental legislation and economic constraints, manufacturers of coatings, ink and adhesives have come under increasing pressure to reduce or eliminate the volatile organic compounds (VOC) and hazardous air pollutants (HAP) content in formulations, because of the hazard they represent to the environment and to the human health. In Europe, this is stated by the Directive 2004/42/EC of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic

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solvents in decorative paints and varnishes, amending the already existing Directive 1999/13/EC (“the Paints Directive”). As a result, formulators and users of industrial coatings now face significant challenges as they try to respond to their customers’ demands for cost-effective, high performance paints and coatings while meeting increasingly stringent regulations. Actually, there are three leading alternative technologies: waterborne, powder and radiation curable coatings. These technologies must be improved to keep up with the results of the appearance and performance obtainable by using the solventborne technology. Therefore, a continuous improvement in formulations is necessary in order to satisfy the increasing requirements. Waterborne paints generate interest for a number of reasons: the environmental legislation, health aspects and the lack of flammability. However, the creation of waterborne paints goes through a number of challenges related to the production process, storage and application. A number of problems are general in nature; some others are typical for paints that are based on waterborne dispersions, like acrylic dispersions and alkyd emulsions, while other problems are directly linked to the resin that is within the dispersed droplets (Beetsma, 1998). Alkyds, in particular, have seen very little conversion to waterborne or lower VOC options, primarily due to the performance gaps related to drying time, gloss, adhesion, and corrosion resistance. Alkyd resins are condensation polymers derived from polyols, a dicarboxylic acid or carboxylic acid anhydride and fatty acids. These resins are polyesters modified with monobasic fatty acids (van Gorkum & Bouwman, 2005). Alkyds are fundamental binder materials for the manufacture of different types of surface coatings. They are outstanding in terms of the versatility of their formulations and applications, low prices and durability. In the traditional solventborne formulations, alkyd resins show very good performance in a wide range of applications such as air-drying varnishes, architectural paints, and marine coatings (İşeri-Çağlar et al., 2014). In our experiments, new formulations for a waterborne paint, using alkyd and linseed oil as binders, were investigated. The first step was to find the proper dispersing agent to form an o/w emulsion; subsequently, other additives were investigated to improve the emulsion stability, and tests were conducted to investigate the ease of application of the coating on a wood substrate, to obtain a homogeneous distribution of the paint. In this case, the different properties (viscosity, density, surface tension) of water and binders are the main obstacle, and additives are necessary to achieve the best balance of properties, taking into account the relative importance of each property (Brown, 2003).

MATERIAL AND METHODS

Main composition of the coating

To generalise, liquid paint, in its simplest form, consists of a pigment, a binder and a solvent. When the binder is soluble in the solvent, no interface is generated between the solvent and the binder, and the mixing process does not require energy;
in the case of alkyd and water, two immiscible components forming an interface upon mixing, the role of the surfactants is to reduce the free energy between two phases, to promote the formation of a stable system (Hellgren et al., 1999). In this experiment, the main components of the emulsion were distilled water as a solvent, alkyd and linseed oil as binders, and surfactants. Only water was used as a solvent, without an organic cosolvent, that is usually present also in waterborne coatings (Hofland, 2012). Linseed oil and alkyd resin were provided by the Riga Varnish and Paint Factory, alkyd was prepared heating 55% of tall oil fatty acids, 25% of phthalic anhydride and 20% of pentaerythritol, resulting in a medium length alkyd. The total amount of the binder in the emulsion varied between 20 and 30%, the initial ratio of alkyd/linseed oil was 2:1; later changed to 4:1. In the last attempts, linseed oil was removed from the formulation. Samples of 9 surfactants were provided by Air Products: they were selected according to their chemico-physical properties and as recommended by the producer for use in waterborne paint formulations. Their generic characteristics are listed in Table 1.

Table 1. Surfactants used and some of their characteristics

<table>
<thead>
<tr>
<th>Name of surfactant</th>
<th>Type-concentration (%)</th>
<th>HLB</th>
<th>Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbowet 109</td>
<td>Nonionic, 60-100%</td>
<td>13.1</td>
<td>Liquid</td>
</tr>
<tr>
<td>Carbowet 125</td>
<td>Nonionic, 100%</td>
<td>12.5</td>
<td>Liquid</td>
</tr>
<tr>
<td>Carbowet 138</td>
<td>Nonionic, 100%</td>
<td>13.9</td>
<td>Liquid</td>
</tr>
<tr>
<td>Carbowet 144</td>
<td>Nonionic, 100%</td>
<td>14.4</td>
<td>Solid wax</td>
</tr>
<tr>
<td>Dynol 800</td>
<td>Nonionic, gemini, 70%</td>
<td>not available</td>
<td>Liquid</td>
</tr>
<tr>
<td>Dynol 810</td>
<td>Nonionic, gemini, 80%</td>
<td>not available</td>
<td>Liquid</td>
</tr>
<tr>
<td>Surfynol 104A</td>
<td>Nonionic, gemini, 50%</td>
<td>4</td>
<td>Liquid</td>
</tr>
<tr>
<td>Surfynol 440</td>
<td>Nonionic, gemini, 100%</td>
<td>8</td>
<td>Liquid</td>
</tr>
<tr>
<td>Surfynol 2502</td>
<td>Nonionic, gemini, 100%</td>
<td>8</td>
<td>Liquid</td>
</tr>
</tbody>
</table>

The concentration of the surfactant varied between 4% for the first attempts to 2% for the last ones. The Carbowet surfactants are linear ethoxylated alcohols, with a chain length varying from 9-11 (Carbowet 109, 125, 138) to 12-15 atoms of carbon (Carbowet 144), Dynol and Surfynol series are acetylenic based surfactants, all containing a triple bond: Dynol 800 and 810 are the same ethoxylated 2,5,8,11-tetramethyl-6-dodecyn-5,8 diol, but at 2 different concentrations, Surfynol 104A is a solution of 50% 2,4,7,9-tetramethyl-5-decyne-4,7-diol in 2-ethylexanol, Surfynol 440 is ethoxylated 2,4,7,9-tetramethyl-5-decyne-4,7-diol, and Surfynol 2502 is ethylene oxide-propylene oxide copolymer diether with 2,4,7,9-tetramethyl-5-decyne-4,7-diol (surfactants of Surfynol series are obtained from 2,4,7,9-tetramethyl-5-decyne-4,7-diol).
Additives

Additives are used in paints for a great number of purposes to improve specific properties such as processing properties in manufacture, in-can stability, application and drying properties, and final film performance. They can be categorised according to their chemistry or can be distinguished between those that influence liquid properties, conversion to a film and dry film properties. A problem with the use of additives is that they can interact with each other and are very system specific; in some cases, one additive can compromise the activity of the other ones (Bulian & Graystone, 2009). The following additives were included and tested in the formulations: cobalt drier to promote film formation, an anti-skinning agent to avoid the top film formation during storage, an antifoam agent to prevent the foam formation during the emulsification process, an anionically-stabilized aliphatic urethane-acrylic hybrid polymer dispersion and fluorinated compounds to reduce the surface tension of water.

RESULTS AND DISCUSSION

Emulsification of alkyd and linseed oil

The first step was the selection of the right surfactants, among the available ones, to emulsify the binders initially without other additives. Our experiments confirmed that the most suitable surfactants were ethoxylated alcohols (Carbowet): they are non-ionic, with a high HLB, are easily and totally soluble in water, and form stable oil/water emulsions with alkyd and linseed oil. Emulsification of alkyd and linseed oil with other surfactants, Dynol and Surfynol, was not successful, due to the separation of phases that rapidly occurred after mixing. Though gemini surfactants have a higher surface activity, thanks to their structure, containing two hydrophobic tails and two polar head groups, in this case, they were not effective due to their poor solubility in water; this was also confirmed by the lower values of HLB. The binders and water were mixed with a magnetic stirrer and an ultra-sonic mixer: to obtain a stable homogeneous emulsion in a shorter time, an ultra-sonic mixer was necessary (mixing time from 10 to 20 min); a magnetic stirrer had not enough power to facilitate the emulsification of binders or, at least, not in the same period of time. During the emulsification attempts, the concentration of binders was gradually increased, whilst the surfactant concentration was reduced; this optimization was necessary also to reduce the amount of the foam formed during sonication, although an anti-foam agent was required anyway.

Investigation of the sequence of emulsification

Once the appropriate surfactants were found, the sequence of addition was investigated during the experiments: initially, binders and additives were added to water containing surfactants, alternating the cycles of sonication and addition of
additives to form the emulsions. This procedure was not a good sequence, the
dispersion of binders was not uniform and small droplets of the binder and the
cobalt drier were visible on the surface of the emulsions. In the next attempts, the
opposite strategy was used: first, the paint base was prepared, mixing the binders,
the drier and other additives till they became a homogeneous phase, and water
and surfactants were added at the end, followed by emulsification. In these new
emulsions, the binder content was 20% and the linseed oil-alkyd ratio was 1:2. The
emulsions obtained in these attempts were more homogeneous.

Additives and stability of the paint

At this stage of the experiments, several coatings were prepared to investigate
the necessary concentration of cobalt, and their drying rate at room temperature.
Compared to the previous attempts where the Co concentration was 0.2%, in these
cases, the Co concentration was slightly reduced. The results of the drying rate are
listed in Table 2. In all cases, the coatings dried, and the formation of a film was
observed. For the coatings EML01, EML02, EML03, the sequence was changed:
Co was added to the binders before the emulsification with water and surfactants.
These emulsions were more homogeneous, and the dispersion was better and more
stable.

Table 2. Mass changes during drying at room temperature

<table>
<thead>
<tr>
<th>EMULSION</th>
<th>Co (%)</th>
<th>Binder (%)</th>
<th>m (g)</th>
<th>m after 24h (g)</th>
<th>m after 48h (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EML01</td>
<td>0.17</td>
<td>21.3</td>
<td>2.00</td>
<td>0.41</td>
<td>0.38</td>
</tr>
<tr>
<td>EML02</td>
<td>0.11</td>
<td>20.9</td>
<td>2.00</td>
<td>0.48</td>
<td>0.40</td>
</tr>
<tr>
<td>EML03</td>
<td>0.13</td>
<td>21.0</td>
<td>2.00</td>
<td>0.39</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Among the 3 emulsions, the most stable was EML03. EML01 and EML02, after
some time, gave phase separation and top film formation was observed. EML03
remained stable after 2 months; this can be explained by the different antioxidative
agent used for EML03: Exkin 2 (Methyl ethyl ketoxime) is an anti-skinning agent
in liquid form used in air-drying paints or inks. Anti-skinning agents complex the
primary driers (usually cobalt and manganese) preventing the top film formation
during storage, whilst minimizing the effect on the drying speed. Another additive
used in these new emulsions was fluorotenside suitable to reduce surface tension
and viscosity. In the last attempts, only alkyd was used as a binder, its concen-
tration was increased to 30% and the surfactant concentration was 2%; 1% of
fluorotenside was added to the alkyd before emulsification, and a reduction in al-
kyd viscosity was visible. Another interesting additive, an anionically-stabilized
aliphatic urethane-acrylic hybrid polymer dispersion, was added at the end of the
emulsification process. This dispersion was in water and could be added by simply stirring the emulsion; no phase separation was observed. Samples coated with this paint showed homogeneous penetration, good adhesion, and once the film dried, good water repellence; its concentration in the formulation was 5%. It eventually can improve the barrier properties of alkyd.

**Evaluation of coating penetration and wettability**

Painting tests were conducted on wood samples of aspen (*Populus tremula*) measuring 150x70x15 mm, to check the ease of the applicability and penetration of the coating. Three layers of the paint were applied with a brush, allowing each layer to dry for 24 h. To verify the response of different substrates, paints were applied on hydrothermally treated and untreated wood samples. Aspen wood was hydrothermally treated at 170°C for 100 min at high pressure in water vapour medium. The application of the paint on hydrothermally treated and untreated wood samples resulted in different behaviours: both the type of the substrate and the composition of the emulsion influenced its absorption. For all emulsions, containing linseed oil and alkyd, a deeper penetration of the paint was observed for hydrothermally treated wood than for untreated wood. For hydrothermally treated wood, the paint penetrated to a depth of 5 to 15 mm, whilst for the untreated wood, it penetrated to a depth of 1 to 4 mm. This can be explained by:

a) the changes in the chemico-physical properties of wood after hydrothermal treatment: wood becomes more hydrophobic and porous, has lower density and reduced moisture content;

b) the presence of linseed oil, which is less viscous and dries slower compared to alkyd, promotes deeper penetration.

The decrease and, in the last attempts, elimination of the linseed oil amount affect ed the penetration of the paint into the wood sample: the penetration was lower, the binder remained closer to the wood surface; in any case, the paint applied on the hydrothermally treated wood showed a deeper penetration.

**Ease of paint application on a wood substrate**

During the painting of wood samples, a non-uniform distribution of the paint was observed. This problem is related to the different drying mechanism of alkyd emulsions compared to solventborne paints. A different rate of absorption for water (faster) and the binder (slower) was observed. Once the binder separated from wa ter, the different viscosity and fluidity affected the rate of absorption, and in some cases the film obtained was visibly uneven. Further investigations and other additives are necessary to modify the alkyd viscosity and the rheological properties of the emulsion without altering its stability.
CONCLUSIONS

Our experiments confirm that ethoxylated alcohols surfactants are effective dispersing agents in waterborne paints, and provide stable emulsions, dispersing alkyd and linseed oil without the disruption of droplets or coalescence; using ultrasonication, the emulsions appear white. The stability of the emulsions is affected by additives; in some cases, by simple stirring, it was possible to restore the emulsions, in other cases, the emulsions irreversibly collapsed. In our experiments, only water was used as a solvent, avoiding the utilization of an organic cosolvent that is usually present also in waterborne paints. Cobalt is confirmed to be a highly efficient drier, also at a low concentration, but there are some problems related to the dispersion and stability of the paint. The proper sequence of mixing order has been characterized; other additives are necessary and must be investigated to improve the paint stability and applicability. The absorption and penetration of the paint is deeper in hydrothermally treated wood than in untreated one: to facilitate it and to obtain a homogeneous film, viscosity modifying agents must be added to the binder.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the National Research Programme “Forest and earth entrails resources: research and sustainable utilization – new products and technologies” (ResProd)” Project Nr.3 “Biomaterials and products from forest resources with versatile applicability”.

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DEVELOPMENT OF A TEST SETUP FOR THE DYNAMIC MECHANICAL ANALYSIS OF WOOD SAMPLES IN TENSILE STRENGTH MODE

Stenzel, M.1, Sanne, M. 2, Larnøy, E. 3, Treu, A. 4, Herold, N. 5 & Pfriem, A. 6

ABSTRACT

Dynamic Mechanical Analysis (DMA) is not very common in wood research. For testing wood, no standards are given. Therefore researchers make up their own test set-ups which makes a comparison of different measurements difficult if not impossible. In this study the development of a method to manufacture the specimens was one goal that had to be achieved. The following results are representative for tensile tests on a DMA with a load cell of ±25 N.

One of the biggest problems of DMA measurements when testing in tensile modus is the clamping system. The clamps face is smaller than the area necessary to hold the specimens in place because wood can’t withstand the pressure due to a low stability across the grain. With this small load cell one can only measure cross sections with about 1 mm². Specimens for tensile tests should be as long as possible.

In this study, carried out in two research institutes, two ways of getting precise specimens were obtained: first method was to sand down a board of 3 mm thickness to 0.3 mm by gluing it partially to a MDF panel. The width of 3 mm is than cut by a router to prevent any saw marks and the result is a square cross section. The advantage is a straight and even stripe having cells which have never been mechanically stressed. A big disadvantage is the need to enforce the ends of the stripes in order to prevent crushing the cells and creating a pull linkage. The second method used micro veneers with a thickness of 100 – 200 µm which were produced with a microtome similar to microscopy specimens. The width is then made by tearing the veneer along the grain. The advantage is a truly orientated strand but

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no squared cross section. In general high numbers of growth rings are essential in the radial section. This could be better achieved by using the microtome method. On the other hand an undamaged wood cell is needed and it is for further investigations if the micro veneer has any micro cracks due to the cutting process. In every case specimens have to be climatized during the tests because of potential moisture evaporation during the measurement. The influence of preconditioning of wood samples and the control of relative humidity during measurements will be investigated in future trials.

Keywords: clamping, sample preparation, DMA, DMTA, tensile test, wood
WOOD SURFACE PHOTOSTABILIZATION USING CERIUM DIOXIDE NANOPARTICLES IN TRANSPARENT WOOD COATINGS

Uselė, U.¹, Ukvalbergienė, K.² & Lazėnė, J.³

ABSTRACT

It is well known that the natural wood surfaces, finished with transparent coatings has a shorter service life and aesthetic view comparing to the wood surfaces, coated with stain. Transparent coatings, used for outdoors, fail within a short time, because the solar ultraviolet (UV) radiation can readily penetrate through the coatings and reach the wood underneath, causing the degradation of the cell walls as well as the organic coating by itself. One of the solution to change the performance of the transparent coating on wood can be enhanced using inorganic metal oxide nano additives. The main objective of this research was to reduce UV transmittance through water-based clear acrylic (AK) wood coating, using cerium dioxide (CeO₂) nanoparticles. Tangential and radial cut planed pine (Pinus sylvestris L.) wood samples were impregnated against biological pests and finished with AK varnish containing five different concentrations of the CeO₂ nanoparticles (up to 7 %). Coated wood samples were exposed for ten months in natural weathering conditions in Kaunas, Lithuania. The colour change of the coated wood samples were evaluated accordingly to CIE-L* a* b* system. During the natural weathering, moisture and visual change of wood samples were observed. The adhesion strength of the coating to the surface of wood was examined before and after 5 months of the natural aging. In order to determine the change of UV absorption of the coatings, the UV-VIS spectroscopy was performed. It was noticed, that increasing the concentration of CeO₂ nanoparticles in the coating, the absorption of UV radiation of the coatings also increases. However, increased CeO₂ concentration caused yellowing of the coatings and the lightness parameter ΔL started to decrease. During the time of exposure, coatings with CeO₂ nanoparticles had a raising trend of redness (+Δa) and yellowness (+Δb). Despite the fact that CeO₂ gives yellow undertone for coating, it keeps durability and UV resistance.

Keywords: pine wood, acrylic coating, CeO₂ nanoparticles, natural weathering, UV resistance

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MOISTURE BUFFERING WOODEN SURFACES

Vahtikari, K.1 & Hughes, M.2

ABSTRACT

This paper presents the results of an initial screening of the moisture buffering performance of various wood species on two humidity levels. In addition, the effect of coatings and variation in three different grain directions regarding the moisture buffering performance were investigated. To create a link from the material behaviour to an end product, wooden interior element demos made in Aalto University student projects are also presented.

The cutting direction and thus the grain direction is the most significant factor influencing the sorption behaviour of wood from material perspective. Moisture buffering value for the crosscut surface of Scots pine was fourfold compared to the radial surface. The choice of coating is also of utmost importance when the moisture buffering ability of wood material is to be retained. Typical coatings used in interiors may decrease the moisture buffering capacity more than 50%.

Keywords: Moisture buffering, coatings, anisotropy

INTRODUCTION

This paper discusses the potential of solid wood surfaces to serve as a moisture buffering element. To emphasize the key factors affecting the moisture buffering performance of wood, examples of the effect of grain direction, species and coatings are presented. The topic is further discussed with relation to wooden interior element demos made in Aalto University student projects, in which the task was to utilize the sorption properties of wood.

MATERIAL AND METHODS

Anatomy and species effect

Within a wood species the main anatomical difference affecting the sorption properties is the grain direction. Tangential and radial surfaces reveal different amount of latewood and early wood. Also the amount and size of pores and ray cells vary depending on the cutting direction, but even more between different wood species. The effect of grain direction (radial vs. tangential surface) was studied with boards

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(thickness 13 mm, width 80mm and length 325mm). Six hardwood and four softwood species were included in the test. Hardwood species included both ring- and diffuse-porous species: black alder (*Alnus glutinosa*), European ash (*Fraxinus excelsior*), European oak (*Quercus robur*), Norway maple (*Acer platanoides*), Scots elm (*Ulmus glabra*) and silver birch (*Petula pendula*). Softwood species in the study were Douglas Fir (*Pseudotsuga menziesii*), European larch (*Larix decidua*), Norway spruce (*Picea abies*) and Scots pine (*Pinus Sylvestris*). The difference between crosscut and radial surfaces was explored with small wooden cubes (25mm*25mm*25mm), since it is not possible to cut a crosscut surface with an exposed area similar to the boards.

**Coatings**

Scots pine boards including both radial and tangential surfaces as well as heartwood and sapwood were used for the coating experiments with water-borne varnish and commercial soap solution. Norway spruce boards were used for the tests with commonly used water-borne interior paints. Coatings were applied to the planed surfaces according to the instructions provided by the manufacturers.

**Moisture buffering test**

The moisture buffering test followed for the most part the protocol of the Nordtest Method (Rode et al. 2005). Test specimens were pre-conditioned in RH50, T=23°C for several weeks before testing and then exposed to high and low humidity loads in a climate test cabinet. Five sides of the specimen (either a board a cube) were sealed with aluminium tape leaving only one surface open. The mass of the specimens was determined with an analytical balance.

The comparison between the species and coatings was made by comparing the moisture uptake and release. With the species difference test, the test cabinet was unable to reach the upper humidity level determined in the Nordtest method due to the large area of exposed wood surfaces. With the coated surfaces there were not enough cycles to reach the stable cycles required for the MBV value. The exposed surface area for the crosscut and radial surface of wooden cubes was smaller and thus the conditions met the criteria and it was possible to determine the MBV value for those samples.

**RESULTS AND DISCUSSION**

**Anatomical and species differences**

The tangential surfaces of hardwood specimens had a slightly larger moisture uptake and release than the radial surfaces. The change in the moisture content of black alder, Scots elm and Norway maple was double compared to the change of MC in European ash, silver birch and European oak. The density of the tested specimens/species was quite uniform and therefore its effect on the species differences
is not included in this discussion. Softwood specimens exhibited bigger changes in moisture content under cyclic humidity loads than hardwood specimens. The difference between cutting direction was not clear. The amount of extractives was not defined.

The difference in MBV value between the radial and crosscut surface of pine was significant: the crosscut surface of Scots pine had a fourfold value compared to the radial surface. The MBV for uncoated pine in Hameury’s (2007) study was 1.36 g/(m²·%RH), which is almost identical to our result for the radial surface.

**Coatings**

Water-borne varnish clearly decreased the moisture uptake and release when compared to the reference with no treatment, but soap treatment had no effect on the adsorption. Moisture buffering values (MBV) showed the same phenomenon: the MBV of the lacquered surfaces was only 50% of the reference boards’ and soap treated boards’ MBVs. All tested paints decreased the moisture uptake 50% or more. Hameury (2007) observed a similar effect in his work with various water-permeable coatings: acrylic latex paint decreased the moisture buffering value (MBV) most, by more than 50%. His test did not include soap or water-borne varnish. The amount of heartwood and sapwood varied in the specimens as well as grain pattern and therefore these results are only indicative and form the basis for a more extensive measurement campaign in the future.

**APPLICATIONS**

Department of Forest Products Technology at Aalto University has organized a 4-credit Master’s level course open to students of wood engineering, civil engineering and wood architecture to explore the material properties of wood from the end use perspective. Students’ task has been to make a design with wood for interiors by utilizing the functional properties of wood. Examples of the projects are presented in Figure 2.

![Figure 2. Examples of student projects: moisture buffering panel (Project group: Ala Brazi and James Stanier), combined acoustic and moisture buffering panel (Project group: Aline Timpte, Elizabeth Kofler and Simen Bie Malde) and a panel for wet spaces (Project group: Ignacio Traver, Mikko Hakola, Sini Koskinen, Yllka Kuçuku and Yuko Konse).](image-url)
The panel on the left in Figure 2 is a moisture buffering panel, made of spruce cubes with visible surface of 80mm*80mm. The crosscut surface of spruce is increased by drilling wholes inside the cubes to maximize the moisture buffering capacity of wood material. In the middle is the panel in which the original goal was to create a wall panel which would improve the acoustics of the space. As an extra feature, the panel has also moisture buffering properties, since it was left untreated and air circulates around the whole tilted cube. The size of the cube is 45mm*45mm. The species was aspen. On the right is the wall panel of the project group focusing on the use of wood in wet spaces. They ended up using aspen shingles in different shades. Colour variation was done with different heat-treatment protocols.

CONCLUSIONS

Moisture buffering wooden surfaces have the potential to enhance the user comfort indoors. All commonly used species presented in this study have the potential to buffer moisture. Most interior surfaces are coated, though, and most coatings decrease the moisture buffering behaviour significantly. However, a typical product declaration for coatings does not provide much information which would support choosing the right material when the aim is to maintain the sorption property of wood. Both professionals (designers and architects) and consumers would benefit from the information regarding the effect of coatings on the moisture buffering properties of various wood-based materials.

ACKNOWLEDGEMENT

The research leading to these results has received funding from two projects: Wood Life and Wood2New. Wood Life is an interdisciplinary research project “Wood Life- Energy-efficient living spaces through the use of wooden interior elements“, where the focus is on the wood material’s potential in enhancing the energy-efficiency of housing. It is part of the Aalto energy-efficiency research programme. Wood2New belongs to the WoodWisdom-Net Research Programme which is a transnational R&D programme jointly funded by national funding organisations within the framework of the ERA-NET Plus Action WoodWisdom-Net+.

REFERENCES

WASTEWATER WOOD BIOMASS AND ITS PRACTICAL APPLICATION

Vitolina, S. 1, Shulga, G. 2 & Reihmane S. 3

ABSTRACT

In the work a study of the efficiency of the recovery of birch biomass from plywood production wastewater using a new developed composite coagulant, representing a polymer-colloid complex of polyethyleneimine (PEI) with polyvalent metal ions was carried out. The performance of the composite coagulant was tested using model wastewater solution (simulating hydrothermal treatment of birch wood). It was established that the optimum content of PEI in CC is 25-35% and optimal coagulation pH is 6.0. Using novel composite coagulant at optimal parameters up to 97% precipitation of total biomass, 65% removal of lignin and lignin-like substances, 92% and 43% reduction of color and chemical oxygen demand respectively can be achieved. Finally, the possibility of using the extracted biomass as an agent for dust suppression was studied. The results revealed that the precipitated biomass is able to glue the dusty sand with the formation of sandy aggregates and it shows potential application as a structuring agent for dust suppression.

Keywords: wastewater; wood biomass; coagulation; composite coagulant; dust suppression

INTRODUCTION

The problem of wastewater treatment of hydrothermal basins that contain plenty of lignocellulosic biomass consisting of hemicelluloses, lignin, lignin-hemicelluloses complexes and wood extractive substances is very actual for the enterprises of the plywood industry in all Eastern Europe. Along with the strengthened public environmental protection awareness the wastewater discharge regulations all over the world are becoming increasingly strict. Therefore, the research on the new technologies for wastewater treatment as well as the improvement for the existing ones is becoming more and more important.

Coagulation-flocculation has been widely applied in wastewater treatment due to its ease of operation and cost-effectiveness. Nowadays, the three major types of coagulants/flocculants widely used for wastewater treatment are inorganic coagulant,
organic and composite coagulants. Research is currently focused on the preparation of composite inorganic–organic coagulants by combining a cationic inorganic coagulant with an organic polymer to effectively combine the properties of both components, leading to improved coagulant stability, a wider effective pH range than conventional coagulants, improved coagulation efficiency and denser flocs with good settling properties (Ovenden and Xiao 2002).

The proper management of precipitated biomass sludge is also an issue of these wastewater treatment plants. Incineration, composting and landfill are the most common sludge disposal methods used over the years. It is known that wood originated by-products can be used for soil improvement (Lakhdar et al. 2010) as well as a dust suppressant for gluing sandy surface (Shulga et al. 2008).

The aim of this work was to increase the efficiency of the recovery of birch biomass from plywood production wastewater using the new developed composite coagulant and to study the possibility of using the extracted biomass as an agent for dust suppression.

**MATERIAL AND METHODS**

The wastewater of the hydrothermal treatment in veneer production was simulated with a model solution obtained by hydrothermal treatment of birch sawdust (Vitolina et al. 2014).

In this study a novel composite coagulant (CC) representing a polymer-colloid complex of polyethyleneimine (PEI, Fluka, molecular mass of 750 kDa) with polyvalent metal ions was developed. The polymer-colloid complex was formed due to the donor-acceptor interactions between imine atoms and metal cations. Besides, the complex was stabilized by H-linkages taking into account the hydration shell around the metal ions. The PEI/metal salt mass ratio in the CC varied from 0.16–1.

The coagulant was added in the range of 25-125 mg/l to the model solution. Experiments were conducted in the temperature range of 13-60°C using a thermostat. The process of the coagulation was performed by mixing equal volumes of the CC and the model solution. After the addition of the coagulant the pH value of the treated wastewater mixture was adjusted in the range of 5–8 by addition of HCl or NaOH. The treated solution was stirred for 1 min at 200 rpm, followed by slow mixing at 40 rpm for 2 min. The effectiveness of the coagulation was defined after a system settling time of 120 min and filtration. The residual concentration of the biomass and lignin was defined by measuring the obtained filtrate’s optical density (A) at 490 and 280 nm using the previously obtained correlation curves for the biomass and lignin. Chemical oxygen demand (COD) and color for the treated model solution were determined according to ISO 6060:1989 and ISO 7887:1994 standards.
The sand aggregates (> 0.25 mm) were obtained by mixing the sand (a fraction < 0.25 mm) with 1.0-5.0 g dl⁻¹ biomass water solutions during 3 min at room temperature. The content of the biomass varied from 0.1% to 0.4% on the sand air-dry sample. The fractional composition of the air-dry structured sand was determined by dry sieving. The structuring coefficients K₁ and K₂ were found as the mass ratios of the sum of artificial aggregates > 0.25 mm to the initial sandy soil (K₁) and of the sum of aggregates > 3.0 mm to the sum of all aggregates formed in the structured soil after the treatment (K₂).

RESULTS AND DISCUSSION

Model solution and separated wood biomass characteristic

The obtained model solution was characterized by an alkaline pH value (9.0), a moderate concentration of dry matter (1400 mg l⁻¹) representing the sum of wood degraded products passing to the hydrolysate, a moderate index of chemical oxygen demand (1285 mg O₂ l⁻¹) and a pronounced brown color (746 mg Pt l⁻¹) associated with the presence of lignin and lignin-like substances. The previous studies (Shulga et al. 2012) of the component composition of the biomass with instrumental analysis (FTIR-, UV-, Raman spectroscopy) indicated that the dominant wood component in the obtained biomass were hemicelluloses. The content of lignin, hemicelluloses and water-soluble degraded wood products in the biomass corresponded to the following mass ratio: 1.2/6.7/1.0 respectively.

Isolation of the wood biomass by coagulation

Fig. 1 shows the results of total biomass and lignin removal efficiency depending on applied CC dosage at pH 6.0. The wood biomass removal at a dosage of the CC more than 50 mg l⁻¹ is enhanced to a lesser extent. At the same time the maximal lignin removal is achieved at the dosage of 100 mg l⁻¹. With the further increase in the dosage of CC up to more than 100 mg l⁻¹ the removal efficiency of the biomass and lignin is decreased.

Fig. 1. Total biomass and lignin removal efficiency depending on applied CC dosage
The total biomass and lignin removal as a function of the PEI content in the CC is shown in Fig. 2. The increase of the PEI content in the CC results in improving the efficiency of coagulation and particularly in lignin removal. The best results for the biomass separation occur by using the CC containing 14-35% PEI in its composition. An increase in the PEI content by more than 35% leads to a rapid decrease in the biomass removal efficiency.

Coagulation was also carried out at various pH values. The optimal pH value for the biomass precipitation varies in a range of pH 6-7, but, for quantitative lignin separation, its pH value is close to pH 6.

The effect of temperature on the efficiency of biomass coagulation with the new CC was also investigated. In a range of 13-60°C, the biomass removal from the model solution changed to a lesser extent, but the lignin removal decreased by 6%.

The obtained results show that applying the CC with the optimum content of PEI (25-35%) the separation of total biomass and lignin from the model solution is 97% and 65% respectively. In this case, the wastewater color and COD removal are 92% and 43% respectively.

The precipitated biomass was studied as a structuring agent for dust suppression (Fig.3). The processing of sewage sludge is difficult due to the fact that biomass-rich sludge are both slow to dewater and form a networked gel at low concentrations. Therefore, in the study a settled biomass sludge layer without dewatering with a solids content of 4-6 wt% was used.
The fractional composition of the obtained sandy aggregates is represented in Fig. 4. With growing content of the biomass (0.2 – 0.8%) the amount of the sandy aggregates in the sand increases, which is in accordance with the values of the structure-forming coefficient K1 (Fig. 5). Simultaneously, with increasing amount of the biomass the structure-forming coefficient K2 also grows. This indicates the formation of large sandy aggregates containing biomass that are able to prevent blowing off the dusty sandy particles from the paved road surface.

The obtained results show potential application of extracted biomass as an agent for dust suppression. Therefore, studies will be continued in varying soil mineral composition.

**CONCLUSIONS**

Using the developed composite coagulant at the optimal coagulation parameters the separation of the wood biomass achieves 97%, but the extraction of lignin and lignin-like substances is more than 65%. The separated wood biomass is able to glue the dusty sand with the formation of sandy aggregates. The obtained results show its potential application as a structuring agent for dust suppression.
REFERENCES


THE INFLUENCE OF LIGNIN AND CARBOHYDRATES CONTENT ON THE AMOUNT OF BIOGAS PRODUCTION FROM VARIETIES: MISCANTHUS AND SORGHUM

Waliszewska, H.¹, Zborowska, M.², Waliszewska, B.³, Janczak, D.⁴ & Lewicki, A.⁵

ABSTRACT

The crop of fast-growing annual and perennial energy plants plays a significant role in the process of biofuel production. Learning about chemical composition, carbohydrates and lignin content is crucial to utilization of plants for biogas production in the future. There is still no complex characteristic of energy crop for example species such as Miscanthus and Sorghum. Literature does not show to which extent both species undergo a methane digestion process. Two fast-growing spices of Miscanthus and Sorghum were analysed. In the research the attempt was to investigate which species and genotype undergo a methane digestion to a better extent and how carbohydrates and lignin content influences biogas production. The research was done in the laboratory scale in bioreactor chambers in a water-jacket for methane digestion. The resulting biogas was transported using drain to measuring cylinders filled with water. The assay for content of carbohydrates and lignin was made according to TAPPI methods. Amounts of (dry basis) biogas have been estimated to be in the range of 504 to 689 m³ t⁻¹ and 373 to 482 m³ t⁻¹ for Sorghum and Miscanthus respectively. After receiving the results, it was determined that species Sorghum underwent digestion process the best due to its lignin content lower than 20%.

Keywords: Miscanthus, Sorghum, energy crop, biofuel, biogas, chemical composition.

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INTRODUCTION

Considering the increase in greenhouse emission and demand for energy it is said more and more often that a lignocellulose material should be used to biofuel production because of its huge potential. [Ragauskas et al. 2006a; Ragauskas et al. 2006b]. Such plants as *Miscanthus* and *Sorghum* despite low care requirements give high yield. 17 species of *Miscanthus* are known [de Vrije et al. 2002; Deuter et al. 2000] and about 60 species of *Sorghum* [Wielka Encyklopedia Przyrody 1998]. *Miscanthus* is perennial tall grass native for tropical and subtropical conditions of Asia. *Miscanthus tinctorius*, *Miscanthus sinensis* and *Miscanthus sacchariflorus* are popular for biofuel production. In order to increase the base of varieties of *Miscanthus*, a genetic hybrid *Miscanthus xgiganteus* from *Miscanthus sinensis* and *Miscanthus sacchariflorus* was grown, and is cultivated broadly in Europe and North America. *Sorghum* is a plant cultivated in South America and Africa. In Europe it is cultivated the most often for agricultural purposes in spite of its huge energetic potential [Brosse et al. 2012]

Lignocelluloses material consists of three main components: cellulose, hemicelluloses and lignin. A characteristic feature of cellulose is a linear structure of a chain created by β-D-glucopyranose molecules. Hemicelluloses are built of different polysaccharides and create branched chains. Lignin is a three dimensional polymer built of structural units of aromatic character which is responsible for rigidity and stability of plant tissues. What is more, it prevents lignocelluloses material from swelling [Brosse et al. 2012; Malherbe et al. 2002]. Content of cellulose, lignin and hemicelluloses in lignocellulose material is a significant indicator in optimisation of biofuel production processes, including biogas.

MATERIAL AND METHODS

Material

The material used for the study was obtained from experimental plots located on the territory of Poland. Three *Miscanthus*: *Miscanthus xgiganteus*, *Miscanthus sacchariflorus*, *Miscanthus sinensis*, varieties were obtained from the Institute of Plant Genetics of the Polish Academy of Sciences in Poznań. The *Sorghum saccharatum* variety was obtained from experimental plots of the University of Wrocław located in Oława. While the *Sorghum bicolor* variety was cultivated in Mochełek near Bydgoszcz on the experimental plots of the University of Technology and Life Sciences in Bydgoszcz.

The raw material was harvested depending on the stage of plant development in the middle of the growing season (spring-summer season) and after the end of the growing season (autumn-winter season). In total, 6 samples of the *Miscanthus* species and 4 samples of the *Sorghum* species were studied.
Analytic methods

Work included the determination of the percentage of selected chemical compounds in the studied lignocellulosic raw materials and the efficiency of the fermentation process of those compounds.

The study of the chemical composition included determination of the content of holocellulose and lignin. The study was performed according to the Tappi Standard Test Method: T 9wd-75 Holocellulose in Wood and T 222om-06 Acid-Insoluble Lignin in Wood and Pulp.

Determination of the fermentation efficiency was performed according to DIN 38 414 German standard including the analysis of biogas production taking into account the dry mass.

Methane fermentation (according to DIN 38 414 standard) is carried out in closed bioreactors immersed in a water jacket at a temperature 35°C to 38°C. The raw material is inoculated with a digestive rich in methane bacteria obtained from a biogas plant which is co-operating with the Institute of Biosystems Engineering of the Poznań University of Life Sciences. Before the start of the fermentation process, it was necessary to determine the content of dry mass according to PN-EN 12 879 standard and the pH value of the tested raw material according to PN-EN ISO 10523:2012 standard.

RESULTS

Carbohydrates and lignin in Miscanthus and Sorghum

The contents of carbohydrates and lignin in the analysed material taking into account the time of harvest is shown in Table 1. Clear differences in the composition can be observed between particular species and varieties of the selected Miscanthus and Sorghum plants. Holocelullose content is in a broad range from 63.4% to 82.8%. In the case of 4 out of all tested species the percentage share of holocelullose was lower in the autumn - winter season. Only in the case of Miscanthus xgiganteus the content of holocelullose in the acquired material was higher after the growing season, amounting to almost 9 percentage points. The lignin content was determined in the studied raw materials at the level from 14.5% to 24.4%. In the case of the Miscanthus species the share of this compound was higher after the growing season, amounting to almost 9 percentage points. The lignin content was determined in the studied raw materials at the level from 14.5% to 24.4%. Given the diversity of the raw material in terms of the time of harvest, more lignin was found in the materials acquired during the autumn-winter season. Komorowicz et al. (2009) reported 24.62% of lignin for the same species. Brosse et al. (2012) report the lignin content for Miscanthus xgiganteus in the range from 12.02% to 12.58%, in the case of Miscanthus sacchariflorus in the range from 12.10% to 12.13%, and for Miscanthus sinensis in the range from 9.23% to 10.23%. Much less, meaning from 14.5% to 16.9% of
lignin was determined in the case of *Sorghum*. As in the case of the *Miscanthus* species the lignin content in the autumn–winter season was higher. The increasing content of lignin during the autumn-winter harvest proves the lignifying process of plant tissue at the end of the growing season. Differences were observed in holo-cellulose to lignin ratio (H:L) in raw materials harvested during the spring-summer and autumn-winter season. It was determined that in plants that were harvested during the growing season the value of H:L coefficient varied from 3.9 to 4.9, while in the case of autumn and winter harvest it varied from 3.4 to 3.9. In each of the analysed variants the coefficient H:L was lower in the plant harvested in autumn and winter season.

**Table 1** Chemical composition of investigated *Miscanthus* and *Sorghum*.

<table>
<thead>
<tr>
<th>Species</th>
<th>Harvest period</th>
<th>Holocellulose (% db)</th>
<th>Lignin (% db)</th>
<th>H:L</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. xiganteus</em></td>
<td>June</td>
<td>74.1</td>
<td>18.4</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>82.8</td>
<td>24.4</td>
<td>3.4</td>
</tr>
<tr>
<td><em>M. sacchariflorus</em></td>
<td>June</td>
<td>72.0</td>
<td>18.4</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>70.0</td>
<td>20.0</td>
<td>3.5</td>
</tr>
<tr>
<td><em>M. sinensis</em></td>
<td>June</td>
<td>74.0</td>
<td>18.0</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>69.1</td>
<td>19.1</td>
<td>3.6</td>
</tr>
<tr>
<td><em>S. bicolor</em></td>
<td>August</td>
<td>66.5</td>
<td>15.4</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>65.3</td>
<td>16.9</td>
<td>3.9</td>
</tr>
<tr>
<td><em>S. saccharatum</em></td>
<td>August</td>
<td>70.5</td>
<td>14.5</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>63.4</td>
<td>16.4</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Data reported on a dry matter basis (db); H:L=holocelulose to lignin ratio

**Holocellulose to lignin ratio and biogas produced**

Figures 1 and 2 show the relationship between the amount of biogas obtained from the studied *Miscanthus* and *Sorghum* species and the coefficient of H:L. It can be seen that with increasing H:L values the quantity of biogas is greater. From the spring-summer harvest 373.6 to 689.1 dm$^3$/kg dry mass of biogas was obtained. The average biogas production was at the level 500 dm$^3$/kg dry mass. Slightly less, meaning from 404.8 to 519.3 dm$^3$/kg dry mass of biogas was obtained from the fermentation of raw material harvested during autumn and winter season. Average production from this raw material was at the level 474.4 dm$^3$/kg dry mass. The coefficient of determination $R^2$ for the autumn-winter harvest is good and amounts to 0.875. In the case of spring and summer harvest such accordance hasn’t been observed.
CONCLUSION

Harvest period of the *Sorghum* and *Miscanthus* species has influence on the content of the main lignocellulosic components in the raw material. The content of carbohydrate compounds in most cases is higher in plants harvested during the spring-summer season. Lignin content is higher during the autumn-winter season. The ratio of carbohydrates to lignin in the studied materials is higher for the raw material harvested in the spring-summer season, while for the autumn-winter harvest the H:L coefficient is lower. The time of harvest affects also the quantity of obtained biogas. More efficient material is the raw material harvested in the spring-summer season.

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   - PN-EN ISO 10523:2012 Water quality - Determination of pH
CHANGES IN POLYSACHARIDE PROFILE IN WOOD OF SCOTS PINE (*PINUS SYLVESTRIS* L.) STUMPS DURING TERM NATURAL DECOMPOSITION

Witczak, A.¹, Skwarek, M.², Lewandowska, A.³, Szadkowski, J.⁴, Sławska, M.⁵ & Radomski, A.⁶

ABSTRACT

Wood decomposition is the result of activation of many factors. Wood contains 45-50% of cellulose. The cellulose is degraded by means of many species of fungi and cellulotic bacterias. Wood contains other polysacharide substances including hemicellulose which constitute 20% of weight of wood. The lignin is resistant to microorganisms attack but also it is ultimately degraded.

Lignin degradation does not occur in the initial phase of the fungus growth. The production of peroxidases and veratryl alcohol and also lignolitic activity occur simultaneously, after depletion of readily available sources. Lignins are phenolic polymers of cell wall and form the second to cellulose, the most common group. Lignins constitute 30% of the organic carbon in plant biomass. Holocellulose constitutes whole carbohydrate fractions of wood substance, remaining after the removal of extraction compounds and lignin. As material to investigation we used Scots pine stumps in uneven-aged, obtained from different habitats: fresh coniferous forest and fresh forest. The fresh stumps obtained from the shelterwood surface we used as the control samples.

The content of cellulose, lignin and hemicellulose was determined with chemical methods. The results showed that the content of cellulose and hemicellulose decreased with the age of the stump, while the lignin content increased relatively. The degradation of cellulose occurred quicker in richer habitat. However, the habitat fertility had no impact on the rate of decomposition of hemicellulose.

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The results of chemical analysis performed on the uneven-aged stumps are very important due to determination of time of the decomposition process of the structural wood components which reserve on down woody debris.

**Keywords:** biodegradation, lignin, cellulose, hemicellulose, holocellulose
IMPREGNATED WOOD PERFORMANCE IN OUTDOOR ENVIRONMENT

Tubli, P.¹, Kallakas, H.², Kers, J.³, Brischke, C.⁴, Humar, M.⁵ & Jones, D.⁶

ABSTRACT

This research project is inspired of a COST Action FP 1303 “Performance of bio-based building materials”. The aim of present performance test was to examine the performance data of Norway Spruce specimens with different impregnations in outdoor environment and analyze Norway Spruce resistance to aging and how different impregnation cycles change the wood resistance to aging. A folding table was set up with 9 specimens made from Norway Spruce with three different vacuum-pressure-vacuum impregnation cycles using chromium free wood preservative – Impralit®-KDS. Specimen groups 1 and 3 were impregnated according to hazard class HC-4 and specimen group 2 according to HC-3, which end uses are respectively for outside ground contact and for outside non ground contact. Specimens made from board number 1 were made with rather long impregnation cycle and the amount of impregnant was about 10 times more than required by the impregnant manufacturer. Specimens made from board number 3 were similar to usual products and amount of impregnant was same as usually used. The boards were fixed with partly stainless and partly galvanized steel screws. 8 electrodes, for measuring moisture content, were mounted into the specimens, specimen 3/3 is without an electrode and it was evaluated only visually. Temperature sensors were mounted into specimens 1/2 and 3/2. All the data was recorded hourly during the duration of the performance test. Decay, discoloration, development of mould and other staining fungi, corrosion, formation of cracks and moisture performance were evaluated regularly. The first results after 3 weeks of exposure showed that the discoloration of the specimens group 2 is slightly smaller than others but the overall discoloration of specimens after 3 weeks is rather similar. Evaluation of surface disfigurement due to mould and staining fungi was done visually and no surface disfigurement was detected. The surface of stainless steel screws was intact, but the surface of galvanized screws was visibly, which means 5-50% of surface was attacked. These results are in correlation with the wood moisture content,

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which was all the time higher than the considered level needed for fasteners corrosion which is 15-20 percent. Specimen group 2 stands out as specimens with most cracks, which could be the result of much lower wood moisture content they have compared to other specimens. Again specimen group 2 stands out as the specimens with lowest wood moisture content and specimen group 3 has specimens with the highest wood moisture content, which was average of 28 percent higher than moisture content of specimen group 2. When wood moisture content did not respond so rapidly to changes of air moisture content then wood temperatures are in direct relation to air temperature.

**Keywords:** Impregnation, Norway Spruce, aging, performance test
MICROSTRUCTURE STUDY OF BIRCH FALSE HEARTWOOD

Bankole, O.S.¹, Rohumaa, A.² & Kers, J.³

ABSTRACT

The microstructure of birch (*Betula pendula*) false heartwood, FHW, was studied in comparison with clear birch samples using FTIR spectroscopy and SEM analysis with the aim of determining whether this defect is as a result of fungal infection or a colour difference due to its secretions. Ground and veneer strips of FHW and clear birch were used for the FTIR study. Microtome device was used to cut thin slices of the birch wood samples in radial-longitudinal, tangential-longitudinal and transverse sections containing both the FHW and clear part was used for the SEM study.

In the FTIR study, similar fingerprints resulted for both the FHW and clear samples for both the veneer and ground samples. However, the FHW samples had stronger intensities and absorbance of the IR spectra, especially in the veneer samples, at the different associated bands of cellulose, hemicellulose and lignin at 898 cm⁻¹, 1032 cm⁻¹, 1233 cm⁻¹, 1323 cm⁻¹, 1368 cm⁻¹, 1420 cm⁻¹, 1460 cm⁻¹, 1596 cm⁻¹ and 1733 cm⁻¹. This is as a result of the higher extractive content in the FHW. Also, the ground samples had missing peaks at 1160 cm⁻¹, 1460 cm⁻¹ and 1651 cm⁻¹ which were present in the veneer samples and a missing peak at 2186 cm⁻¹ for the veneer sample which was present in the ground sample.

The variations observed in the SEM study include wider lumen in FHW samples, thicker cell walls in clear sample fibres, simple pitting in clear sample fibres, more uniseriate wood rays in clear samples in clear sample. As a result, there will be larger space for extractives to be secreted in the cell lumens of the FHW, clear samples will be stronger than the FHW samples because of its thicker cell walls, more extractive locked in the cell lumens of the FHW because of lack of pitting and more multi-seriate wood rays in the FHW samples may have a negative effect on the strength. The FHW is therefore more as result of chemical activities in the wood structure, because fungal attacks in the wood cell wall were not detected with SEM analysis.

Keywords: Birch (*Betula pendula*); false heartwood (FHW); discoloured wood; FTIR; SEM

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INTRODUCTION

Birch (*Betula pendula*) is one of the popular tree species used in many wood industries. One of the reasons for this is because, though it is a hardwood, it does not have the heartwood part. This enables manufacturers to be able to maximize its yield. However, some birch logs do have a discoloured portion in their core but with irregular patterns unlike the heartwood [1, 2]. This discoloured portion is referred to as false heartwood, FHW.

The major conditions for heartwood formation, which are cell death, depletion of nutrients, deposits in cells with darkening of tissues, are also required for the formation of discoloured wood or FHW, however, there are other processes too [3].

MATERIAL AND METHODS

**FTIR Spectroscopy**

FHW and clear samples of birch were prepared in two forms, veneer and powdered form, for the FTIR study. The background spectra was first obtained on the Interspec 200-x FTIR spectrometer with Specac Attenuated Total Reflection (ATR) unit. Two (2) 0.5 mm thick veneers of clear and FHW birch were prepared, cleaned and cut into about 2 x 5 cm each, making a total of four (4) samples and two (2) ground samples of clear wood and FHW were ground into fine dust of particle size ≤ 0.36mm. This was followed by placing both the veneer and powdered samples on the device and their respective spectra were obtained. The spectra of the FHW veneers were compared with those of the clear veneer samples and that of the ground FHW sample were compared with the clear powdered sample.

**SEM Analysis**

In the SEM study, thin slices from the microtome, between 100 -300 µm, were used. The wood slices which have been cut along the three (3) principal directions (radial, tangential and transverse) were attached to pin stubs and first coated in a Rotary-Pumped Sputter Coater with Au/Pd target (80/20). This enables the samples which are biological materials to be conductive in the Ziess Ultra 55 SEM. The observed images of both the FHW and clear samples were compared and checked for variations at different magnifications.

RESULTS

Fig. 1 shows the combined ATR FTIR spectra of the FHW and clear birch veneer samples. Similar fingerprints were observed because they are from the same species and have similar constituents. However, the FHW 1 sample had the highest
absorbance especially at 1032 cm\(^{-1}\). The combined ATR FTIR spectra of the FHW and clear birch powdered samples is shown in Fig. 2 showing similar fingerprints for both samples, just like the veneer samples. This emphasizes the fact that they were taken from the same tree species and contain basically the same chemical components which share the same bond types. Also there are some noticeable differences at some peaks. While the clear sample showed a small peak at 1460 cm\(^{-1}\) and 1651 cm\(^{-1}\), the FHW sample does not and the FHW samples generally had higher absorbance than the clear samples.

![Figure 1: Combined ATR FTIR spectra of clear and FHW birch veneer samples](image1)

![Figure 2: Combined ATR FTIR spectra of clear and FHW birch ground samples](image2)

From the FTIR spectra, a quick summary of the proportion of lignin, carbohydrates, proteins, lipids, aromatic and other compounds is given [4]. Table 1 represent the FTIR bands of both the veneer and powdered birch samples and their respective tentative assignment to wood components.
Table 1: FTIR bands of ground and veneer birch samples and their tentative assignment to wood components

<table>
<thead>
<tr>
<th>Wavenumber, cm⁻¹</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>898</td>
<td>=C-H &amp; =CH₂ (out-of-plane bending) cis-RCH=CHR in cellulose</td>
</tr>
<tr>
<td>1032</td>
<td>C-O vibration in cellulose and hemicellulose</td>
</tr>
<tr>
<td>1160</td>
<td>Syringyl ring and C-O stretch in lignin and xylan</td>
</tr>
<tr>
<td>1233</td>
<td>C-H vibration in cellulose and C-O vibration in syringyl derivates</td>
</tr>
<tr>
<td>1323</td>
<td>C-H deformation in cellulose and hemicellulose</td>
</tr>
<tr>
<td>1368</td>
<td>C-H deformation in lignin and carbohydrates</td>
</tr>
<tr>
<td>1420</td>
<td>CH₂ &amp; CH₃ deformation in lignin and carbohydrates</td>
</tr>
<tr>
<td>1508</td>
<td>Aromatic skeletal in lignin</td>
</tr>
<tr>
<td>1596</td>
<td>Aromatic skeletal vibration in lignin</td>
</tr>
<tr>
<td>1651</td>
<td>Absorbed O-H and conjugated C=O</td>
</tr>
<tr>
<td>1733</td>
<td>C=O in xylans (hemicellulose)</td>
</tr>
</tbody>
</table>

From the SEM study, different images obtained and were compared as discussed below.

**DISCUSSION**

There is noticeable increase in the lignin content of the FHW in relation to the clear samples for both the veneer and ground sample from the increase in the relative height of the lignin associated bands at 1233 cm⁻¹ and 1596 cm⁻¹ in Fig. 1 and 2.

Similar fingerprints in the FTIR spectra obtained with varied relative height of fingerprints suggest that the FHW contains some other materials in the form of extractives which helped to absorb more radiation than the clear samples. Also, as the peaks were attributed to the various chemical constituents of the tree such as cellulose, hemicellulose, lignin and extractives, they do not suggest any fungal activity. However, once the FHW is formed, this can then make the wood more susceptible to fungal attack. These attacks further alter the chemical composition of the wood and alter the position of the peaks accordingly, though most times only slightly [5, 6].

In the SEM images, vessel-to-vessel pitting are seen to be closely packed for both the clear birch samples and the birch FHW samples. From the radial sectional view at 2000x, the fibre of the FHW samples are observed to be without simple pits connections, Fig. 3a, thereby making them more of the fibre tracheids structure while the clear samples are connected by simple pits, Fig. 3b, making them more of the libriform fibres structures [7].
At higher magnification from the transverse section, it can be observed that the FHW sample has their fibre tracheids with much wider lumen, Fig. 4a, than the clear samples, Fig. 4b, playing important role in the fibre’s ability to secret more substances than the ones with more narrow-lumen. This also translates to thinner cell walls in the FHW samples and thicker cell walls in the clear samples. These secretions can further affect the wood in that it will alter its quality and properties in those regions.

From the tangential section, ray-like features can be seen running from the pith of the tree to the bark and shooting out between the longitudinal elements as shown in Fig. 5. They lay perpendicular to the longitudinal elements in short bands and containing parenchyma cell and used for food storage. The wood rays in both the FHW and clear samples are homogeneously arranged with only a few uniseriate wood rays present in the FHW sample, Fig. 5a, while the clear samples tend to have more, Fig. 5b.
CONCLUSION

The colour difference between the FHW and clear samples is as a result of the extractives in the FHW. After carrying out the FTIR and SEM study on the birch FHW, with the aim of determining whether this defect was as a result of fungal infection or just a mere colour difference due to its secretions, the following observations were made:

- Both the FHW and clear samples gave similar fingerprints on the FTIR spectra though there were some slight noticeable differences in their peaks at 1160 cm\(^{-1}\), 1460 cm\(^{-1}\), 1651 cm\(^{-1}\) for the veneer samples and 2186 cm\(^{-1}\) for the ground sample.
- The FHW samples generally had increased peak heights in comparison to the clear samples. FTIR spectra are compared at the different associated bands of cellulose, hemicellulose and lignin at 898 cm\(^{-1}\), 1032 cm\(^{-1}\), 1233 cm\(^{-1}\), 1323 cm\(^{-1}\), 1368 cm\(^{-1}\), 1420 cm\(^{-1}\), 1460 cm\(^{-1}\), 1596 cm\(^{-1}\) and 1733 cm\(^{-1}\).
- From the SEM images, both samples had similar microstructural elements but with some variations at higher magnifications.
- The variation in the SEM images include wider lumens in FHW samples, thicker cell walls in clear sample fibres, simple pitting in clear sample fibres, more uniseriate wood rays in clear samples.
- No fungal infection or degradation in FHW cell wall or in cell lumens was detected in SEM analysis.
REFERENCES


IDENTIFICATION OF WOOD EXTRACTIVES FROM \textit{POPULUS MAXIMOWICZII}

Lewandowska, A.\textsuperscript{1}, Szadkowska, D.\textsuperscript{2}, Szadkowski, J.\textsuperscript{3}, Witczak, A.\textsuperscript{4}, Zielenkiewicz, T.\textsuperscript{5} & Radomski, A.\textsuperscript{6}

ABSTRACT

The current interest in renewable energy has raised the idea of using wood in order to obtain green energy. The most important step of obtaining bioethanol from wood is the enzymatic hydrolysis. Wood consists of cellulose, hemicelluloses, lignin and number of substances which are named extractives. These substances are, for example: tannins, flavonoids, phenolic substances and many others. Some of them are designed to protect against attack of pests and fungus. These substances can be inhibitors of the enzymes applied during enzymatic hydrolysis. This study was carried out to assess which substances may be inhibitors or determine which groups of substances are inhibitors. These research has used other solvents so that they are correct to extract certain groups of compounds and determine their contents. It was carried out on poplar (\textit{Populus Maximowiczii}). Extractions with solvents: water, ethanol, cyclohexane, water-ethanol-cyclohexane, cyclohexane-ethanol-water were performed. Contents of these substances were determined, then extracts were analysed with GCMs.

\textbf{Keywords:} extractives, poplar, solvent, GC-MS

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WITHIN SPECIES VARIATION OF STRUCTURAL INTEGRITY – A TEST ON 204 SCOTs PINE TREES FROM NORTHERN EUROPE

Zimmer, K. & Brischke, C.

ABSTRACT

The structural integrity of wood can be quantified as resistance to impact milling (RIM). In a High-energy multiple impact (HEMI) – test steel balls were used in a heavy vibratory mill for crushing wood samples. Thousands of single events were captured by analyzing the fragments. Based on the degree of integrity I and the percentage of fine fragments F (< 1 mm) an indicator has been defined to detect structural changes on cell wall level with high sensitivity. The method has earlier been used to detect changes in structural integrity which were caused by chemicals, thermal energy, radiation and different organisms.

Little, however, is known about the within species variation of the degree of integrity, the percentage of fine fragments and the resistance to impact milling. It was therefore the aim of this study to investigate the within species variation of these measures on 204 Scots pine (Pinus sylvestris L.) trees from Northern Europe and see whether wood properties or growth conditions influence the structural integrity.

Significant differences between stands were found for the degree of integrity. Linear mixed models showed that for the degree of integrity, the variance was distributed to 30.6 % on stand variance and 69.4 % on residual variance between trees. Annual height increment and slenderness coefficient could reduce the total variance by roughly 10%, and it was the stand variance which was reduced in both cases. With the data available, it was only possible to reduce the variance between stands, while the variance between trees remained unchanged.

It still remains unclear which wood inherent factors influence degree of integrity, the percentage of fine fragments and the resistance to impact milling. RIM - as a function of both, F and I - turned out to be almost unaffected by wood property variations within the species Pinus sylvestris. It is possible, that these measures are influenced by the anatomical and chemical structure and composition of the wood.

Keywords: High-energy multiple impact (HEMI) tests, structural integrity, within species variation, Scots pine, wood growth indicators

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INTRODUCTION

The structural integrity of wood can be quantified as resistance to impact milling (RIM). In a High-energy multiple impact (HEMI) – test steel balls are used in a heavy vibratory mill for crushing wood samples. Here, thousands of single events are captured by analyzing the fragments. The ratio between the degree of integrity $I$ and the percentage of fine fragments $F$ ($< 1$ mm) is an indicator in detecting structural changes on cell wall level with high sensitivity. The method has earlier been used to detect changes in structural integrity which were caused by chemicals, thermal energy, radiation and different organisms (Brischke 2014, 2016). The method allows the detection of small changes in structure, which are not detectable with standard methods such as strength measurements. Often, however, $RIM$ does not correlate with these measures, as shown in figure 1, displaying the interrelationship between impact bending strength and $RIM$.

![Figure 1](image_url)

**Figure 1**. Interrelationship between impact bending strength and resistance to impact milling of nine different wood species determined on axially matched specimens (updated results taken from Brischke 2014).

There is only limited knowledge on which factors influence the degree of integrity, the percentage of fine fragments or the resistance to impact milling. It was therefore the aim of this study to investigate the within species variation of these measures on 204 Scots pine (*Pinus sylvestris* L.) trees from Northern Europe and see whether wood properties or growth conditions influence the structural integrity.
MATERIAL AND METHODS

Scots pine material

Scots pine trees were harvested at 25 stands in Northern Europe (Norway (N1 – N9), Sweden (S1 – S6), Finland (F1 – F5), Estonia (E1, E2), Lithuania (L1), Scotland (Sc1, Sc2)), displaying a large geographic range, different altitudes and a variety of growing conditions. At each location, nine Scots pine trees (three trees from three diameter classes) were harvested and the samples were produced from the North facing sapwood part of the log. For each stand, the exact position and data about the respective stand density and climate were collected. For each single tree data on the diameter, the total tree height and the age were recorded and different growth increments (annual height increment and annual diameter increment) were calculated. Wood density, annual ring width, latewood content and the number of resin canals per mm² cross section were measured. The sample material and material processing is described in detail in Zimmer et al. (2014).

High-energy multiple impact (HEMI) - tests

20 oven-dried specimens of 10 (ax.) x 5 x 20 mm³ were placed in a 140 mm bowl of a heavy-impact ball mill (Herzog HSM 100-H; Herzog Maschinenfabrik, Osnabrück, Germany). Steel balls of 35 mm, 12 mm (3x) and 6 mm (3x) were added. The bowl was shaken for 60 s at a rotary frequency of 23.3 s⁻¹ and a stroke of 12 mm. The fragments of the 20 specimens were fractionated on a slit sieve according to ISO 5223 (1996) with a slit width of 1 mm using an orbital shaker at an amplitude of 25 mm and a rotary frequency of 350 min⁻¹ for 2 min. The degree of integrity (I), the fine fraction (F) and the resistance to impact milling (RIM) were calculated as shown in table 1.

Table 1, explanation of degree of integrity I, the percentage of fine fragments F and the resistance to impact milling RIM

<table>
<thead>
<tr>
<th>Measure</th>
<th>equation</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>( \frac{m_{20}}{m_{all}} \times 100 % )</td>
<td>I is the ratio of the mass of the 20 biggest fragments (m_{20}) to the mass of all fractions (m_{all}) after crushing</td>
</tr>
<tr>
<td>F</td>
<td>( \frac{m_{fragments&lt;1mm}}{m_{all}} \times 100 % )</td>
<td>F is the ratio of the mass of fragments &lt; 1 mm to the mass of all fractions (m_{all}) multiplied by 100</td>
</tr>
<tr>
<td>RIM</td>
<td>( \frac{(I - 3 \times F) + 300}{400} % )</td>
<td>RIM is the resistance to impact milling as a measure for the structural integrity of the material.</td>
</tr>
</tbody>
</table>
Statistical analysis

$I$, $F$ and $RIM$ were analyzed with ANOVA and Tukey Kramer comparisons to find if there are differences between the stands.

A linear discriminant analysis was performed in order to study whether the two groups of $I$ (small $I$ and large $I$) can be distinguished by means of stand, tree and growth data (Table 3).

Also, linear mixed models used, where the random variance was divided into stand variance and residual variance. $I$ and $F$ were calculated as a mean for each tree, the residual variance represented variance between trees within the stand. The models were calculated using the restricted maximum likelihood (REML) method in JMP®, Version 12 (SAS Institute Inc., Cary, NC, 1989-2015).

RESULTS AND DISCUSSION

Analysis of distribution of $F$, $I$ and $RIM$

In total, 204 samples were tested. For $RIM$, $F$ and $I$, the data was normally distributed with equal variances according to the Levene test. The variation of $RIM$ and $F$ is very small for the entire sample set, with a range of 7.5 % and 13 % respectively. Only $I$ displays a larger variation with a range of 30.3 % (Table 2).

Table 2, distribution of parameters representing the structural integrity of wood

<table>
<thead>
<tr>
<th></th>
<th>$RIM$ [%]</th>
<th>$I$ [%]</th>
<th>$F$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>81.1</td>
<td>37.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Std Dev</td>
<td>2.45</td>
<td>6.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Range</td>
<td>13.2</td>
<td>30.3</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Differences between stands $F$, $I$ and $RIM$

A comparison of $RIM$, $F$ and $I$ for the different stands showed that there are significant differences between some of the stands. For $RIM$ the stands with the largest difference were N1 and L1 with 85.4 % and 78.3 %, respectively. N4 had the largest $F$ value with 7.3 %, while Sc2 had the lowest $F$ value with 2.5 %. For $RIM$ and $F$, the differences between the stands, however, were small. The differences in $I$ between stands were larger. Figure 1 (right) shows the mean $I$-values for all stands. The stands with the largest difference were N1 and E1. The group of stands N1, N9 and N2 are significantly different from the group S1, F3, L1 and E1.
Largest variation for $I$: is it possible to distinguish the stands with linear discriminant analysis based on variables available?

The largest variation between stands was found for the $I$-value with a range of 30.3 % and a difference of 18.8 % between the mean values of the stands with the largest difference. With linear discriminant analysis, the two groups of extreme $I$-values (Table 3) were used to classify the material with the available data on stand, tree, growth and wood properties.

Table 3, description of stands allocated groups with high and low $I$-value

<table>
<thead>
<tr>
<th>Stand ID</th>
<th>N</th>
<th>mean $I$ [%]</th>
<th>group</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>3</td>
<td>49.2</td>
<td>high</td>
</tr>
<tr>
<td>N9</td>
<td>9</td>
<td>45.2</td>
<td>high</td>
</tr>
<tr>
<td>N2</td>
<td>6</td>
<td>45.1</td>
<td>high</td>
</tr>
<tr>
<td>L1</td>
<td>9</td>
<td>31.9</td>
<td>low</td>
</tr>
<tr>
<td>E1</td>
<td>9</td>
<td>30.4</td>
<td>low</td>
</tr>
</tbody>
</table>

With only annual mean temperature during growing season, the 36 trees could be correctly classified to the two groups. With latewood content as only variable, only 5.5 % of the trees (2 trees) were misclassified. A similar result was obtained for annual height increment, were 3 trees (8.3 %) were misclassified. With density and slenderness coefficient the classifications were not as successful, where 6 (16.7 %) and 7 (19.4 %) of the trees were misclassified. The analysis, however, indicates that there are differences between the trees and between the stands that might account for the variation in $I$ (Figure 2). Single correlations of the same factors on the entire sample set, however, did not show significant results.
Figure 2, comparison of stand, tree, growth and wood properties for the two groups of extreme $I$-values

**Linear mixed models: variance distribution, how do fixed factors change this distribution?**

The application of Linear mixed models on the dataset showed, that for the fine fragments the variance is distributed by 22.4 % on stand variance and by 77.6 % on the residual variance between trees. By adding data on stand, tree and growth the variance was not significantly reduced, nor could the allocation of variance be changed. Factors describing growth of the trees such as annual diameter increment, annual ring width and slenderness coefficient were significantly influencing the amount of fine fragments. Wood properties, such as density or latewood content, however, were not.

For the degree of integrity, the variance was distributed to 30.6 % on stand variance and 69.4 % on residual variance between trees. For the degree of integrity, annual height increment and slenderness coefficient were significant. Both reduced the total variance by roughly 10 %, and it was the stand variance which was reduced in both cases to 22.7 % and 24.0 %, respectively. With the data available, it was only possible to reduce the variance between stands, while the variance between trees remained unchanged. Wood properties such as density or latewood content were not significant and did not reduce the residual variance on tree level, either.

It still remains unclear, which wood inherent factors influence degree of integrity, the percentage of fine fragments and the resistance to impact milling. It is possible, that these measures are influenced by the anatomical and chemical structure and composition of the wood. Tracheid size, cell wall thickness, amount of parenchyma cells in the wood and ray composition, as well as the extractive content and chemical composition of the cell wall are crucial for the wood properties and directly affected and altered when structural changes, caused by chemicals, thermal energy, radiation and different organisms, occur. Here, further research is necessary.
CONCLUSIONS

The variation of $RIM$ and $F$ is very small for the entire sample set, only the degree of integrity $I$ displays a larger variation with a range of 30.3%. Differences in $I$, $F$ and $RIM$ were found for some of the stands. When regarding only the stands with the extreme $I$-values, and by means of linear discriminant analysis it was possible to categorize low and high $I$-value groups based on single factors such as annual mean temperature during growing season, latewood content annual height increment, with small failure rate.

Linear mixed models showed that for $I$, the variance was distributed to 30.6% on stand variance and 69.4% on residual variance between trees. Annual height increment and slenderness coefficient reduced the total variance by roughly 10%, and it was the stand variance which was reduced in both cases to 22.7% and 24.0%, respectively. With the data available, it was only possible to reduce the variance between stands, while the variance between trees remained unchanged.

It still remains unclear which wood inherent factors influence the degree of integrity, the percentage of fine fragments and the resistance to impact milling. It is likely, that these measures are influenced by the anatomical and chemical structure and composition of wood.

REFERENCES

NORWAY SPRUCE DINAMIC MODULUS OF ELASTICITY

Šilinskas, B.\(^1\), Škėma, M.\(^2\) & Aleinikovas, M.\(^3\)

ABSTRACT

One of the main wood mechanical properties is elasticity. By evolving nondestructive timber measurement methods, we can obtain information about growing trees wood mechanical and physical properties. The dynamic modulus of elasticity is obtained by calculating two parameters: ultrasound velocity and density of the wood. In this paper, the sound propagation speed of the wood was measured with an acoustic tomography Arbotom 3D and the density is determined by the device Lignostation. The study was conducted from 7 trees have been cut-sheet lower, middle and apical parts. After cutting works we get retrieved 21 parts. In these parts was measured sound propagation speed in 3 different heights. Density was measured at the ends of parts. All indicators were converted to 12\% moisture content. After measuring works according to a formula was calculated dynamic modulus of elasticity.

**Keywords:** dynamic MOE, wood density, ultrasonic velocity

INTRODUCTION

The main purpose of nondestructive measurement techniques is to explore the characteristics of wood products, which have influence on the biological nature of the tree. There are many different nondestructive measurements methods, for different wood characteristics. Tomography is a wave-based technique used to picture tree cross-sections; specifically, impulse tomography uses data given by the passage of impulse waves, which were primarily influenced by density, modulus of elasticity, and moisture content of wood. (Pereira-Rollo, 2014 etc.).

Wood is composite biological material and its mechanical properties depend on many factors. It is influenced by tree species, habitat conditions wood quality, wood fiber direction. It was found that stress waves travel through sound wood faster than through damaged wood.

Ultrasonic imaging is a technique widely used to reconstruct the properties of the wood.

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materials under inspection from global wave propagation data. Acoustic tomo-grams provide an excellent noninvasive means of obtaining information about in-homogeneous media as noted by many investigators (Douglas Mast 1999 etc.).

This aim of the article is to determine Norway spruce wood dynamic modulus of elasticity by nondestructive methods.

**MATERIALS AND METHODS**

The 7 Norway spruce trees were selected in 90 years old spruce stand. The stand structure - 80 percent spruce, 10 percent oak and 10 percent – birch. The selected trees parameters were presenting in Table 1.

**Table 1.** Average parameters of trees.

<table>
<thead>
<tr>
<th>Tree number</th>
<th>Diameter at breast height, cm</th>
<th>Stem high, m</th>
<th>Moisture content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>23.0</td>
<td>46.45</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>23.5</td>
<td>53.28</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>31.0</td>
<td>40.55</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>28.5</td>
<td>49.23</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>25.0</td>
<td>57.06</td>
</tr>
<tr>
<td>6</td>
<td>26</td>
<td>22.0</td>
<td>56.53</td>
</tr>
<tr>
<td>7</td>
<td>32</td>
<td>32.5</td>
<td>47.17</td>
</tr>
</tbody>
</table>

Three logs (2.1 m long) – but log, middle log and top log, were sampled from each tree (total- 21 logs) and taken to for testing (Fig 1.).

![Fig 1. Logs sampling scheme](image)

The sound propagation speed of the wood was measured with an acoustic tomography unit “Arbotom 3D”. A total of 24 impulse sensors, placed around the log in three different height, were used to obtain the 3D image of sound speed of the log. The collected data is simultaneously sent to a computer which will turn the data into a coloured image of the tree’s cross-section (Fig 2).
The sound speed is converted to a normalized 12% humidity according to the formula (Sandoz, 1993).

\[ V_{12} = 580 + V_u + 4 \times (W - 32); \quad W > 32\% ; \]

where:

- \( V_{12} \) - sound propagation speed at 12% humidity, m/s;
- \( V_u \) - ultrasound velocity, m/s;
- W - humidity, %.

After determined of sound speed of the logs, the 42 disks (5 cm height) were cut from each log buttend and topend. The ring-width and density as well as early and latewood width and density were determined by the device “Lignostation”.

Dynamic modulus of elasticity (DMOE) was calculated from the stress wave velocity and wood density using the following formula:

\[ E = V^2 \rho \]

where:

- \( E \) - dynamic modulus of elasticity, (N/mm²);
- \( \rho \) - wood density (kg/m³);
- \( V \) - ultrasound velocity, (m/s).

All analyzes were done in the “Timber use, quality and processing technologies” laboratory Institute of Forestry, LAMMC.

**RESULTS**

The speed of sound, accomplished in our investigation of Norway spruce trees varies from 1800 m/s to 2400 m/s. The highest average of speed of sound the top logs and the lowest at the butt logs (Fig 3), and differences were significant.
The interesting thing is, that in the given case, the speed of sound has low correlation with wood density, which was lowest in top logs, even though merely, but in the middle log, the wood density was the highest (Fig 4). It shows, that spruce wood density increasing, while height of tree increasing too, but in middle of the stem density begins to decrease.

The analysis of spruce wood density show that the highest density was in the center of stem and going from stem centre till the bark wood density decreasing. This is going in all high of stem (Fig 5).
The analysis of wood density and sound-tolerance of speed through the wood, given the calculations of DMOE throughout the length of the stem. (Fig. 6)

![Graph showing distribution of wood DMOE of spruce wood.](Image)

**Fig 6.** Distribution of wood DMOE of spruce wood

Analysing the DMOE of different stem heights we can see clearly that they are not very significant. The average DMOE increases with the height of the stem, but the difference between the top and the middle log wasn’t significant.

**REFERENCES**

THE IMPACT OF HEARTWOOD AND SAPWOOD ON BIOLOGICAL DISCOLORATION OF A PAINTED SURFACE

Sjökvist, T. & Blom, Å.

ABSTRACT

Wood material has advantages, it comes from a renewable source and it is easy to manage. But one disadvantage when used outdoors is biological discoloration of the material. Some impact on the discoloration is the presence of moisture and nutrients, necessary components for the microorganisms to grow and start a colonisation. Samples made of Norway spruce (Picea abies (L.) Karst) heartwood or sapwood coated with two different film forming paints was studied. The paints had a binder formula made of alkyd or acrylate. Additional parameters related to study the influence of moisture content on discoloration were high and low density material, with and without impregnation oil. Outdoor exposure was made during five years in the southern part of Sweden. The samples were hung with 45 degree inclination, facing south direction. Visual differences in biological surface discoloration were observed for samples within the same paint, which could be explained by differences in heartwood and sapwood.

Keywords: Discoloration, Heartwood, Sapwood, Paint

INTRODUCTION

Discoloration of painted surfaces is one of the first sign of degradation on the material. It is also one of the most complained subjects by house owners. Fungus, bacteria and algae are common microorganisms causing discoloration on painted surfaces (Gaylarde and Gaylarde 2005). The presence of moisture and nutrients is vital for the microorganisms to establish on a surface. For untreated wood, natural material variability plays an important role for the discoloration. Sapwood has shown to have higher susceptibility to biological discoloration compared to heartwood (Blom, Johansson et al. 2013). Sapwood has also a higher water uptake compared to heartwood (Metsä-Kortelainen, Antikainen et al. 2006, Vestøl and Sivertsen 2011). Another wood parameter affecting water uptake is wood density (Sjökvist and Blom 2016).

Paint is a common alternative to protect wood surfaces. Due to the permeability of the film, interaction still occurs between the wood material and the surface. Nutri-

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ents may migrate through the film. Van den Bulcke suggested that the nutrient content in coated Scots pine sapwood is one of the reason why the surface was more severe stained compared to other tropical species (Van den Bulcke, Van Acker et al. 2007). Spruce sapwood coated with an acrylic latex paint has also been found to have higher degree of discoloration compared to heartwood (Sandberg 2008). One method to increase the durability of painted panels is to use impregnation oil before paint application. The oil decreases the water uptake in wood, imitating the protective function similar to extractives in heartwood.

This paper studies the impact of Norway spruce heartwood and sapwood on the biological discoloration of a painted wood surface, with emphasis on the influence from wood moisture content.

**MATERIAL AND METHODS**

Logs of Norway spruce (*Picea abies* (L.) Karst) from the area of Växjö, Sweden were selected and freshly cut for this experiment. At the time of felling, the sapwood border was marked. The density of the material was for low density samples 300-500 kg/m$^3$ and for high density samples 400-600 kg/m$^3$ at 12% moisture content by dry weight basis (MC). The planks where selected to be free from knots, cracks and resinous streaks. They were straight-grained and divided into heartwood, sapwood, high density and low density. The planks where dried in an industrial kiln with a maximum temperature of 70°C. The drying process was run to a MC of approximately 17%. The dried material where downsized to a sample size of 20x100x375mm (radial x tangential x longitudinal direction). All surfaces were planed to a smooth and uniform finish. Acclimatization prior to coating were made for the samples to a MC of about 12% in a climate chamber at 20°C and 65% relative humidity (RH).

The samples were coated with a water-borne alkyd (A) or a water-borne acrylate (B) paint system. The alkyd system (A) had also the combination with or without impregnation oil. All samples were coated on the side facing the bark side of the tree and on side faces and end-grains. The back sides of the samples were left un-coated. The coating was done according to the manufacturer’s recommendations regarding layers, thickness and drying. The samples were dried between each layer at 20°C and 65% RH. A total of 60 samples were made with 5 replicas of each combination.

Samples were exposed outdoors during five years from October 2011-June 2016. The place where at Asa research station, 40 km north of Växjö, Sweden. The samples were hung on racks vertically on a 45-degree inclination to the south. Every second month, the samples were weighed with an accuracy of 0.1g. The MC by dry weight basis for the samples was calculated from the weight. Mould growth were measured in June 2016 according to standard EN ISO 4628-1 (Standardization 2004) using grade 0-5 (Fig. 1), where grade 0 = no detectable defects / discoloration up to grade 5 = dense pattern of defects/discholoration.
RESULTS

The discoloration of sapwood samples was higher or at equal level compared to heartwood for almost all samples, Fig. 2. The only combination with lower discoloration on sapwood than heartwood was for low density spruce coated with an acrylate system (B).

Largest difference in discoloration between heartwood and sapwood was found in samples painted with alkyd system (A) without impregnation oil as illustrated in Fig. 3.
All samples treated with impregnation oil except one combination had similar or slightly less discoloration compared to corresponding samples without impregnation oil (Fig. 2). The only exception was for high density sapwood. No correlations could be found between density of spruce and degree of discoloration.

The average MC was calculated as the average of all collected data for each sample combination independent of the time of data collection. The result is illustrated in Fig. 4. Sapwood samples had higher MC compared to heartwood samples for all combinations. Low density spruce samples had higher MC compared to samples with high density spruce for all sample combinations. The oiled samples had lower MC compared to corresponding samples without impregnation oil for all combinations except for low density heartwood.

DISCUSSION

The result with higher discoloration for sapwood is similar to previous result with uncoated spruce (Blom, Johansson et al. 2013) and also for coated spruce (Sandberg 2008). The trend was clear for samples painted with an alkyd system (A) but had some ambiguity for the acrylate system (B). The exception from the trend was sapwood samples made of low density spruce and coated with an acrylate system (B). This is in contradiction with previous results by (Sandberg 2008) who tested a similar paint system made of acrylic latex. It can be difficult to compare between different paint systems. The only known ingredient in the paints is the binder. For example is the amount of biocides unknown. The amount of biocides has an impact on the degree of discoloration. Effectiveness to reduce the discoloration by the biocide depends on the amount and the type of chemical, which there are limited information about. Conclusions can therefore only be made on the differences within the same paint system.
Samples with impregnation oil had in general lower discoloration compared to its corresponding samples without impregnation oil, Fig. 2. Exception was found for high density sapwood samples with higher discoloration on the oiled samples. The difference in discoloration for the deviated data is too small (without oil = 3.8, with oil = 4.0) and within the standard deviation interval for being considered as relevant.

When studied the differences of MC in Fig. 4, one could see that sapwood gained higher average MC compared to heartwood, in all combinations. The higher water uptake for coated sapwood samples is similar to the behaviour shown for uncoated samples (Metsä-Kortelainen, Antikainen et al. 2006, Sivertsen and Flæte 2012). The result with higher MC for low density samples compared to high density samples was also similar to previous experiments shown by Sjökvist (Sjökvist and Blom 2016).

It seems to be a correlation when comparing degree of discoloration in Fig. 2 and average MC in Fig. 4. Samples made of sapwood have both higher discoloration and higher MC compared to samples made of heartwood. Moving to the samples with impregnation of oil, these samples had lower MC compared to correlated samples without impregnation of oil. The oil treated samples had as well lower degree of discoloration compared to samples without impregnation oil. Low density samples had higher MC but no correlations could be found with a higher discoloration. In contrary, it seems to be randomized.

CONCLUSIONS

New findings raised new questions. Samples made of sapwood with an alkyd based paint had higher discoloration compared to heartwood. The MC was also higher for sapwood that heartwood samples. Low density wood had higher MC than high density wood but it didn’t correlate to a higher degree of discoloration. The question remained to be answered in future work is; whether the difference in discoloration is because of the presence of nutrients in sapwood or the higher MC in sapwood.

ACKNOWLEDGEMENTS

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REFERENCES


IMPACT OF CRACKS TO THE
HYGROTHERMAL PERFORMANCE OF CROSS
LAMINATED TIMBER

Kukk, V.¹, Püssa, M.², Kallakas, H.³ & Kers, J.⁴

ABSTRACT

Cross laminated timber (CLT), also known as “Engineered wood” developed initially in Europe (Switzerland) in early 1990s and it is designed mostly for multi-storey buildings as load-bearing elements because of its versatility compared with other timber products such as glue laminated timber. This research is focused on the problem of cracks formation caused by moisture movement during initial service period of CLT panel and its impacts to panel’s hygrothermal performances. Due to that following main objective was set: to evaluate the impact of presumably set cracks to CLT panel’s performances of water vapour resistance. Simulated cracks impact to water vapour resistance was examined in this research through scientific experiment. Experiment was carried out by “Cup test” accordance to standard ISO/DIS 12572 and specimen types what were used for experiments were plane-glued solid wood panels (two layers) from which two were with drilled hole with diameter of 2 and 6 mm for simulating cracks. Specimens were placed between almost 0% (inside the cup) and 50% (surrounding environment achieved by climate chamber) of relative humidity (RH). Almost 0% of RH was achieved by CaCl₂. Results were recorded by weighing the cups after each 72 hours and test ended when change of cup weight stayed constant. Results showed that the mean value of water vapour resistance factor µ of plane-glued solid wood panels was about 286, specimens with 2 mm diameter hole was 259 and with 6 mm diameter hole was about 198. From analyses of the results it was found that the impact of crack growth between 2 and 6 mm diameter simulated cracks in CLT panels is considerable to water vapour resistance of panels. Crack with diameter of 2 mm decreased water vapour resistance of CLT panel about 9% and 6 mm diameter crack decreased 30 % of resistance. For further studies it was proposed to study possible effects of decreased of water vapour resistance in cracks location to CLT panels in wall assembly.

Keywords: Cross laminated timber, cracks formation, water vapour resistance

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OVERVIEW OF RESEARCH TOWARDS MULTIFUNCTIONAL PLYWOOD SANDWICH PANELS

Kalnins, K.1

ABSTRACT

Development steps towards innovative birch plywood sandwich panel production technology by integrating (heat insulation, vibration, damping, impact resistance) will be presented. It is proven than lightweight sandwich structures are mechanically the most efficient way of applying plywood for large span load-bearing applications. It allows to save significant amount of material and also to reduce weight of the structures. In addition, there is a possibility to integrate additional function in sandwich panel core by adhesive bonding with various foams or optimizing layout of stiffeners to increase performance in other fields of application. Accumulated knowledge starting from single coupon specimen tests up to various actual scale prototypes manufactured both in laboratory and manufacturing plant will be discussed.

In order to fully explore a multifunctional potential of plywood sandwich panels reliable and safe design methodology should be developed. For this reason reliable input data (mechanical and thermal properties) is necessary in order to acquire accurate numerical models. It has been found that there is great difference between birch specimens and properties of compressed birch veneer with adhesive. In addition series of bending tests (according to EN 789) have been performed for the sandwich panels with I-type stiffeners and corrugated core in order to validate accuracy of the numerical models. Some evaluation of multifunctional properties indicate that foam bounded sandwich panels have an advantage among others of vibration damping due to lower core stiffness. The results of low velocity impact tests shows that thin elastic middle layer improve penetration resistance of plywood board, although Impact resistance of large thickness panels is mainly dependant on resistance of outer surface layer. Results of mechanical and thermal performance optimisation of sandwich panels with natural foam core could be applied to pick the most efficient design between three response values or to design structures with lowest possible U-values.

Furthermore developed methodology of design of lightweight sandwich panels to match bending performance of conventional plywood boards developed within Latvia State research programme: Innovative and multifunctional composite materials for sustainable buildings (IMATEH) is approbated in scaffolding deck application.

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INFLUENCE OF SIZE DURING THERMAL MODIFICATION ON PROCESS AND RESULTING WOOD PROPERTIES – COMPARISON OF INDUSTRIAL AND LABORATORY TREATMENT

Källander, B.¹,²

ABSTRACT

The studies presented in this paper focus on how the size of the batches treated and the size of the individual wood samples treated influence the process and resulting mass loss, EMC reduction, and reduction in impact bending strength of the wood. Treatments were made in superheated steam according to the Thermowood® process. Resulting properties after industrial treatment and laboratory treatment were compared.

Paired samples cut from Norway spruce and Scots Pine planks were heat treated in industrial Thermowood® kilns together with the regular production and in a laboratory autoclave equipped with X-ray CT-scanner. Paired test samples were made by cutting each test plank into cross sections of length 10mm, 50mm, 100mm, and either 1.25 m or 1.6 m before treatment. Reference samples from each plank were used to determine properties of untreated material.

The studies showed a strong size effect where small samples showed both different reactions to the surrounding climate and different resulting material properties after treatment as compared to larger samples and full size planks. Laboratory treatment lead to greater mass loss than industrial treatment. The results show that the size influence is different for reduction of EMC, mass loss, and reduction of impact bending strength.

Keywords: thermal modification, size effect, EMC, mass loss, impact bending strength

INTRODUCTION

Research on wood drying and wood modification is primarily done in laboratories, using clear wood specimens treated under well-defined conditions in laboratory cabinets. Laboratory tests differ from industrial treatment both regarding the size and homogeneity of the material treated, and the size of the batch and kilns used. Influence of dimensions during treatment of wood at elevated temperatures was

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recognised more than 100 years ago, as is shown by Tiemann (1915), but the author has only found four earlier studies published where results from treatment of small clear wood samples and dimensional timber have been compared (Kozlik, 1968; Obataya et al., 2006; Källander and Landel, 2007; Källander, 2010). Knowledge about how the size of the material treated and the size of the batch or kiln influence the results is limited, which makes it difficult to utilize results from laboratory research in development of industrial processes. A better understanding of the influence of size can also improve the possibilities to design laboratory studies so that the results are easier to implement industrially.

MATERIAL AND METHODS

Samples from 42x98mm Norway spruce (Picea abies) and 50x100mm and 50x150mm Scots Pine (Pinus sylvestris) planks were heat treated in industrial Thermowood® kilns together with the regular production and in a laboratory autoclave. The test planks were randomly selected from industrial batches of Thermowood grade planks. Average MC before heat treatment was 14.7% for the spruce planks, 17.0% for 50x100mm pine, and 18.8% for 50x150mm pine.

Paired test samples were made by cutting each test plank into cross sections of length 10mm, 50mm, 100mm, and either 1.25 m or 1.6 m before treatment. Thermocouples to record process temperatures in the wood and surrounding atmosphere were placed in the centre of one sample of each dimension, at different depths of the longer planks, and in various locations in the industrial batch.

The wood was treated according standard Thermowood D schedules, in superheated steam and maintaining 2-3 h wood temperature at the 212°C plateau temperature. The laboratory schedules were designed with set-point values for dry bulb and wet bulb temperatures copying the industrial schedules with corresponding treatment times as shown in Figure 1.

![Fig. 1. Examples of trend curves from an industrial and a laboratory treatment.](image-url)
Laboratory treatments according to the Thermowood process were conducted at Luleå Technical University in Skellefteå, in a laboratory autoclave combined with a medical X-ray Computed Tomography scanner (CT-scanner) capable of measuring the internal density distribution of the wood during the process.

All samples were conditioned in 23 °C / 50% RH after treatment until stable mass was reached. EMC after treatment was determined by measuring MC of the conditioned samples by the dry weight method on the 10mm long cross sections treated, as well as on 10mm long cross sections cut from the centre of samples treated at pre-cut lengths of 50mm, 100mm, 200mm, 1250mm, and 1600mm. Mass loss during treatment was determined on Scots pine samples by comparison of dry weight of the paired untreated and thermally modified samples. Mass loss was calculated according to Equation 1.

$$ML(\%) = 100 \times \left( \frac{M_{dryUntreated}}{L_{dryUntreated}} - \frac{M_{dryTreated}}{L_{dryTreated}} \right) \Bigg/ \frac{M_{dryUntreated}}{L_{dryUntreated}}$$  \hspace{1cm} (Eq. 1)

Impact bending strength was determined according to the principle in DIN 52189 with 10mm x 10mm sticks cut from different parts of the cross section. The broken samples were re-conditioned in 23 °C / 50% RH after testing and EMC was determined.

RESULTS

Figure 2a shows internal temperature of 10 mm long samples and 1.6 m long samples of 50x100mm Scots pine during the initial heating. As the heating phase finished, the temperature of the smallest, 10 mm long, samples had reached the temperature of the surrounding steam. The internal temperatures of the longer samples show a clear gradient also after the heating phase.

The temperature gradient is reversed as the wood reaches the plateau temperature and the internal temperature rises above the temperature of the surrounding steam, as shown in Figure 2b. The temperature of the 10mm long sample closely follows the surrounding steam temperature whilst the 1.6 m long samples show up to 6 °C higher temperature in the core than the surrounding steam.
EMC reduction of both Spruce and Pine was lower for smaller samples as compared to larger samples, as shown in Figure 3a. As opposed to EMC-reduction, mass loss was higher in shorter samples as compared to longer samples, as shown in Figure 3b. Mass loss shows a sudden increase in the shortest samples as compared to longer samples for samples cut from both 50x100mm and 50x150mm pine.

Fig. 3. Influence of sample length during treatment on reduction of EMC and mass loss.
EMC after treatment of long samples and full size planks show a clear gradient, where EMC is reduced more in the core of the planks as compared to close to the surfaces, as shown in Figure 4a. Impact bending strength on the other hand show a different pattern where no gradient is seen or even possibly a lesser strength reduction in the core as shown in Figure 4b.

![Fig. 4a. EMC reduction](image)

![Fig. 4b. Reduced impact bending strength](image)

**Fig. 4.** Reduction of EMC and impact bending strength in different positions over the cross section of pine planks.

Laboratory treatment using similar treatment schedules as industrial treatment resulted in clearly higher mass loss in 10mm long samples, as shown in Figure 5.

![Fig.5. Mass loss measured after industrial treatment of 10mm long Scots pine samples and laboratory treatment copying industrial schedules. Open symbols = laboratory. Closed symbols = industrial.](image)
DISCUSSION

The temperature measurements show how small samples quickly adapted to surrounding climate, while longer pieces reacted slower and showed gradients within the material.

An internal wood temperature at the same level as surrounding steam is a strong indication that moisture no longer is evaporating, showing that the 10mm long sample was almost or completely dry after the heating phase. The temperature gradient in the larger samples on the other hand, show that drying is occurring.

The higher internal temperature in the larger samples during the plateau phase is caused by exothermal reactions in the wood, which has been shown in several earlier studies such as (Johansson and Morén, 2006; Rémond et al., 2010; Turner et al., 2010; Trcala and Cernak, 2015). If such reactions also take place in the smaller samples, they do not lead to an increase in internal temperature due to the small dimensions. Larger samples will thus be show a higher internal temperature than smaller samples treated in the same climate.

Both reduction of EMC and mass loss were strongly influenced by the size of the samples treated. However, whereas EMC reduction was lower for small samples than larger samples, mass loss showed an opposite pattern. This could indicate that EMC reduction and mass loss are governed by different processes.

Reduction of impact bending strength also show a different pattern as compared to reduction of EMC. The reduction of EMC is clearly higher in the core of planks, whereas the reduction of impact bending strength not show such a pattern.

The most surprising result from the study may be the higher mass loss of 10mm long samples treated in laboratory as compared to the paired samples treated in an industrial kiln. As the treatment schedule in the laboratory kiln was designed to closely copy the industrial trend curves, the impact on the wood material was expected to be similar.

The different influence of size during treatment on the different material properties in combination with the different results from laboratory treatment to industrial treatment make it difficult to transfer results from laboratory tests to industrial processes. New strategies may be needed.

CONCLUSIONS

Internal wood climate will be considerably different in a small sample as compared to a large sample when treated in the same climate.

Size of samples during treatment influences EMC reduction, mass loss, and reduction of impact bending strength in different ways.
Laboratory treatment of small samples lead to considerably higher mass loss than similar treatment in industrial kilns.

REFERENCES


EXTRACTIVES INFLUENCE ON THE WETTABILITY AND SWELLING OF THERMALLY MODIFIED SCOTS PINE

Källbom, S.,1 Sedighi Moghaddam, M.,2 Segerholm, K.,3 Jones, D.4 & Wålinder, M.5

ABSTRACT

The presence and distribution of wood extractives can be related to the physico-chemical properties of wood. Wood extractives are constituted of compounds that can easily migrate within the wood. Relocalisation of extractives occurs naturally during different wood treatments and processing. In this study the extractives influence on the wettability and swelling properties of thermally modified Scots pine (Pinus sylvestris L.) was investigated using a multicycle Wilhelmy plate method, which enables measurements of apparent contact angles, sorption dynamics and dimensional stability. Samples were prepared from matched boards of thermally modified wood (modified according to the ThermoWood®D process) and unmodified wood. Extracted samples were prepared by a Soxtec system using acetone and ethanol/toluene. Initial data showed that the contact angle for the TM samples was not much affected by the different extractions. The lowest dimensional stability was observed for the unmodified wood samples extracted with acetone. The liquid uptake for thermally modified wood was reduced for the samples extracted with acetone and acetone+ethanol/toluene compared with the non-extracted samples.

Keywords: Thermally modified wood, extractives, wettability, swelling

INTRODUCTION

The presence and influence of wood extractives is crucial for certain behaviour and properties of the wood. Wood extractives are constituted of compounds that can easily migrate within the wood. Relocalisation of extractives occurs naturally during different wood treatments and processing (Nussbaum, 1996 and 1999) or

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ageing (Wäne, 2009). The presence of extractives can have effect on properties such as wettability and swelling. The Wilhelmy plate method is an approach that has been used to determine for example contact angle (Gardner et al., 1991; Mantanis and Young, 1997; Wålinder and Ström, 2002; Sedighi Moghaddam et al., 2013) and dynamic wetting behaviour (Pu and Stevertson, 2008; Son and Gardner, 2004).

One approach to increase the dimensional stability of wood is by thermal modification. This kind of modification will also lead to a lower equilibrium moisture content of the wood and a decreased risk of biodeterioration. This will furthermore influence the durability and in-service behaviour of bio-based wood products, especially when exposed to moist conditions in outdoor use. A patented process for thermal modification is the ThermoWood®D process (Anonymous, 2003), where the wood is heated in the presence of steam up to about 200 °C. In this study the influence of extractives on wettability and swelling was studied for thermally modified and unmodified scots pine wood.

**MATERIAL AND METHODS**

Thermally modified (TM) and unmodified (UM) matched samples of Scots pine (*Pinus Sylvestris* L.) were obtained from Heatwood AB (Hudiksvall, Sweden). The thermal modification was performed according to the ThermoWood®D process. Wood samples of dimensions 30x7x10 mm³ of heartwood were prepared from roughly the same annual rings for both the UM and TM wood. A portion of these wood samples were extracted with different solvents using Soxtec System HT6 (Soxtec System HT6, 1983). Both UM and TM samples were divided into four different groups (A-D), where A consisted of non-extracted wood; B was extracted using a mixture of ethanol and toluene (1:2), C was extracted with acetone; and D was extracted firstly with acetone and then ethanol/toluene. The wood samples prepared for the swelling and wettability measurements were initially end grain-sealed on one side with polyurethane lacquer in terms to prevent end grain sorption. For the wetting experiments, veneers of dimensions 30x7x1 mm³ were cut with a chisel just before the measurement.

2-3 g in duplicates of UM and TM wood extraction samples were used for the extraction procedure. The extraction samples were dried in a ventilated conventional oven for 3 h (103 °C) in order to obtain the dry weight. The dry extraction samples were then placed into Whatman® cellulose extraction thimbles and placed in the Soxtec. Aluminium extraction cups were dried for 30 min (103 °C), cooled in a desiccator over orange silica gel and weighted before adding 25-50 mL of solvent. The extraction cups were placed in the Soxtec and the extraction thimbles immersed into the solvent solution. The extraction procedure implied two steps; boiling and rinsing. The boiling meant that the extraction thimbles including samples were immersed into the boiling solvent for a certain amount of time (30-50
During the rinsing the extraction thimbles were pulled up from the solvent and the extraction thimble with the sample was rinsed by the condensed solvent for 2-2.5 h.

The wettability and swelling was determined using the multicycle Wilhelmy plate method (Sedighi Moghaddam et al., 2013). The measurements were performed using a Sigma 70 tensiometer from KSV Instruments. The veneers were initially dried for 1 h (103 °C) in a conventional ventilated oven and then immersed for 20 cycles in ultrapure water (resistivity >18 MΩ·cm), 2 cycles in n-octane (≥99%) from Alfa Aesar), then dried for 1 h (103 °C) in the oven, and then immersed for another 10 cycles in n-octane. The method determines the force acting on a plate that is immersed in a liquid, described according to the following equation:

\[ F(h, t) = P\gamma \cos \theta + F_w(t) - \rho A h g \]  

where \( F \) is the detected force, based on the wetted perimeter of the plate \( P \), the surface tension of the probe liquid \( \gamma \), the liquid-solid-air contact angle \( \theta \), the probe liquid density \( \rho \), the cross-sectional area of the plate \( A \), the immersion depth \( h \), the gravitational constant \( g \) and the force due to wicking and sorption of the liquid \( F_w(t) \) at time \( t \).

The contact angle can be determined by linear regression to the zero depth from a single cycle Wilhelmy measurement, including the advancing and receding contact angle as shown in Equation 2 and 3.

\[ \cos \theta_A = \frac{F_A}{P\gamma} \]  
\[ \cos \theta_R = \frac{F_R - F_f}{P\gamma} \]

\( F_A \) is the advancing force, \( F_R \) is the receding force, at zero immersion depth, and \( F_f \) is the final force corresponding to the sorbed liquid in the sample after an immersion cycle. Also the dynamic sorption and swelling can be determined by linear regression of the final force to the zero depth of a cycle. The change in mass liquid uptake of the veneer after the \( n \)th cycle is described by Equation 4 (Sedighi Moghaddam et al. 2013):

\[ l_n(\%) = \frac{F_{fn}}{W_o} \times 100 \]

where \( W_o \) is the dry weight of the veneer and \( F_{fn} \) is the final force after the \( n \)th cycle. To determine the dimensional change, the perimeter can be measured before and after octane immersion (Sedighi Moghaddam, Wålinder et al. 2013). The final perimeter change is described by the following equation:

\[ \Delta P_n(\%) = \frac{P_n - P_0}{P_0} \times 100 \]

where \( P_0 \) is the initial veneer perimeter measured by immersion in octane.
RESULTS

Initial as well as final liquid sorption properties of the samples in terms of water and octane uptake are shown in Table 1. Not much difference among the UM A-D samples for the initial water uptake could be seen. For the TM samples there were slightly more variations for the initial water uptake but also more variation in standard deviation. The water uptake for A-D was in general lower for the TM samples compared with the UM samples. Exceptionally high standard deviation values are shown for TM B as a result of scattered results for the three sample replicates. Comparing the results of the non-extracted and extracted samples, it can be seen that the non-extracted thermally modified samples had slightly higher liquid uptake compared with the extracted thermally modified samples C and D.

Table 1. The result of the initial and final water uptake is shown together with the octane uptake for the unmodified (UM) and thermally modified (TM) samples A-D. The liquid uptake for water and octane is obtained from Equation 4. The numbers are showing the average of three replicate samples including standard deviation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initial water uptake $l_1$ (%)</th>
<th>Final water uptake $l_{20}$ (%)</th>
<th>Octane uptake $l_{10}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>11.6 (1.8)</td>
<td>30.2 (2.5)</td>
<td>30.2 (3.5)</td>
</tr>
<tr>
<td>B</td>
<td>11.8 (2.2)</td>
<td>35.2 (4.3)</td>
<td>30.0 (2.9)</td>
</tr>
<tr>
<td>C</td>
<td>12.2 (2.3)</td>
<td>35.8 (1.6)</td>
<td>26.2 (2.6)</td>
</tr>
<tr>
<td>D</td>
<td>11.8 (2.3)</td>
<td>31.9 (4.2)</td>
<td>26.1 (2.5)</td>
</tr>
<tr>
<td>TM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>10.7 (1.5)</td>
<td>29.9 (6.3)</td>
<td>28.2 (5.2)</td>
</tr>
<tr>
<td>B</td>
<td>13.0 (4.7)</td>
<td>49.9 (18.8)</td>
<td>37.0 (13.9)</td>
</tr>
<tr>
<td>C</td>
<td>8.6 (1.0)</td>
<td>19.0 (1.2)</td>
<td>23.5 (3.9)</td>
</tr>
<tr>
<td>D</td>
<td>11.5 (4.1)</td>
<td>21.5 (7.4)</td>
<td>25.7 (5.9)</td>
</tr>
</tbody>
</table>

Initial results for the contact angle measurements are shown in Table 2 together with the perimeter change. The contact angles for the different extracted and non-extracted thermally modified samples were rather similar, while a slightly higher variation could be seen among the UM wood samples. In general there were smaller changes in dimensional stability for the TM samples compared with the UM samples. The perimeter change, was somewhat lower for the non-extracted TM wood samples compared with the non-extracted UM samples. This could be expected as a result of the thermal modification. The highest perimeter change for UM was seen for the C samples (acetone extracted).
Table 2. Contact angles and dimensional stability (perimeter change) for the different samples of extracted and non-extracted unmodified (UM) and thermally modified (TM) wood, based on three replicate including standard deviation in parenthesis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Contact angle (°)</th>
<th>(%)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>100 (14)</td>
<td>2.2 (1.4)</td>
</tr>
<tr>
<td>B</td>
<td>90 (1)</td>
<td>3.8 (1.5)</td>
</tr>
<tr>
<td>C</td>
<td>93 (7)</td>
<td>6.4 (0.6)</td>
</tr>
<tr>
<td>D</td>
<td>83 (3)</td>
<td>4.2 (4.5)</td>
</tr>
<tr>
<td>TM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>88 (3)</td>
<td>0.8 (0.2)</td>
</tr>
<tr>
<td>B</td>
<td>90 (0)</td>
<td>3.4 (1.9)</td>
</tr>
<tr>
<td>C</td>
<td>88 (7)</td>
<td>1.3 (2.0)</td>
</tr>
<tr>
<td>D</td>
<td>89 (2)</td>
<td>4.0 (1.7)</td>
</tr>
</tbody>
</table>

\(^1\) Obtained from Equation 5

CONCLUSIONS

The wettability and swelling properties were analysed for different unmodified and thermally modified extracted and non-extracted samples. The results indicated that the contact angle of the thermally modified wood were rather similar among the different extracted and non-extracted samples, compared with the unmodified that were more scattered. The non-extracted thermally modified samples were also more dimensionally stable compared with the non-extracted unmodified samples. Among all samples, the solely acetone extracted unmodified samples showed the highest swelling, i.e. the lowest dimensional stability. Non-extracted thermally modified wood showed a slightly higher liquid uptake compared with the extracted thermally modified samples extracted with acetone (C) and with acetone+ethanol/toluene (D).

ACKNOWLEDGEMENT

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REFERENCES

DIMENSIONAL STABLE AND DURABLE LAMINATED VENEER LUMBER (LVL) FROM EUROPEAN BEECH (FAGUS SYLVATICA) BY IMPREGNATION WITH LOW MOLECULAR WEIGHT PHENOLIC RESIN

Bicke, S.1, Biziks, V.2 & Militz, H.3

ABSTRACT

This work deals with the evaluation of Laminated Veneer Lumber (LVL) made from rotary cut beech (Fagus sylvatica L.) veneers, which were treated with low molecular weight alkaline phenolic resins with the aim of cell wall modification. Beech-LVL, and derived products from it, are already used and accepted for structural purposes, e.g. fabrication halls and multi-storey buildings, though they benefit from its higher mechanical properties compared to softwoods. On the other hand, susceptibility to biological decay and possibility of dimensional changes limit the applicability to dry climate conditions. Therefore, it is the aim of the BMBF funded research project DauerBuche, belonging to the BioEconomy Cluster e.V., to achieve durability against fungal decay, increase of weathering performance and dimensional stability. As modification of the cell wall is the best way to provide dimensional stability and durability to protect wood and wood products against these corrupting influences, a modification on basis of phenol formaldehyde was chosen. This seemed to be more attractive than other chemical treatments or thermal treatment, because earlier work showed a sufficient preservation of the mechanical properties, which is crucial for building applications. The dimensional stability was evaluated in a 4h-boiling test with a subsequent drying and evaluation for delamination. Volumetric swelling was found to be reduced by 57% at moderate Weight-Percent-Gain (WPG) for undensified boards. The durability of the LVL against white rot fungus Trametes versicolor has been tested for 16 weeks according to the standard ENV 12038. This test offered that the mass loss was decreased to less than 1% by the PF-treatment. The mechanical properties modulus of rupture (MOR), modulus of elasticity (MOE) and impact bending strength have been assessed. It came out that for the undensified products the MOR could be preserved and MOE was significantly increased. The modification also enabled densification which resulted in further increase of MOR and MOE. Due to the loss of flexibility.

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the absorbed energy at the impact bending test was considerably lower. Over all it was concluded that the WPG could be much lower than it was found in former studies for this type of modification. Especially for products that are wished to have high strength values and a resistance against fungal decay, but do not have to have the highest dimensional stability, 15% WPG was sufficient. The possibility of reducing the product volume for a building project because of its elevated mechanical strength qualifies the additional costs for the modification.

**Keywords:** beech, durability, dimensional stability, laminated veneer lumber, phenolic resin

### INTRODUCTION

Timber framed halls and multi storey houses are already build from it, but only few years ago no one could imagine that LVL made from German beech wood has this great potential, until the Pollmeier Company started in 2014 their plant in Creuzburg. Today many reference objects prove the applicability of this product. It is now the aim to expand the field of application towards situations where weathering is expected.

Generally the sorption and desorption of water within the cell wall of wood lead to swelling and shrinkage. Severe stresses occur under varying climate conditions and damage of the wood structure can result. Furthermore high moisture content leads to degradation of the wood by basidiomycetes. To protect wood and wood products against these corrupting influences, the modification of the wooden cell wall to inhibit the water uptake, is the best way to provide dimensional stability and durability (Rowell 1999). Thermal treatment is probably the best known method, but always leads to considerable decreases in the strength properties. Some decrease in the strength properties also occur for the acetylation of wood, nevertheless exists a marketable product for the building sector based on radiata pine. The impregnation treatment is just as well relevant. If the impregnation treatment is applied, it is distinguished between self-polymerising chemicals (e.g. phenol formaldehyde) and cellulose-cross linkers (e.g. DMDHEU). 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU) is a resin originally used in the textile industry, but the technology has successfully been transferred to the wood modification (Krause, Jones et al. 2003). It is known that DMDHEU or its derivatives improve the durability and the dimensional stability of solid wood (Militz 1993) and plywood (Wepner, Krause et al. 2006).

The use of phenol formaldehyde as an impregnate for beech veneers is a long-known method to protect plywood against fast wetting (Stamm, Seborg et al. 1938; Stamm 1939; Stamm, Seborg et al. 1942; Stamm, Seborg et al. 1955) and to improve weathering stability (Evans, Gibson et al. 2013). Own studies (Bicke, Mai et al. 2012; Bicke and Militz 2014), as well as the studies of Furuno et al. (2004), indicate a high durability against fungal attack if alkaline low molecular weight
phenolic resins are used. However the former commercial use of phenolic resins led to filled cell lumina and high incompressibility with consequently lesser water uptake at high density. Own tests suggested that, if there was no sufficient cell wall penetration, still degradation by fungi was possible. So it was the aim of the treatment to decrease the water uptake and the extent of dimensional changes by incorporating the phenol formaldehyde resin inside the cell wall polymers to achieve a permanent bulking and a resistance against fungal decay. Results for the penetration have been presented at the 46th IRG Annual Meeting (Biziks, Bicke et al. 2015). More results on penetration and durability as well, were shown at the 47th IRG Annual Meeting (Biziks, Bicke et al. 2016).

For the structural application of LVL it is crucial to possess high strength values. Therefore densification is adorable if mechanical properties are linearly increased. This work explored the connection of the LVL made from PF-modified beech veneers and its properties.

The whole project is run under the BioEconomy programme and financed by the BMBF and the Pollmeier company.

MATERIAL AND METHODS

Modification and board production

Rotary cut beech (Fagus sylvatica L.) veneers were treated with low molecular weight alkaline phenolic resins with the aim of an optimal cell wall modification. The process contained a two step impregnation, within a vacuum was followed by atmospheric pressure, and a pre-drying. The final curing took place while gluing the veneers in a heated press to form LVL-boards. The used resins were water-soluble alkaline types with a low molecular weight and commercially available. Related to the used PF-concentration in the solutions, medium, middle and high dry weight gains (WPG) were achieved. For each board 8 plies were glued one-sided with a standard PF-glue and assembled parallel to the grain. The pressing time and the pressing temperature were constant, whereas the pressure was varied to achieve different levels of densification.

Test methods

The dimensional stability was examined in a simplified 4h-boiling test with a prompt drying at 80 °C (18 h) and evaluation for delamination. The samples were taken from the boards one day after board production, were not further acclimatized and were measured wet (weight and dimensions) after cooling in water. Sample size was 100 * 50 * d mm³ (d = thickness of board).

The durability of the LVL against white rot fungus has been tested for 16 weeks according to the standard ENV 12038. Prior to the main test with incubation on the white rot fungus (Trametes versicolor), a leaching test according to EN84 was
performed. It consisted of 14 days of immersion of each variant in water and ten times changing the water. Before and after the leaching test, the dry weights were measured to calculate the mass loss due to the immersion. Additionally this procedure allowed calculating water uptake and dimensional changes.

The mechanical properties of the LVL were assessed by modulus of rupture (MOR) and modulus of elasticity (MOE) in a 3-point-bending test according to DIN 52186. It was decided to use the standard for solid wood because of the solely parallel orientation of the veneers. The sample size was 50 * 480 * d mm³ and the span was 15 times the height (thickness of the board). The impact bending strength was done according to standard DIN 52189 with a span width of 210 mm. The sample cross section measured 20 mm* d and the length was 300 mm. Samples were placed in a way that the 150J-hammer hit parallel to the glue line.

**RESULTS AND DISCUSSION**

**Board density**

The PF- modification of veneers alters their compressibility before hardening significantly. Whereas higher pressing pressures can achieve only limited raw densities for unmodified veneers, the densities for modified veneers in this work reached at highest 1197 kg/m³ with a WPG of 60%, but already 994 kg/m³ with 15% WPG (Table 1). Compared to the untreated series, this is a densification ratio of 58% and 31%.

**Table 1:** Mean oven-dry densities of the board samples.

<table>
<thead>
<tr>
<th>WPG</th>
<th>Densification</th>
<th>Oven-Dry Density [kg/m³]</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>undensified</td>
<td>703</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>densified</td>
<td>757</td>
<td>14</td>
</tr>
<tr>
<td>15%</td>
<td>undensified</td>
<td>792</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>densified</td>
<td>994</td>
<td>81</td>
</tr>
<tr>
<td>30%</td>
<td>undensified</td>
<td>870</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>densified</td>
<td>1110</td>
<td>79</td>
</tr>
<tr>
<td>60%</td>
<td>undensified</td>
<td>979</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>densified</td>
<td>1197</td>
<td>68</td>
</tr>
</tbody>
</table>

**Dimensional stability**

Volumetric swelling was found to be reduced by 57% for undensified and by 79 % for densified boards at moderate WPG. A doubled WPG achieved just minor improvement. The lowest WPG in comparison only slightly improved dimensional stability without any compression, but failed with compression, because it could not prevent from back spring which increased the swelling.
Mechanical properties

In consideration of the structural purpose of LVL, i.e. building products, the mechanical properties are fundamental qualities.

Figure 2 shows that the modulus of rupture (MOR) remained nearly unchanged for undensified modified products independent from the resin and WPG. This is a contrast to most of the other known modification methods for wood. The results of the densified products were more variable. As some densification of the untreated variant occurred, the MOR was increased to some extent as well. It could be seen as benchmark. The series at low and moderate WPG - except variant K – profited from the densification, because they met this value or outreached it. At the highest WPG only resin type A showed a sufficient improvement of the MOR, which was equal to the 30% WPG.
Table 2: Modulus of Elasticity for beech LVL with variable WPG and Type of Resin differentiated from densification

<table>
<thead>
<tr>
<th>WPG</th>
<th>Type</th>
<th>Mean MOE [N/mm²]</th>
<th>STD MOE [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>undensified</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>Reference</td>
<td>13820</td>
<td>941</td>
</tr>
<tr>
<td>15%</td>
<td>A</td>
<td>15326</td>
<td>1088</td>
</tr>
<tr>
<td></td>
<td>F</td>
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<td></td>
<td>K</td>
<td>17291</td>
<td>14</td>
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<td>30%</td>
<td>A</td>
<td>15684</td>
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<td>K</td>
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<td>272</td>
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<tr>
<td>densified</td>
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<td></td>
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<tr>
<td>0%</td>
<td>Reference</td>
<td>15826</td>
<td>1042</td>
</tr>
<tr>
<td>15%</td>
<td>A</td>
<td>19321</td>
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<tr>
<td></td>
<td>K</td>
<td>19999</td>
<td>984</td>
</tr>
</tbody>
</table>

The MOE was significantly increased for all modified series compared to untreated references. Densification resulted in further increase of the MOE, for treated samples and untreated as well. The increase in MOE for the best densified 15%WPG-variant was 34%. Higher WPG did not automatically achieve higher values of MOE, but shifted the curves to a higher density for equivalent MOE (Figure 3). This resulted in a lowered efficiency of the modification and it might be concluded that the combination of a lower WPG with a higher density is preferable.
Figure 3: Modulus of Elasticity for beech LVL with variable WPG differentiated from the oven-dry density

The impact bending work is strongly affected by the modification. As the MOE indicated, high stiffness is achieved due to the PF-modification. Figure 4 shows that there was a nonlinear reduction of the impact bending work due to increasing WPG. The reduction until a WPG of 15% encompassed 36% - 46% of the value of the untreated references. A further reduction of 60% - 62% was found for the WPGs 18% and 30%. The densification of the treated LVL (Figure 4, right side) increased the impact bending work somewhat, but this increase was not proportional to the increase in density.

Figure 4: Influence of WPG with resin F (left) and densification with resin A (right) on the impact bending work of Beech-LVL.

Durability

The durability test showed that the modification of beech veneers with suitable PF-resins can achieve the highest durability against the wood deteriorating white rot fungus *Trametes versicolor* (Figure 5). The test was valid because references and virulence samples had a mass loss above 20%. Except resin K and D, the mass loss decreased for the most part of the resins to less than 1%. Thus the WPG above 15% or the densification had no influence on the results. It was interesting that no constrains of fungal growth could be observed and the moisture content of the
undensified samples was above 20% and fungal growth had been possible. This result is outstanding, because conventional products of PF-resin impregnated veneer products exhibit a WPG of 50-60%.

![Graph showing improvement in durability against white rot Trametes versicolor due to PF-modification.](image)

**Figure 5:** Improvement in durability against white rot Trametes versicolor due to PF-modification.

**CONCLUSION**

It can be concluded that LVL from the PF-modified beech veneers is highly durable against wood degrading white rot fungus *Trametes versicolor* and at the same time dimensionally stable. The WPG can be much lower than it was found in former studies for this type of product. Especially for products that are wished to have high strength values and a resistance against fungal decay, but do not have to have the highest dimensional stability, 15% WPG is sufficient. The possibility of reducing the product volume for a building project because of its elevated mechanical strength qualifies the additional costs for the modification.

The cell wall modification with PF also provides a higher compression at relatively low production pressures, which is why increased modulus of elasticity and modulus of rupture are achieved. On the other hand it has to be dealt with an increased stiffness and a reduced impact bending work. Thus, it will be the issue to identify the needed material characteristics for a specific product application and to adapt the process.

Even though there is still research to be done concerning natural weathering and other corrupting influences, it is believed that the modification with PF at low and moderate WPGs can lead to durable products in structural and outdoor application.

**ACKNOWLEDGEMENT**

The authors kindly thank the Pollmeier Furnierwerkstoffe GmbH, Creuzburg, Germany, for the good cooperation and the German Federal Ministry of Education and Research for the financial funding.
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ABSTRACT

Wood modification with phenolic resin is widely and commercially used to improve certain wood properties such as durability, certain mechanical properties or dimensional stability due to hydrophobic properties of the resin. Depending on the phenolic resin formulation (e.g. used catalyst, molecular weight or pH value) different characteristics are noticed. The chemical composition of various wood species can differ and thus, can influence the curing reaction of phenolic resins impregnated in wood.

In this study the process parameters for curing behavior of two phenolic resins impregnated in thin beech (*Fagus sylvatica* L.) veneer was determined. Two commercial available phenolic resins with different molecular weight were observed. The curing temperature of phenolic resin impregnated in thin beech veneer is determined by using differential scanning calorimetry. Furthermore the curing behavior is observed by shear oscillations measurements. Thereby the transformation of viscosity attributed to the curing steps of phenolic resin mixed with milled wood flour. The starting temperature of polycondensation is determined by shear oscillation measurement. Subsequently, specimens of (60 x 60 x 0.6) mm were impregnated with each PF and cured for various durations (20, 60, 90 min). For verification of the degree of polymerization a leaching tests were accomplished. In order to compare the applied phenolic resins, the WPG is determined.

**Keywords:** Phenolic Resins, Beech veneer, Curing behavior, Leaching

INTRODUCTION

Wood modification with phenolic resin is a well-known process in order to improve particular wood properties. The modification with phenolic resin (PF) reduces moisture uptake and liquid flow through wood (Stamm and Seborg 1942). For that the fixation of PF polymers in wood is necessary. Penetration of phenolic resin into cell walls mainly depends on the molecular weight of the prepolymer (Furuno *et al.* 2004). Low molecular weight resin compared to medium molecular weight resin penetrates easier into the cell walls. PF fractions of larger particle size stay in the cell lumina (Furuno *et al.* 2004). E.g. for improving the dimensional

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stability the formation of phenolic resin polymers inside the cell walls plays an important role (Gabriellie and Kamke 2010). A study from He and Yan (2005) showed that for best adhesive performance the molecular weight and molecular weight distribution of phenolic resin are also important factors.

By application of PF for wood modification the curing behavior of PF in wood is relevant. In general, the curing process of phenolic resin contains three reaction mechanism; gelation, vitrification and crosslinking (He et al. 2001). By vitrification a transformation from liquid to glassy state as a result of increase molecular weight is observed. And the crosslinking of polymers appears and develops after gel time (Laza et al. 2004). However, the presence of wood substrate influences the curing behavior of PF resins. The activation energy of PF increases caused by the acidic character of wood (He and Riedl 2004).

A sufficient degree of polymerisation of the PF inside the wood cell wall must be achieved to prevent leaching out of the polymer. On the one hand, forming of complex networks during polymerisation locks the resins inside the cell wall, on the other hand due to forming of covalent bonds between lignin and PF. Thus, leachability of the polymer is reduced (Hill 2006).

The aim of this study is to determine process parameters (such as curing duration and required temperature) for curing behaviour of phenolic resin impregnated in beech (Fagus sylvatica L.) veneer.

**MATERIAL AND METHODS**

**Phenolic resin**

The used PF were provided by Prefere resins GmbH, Erkner, Germany. The used phenolic resins were selected according to their mean molecular weight (M<sub>n</sub>). However, curing behaviour of PF is mainly attributed to pH value, catalyst and applied temperature (Pizzi and Mittal 2003). Further properties are describes in Table 1.

<table>
<thead>
<tr>
<th>Molecular weight Mn</th>
<th>Viscosity 20°C [mPas]</th>
<th>pH-values</th>
<th>Solids [%]</th>
<th>Catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lmw</td>
<td>246</td>
<td>15</td>
<td>9.30</td>
<td>45.2</td>
</tr>
<tr>
<td>Mmw</td>
<td>449</td>
<td>216</td>
<td>9.38</td>
<td>55.9</td>
</tr>
</tbody>
</table>

The beech (Fagus sylvatica L.) veneer (0.6 mm thickness) were impregnated with the PF for 24 h at 100 mbar. The veneer was commercially produced and not steamed. Prior impregnation, the specimens were dried at 80° C to constant weight.
Differential Scanning Calorimetry

In order to evaporate the water content, prior Differential Scanning Calorimetry (DSC) measurements the specimens were pre-dried at 80°C for 3.5 h. Subsequently, the impregnated specimens were cut after pre-drying into semicircles of 3 mm. The impregnated and pre-dried specimens were added into standard aluminum DSC crucibles with a standard pierced lid (Ø 0.05mm). Measurements were performed using a Netzsch DSC 204 F1 Phoenix. A heating ramp of 10 °C/min from 20 to 200 °C was applied. All experiments were carried out under nitrogen atmosphere with a purge gas flow of 100 ml/min. For each PF two specimens were measured.

Shear oscillation measurement

For shear oscillations measurements beech veneer were pulverized and subsequently screened to a maximal particle size of 630 µm. The wood flour was impregnated with PF for 2 h at 100 mbar. Measurements were performed using a Rheometrics Scientific ARES Rheometer. For shear oscillation measurement the wood flour mixed with phenolic resin was placed between two aluminium plates (Ø 25 mm). The heating ramp of 3 °C/min was approached from 30°C to 130°C. For measurement a strain of 10 % and a gap of 1.5 mm was selected. Measurements were cancelled by sudden increase of viscosity. Shear oscillation measurements were carried out two times for each PF mixed with wood flour.

Leaching test

For leaching test the used veneer was cut into specimens with the dimensions of 60x60 mm² and impregnated with each PF for 24 h at 100 mbar. The specimens were cured at 140°C for various durations (20, 60, 90 min). The leaching test includes three cycles. In each cycle the specimens were conditioned 24 h under room atmosphere. Afterwards, they were impregnated for 20 minutes at 400 mbar with deionized water and kept submerged for 72 h. The next step was a 48 h long conditioning at room atmosphere. Finally, the specimens were dried for 48 h at 80°C.

Weight percentage gain

After each cycle the mass loss was determined. The mass uptake of each veneer during the impregnation process and the mass loss during leaching test was determined as weight percentage gain (WPG) according to Eq. 1.

\[ WPG = \frac{(W_t - W_u)}{W_u} \times 100\[%\]  \hspace{1cm} (1)
where WPG is the weight percentage gain of the sample after impregnation \(\times\) after leaching test [%]. \(W_t\) is the weight of the sample after impregnation, respectively after leaching cycle [g]. And \(W_u\) is the weight of the absolutely dry sample [g].

**RESULTS /DISCUSSION**

A significant difference of the curing temperature between Lmw and Mmw PF was not observed by DSC measurements. DSC measurement displayed an average peak-maximum of 137° C for low molecular phenolic resin (Lmw) (Figure 1). For medium molecular phenolic resin (Mmw) an average peak maximum of 138° C was determined. The used PF is water diluted with a solid content between 45 % and 55%. Even so the specimens were pre dried prior DSC measurements, an endothermic peak at 100° C was observed. This might be attributed to evaporation of remained water. Additionally, during polycondensation water emerges as reaction product and could influence the measurement. Thus, the starting temperature of polycondensation could not be determined by DSC.

![Figure 1: DSC Measurements, phenolic resin impregnate in beech veneer](image)

However, starting temperature of polycondensation can be determined by viscosity changes using shear oscillation measurements additionally. For both PF formulations mixed with beech wood flour, the measurements displayed a sudden increase of viscosity at \(\text{appr. } 120°\ C\).

No significant differences of the starting of the polycondensation process between Lmw and Mmw were observed.

Based on DSC measurements the curing temperature for specimens was appointed at 140° C. A leaching test was applied to estimate the required curing time. Figure 2 displays the WPG of specimens after curing and after the third leaching cycle.
It was recognized that after 20 min of curing the highest mass loss for Lmw as well as for Mmw PF was determined. After 20 min of curing 50.39 % of Lmw PF and 23.03 % of Mmw PF were leached out. After 60 min of curing a percentage share of 6.98 % of Lmw PF and 5.28 % of the Mmw PF were leached out. Leaching could be included PF or wood composites, a more accurate determination of leaching content was not carried out. Furthermore, alkaline milieu of the applied resols can additionally lead to cleavage of ether linkages between lignin units and thus result in degradation of structural compound which might be leached out (Yelle and Ralph 2016). However, due to leaching tests it is not clear, if only PF which cured inside the cell lumina, or also PF from inside the cell wall is leached out. Thereby, for both PF, differences in WPG loss between curing for 60 and 90 min were negligible small. Thus, the obtained data indicate that the main part of PF already cured after 60 min.

The used Lmw PF has a lower solid content than Mmw PF. As a consequence the Lmw PF contains higher amount of water which has to evaporate during curing. Compared to Mmw PF, the Lmw PF displayed higher mass loss during the three leaching cycles. The high differences in WPG of 20 min cured specimens with Lmw PF could be a result of remaining water due to the relative short curing time. Additionally, water that emerged during polycondensation could also influence the measured weight and could be interpreted that the polymerisation of the PF is not completed after 20 min. According to the Lmw PF solid content, a WPG of *appr.* 60 %- 65 % should be achieved.

![Figure 2: Leaching test of PF impregnated specimens with curing times of 20, 60 and 90 minutes cured at 140° C](image-url)
CONCLUSION

DSC measurements in combination with rheometric measurements provide to be a suitable tool for determine process parameters of PF curing behaviour in beech veneer. The combination of both leaves a reasonable method to determine different process parameters. The leaching test is a simple method to investigate the curing time of PF in wood. Furthermore, the collected data showed that 60 min of curing at 140° C are sufficient to obtain a stable PF polymer inside wood. No significant differences between the two applied PF were noted.

ACKNOWLEDGEMENTS

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A PRELIMINARY STUDY OF THE MECHANICAL PROPERTIES OF SCOTS PINE IMPREGNATED WITH A HIGH MELTING POINT WAX

Paajanen, O.¹, Turunen, H.² & Peura, J.³

ABSTRACT

The objective of this short study was to evaluate the properties of pine wood specimens impregnated with a high melting point wax. The tests are currently ongoing at the Mikkeli University of Applied Science, using recently built wood modification equipment. The specimens were impregnated using a high melting point wax. The mechanical properties of the test specimens were tested using two methods: bending strength test and impact bending test. The results are then compared to untreated reference material as well as thermally modified specimens.

Keywords: wax impregnation, high melting point wax, wood modification

INTRODUCTION

In wood modification, the aim is to improve the properties of wood products, e.g. the mechanical strength, dimensional stability or durability (Navi & Sandberg 2012). Common modification methods include impregnation with different substances, thermal and chemical modification.

A new piece of modification equipment was installed in the spring of 2016 at the Mikkeli University of Applied Sciences. It was acquired and developed in a wood modification project that is funded by European Regional Development Fund through South Savo Regional Council, as well as six local companies. The aim of the project is to study wood modification with different hot oils and high melting point waxes.

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MATERIAL AND METHODS

Treatment equipment

The new modification equipment is shown in figure 1. Diameter of the impregnation chamber is 380 mm and length 2200 mm. As the chamber is relatively large, modification of full size components and therefore also pilot scale manufacturing is possible. Maximum operating temperature is 200°C and maximum pressure with nitrogen gas 11 bar and with air 15.5 bar. Temperature and pressure conditions in the impregnation and storage cylinders can be controlled separately. Heating and cooling is managed with separate temperature control unit. The equipment can be used in many different kinds of processes, from drying and heat treatment to various impregnation and modification techniques.

![Fig. 1 The equipment](image)

Test setup and materials

The wood specimens were treated with a high melting point wax using a new piece of equipment at the Mikkeli University of Applied Sciences. The aim of the test was to evaluate both the performance of the test equipment and also start the wood material testing with wax treated specimens.

The test material was Scots pine both in kiln dried as well as thermally treated form. The thermally treated material is commercially available as Thermo D, i.e. the heat treatment temperature is 212 °C. The wood material was attached to a tray, with some wood strips between the pieces separating them. The wood material for these tests was cut into 20 mm x 20 mm x 2000 mm sticks. The wax used was bleached montan wax, with relatively high melting point, 99-105 °C. The process steps were following: After preheating stage, the wood was loaded into the cylinder. The temperature of the cylinder was then raised to 120 °C. The temperature of the wax was 160 °C as it was introduced into the cylinder. The wax treatment and
the tempering stage lasted approx. 100 minutes. Finally, the cylinder was cooled. It must be noted that the parameters were chosen with the testing of the equipment in mind. In other words, they were not optimized in any way and also the weight gain during the process was low, less than 10 %.

**Mechanical tests**

Bending strength test was set up according to EN 408. As the thermally treated wood is more brittle than untreated wood, it was decided to try assess also the impact strength of the specimens. The test was adapted from the ISO-179-1 (2010). The available test rig was equipped with a 300 J hammer – mainly intended for testing metals. Composite materials, plastics and wood specimens have been tested with various setup, for example Lokaj & Vavrušová (2010) tested various wood species and Sailer et al. (2000) oil heat treated specimens. While the test results are not comparable between different test rigs, the results from different type of treatments can still be compared against each other. The specimen size was 20 mm x 20 mm x 80 mm and they force was from radial direction to represent the loading of a decking material. At this stage, there were only a limited number of test specimens available: in bending tests there were 9 sticks per group, whereas in impact tests there were 23…30 specimens per group. The reason for the low number of specimens was the limited amount of raw material and large number of natural defects.

**RESULTS**

The bending strength results are shown in figures 2 and 3 and the impact strength results are shown in figure 4. The bending results show that the treatment with wax did not change the bending strength but the specimens from heat treated material are weaker. The modulus of elasticity is lower with wax treated specimens with both specimen materials. mm²

![Fig. 2 The bending strength](image-url)
The untreated reference material has the highest impact strength. The wax treated standard pine lost almost half of its strength, but on the other hand the wax treated thermowood specimens were equal to the reference thermowood. The loss of strength could be explained by the heat treatment process – in the case of thermowood specimens the initial heat treatment has already caused a large loss in impact strength. In the case of kiln dried material the high temperature in the wax process could cause the significant decrease in the impact strength.

CONCLUSIONS

In the bending tests the wax treatment did not affect the bending strength. The specimens from the heat treated raw material were weaker, as can be expected. After the wax treatment, the modulus of elasticity is lower. In the impact tests the wax treated kiln dried specimens were significantly weaker than reference. There was no significant difference in the specimens from the heat treated raw material. This could be explained by the fact that the temperature during the wax process is high enough (160 °C) that it affects the impact properties. The number of test specimens

Fig. 4 The impact strength test
presented here is relatively low because of limited amount of raw material. Also only one treatment temperature combination was used in these tests. Therefore, these results should be taken as preliminary. More test results are expected to be available by the WSE conference in September 2016. These should also include wax treatments using lower temperatures. Also other tests are ongoing, for instance the effect of the wax treatment on the weather resistance and biological durability.

ACKNOWLEDGEMENT

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WOOD DURABILITY ENHANCEMENT BY ACETYLYATION AND IMPREGNATION WITH VEGETABLE OIL

Morozovs, A.¹ & Laiveniece, L.²

ABSTRACT

Wood is used as construction material because its strength and aesthetical properties from time immemorial. The shortages in wood application are bio-deterioration and swelling or shrinkage in variable humidity conditions. Acetylation with acetic anhydride of wood is well accepted and commercialized the wood modification method. Vegetable oils are used to make wood water repellent and to decrease its dimensional changes. Simultaneous used of different agents may exhibit synergistic effect on the wood protection against water. Wood acetylation and impregnation with rapeseed oil was used as joint modification method. The modified wood samples cyclic treatments with soaking in hot water with subsequent-freezing and drying were used to evaluate each method individual and combined influence.

Keywords: acetic anhydride, acetylation, impregnation, rapeseed oil

INTRODUCTION

Due to ecological reasons wood is increasingly used in the timber constructions. The environment relative humidity and wood chemical composition and structure determine wood equilibrium water content. Wood substances (cellulose, hemicelluloses and partly lignin) hydroxyl groups are assumed to determine water sorption in to the wood cell wall mostly (Skaar, 1988). The tightly bound by hydrogen bonds water molecules induce swelling by forming wood and water solid solution. Wood dimensional instability in a changing moisture environment might cause problems in constructions with wood elements.

Wood chemical or thermal modification alters it composition and structure on the molecular level decreases wood hydrophilic properties (Hill, 2006). The alterations in wood biopolymers network in some extent are exposed as swelling in case of chemical modification or shrinkage during thermal treatment (Thybring, 2013) that decreases wood network swelling probability. Wood acetylation with acetic anhydride is studied world-wide and has reached commercialization (Hill, 2006).

The decrease of water sorption is one of objectives of wood acetylation. Water sorption decrease by wood hydroxyl group bulking by acetylation is accepted

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(Hill, 2006). The bulking of hydroxyl groups on cell wall surface theoretically might be possible to perform with bulky molecules like triglycerides of fats that could decrease the required acetylation degree, because theoretically only about 42 percent of acetic anhydride is transformed into acetyl groups that are covalently tied with wood. The acetylation outcome on base of acetic anhydride is much lower due to hydrolysis of acetic anhydride with moisture present in wood in practise.

The objective of presented paper is the examination of combined wood acetylation and oil treatment with the aim to decrease wood’s hygroscopic properties with environmentally sound way.

**MATERIAL AND METHODS**

**Wood modification**

The aspen (*Populus tremula* L.) wood specimens with dimensions (100 x 100 x 20) mm (fibre x tangential x radial direction) were cut-off from selected timber without faults and dried in oven at (103 ± 2) °C till constant mass. Wood specimens were vacuumed at 0.2 kPa residual pressure for 6 h and then impregnated with acetic anhydride for 24 hours at room temperature. Wood acetylation reaction was carried out for 20 hours at (120 ± 3) °C and then dried in a ventilated drying oven at (103 ± 2) °C till constant mass. Mass percent gain (WPG) of modified wood by acetylation was (24.1±0.5) %.

The impregnation with rape seed oil of un-modified wood was carried out by preliminary vacuuming at 120 °C and saturation with oil for 1 hour at 115 °C, and then impregnated wood specimens were cured in oven at (103 ± 2) °C till constant mass. WPG of impregnated with oil of aspen wood was (50±15) %.

The both acetylation and impregnation with rapeseed oil was performed by two different modes.

By the first one the dried aspen wood specimens were vacuumed for 2 hours and saturated with acetic anhydride at room temperature, then acetylated for 14.5 hours at 100°C then cured in a ventilated drying oven at (103 ± 2) °C. The total WPG by acetylation and impregnation with oil of aspen wood was (52±10) %.

By the second mode the specimens were vacuumed for 17.5 hours then saturated with acetic anhydride for 6 hours. Specimens were weighted and acetic anhydride retention (58±3) were detected. Impregnated with acetic anhydride specimens were immersed in ripe oil for 16 hours at 125 °C with distilling off volatiles and after all hardened in an oven at (103±2) °C. The total WPG was (58±30) %.

**Cyclic wood swelling-freezing-drying tests**

Modified and un-modified wood samples were weighted and measured with electronic sliding callipers in each of corners in vertical and horizontal plane of sample
as well in the centre of sample in perpendicular directions (totally 10 measurements apiece). Weighted and measured wood samples were packed in blocks with 2 mm in diameter bamboo spacers between them and submerged in distilled water in the reactor with controlled heating (75±5) °C for 3 days. After wood specimens were cooled under water tap, weighted and measured. Collected in blocks and sealed in PE bags and placed in refrigerator at (-20±2) °C for 3 days. The wood sample were dried 3 days at (103±2) °C and weighted and measured before the second cycle.

Water absorption in modified or un-modified (reference) wood was expressed as ratio of absorbed water against mass of wood sample before modification. The swelling of wood was expressed as difference of volumes between swelled and dried sample ratio with volume of dry wood sample volume before modification.

RESULTS

Fig. 1. Results of water absorption measurement

Fig. 2. Results of wood swelling measurement
The presented experimental results are modified implementation of researches on wood transesterification (Morozovs, 2005). When solid wood is acetylated with acetic anhydride, formed acetic acid dilutes reagent and may change its properties, that influences reactivity and create un-known synergistic effects on wood like with other organic liquids has shown by Meier et al., (2005). Acetic anhydride and acetic acid swells wood (Rowell, 2005) that presents evidence on wood partial dissolving in both organic liquids and wood solid solution origination which is transformed in acetylated wood solid solution like with other organic liquids has shown by Meier et al., (2005). Swelled wood cell wall may be more reactive and more permeable to voluminous molecules. Rapeseed oil was chosen as such bulky reagent as some kind of tracer to evaluate potential synergistic effected between acetic anhydride or acetic acid and fatty acid triglyceride.

Comparison of effects of wood impregnation with rapeseed oil, wood modification with acetic anhydride, acetylation and impregnation with vegetable oil without complete isolation of acetic acid, and wood impregnation with acetic anhydride and subsequent impregnation with oil on water absorption (Fig. 1) shows that acetylation with acetic anhydride in presence of rapeseed oil is diminished. To enhance effect of oil on acetylation process the lowered reaction temperature was used in the first combined acetylation mode. More pronounced the implication of oil on acetylation process is shown by calculation of anti-absorption efficiency (AAE) according Eq 1.

\[
AAE = \frac{A_R - A_M}{A_R} \times 100
\]  

Where: \(A_R\) and \(A_M\) are absorptions of hot water in the un-modified and modified wood specimens accordingly.

![Fig 3. Anti-absorption efficiencies of different modes of modification for aspen wood. Oil – impregnation with rapeseed oil; Acet.+oil – acetylation with subsequent impregnation with oil; Ac2O+oil – impregnation with acetic anhydride and oil.](image-url)
During the initial soaking-freezing-drying cycles there was some reduced water absorption in comparison with natural wood, but it was less than into wood impregnated with oil or acetylated wood. It must be indicated that wood impregnation with acetic anhydride and oil (the second mode) has more pronounced effect than in case of the first mode of combined modification that gives higher AAE values (Fig. 3). It may be explained by dilution rapeseed oil that decreases its viscosity.

The difference between swelling in water of un-modified and modified wood sample shows modification agent interaction with wood cell wall substances (Fig. 2). All modes of modification including impregnation with oil decreased wood swelling in water. But wood modification with both combined modification modes has unsteady influence during cyclic wood wetting and drying. The anti-swelling efficiency (ASE) was calculated by Eq. 2.

$$ASE = \frac{S_R - S_M}{S_R}$$

Where: $A_R$ and $A_M$ are swelling in hot water of un-modified and modified wood specimens accordingly.

The ASE calculation results are presented in the Fig. 4.

![Fig. 4. Anti-swelling efficiencies of different modification modes.](image)

The wood acetylation with acetic anhydride gives the highest and stable ASE values that are well-known (Hill, 2006). Calculated ASE value decreases by 9 % during cyclic hydrothermal impact during 9 cycles in case of wood acetylation with acetic anhydride.

As shown above with water absorption results discussion, the combination of oil impregnation with simultaneous acetylation gives diminishing of wood swelling that is not stable under cyclic hydrothermal impact. Wood simultaneous acetylation with acetic anhydride and impregnation with rapeseed oil gives negative synergic effect.

Uncommon are increasing ASE values by 14% of wood samples impregnated with rapeseed oil during cyclic tests. It may be supposed that during hydrothermal treat-
ment the penetration into wood cell wall of semi-curing rapeseed oil is possible. About such possibility indicated sticky high viscosity semi-polymerized oil film spots on the sample surface and reactor top walls and water surface.

During experiments the aspen wood sample surface deformation were observed by differences in the shrinkage of early and late wood during drying in the oven at (103±2) °C with the exception of acetylated with acetic anhydride wood.

CONCLUSIONS

The aspen (Populus tremula L.) wood was modified: by acetylation with acetic anhydride and by two modes of simultaneous modes of acetylation combination with impregnation with rapeseed oil as well as impregnation with the oil. Each modification mode effect on water absorption and wood swelling was evaluated by cyclic saturation in hot water with subsequent-freezing and drying. It was found that rapeseed oil create negative synergic effect on wood acetylation process. Only acetylation with acetic anhydride prevented wood sample surface deformation contrary to other tested modification modes due to differences in shrinkage of early and late wood of these samples. The swelling of impregnated with rapeseed oil decreased during cyclic hydrothermal treatment.

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Mapping and visualization of structural changes due to the modification of wood would increase the understanding of chemical modification processes and facilitate optimization of the process parameters. The 2D and 3D microstructure of acetylated and furfurylated softwood and hardwood were visualized using X-ray computed tomography and some anatomical features were investigated such as total porosity, cell wall thickness and maximum opening of tracheid lumens. The wetting properties of chemically modified samples were related to the microstructural properties. Significant changes in the wood structure were observed for furfurylated sapwood samples mainly indicated by a change in tracheid shape and filling of tracheids by furan polymer, whereas no microstructural changes were noted for acetylated samples. Furfurylation significantly decreased the porosity of the sample in both earlywood and latewood regions; whereas for acetylated samples the total porosity of modified and unmodified samples was rather similar. This is in line with results of wetting showing that furfurylation reduced both swelling and capillary uptake in contrast to acetylation which reduced mostly swelling.

Keywords: Acetylation, furfurylation, microstructure, X-ray Computed Tomography, wettability

INTRODUCTION

Wood is modified in order to improve decay resistance, dimensional stability and weathering performance, and to reduce water sorption (Hill 2006). Chemical
modification of wood can cause changes of wood characteristics such as chemical composition, wetting properties, biological durability, and mechanical properties. Mapping and visualization of these structural changes would increase the understanding of chemical modification processes and facilitate optimization of the process parameters. There are only a few studies devoted to the microstructural changes induced by chemical modification of wood (Kwon et al. 2007; Wålinder et al. 2009; Sander et al. 2003). However, quantification of microstructural properties and remaining air-filled voids in acetylated and furfurylated wood samples have not previously been described in detail in the literature.

Wood is a complex anisotropic material with a cellular structure and several hierarchical levels of organization that can affect the wood properties at different length scales. As a result of the wood structure complexity, wetting phenomena such as water uptake are complex as they are affected by the three-dimensional morphological characteristics (Sedighi-Gilani et al. 2012). Several imaging techniques have been used for studying the wood structure, mainly including classical transmission light microscopy, scanning and transmission electron microscopy. Most of these techniques can provide only 2D images. X-ray Computed Tomography (XCT) is a useful non-destructive technique to visualize the three-dimensional structure of wood without complicated sample preparation, from macro to micro- and nanometer scales (Svedström et al. 2012). It was shown that X-ray tomography is a valuable technique for investigating the detailed microstructural properties of wood samples such as porosity, diameter of tracheid, cell wall thickness (CWT) and pit sizes (Trtik et al. 2007).

In a previous study (Sedighi Moghaddam et al. 2015) by using the multicycle Wilhelmy plate (mWP) method, it was demonstrated that acetylation reduced water uptake mainly by reducing the swelling. Conversely, the sorption data suggested that furfurylation reduced both swelling and the void volume in the sample. These observations suggest significant microstructural differences between acetylated and furfurylated wood, and to clarify these is one main motivation for the present work. To elucidate these changes X-ray computed tomography was utilized to visualize anatomical details and to quantify micro-structural properties after acetylation and furfurylation.

**MATERIAL AND METHODS**

Boards of Southern yellow pine (SYP), *Pinus palustris*, with dimension of 40×14×2.5 cm³ (in the L×T×R directions, respectively) were acetylated in a pilot plant at SP in Borås, Sweden. The acetylation process was performed in a microwave-heated reaction vessel following procedures described in Rowell et al. (1985) to 15.9 and 22.2% acetyl content (SYPacet15.9 and SYPacet22.2). Two unmodified matched samples from the same boards were utilized as control samples (SYPctrl15.9 and SYPctrl22.2). The furfurylation process was performed in an autoclave
by a pressure process, and cured and dried in a vacuum drying kiln following procedures described in Lande et al. (2004) at a pilot plant at Kebony AS, Porsgrunn, Norway. Based on this process the following furfurylated samples were prepared: (1) furfurylated SYP (SYP$_{furf28}$ and SYP$_{furf45}$) with weight percentage gain (WPG) of ca. 28 and 45% respectively, and (2) furfurylated maple (Acer platanoides) (Maple$_{furf32}$) with WPG level of ca. 32%. The unmodified maple sample (Maple$_{ctrl}$) was collected from the same board.

Needle shaped samples measuring approximately 1 mm (R), 1 mm (T) and 5 mm (L) (or smaller) were cut with a razor blade from larger wood blocks. For each sample type, two pure earlywood (EW) and pure latewood (LW) samples were prepared. The samples were then dried at 104 ºC for 1 h in an oven in order to have the same conditions as for the wetting measurements (see below). The samples were then glued on a cylindrical pencil lead sample holder.

The central part of each needle shaped sample, measuring approximately 0.5 x 0.5 x 0.5 mm$^3$ was scanned using Nanowood, a state-of-the-art X-ray CT scanner developed at UGCT at Ghent University, Belgium (Dierick et al. 2014). At least two replicate samples were scanned for each sample type. Scans were made at an average voltage of 50 kV and with a rotation step size of 0.36º. A single scan, with 1001 projections and 1500 ms exposure time per projection, took approximately 1 hour. Reconstruction was performed using Octopus, a tomography reconstruction package for parallel, helical and cone beam geometry (Vlassenbroeck et al. 2007) licensed by InsideMatters (www.insidematters.eu), resulting in an approximate voxel pitch of 0.8 µm. All scans were phase filtered using the Paganin algorithm. Reconstructed volumes were then processed with Morpho+ (Vlassenbroeck et al. 2007), a software package for volume analysis, currently known as Octopus Analysis and also licensed by InsideMatters. Volumes were median and bilateral filtered for noise removal. Wood and air were thresholding and the total porosity was calculated. The porosity of specific structural features (e.g. tracheids in softwood samples) was determined by automated labelling and subsequent manual selection of the anatomical features of interest. Cell wall (CW) thicknesses were calculated using MATLAB® (see details in (Van den Bulcke et al. 2009) and in supporting information).

The wetting studies were performed using acetylated and furfurylated samples prepared in the same manner as those used for the microstructural studies. The multicycle Wilhelmy plate method that was employed has been described in detail elsewhere. Here we further analyses findings described in our previous paper (Sedighi Moghaddam et al. 2015).
RESULTS

As an example of visualization of modified wood samples, Figure 1 demonstrates 2D microstructural images of furfurylated maple samples. The images clearly show that significant microstructural changes have occurred due to furfurylation. Extensive furan polymer deposits can be distinguished in the vessels, fibers and rays. Ray cells were mostly filled while only some of the vessels were filled and most of the fibers remained empty.

Table 1 summarizes structural features (total porosity, cell wall thickness (CWT), maximum opening of tracheids) and wetting results for different samples. The maximum opening of a tracheid is defined as the diameter of the largest sphere that fits in the tracheid lumen, and it is thus a 3D parameter. For the acetylated samples (in both EW and LW areas), the total porosity is similar (SYP_{acet22.2}) or slightly lower (SYP_{acet15.9}) than for the corresponding control samples. Conversely, the results show that furfurylation significantly reduces the porosity of the sample in both EW and LW areas.

![Figure 1. X-ray computed microtomography images of different sections of furfurylated maple (Maple_{furf32}): (a) transverse, (b) radial and (c) tangential; and of unmodified maple (Maple_{ctrl}): (d) transverse, (e) radial and (f) tangential cross-section. The scale bars correspond to 100 µm.](image-url)
Table 1. Liquid uptake, total porosity, cell wall thickness and maximum opening of tracheid lumen of different acetylated and furfurylated samples. Water and octane uptake are based on 20-cycle and 10-cycle Wilhelmy plate measurements, respectively (Sedighi Moghaddam et al. 2015).

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Water uptake (%)</th>
<th>Octane uptake (%)</th>
<th>Total porosity (%)</th>
<th>Cell wall thickness (µm)</th>
<th>Max. opening of tracheid lumen (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>earlywood</td>
<td>latewood</td>
<td>earlywood</td>
<td>latewood</td>
<td>earlywood</td>
</tr>
<tr>
<td>SYP acet15.9</td>
<td>34.1±1.6</td>
<td>21.0±1.5</td>
<td>73.8±1.8</td>
<td>24.1±5.2</td>
<td>5.7±2.1</td>
</tr>
<tr>
<td>SYP ctrl15.9</td>
<td>54.3±1.5</td>
<td>28.0±2.9</td>
<td>76.1±1.8</td>
<td>29.3±1.0</td>
<td>5.3±2.0</td>
</tr>
<tr>
<td>SYP acet22.2</td>
<td>41.9±3.7</td>
<td>34.8±6.2</td>
<td>76.6±0.6</td>
<td>26.4±0.8</td>
<td>5.5±2.2</td>
</tr>
<tr>
<td>SYP ctrl22.2</td>
<td>70.6±4.2</td>
<td>36.3±3.2</td>
<td>75.3±0.9</td>
<td>27.5±4.4</td>
<td>5.5±2.1</td>
</tr>
<tr>
<td>SYP furf28</td>
<td>21.3±4.5</td>
<td>11.8±0.6</td>
<td>66.2±3.8</td>
<td>16.7±3.5</td>
<td>8.4±4.5</td>
</tr>
<tr>
<td>SYP furf45</td>
<td>12.7±1.5</td>
<td>8.5±0.7</td>
<td>61.1±2.7</td>
<td>18.0±1.0</td>
<td>9.2±5.0</td>
</tr>
<tr>
<td>Maple furf32</td>
<td>13.9±2.4</td>
<td>9.6±1.4</td>
<td>38.9±1.3</td>
<td>n/d</td>
<td>n/d</td>
</tr>
<tr>
<td>Maple ctrl</td>
<td>59.2±3.4</td>
<td>30.0±2.6</td>
<td>51.3±2.7</td>
<td>n/d</td>
<td>n/d</td>
</tr>
</tbody>
</table>

This can be related to the wetting results where no changes in octane uptake were observed for acetylated samples, yet changes do occur for furfurylated wood. Figure 2 shows that the total porosity and octane uptake (capillary uptake) are related for both acetylated and furfurylated softwood/hardwood samples. The total porosity of each specimen was calculated based on the EW/LW proportion of that specimen and the porosity of EW and LW volumes obtained by means of XCT. According to this relation, a wood sample with higher porosity has higher wicking and capillary uptake.

The porosity of different anatomical features of the wood can also be determined using the scanned volumes. An example is presented in Figure 3 that shows the total porosity and the porosity of the vessels, fibers and rays for a furfurylated hardwood sample (Maple furf32) and its corresponding control sample (Maple ctrl). The large variation in porosity values (especially for vessels in the unmodified sample) is due to absence or presence of single large vessels in the scanned samples. This detailed microstructural study demonstrates that furfurylation mostly occurred in rays and partly in some vessels, while the wood fibers were less affected by the modification. This is mainly shown by the reduction of the porosity of the rays and vessels, whereas no detectable change in the porosity of the fibers is detected due to furfurylation.
Figure 2. Octane uptake as a function of total porosity for different modified and unmodified wood samples. The octane uptake and porosity results are based on four replicates. The porosity results are calculated based on porosity of EW and LW regions obtained from two XCT scans and EW/LW proportion of each replicate.

Figure 3. Total porosity and porosity of different microstructural components of furfurylated maple and unmodified maple.

CONCLUSIONS

The microstructure of acetylated and furfurylated sapwood (southern yellow pine) and hardwood (maple) samples was investigated using X-ray computed tomography. This facilitated quantitative measurements of anatomical changes in wood due to the chemical modification. Significant micro-structural changes were observed for the furfurylated wood samples. By determining the porosity of different anatomical features of modified and unmodified wood samples, it was possible to elucidate which anatomical features that were most strongly affected by the chemical modification. The results indicate that the microstructural characteristics strongly affect wetting properties, especially the capillarity. The porosity of the
furfurylated SYP samples decreased due to the chemical modification, whereas it hardly was affected by acetylation. Consistent with this, the wetting results revealed that acetylation predominantly reduces swelling, while furfurylation reduces both swelling and capillary uptake.

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VARIOUS INSTRUMENTAL METHODS FOR QUANTIFYING PHENOL-FORMALDEHYDE RESIN INTO BEECH WOOD

Biziks, V.¹, Bicke, S.², Koch, G.³, Van den Bulcke, J.⁴, Van Acker, J.⁵ & Militz, H.⁶

ABSTRACT

In this paper, phenol-formaldehyde (PF) resins with different average molecular weight (M_w) oligomers were used, to evaluate the effect of molecular size on the allocation of impregnated chemicals in wood microstructure at different hierarchical levels (from wood tissue to single cell wall layers). Light microscopy (LM) and various other alternative instrumental methods, as UV microspectrophotometry (UMSP) and micro X-ray computed tomography (µXCT), have been used and to determine, as well visualize, the micro-distribution and penetration depth of resin into wood matter. Therefore, European beech wood (Fagus Sylvatica L.) blocks of 25x25x10 mm³ were vacuum impregnated with different molecular sizes at three aqueous solutions concentration of 9, 18 and 27%. Due to different procedure and physical background of methods, obtained micro-images passed certain level of image processing and comparison between methods were performed (Fig 1).

The presence of chemical agent in the wood, in terms of LM, was detected by way of their identification on the specimen cross-section as result of different intensity of safranin staining, but in UMSP, based on UV light absorbance at 278 nm by phenolic-based compounds. While, the incorporation of resin into wood can be measured and visualized by using µXCT, only based on porosity changes between one and the same volumes of interest (VOI) selected from one and the same sample before and after the treatment. Despite of so such distinctness between techniques, our results appears stronger or weaker positive correlation between the methods.

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Based on roughly estimation of obtained results, might be that LM could be useful to give first expression (quantitative) on resin distribution into wood tissue and in some cases could substitute more complicated method as UMSP. Concerning to X-ray CT, our preliminary results shows, that it might be the promising technique to evaluate and visualize resin distribution into wood at different hierarchical levels and 3D.

**Keywords:** Phenol-formaldehyde resin, light microscopy, micro X-Ray CT, UMSP

**Figure 1.** Obtained Micro-images using different methods corresponding the presence of resin into wood after the treatment due to color changes

**INTRODUCTION**

Within the next 20-30 years, large amounts of beech wood will be available on the market. Therefore, some of the wood processing enterprises in Germany, as Pollmeier Massivholz gmb& co, are already looking forward to broaden the application area for beech wood via new, innovative products. A promising use of beech wood would be the production of laminated veneer lumber (LVL) from modified veneers (Bicke and Militz 2014) and medium density fibre boards (MDF) with modified fibres, where the modification agents could be aromatic compounds from synthetic oil refinery or bio-based aromatic compounds from pulp and paper industry (different types of lignin). Detailed study of the impact of the treatment of beech is, therefore, a prerequisite for product optimization.

The most commonly applied methods to study the microstructure of untreated wood as well as wood treated with PF resin oligomers of different molecular sizes, are light microscopy (LM) and scanning electron microscopy (SEM). Furuno et
al. (2004) and Biziks et al. (2015) observed that PF resin in wood tissue is mainly localized in the vessel and fibre lumen, when wood is treated with large molecules of PF resin oligomers. However, it should be noted that with LM and SEM, there is a risk of inducing artefacts during sample preparation, such as artificially damaging the resin film in vessel or fibre lumen, during sectioning, surface preparation and micro slide preparation. This is especially valid for resin treated wood, which breaks more easily due to its increased brittleness. To minimize the breaking of cell walls during slicing of 1 μm thick slices, emending of sample in Spurr’s epoxy resin is applied by UV-micro-spectrophotometry (UMSP). Aforementioned methods are also limited in obtaining data on the internal volume of samples (latent porous structure).

Micro-X-ray Computed Tomography (µ-XCT), however, offers the opportunity to investigate wood microstructure without generating artificial defects during sample preparation. The last decade, high resolution X-ray computed tomography (XCT) has matured as a modality for three dimensional (3D) characterization of many materials, including wood; wood based products and modified wood.

The aim of this work was to compare the information obtained between different methods about changes in anatomical structure at different hierarchical levels: macro-level (macro porosity); at micro level – changes in cell wall thickness, distribution of resin into wood cell wall at different cell wall layers; as well distribution of treatment agent at 3D - after treatment, with different molecular sizes of PF resin oligomers.

MATERIAL AND METHODS

Wood

Two types of specimens were cut from European beech (Fagus sylvatica) wood. Prior to the evaluation of biological durability of PF resin treated wood, specimens measuring 25x15x50 mm³ were cut to investigate the distribution of the resin in the block. To assess the resin penetration in the cell wall (bulking coefficient) second type of specimens with dimensions of 25x25x10 mm³ (r x t x l) were prepared. After the drying at 103±2°C for 24 hours the specimens were impregnated using vacuum at the same day. Ten blocks per treatment were used.

Phenol-formaldehyde resins

Before being used for impregnation, the stock solutions of different types of PF resin were diluted to 9%, 18% and 27% (w/w). As listed in table 1 four types of resin with different characteristic parameters were used to prepare the aqueous solutions.
Table 1: Characteristic parameters of PF resin compositions used in the study

<table>
<thead>
<tr>
<th>Resin composition</th>
<th>Solid content [%]</th>
<th>Catalyst</th>
<th>Amount of Catalyst [%]</th>
<th>Amount of formaldehyde [%]</th>
<th>Free phenol [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>49.5</td>
<td>NaOH</td>
<td>1.6</td>
<td>&lt;1</td>
<td>&lt;4</td>
</tr>
<tr>
<td>B</td>
<td>49.0</td>
<td>NaOH</td>
<td>1.6</td>
<td>&lt;1</td>
<td>&lt;4</td>
</tr>
<tr>
<td>C</td>
<td>58.4</td>
<td>NaOH</td>
<td>1.6</td>
<td>&lt;1</td>
<td>&lt;4</td>
</tr>
<tr>
<td>D</td>
<td>47.8</td>
<td>NaOH</td>
<td>1.6</td>
<td>1.88</td>
<td>0.24</td>
</tr>
</tbody>
</table>

**Treatment of wood**

Oven-dried specimens were impregnated with solutions of PF resin in an autoclave by using a two-step vacuum impregnation method. After the impregnation, to assess the amount of PF resin in the wood, specimens were oven dried and the weight percent gain (WPG) was calculated.

**Light microscopy**

To achieve high quality transversal cuts of PF treated wood, with thickness of 25-30µm, Leica microtome blades (Leica DB80 HS) were used and adapted to the microtome (Sartorius Werke, Göttingen, Germany). The slices were stained with 0.09 % safranin solution for 5-7 minutes and then the cuts were dehydrated with two ethanol solutions (50% and 99%). Prior the embedding the slices on glass with Euparal 3C-239 (Waldeck GmbH & Co KG), they were additionally dried at 42°C for 15-20 min. An Elipse E600 microscope (Nikon, Japan) equipped with the digital camera Nicon DS-Fi1c linked to a computer was used. Image processing was done using the software of NIS-elements (version 4.10). The measurement of the penetration depth of PF resin into wood was carried out by way of their identification on the specimen cross-section as result of different intensity of safranin. The assumption was, that, the higher the intensity of safranin is, and the less resin is in the specimen cell walls and vice versa.

**RESULTS AND DISCUSSION**

**Light microscopy (LM)**

To get deeper insight in how molecular sizes of PF influence the resin penetration and distribution in beech wood due to oligomers, investigations by light microscopy were done. The existence and distribution of PF resin in wood tissue and different cell walls was observed by LM. Our experimental set up and microphoto-images clearly show that we were able to observe the retained resin in wood tissue, the quantification of resin was done based on different availability of cationic dye
as safranin to bonding on the surface of wood tissue. Transversal sections of the untreated and treated European beech wood with PF resin stained by safranin are shown in (Figs. 3a and 3b). 27% and 3% weight increase in untreated and PF resin treated slices after staining was observed, respectively. It appears that more safranin was adsorbed between the cell wall constituents of untreated wood compared to the treated one, evidently, it might be related to gradual occupancy of wood tissue by the resin, which resulted in less accessible area available for molecules of dye. As well it might be due to changes on surface energy (polarity) of treated wood, where the availability to develop enough strong and number of bonds between dye and wood cell wall polymers are diminished.

![Figure 3](image)

**Figure. 3** Transversal section of untreated (a) and treated (b) beech wood with PF resin at resin concentration of 27%. Scale bar = 100µm

In the case of specimens treated with a different concentration of resin, LM observations showed that the amount of adsorbed safranin into the wood slightly decreases with raising the solution concentration. The purple color of untreated section (Fig. 3a) slightly changed to light violet/light yellow (Fig. 3b) by treatment with a higher concentration. Those color changes can be explained by increased quantity of resin penetrated into the wood. The same tendency was observed between wood specimens treated with different Mₖ of resin oligomers. Remarkable difference in WPG was not observed between transversal sections of wood blocks treated with LMW and HMW resins. However, the extent of color changes between PF resin treated specimens was obvious. The more violet-white/yellow light color increased proportionally in wood blocks treated with LMW than those of HMW oligomers. We can confirm that those dissimilarities also might be explained by different dislocation (retention) of resin across the specimen, which mainly belongs to the color changes of wood cell walls, hence related to quantity of resin incorporated in the cell walls.
(Fig. 4) shows good correlation between bulking of cell walls and amount of safranin on the transverse section of beech wood caused by treated with different molecular weight of resins.

All results related to resin distribution into beech wood evaluated by UMSP and X-ray micro-computed tomography X-ray µCT will be presented during the conference.

**CONCLUSIONS**

Herein, the influence of $M_w$ of PF resin oligomers on the penetration depth of resin into beech wood cell walls was studied. Beech wood treated with highest concentration of PF resin with different molecular sizes of PF resin oligomer solutions exhibited highest weight percent gain (WPG) about 21-24%, while bulking coefficient (BC) was between 9 till 15%. Hence, there was no any impact of oligomer sizes to WPG (penetration into woody tissue) observed, whereas penetration depth into cell walls significantly depends from molecular size of oligomers. Both PF-A
and PF-B resins showed about 30 till 40% better penetration ability into cell walls compared to resins PF-C and PF-D. In comparison with previous researches, we have developed of LM method which is suitable for the determination of PF resin at micro-scale level. This study demonstrated that safranin is useful indicator to visualize and quantify the cell walls penetrated with resin from non-penetrated ones. Good correlation between reduced amount of safranin colour and presence of resin into the cell walls was found. The cell walls were in higher extend penetrated by resin with low average molecular weight oligomer compare to HMW resins.

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DEVELOPMENT OF FAST STILBENE CONCENTRATION MEASUREMENT METHOD BASED ON UV-FLUORESCENCE

Pulkka, S.1, Harju, A.M.2, Venäläinen, M.3 & Antikainen, J.4

ABSTRACT

A candidate method based on UV-fluorescence of stilbenes is under development for fast measurement of stilbene concentration on solid heartwood of Scots pine (*Pinus sylvestris* L.). Development is focused on to replace the stilbene concentration measurements achieved by gas chromatography mass spectrometry (GC-MS) having multiple pretreatment steps. Measurements of stilbene concentrations of Scots pine are important due to their effect on decay resistance. The cost-effective and reliable methods for phenotyping and measuring widely varying and strongly inherited stilbene concentrations are increasingly needed in Scots pine improvement due to soon available tools of genomic selection also in this field. The features of the measurements of stilbene concentrations on solid heartwood samples by using the studied device are discussed.

**Keywords:** Spectrometry, stilbenes, heartwood

INTRODUCTION

Phenolic extractives, stilbenes are important compounds related to natural durability on Scots pine (*Pinus sylvestris* L.) heartwood (Harju and Venäläinen, 2006; Leinonen et al. 2008). There is wide variation among individual trees and thus, in order to grade timber or to breed for high stilbene concentration of Scots pine heartwood, fast and reliable ways to measure stilbene content is required. NIR spectroscopy is one promising candidate to predict both decay resistance (Flaete & Haartveit, 2004) and the concentration of stilbenes (Leinonen et al. 2008, Pulkka et al. 2016). However, for the moment there is no equipment available for automated stilbene measurement from increment core samples from standing trees.

Scots pine heartwood can be detected based on the fluorescence information emitted of stilbenes and a fluorescence imaging system has been developed suitable

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on an industrial line (Antikainen et al. 2012). To build a tailor-made equipment to measure stilbene content from increment core samples would be possible using the fluorescence-based approach. An automated measurement system would speed-up the measurement and the data management. The aim of our two-year research project is to develop a technical setup, running software and procedures to measure Scots pine heartwood stilbene content fast and reliably from the solid wood surface of increment cores. In this paper the results from the measurements of the stilbene impregnated sapwood samples are presented.

MATERIAL AND METHODS

Material and sample preparation

The UV-fluorescence method was studied using increment core samples of Scots pine sapwood. To get the stilbene range wide enough, the sapwood samples were impregnated with the known concentration of crude stilbene solution. Before impregnation, the sapwood samples with the length of 25 mm were extracted first with hexane and then with ethanol-water by using Accelerated Solvent Extraction (ASE) to remove all resin acids, stilbenes and other extractives. After extraction the samples were dried in the oven at 60 °C, weighed and stored in desiccator at room temperature in darkness.

Preparation of crude stilbene extract

Heartwood sawdust was freeze dried and extracted by hexane for 5 min at 90 °C at the pressure of 113 bar. Extraction was repeated three times. Stilbenes were extracted by ethanol-water liquid (95/5, v/v) for 5 min at 100 °C at the pressure of 113 bar. Stilbene extract was concentrated by using a rotary evaporator. Solution was protected from daylight. Stilbene concentration was quantified by using gas chromatography mass spectrometry (GC-MS) to be 20.5 g/l.

Impregnation of sapwood samples

Five solutions of stilbene wood extract were diluted and several sapwood samples for each concentration were prepared and weighed. The samples were immersed in solution with volume of 25 ml in 50 ml tubes. Loose stoppers were put under the liquid level to ensure samples total immersion and allow free pressure fluctuation. Vacuum was produced by a water flow device. Samples were kept 30 min under vacuum at room temperature, after which the pressure was normalised atmospheric. The vacuum treatment was repeated first for 60 min, and then for 30 min, after which the samples were allowed to stabilize under atmospheric pressure for about 60 min. Samples were slightly dried with kitchen paper and weighed to get the mass of the impregnated stilbene solution. The samples were then dried in the oven
at 60 °C about 40 h, their dry mass was measured, and the samples were stored short time in desiccator in darkness at room temperature. The concentration of STB in the sample was calculated based on the retention of crude stilbene solution into wood divided by dry mass of wood.

**The measurement of stilbene concentration using gas-chromatography mass spectrometry**

Stilbenes pinosylvin (PS) and pinosylvin monomethyl ether (PSM) were measured by GC-MS from the same sample that was measured using the UV fluorescence device. The procedure is described in Pulkka et al. 2016 (in press). Their sum STB was used in the analyses, since UV-fluorescence cannot separate the individual stilbenes.

**Device and its calibration**

The device (Fig. 1) built in Electronics 3K Factory of Mikkeli University of Applied Sciences to measure UV fluorescence of Scots pine heartwood stilbenes (STB) on solid wood was used. UV-fluorescence was produced using UV-LED excitation source (~320 nm). The UV-LED light was stabilised for few hours before measurements. The stability of intensity of light was checked by measuring black, reference white and reference violet in every one minute during one hour. The checking time was reduced into 15 min and 25 min when light was kept on longer time.

**The measurement of UV-fluorescence of stilbenes on solid wood samples**

For the fluorescence measurements the sapwood samples impregnated with stilbenes were cut longitudinally into two halves and the other half was put into a sample tray. Fluorescence spectra $S$ were measured on about 21 points along the longitudinal axis by moving the the sample with a linear stage. Ten measurements with integration time of 500 ms were taken in every measurement point. Average of their spectra represents each measurement point. The fluorescence spectrum of the reference violet $V$ was measured with 20 ms integration time, and the values of 10 measurements were averaged. Black background $B$ and reflectance of white reference $W$ were measured with the same settings (20 and 500 ms). The measurements were corrected as following: $S_{\text{cor}} = S - B$, $V_{\text{cor}} = V - B$ and $W_{\text{cor}} = W - B$. Then the measurements were corrected by subtracting the white reference $S_{\text{cor}} = S_{\text{cor}} - W_{\text{cor}}$ and $V_{\text{cor}} = V_{\text{cor}} - W_{\text{cor}}$. Two variables to describe the sample fluorescence were used. First variable $A_{\text{rel}}$ (relative area 410 - 430 nm) was calculated by dividing the values $S_{\text{cor}}$ by $V_{\text{cor}}$ within the corresponding wavelength region and finally the measurements points were averaged for each sample. Second variable
$P_{\text{rel}}$ (relative fluorescence peak) was calculated by dividing the average maximum intensities of $S_{\text{cor}}$ by average maximum intensities of $V_{\text{cor}}$ for each sample.

![Diagram of the device to measure UV-fluorescence of Scots pine stilbenes.](image)

**RESULTS AND DISCUSSION**

**Measurement of the light stability**

The stability of the UV light source was studied by measuring the fluorescence of the violet reference after lamp had stabilized for 1.25 h. The measurement was performed during one hour at intervals of one minute and the result was calculated as an area between the wavelengths 410 – 430 nm (Fig. 2a) and as a maximum peak of fluorescence (Fig. 3a) using 20 ms integration time. Furthermore, longer light stabilization times were studied as well (Fig. 2b and Fig. 3b). It is important to study the stability of the UV light because the area between the wavelengths of 410 – 430 nm and the maximum peak of fluorescence of the reference violet are used as divisors for results to control the variation of light intensity. The measurement averages and their coefficient of variation are shown in Table I. There can be seen that UV light is very stable along the whole measurement day. The decrease of light intensity does not have high effect on results.

![Table I. Measurement of UV light source stability](image)

<table>
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<tr>
<th>Series</th>
<th>Stabilization time, h</th>
<th>Number of measurements</th>
<th>Average, $A_{\text{rel}}$</th>
<th>CV, %</th>
<th>Average, $P_{\text{rel}}$</th>
<th>CV, %</th>
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<td>46138</td>
<td>0.04</td>
<td>50914</td>
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</tr>
</tbody>
</table>

CV = coefficient of variation
Crude stilbene solution of five dilutions were successfully impregnated into sapwood samples. Calculated stilbene concentration correlated highly with concentrations measured by GC-MS supporting that later on GC-MS analyses are not necessarily needed (Fig. 4).
The measurement of UV-fluorescence of stilbene on solid wood samples

Spectra of the samples were measured by UV fluorescence device and examples of the corrected spectra are shown in Fig. 5. The spectra of the two highest concentrations overlapped (Fig. 5 and Fig. 6). The reason for overlapping remains to be solved.

![Graph showing corrected intensity of STB fluorescence measured from impregnated sapwood samples of Scots pine.](image)

**Fig. 5.** The average spectra of the corrected intensity of STB fluorescence measured from impregnated sapwood samples of Scots pine.

Stilbene concentration of each sample was estimated using two variables calculated from stilbene spectra measured on each increment core. The results were compared to the reference method (Figure 6). It is shown (Fig. 6 a,c and b,d) that both $A_{rel}$ and $P_{rel}$ are nearly equally good. In addition, it is shown that UV fluorescence measurements correlate slightly better with calculated stilbene concentrations than with STB concentrations measured by GC-MS (Fig. 6). The advantage of the fluorescence measurement was rate, since the measurement itself took only 5 min per 10 samples, and there was no need grind the samples or to make any derivatives as in chemical analysis.
CONCLUSIONS

The measurement of STB impregnated sapwood samples using the new UV fluorescence measurement device with movable sample stage showed promising results regarding the measuring rate and precision. Thus the next development step is to measure a series of Scots pine heartwood samples with wide natural variation in the stilbene content. The reference values will be obtained by GC-MS. For certain applications, such as the grading of sawn timber, the relative differences in STB concentration could be sufficient.

The challenge of the future work will be to build a calibration model that provides a prediction of the STB concentration based on the UV-fluorescence spectra. The effect of the surface properties of the wood specimen, their color, thickness of and density on the predicted STB concentration needs further examination.
ACKNOWLEDGEMENTS

The authors thank all the staff that participated in sampling, preparation, and analyses of the increment cores. Our collaborations Henri Montonen and Elmar Bernhardt from MAMK/Electronics 3K Factory are acknowledged for their skilled construction of the UV fluorescence measurement device. Financial support from Regional Council of South Savo and the City of Savonlinna are greatly acknowledged.

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APPLICATION OF INVERSED SIZE EXCLUSION CHROMATOGRAPHY FOR THE DETERMINATION OF PORE SIZE DISTRIBUTION IN POPLAR (POPULUS SP.) WOOD AND PULPS BEFORE AND AFTER STEAM EXPLOSION

Szadkowski, J.¹, Radomski, A.², Zielenkiewicz, T., Lewandowska, A. & Witczak, A.

ABSTRACT

The aim of this paper is to apply the innovative technique, which is reversed size exclusion chromatography, to study the differences of porous structure of Poplar Sp. wood and pulps from Poplar Sp. wood after steam explosion. Reversed size exclusion chromatography consist on the application of analyzed material as the stationary phase in the chromatographic column with the solution of the set of polymers of known molecular mass as the mobile phase during chromatographic experiment. The volume of pores with specified radius may be determined on the basis of retention times of different polymers. Developed porous structure is an advantage in case of the material application as a substrate for the enzymatic hydrolysis. The information about pore distribution may be helpful for the proper choice of material for further processing.

Additionally, the influence of steam explosion on the porous structure development of these species was analyzed. Steam explosion is the experiment which develops porous structure of biomass. It was performed in three different temperatures: for pulps from Poplar Sp. wood 130, 145 and 160°C and for Poplar Sp. wood in 130, 160 and 190°C in stainless steel reactor. The changes in pore distribution could be observed and the most effective temperature of pretreatment could be chosen. Presented method of reversed size exclusion chromatography is relatively fast. Moreover the results show that its accuracy is satisfactory.

Keywords: Pore distribution, poplar, ISEC’s- reversed size exclusion chromatography, steam explosion, pulps

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COMPARISON OF THREE METHODS OF PORE SIZE DISTRIBUTION ANALYSIS IN POPLAR BIOMASS SUBMITTED TO STEAM TREATMENT

Zielenkiewicz, T.¹, Szadkowski, J.², Radomski, A.³, Gołofit, T.⁴, Lewandowska, A.⁵ & Marchwicka M.⁶

ABSTRACT

Poplar biomass is a promising source for the 2nd generation biofuels production. It is fast growing species with the possibility of carbohydrates content increase after genetic modification. Enzymatic hydrolysis of carbohydrates is one of the way of its processing and bioalcohols are the final product then. Before it is processed, material may be submitted to physical or chemical pretreatment (steam treatment was chosen to perform in this work) in order to degrade polysaccharides initially and develop its porous structure in order to increase the accessibility for enzymes during hydrolysis. Generally mesopores and macropores are available for enzymes, while high volume of micropores is the disadvantage. To analyze pore size distribution before and after treatment, proper method of porosity analysis must be chosen. The aim of this work is to compare three different methods of pore size distribution. These are: the most known nitrogen absorption method, inverse size exclusion chromatography (ISEC) and thermoporometry method. The way of sample preparation, measurement performance and first of all, theoretical assumptions of methods are completely different and completely different information is given as the result. That is why the choice should be well considered.

Keywords: poplar, pretreatment, porosity, pore size distribution, enzymatic hydrolysis

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INFLUENCING FACTORS TO ENABLE AUTOMATION OF WOOD FURNITURE PRODUCTION

Johansson, J.1, Blomqvist, L.2, Nilson, H.3 & Landscheidt, S.4

ABSTRACT

The wood furniture industry in Sweden has an identified need of technological development in order to stay competitive. Especially the necessity to focus on automation has been identified. In the industry there are often needs to handle large levels of customization at the same time as keeping the production effective. This requires flexible automation solutions, often described as automated equipment that can rapidly be reconfigured for new products.

Before automated applications are implemented in an industry there are issues to solve related to organisational, human and technological aspects. Based on this, the project - Flexible automation in manufacturing of laminated veneer products was initiated. The project is running since January 1, 2016 and is a two year national Swedish project. The aim of the project is to investigate challenges concerning automation in the wood furniture industry and especially focusing on bended laminated veneer products.

In the project a case-study with the aim of identifying factors important for successful automation implementation in an involved wood manufacturing industry was performed. Key persons and staff of the company were asked to tell their life stories and a process mapping of the production was conducted.

The results indicate a problematic relation between the management and the production staff, which partly can be referred to the shift from a family business to a private owned firm. Based on the process mapping, internal transport and handling are identified improvement areas. Productivity is disturbed by stops caused by processing residues and poorly defined materials. There is potential for improvement by adapting a process-oriented approach and defining the materials used.

The case–study confirms the need to consider organizational and human aspects in production before initiating production. The study concludes the need to consider the special aspects of the wood material in production development.

Keywords: industrial robot, laminated veneer products, production development, process development

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INTRODUCTION

From a manufacturing perspective wood furniture may be seen as an example of products with a large inherent complexity (see e.g. Culbreth et al. 1996). Furniture parts are often not simple rotational or prismatic shapes, the raw material is not homogenous, the surface often contain imperfections, wood is hygroscopic and machining processes can produce large pieces of scrap that must be handled and disposed of. All these aspects are identified by Culbreth et al. (1996) to contribute to the complexity of furniture products.

In Sweden the wood manufacturing industry plays a significant economical role. Today the industry has 31 000 direct employees and an export value of approximately 3 billion EUR (TMF 2015). Sandberg et al. (2014) further show that furniture products is the wood product that contributes with the highest added value to the raw material. This product is followed by joinery. In Sweden as well as in other countries the wood manufacturing sector is unfortunately performing below manufacturing average (see e.g. Sowlati and Vahid, 2006). Furthermore, the industry is historically slow in engaging in activities increasing its efficiency (Pirraglia et al., 2009; Bumgardner et al., 2005; Sowlati and Vahid, 2006). In a Swedish long term perspective this is threatening and there is a great need to improve the industries performance to stay competitive both in relation to other countries as well as other materials.

One way of improving the performance is to work with production development. In many furniture industries in Sweden there is a need to handle large levels of customization in the same time as keeping the production effective. Production development such as automation solution therefore requires flexibility to rapidly be reconfigured for different products. Use of robots as a part of the production system may be a possible solution in order to obtain great flexibility together with effectiveness. Robots may contribute with rapidity, repeatability, and accuracy (e.g. Andersson 2011). With increasing computer capacity and improved intelligence such solutions may be a part of the production system also in manufacturing processes with high degree of customisation, and industries’ need of small order sizes.

Implementation of new technical solutions in the furniture industry is, however, challenging from other aspects than the technical ones. Winroth et al. (2007) mean that the quality management system should be supportive to the technology level chosen. The skill level of the personnel further needs to be considered as well as authority levels and systems production planning and control.

To handle wood in these production systems will, as indicated, be challenging. Not only have different wood pieces different characteristics. Also the characteristics within the material vary and will change in relation to surrounding conditions e.g. due to changes in relative humidity.

To work on automation aspects in the wood furniture industry the project - Flexi-
ble automation in manufacturing of laminated veneer products was initiated. The project is running since January 1, 2016 and is a two year national Swedish project. The aim of the project is to investigate challenges concerning automation in the wood furniture industry. The project especially focuses on bended laminated veneer products. Blomqvist (2015) has shown that the manufacturing of bended laminated veneer products is a very complex process. The interaction between the materials and process parameters strongly influences the properties of the final product. To receive a good result the skilled craftsmen today have a great importance in matching the different veneers in relation to their characteristics. If considering automation of the process these aspects must be handled and fully understood. In the project a traditional wood manufacturing industry, together with academia and a company delivering fully integrated automation solutions, work together. The project is financed by The Knowledge Foundation.

This paper reports on initial results from the project with the aim of identifying factors important for successful automation implementation in an involved wood manufacturing industry.

MATERIAL AND METHODS

The study was performed as an industrial case study within a company manufacturing bended laminated veneer products for the furniture and joinery industry. Data collection was made through collecting life stories together with a process mapping of one production line in the factory.

Life stories as methodology

22 key persons were picked out from the criteria of length of employment and experience from change. The attendants were asked to tell their life story out from their position in the firm and were given a free choice to talk about whatever they found interesting or critical (Johansson, 2005). Extra questions were asked on topics about family business, change and use of robots. The length of the stories varied from 30-75 minutes. The methodological choice of life stories was based on an inductive approach with an interest of getting to know the individuals’ thoughts about critical issues. Furthermore, life stories were used to spread light not only on what but how things are done (Gabriel, 2000). It could also be seen as a complement to process mapping and its focus on technical rather than human issues.

Process mapping

The process mapping was concentrated to one production line in the factory. This production line produces mainly one seat shell to a chair. The production line already contains a certain degree of automation and use of robots. However, possi-
bilities of development and improvement were identified. The process mapping was conducted to determine how that automation approach works in order to build further on the experiences of the company. It also contributed that the company’s largest customer required volume increases and lower prize.

RESULTS AND DISCUSSION

The results indicate a problematic relation between the management and the production staff, which partly can be referred to the shift from a family business to a private owned firm. The former family business run by the father of the family with several positions occupied by family members complicates change. Problems arise when the production staff is used to management that both has the knowledge and interferes in every day details. This is quite opposite to the new management, which by the employees is experienced to have all their focus on sales figures without considering the possibilities of producing the forecasted volumes. This problem is, however, understood by the management and efforts have been made to employ a factory manager with a technical expertise. The hiring process has unfortunately been slow.

The shift in leadership furthermore results in a change of the staff’s actions: e.g. declined responsibility and initiative as well as feelings of no longer required efforts that earlier was a part of the family business system (Hall & Melin, 2012). All respondents are, however, welcoming new investments and increased levels of automation. Related to the work culture there is among the production staff an unwillingness to share knowledge about working procedures. Based on the process mapping, internal transport and handling are identified areas with potential for improvement. Moreover, the flow through the factory is hampered by poor cleanliness, workplace appearance and unstructured interim storages. The plant needs to be straightened up and improved concerning structure. Productivity is disturbed by stops caused by processing residues and poorly defined materials. There is a large potential for improvement by adapting a more process-oriented approach and defining the materials used in the products.

Implementation of industrial robots

Both Ahmad and Sullivan (1993) and Nof (1999) describe the importance of clear communication and good collaboration between management and production personnel in regards to introduction and implementation of new automatic equipment. It is necessary by the management to explain thoroughly why and how the implementation of automation equipment is thought to take place. Without good communication a very common demeanor is that workers often believe that industrial robots will take over their tasks and duties and on the long run their positions. This can cause bad working climate and a loss in production efficiency.
However, as the results of the interviews indicate, the often displayed common disregard of new machinery acceptance of robotic automation in production is not the case for production personnel in this company. Partly because there are already well functioning robot cells available and workers have understood the importance of the equipment for production capacity, and the company’s future overall. Nevertheless, successful implementation of new industrial robot cells might be hindered through workers attitude or the employees’ feelings of not being involved in the decision making process. In addition, implementation is also slowed down by process problems, e.g. unstructured interim storages and the overall cleanliness of the working place.

**CONCLUSIONS**

The conducted case study confirms the need to consider organizational as well as human aspects in production before considering initiating production changes or automation implementation. It also shows that the shift from a family business to a private firm is complicated with special regards to human actions and feelings. The study furthermore concludes the need to consider the special aspects of the wood material concerning production development.

**REFERENCES**


PLYWOOD RIB STIFFENED SANDWICH PANELS FILLED WITH BIO-BASED RIGID POLYURETHANE FOAMS

Labans, E. 1,3, Kalnins, K. *, Kirpluks, M. 2, Japins, G. 1 & Cabulis, U. 2

ABSTRACT

Plywood rib stiffened sandwich type panels could be used to substitute conventional plywood boards in structures where weight reduction is necessary. Filling core between plywood ribs with lightweight polymer will give additional benefit of soundproofing and it will increase the thermal insulation properties moreover it will enable improved production process of sandwich panels. Rigid polyurethane (PU) foams provide those mentioned manufacturing and physical benefits. In current research all plywood rib stiffened sandwich type panels were produced by direct PU foam injection into core between ribs. Such foam application allowed to produce sandwich panels without preliminary use of adhesive for structural integrity. Two different PU foam formulations were examined and tested as core filler. Commercial PU foam system from BASF (Elastopor H 1700/10) was initial choice - used as reference material. A second one - PU foam formulations based on polyols from renewable resources were used as sustainable alternative. PU foams from renewable resources were developed from tall oil, which is cellulose production by-product. Polyols were synthesized from tall oil by carboxylic acid esterification with polyfunctional amide based alcohol – diethanolamine. PU foam formulation with slow technological parameters (cream time – 20-30 s) were developed to be used for injection into core of plywood sandwich panels. PU foam morphology in core of PU foam and in adhesion layer was evaluated by SEM microscopy. The adhesion strength and the mechanical (tensile and compression strength) properties of PU foams were used as input data in numerical modelling. Sandwich panel stiffness and effective thermal conductivity were acquired by means of numerical analysis in ANSYS software. Consequent numerical optimization was performed to evaluate trade-off between sandwich panel masss, stiffness and thermal conductivity. Comparing rib stiffened sandwich structures with tradition plywood boards it is possible to found an equivalent stiffness sandwich panels with weight reduction up to 35 % and effective thermal conductivity of 0.029 W/m·K (reference to 0.12 W/m·K for solid plywood board).

Keywords: Plywood composite, rigid polyurethane foam, lightweight structure, finite element modelling, mechanical testing, ANSYS, Pareto optimality front

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INTRODUCTION

Plywood - widely explored and applied in all fields of engineering has decent mechanical properties/weight ratio comparing with other conventional materials like steel or reinforced concrete. However for thick plywood boards there is still significantly high density and corresponding costs compared to other board materials. In that sense thick plywood boards are especially ineffective as large span decking structures. In such a case sandwich concept of replacing solid core to lightweight and cost effective stiffener/foam core could serve as efficient alternative in order to reduce weight and cost of the inner layer material.

Most extensive theoretical base on sandwich design is summarised in great detail by Zenker (2008) with some focus on foal filled core sandwich panel designs. Considering that there is several design variables for sandwich panel cross-section, the numerical optimization would allow to set the most efficient combinations of these variables. Those gained advantages of stiffness and weight optimisation for sandwich panels with a low density foam cores are described in several research articles by Kawasaki et.al. (2006), Fernandez-Cabo et.al. (2011) and more recently by Labans et.al. (2015). An extension of optimisation of the rib-stiffened panels without any core filler is given in previous research by Labans and Kalnins (2014) where clear weight saving of more than 60 % comparing with reference plywood boards has been achieved. In additional optimisation results were experimentally validated by making 4-point bending tests on panel prototypes. Novel contribution to design and optimisation of plywood based sandwich panels also has been provided in several recent articles among others Slisers et.al (2013) and Banerjee and Bhattacharyya (2011).

In current research foam core was introduced mainly to address one shot manufacturing process of the sandwich panels with rib-stiffened core. Additional benefits of the foam core filler are improved shear rigidity of the core and consistent quality of sound/vibration and thermal insulation. Therefore trade-off between mechanical and thermal properties was the aim of optimisation procedure.

Polyurethane (PU) materials have a broad range of applications such as flexible foams, rigid foams, thermoplastic elastomers, coatings and adhesives, etc. About 29% of the PU material industry is attributed to rigid PU and polyisocyanurate (PIR) foam production as described by Ionescu (2005). These materials are mainly used as heat insulating materials in civil engineering and the refrigeration industry due to their low thermal conductivity (λ). The industry standard of λ for rigid PU/PIR foams is 0.018-0.028±0.002 W/m·K, which, compared to the case of other insulation materials like extruded polystyrene (XPS), expanded polystyrene (EPS), glass or mineral wool is almost twice lower The properties of different insulation materials were summarized by Jelle (2011) and Szycher (1999).

Sustainable solutions have been studied across a whole range of polymer materials and these studies are revived by Guner et.al. (2006) and Espinosa et.al. (2010).
Emphasis has been placed on PU materials because at least one component of a polymer material can be obtained from renewable resources which are described in several research articles by Petrovic (2008), Stirna et.al. (2008) and Cabulis et.al. (2014). Unfortunately, the majority of PU materials are produced from petroleum based feedstocks. Nevertheless rigid PU foams from sustainable materials show comparable λ values, mechanical properties and dimensional stability to be used on industrial scale and replace petrochemical products which was reported in research articles by Zilaucs et.al. (2015), Kirpluks et.al. (2013) and Kuranska et.al. (2015).

MATERIALS AND METHODS

Materials

For this study rigid PU foams were obtained from cellulose production by-product – tall oil. Tall oil is mixture of different fatty and rosin acids and does not contain hydroxyl groups that could react with isocyanate to form PU polymer. Polyol, one of PU material production components from tall oil was synthesized buy amidization reaction of tall oil carboxylic acids with diethanolamine. Obtained polyol was characterized by following characteristics: hydroxyl value: 270.8±5.1 mgKOH/g; acid value: 1.6±0.5 mgKOH/g; water content 0.135±0.020 %.

From synthesized polyol rigid PU foam formulation was developed with appropriate technological characteristics for injection moulding and slow pouring into narrow spaces. Rigid PU foam formulation contained following materials: tris (1-chloro-2-propyl phosphate 99% (TCPP) as flame retardant (Albermarle, UK), Solkane® 365mfc/277 as physical blowing agent, (Solvay Special Chemicals, Germany), distilled water as chemical blowing agent, Lupranol® 3422 a higher functional polyether polyol based on sorbitol, (BASF, Germany), pure glycerol as crosslinking reagent (Sigma-Aldrich, USA) potassium acetate (PC CAT® TKA30) (Performance Chemicals, Germany) and tertiary amine (Polycat® NP-10) as catalysts (Air Products Europe Chemicals B.V., Netherlands) and Niax Silicone L-6915 as surfactant (Momentive Performance Materials Inc., Germany).

As isocyanate (NCO) component ISOPMDI 92140 was used for PU materials. It is a solvent free product based on 4,4′-diphenylmethane diisocyanate (MDI) and contains oligomers of high functionality (Polyurethanes, BASF Groupe). The average functionality is 2.8 to 2.9 and NCO content is 31.5%

Bio-based rigid PU foams were compared to commercially used rigid PU foam formulation from BASF - Elastopor H 1700/10. The material is used where good flowability and adhesion are demanded. This rigid PU foam formulation is injected/poured into narrow spaces of buildings and other objects to obtain desired insulation layer.
Table 1. Used rigid PU foam technological parameters, apparent density, mechanical properties and thermal conductivity

<table>
<thead>
<tr>
<th>PU foam formulation</th>
<th>Tall oil based PU foams</th>
<th>Elastopor H 1700/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time, s</td>
<td>23</td>
<td>37</td>
</tr>
<tr>
<td>Gel time, s</td>
<td>90</td>
<td>190</td>
</tr>
<tr>
<td>Tack free time, s</td>
<td>156</td>
<td>n/a</td>
</tr>
<tr>
<td>Rise time, s</td>
<td>144</td>
<td>305</td>
</tr>
<tr>
<td>Apparent density, kg/m³</td>
<td>59.0</td>
<td>58.0</td>
</tr>
<tr>
<td>Closed cell content, %</td>
<td>98.2</td>
<td>93.4</td>
</tr>
<tr>
<td>Compression modulus, MPa</td>
<td>8.46</td>
<td>8.56</td>
</tr>
<tr>
<td>Compression strength, MPa</td>
<td>0.38</td>
<td>0.36</td>
</tr>
<tr>
<td>Thermal conductivity, W/m·K</td>
<td>0.022</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Numerical modelling

Mechanical and thermal responses have been acquired by the means of numerical models based on Finite Element Method (FEM). Commercial software ANSYS has been employed for this purposes. Combined shell and solid element types have been combined for stiffness calculations with 4-node SHELL181 elements and 8-node SOLID185 elements. For the purposes of further validation of the shell elements 4-point bending load appliance scheme were applied with the distance between load appliance points of 300 mm and distance between supports of 1100 mm (distances according to EN789). Simply supported boundary conditions were applied at the nodes of both sandwich panel ends. Nodes with coupled vertical displacement were used for simulating of linear bending loads. Multi-layered element structure involves taking into account stiffness effect due to material orientation in the layer of every single ply in given cross-section. Approximate thickness of one layer is 1.3 mm. Mechanical properties of plywood veneer determined in previous study Labans et.al. 2014 and compared with Plywood handbook (1999) are as follows elastic modulus in longitudinal direction $E_L = 17$ GPa; elastic modulus in radial and transversal direction $E_R = E_T = 0.5$ GPa; shear modulus $G_{RT} = 0.04$ GPa, $G_{LR} = G_{LT} = 0.7$ GPa; Poisson’s ratio $\nu_{RT} = 0.25$, $\nu_{LR} = \nu_{LT} = 0.035$ and density of 630 kg/m³. Mesh density with element size of 10 mm has been assigned to the structure as shown in Figure 1.

![Fig.1. a - mesh pattern and b - deformed shape of the panel single section.](image)

As a foam filler rigid PU foam has been applied. The linear relation between modulus of elasticity and density is given in Figure 2c. Thermal model of the cross-section numerically represented in 2D model with PLANE55 elements. Steady state
analysis with loads applied as temperature on lower and upper nodes of the mesh. Mesh pattern and heat flow is also given in Figure 2.

![Fig.2. a - mesh pattern; b - nodal temperatures at thermal equilibrium; c – density and modulus of elasticity curve](image)

As the result of the thermal simulation – the sum of heat flow magnitudes from base nodes are extracted and thermal conductivity $k$ is calculated by Fourier’s law (1):

$$k = \frac{d \cdot q}{A \cdot \Delta T}$$

where $d$ is thickness of the sandwich, $q$- heat flux, $A$- sandwich base area and temperature difference between upper and lower plate.

**Optimisation procedure**

The cross section of a corrugate panel has been characterised with five design variables (Table 2). Separate parameter assigned for core density $P_5$, which has linear relation with foam mechanical properties. The design space and parametrical increment for the variables are given in Table 1. In the case of plywood core, core wall thickness is expressed by the number of plies. Acquired response parameters resulting from numerical calculations are maximum deflection at the middle of span and mass of the panel calculated by means of densities. Effective thermal conductivity has been extracted by running the same design of experiments exclusively for thermal 2D model.

**Table 2. Design variables**

| Parameter                           | Lower bound | Upper bound | Step | Units 
|-------------------------------------|-------------|-------------|------|------
| Number of surface plies - $P_1$     | 3           | 7           | 2    | -    |
| Number of stiffener plies – $P_2$   | 3           | 7           | 2    | -    |
| Stiffeners distance – $P_3$         | 10          | 80          | 10   | mm   |
| Total section height – $P_4$        | 30          | 70          | -    | mm   |
| Foam E-modulus - $P_5$              | 75          | 300         | -    | MPa  |

In the present research a sequential space filling design based on Latin Hypercube with Means Square error criterion has been evaluated by the in house EdaOpt software - Auzins and Janushevsksis (2007). All responses have been approximated
employing Adaptive Basis Function Construction (ABFC) approach proposed by Jekabsons (2010).

RESULTS AND DISCUSSION

For efficient evaluation mechanical and thermal properties of sandwich panels were compared with conventional plywood boards. It is commonly known that sandwich panel thickness could be raised to increase bending stiffness without any significant weight penalty. Therefore in the first optimisation step combinations of variables have been selected. This guarantee deflection restrain not to over exceed values obtained from numerical analysis of conventional plywood board. Relative mass indicator is obtained dividing sandwich panel mass by mass of plywood board of the same stiffness.

Table 3. Optimised sandwich panels in comparison with conventional plywood

<table>
<thead>
<tr>
<th>Cross-section parameter values</th>
<th>Equivalent of 30 mm plywood</th>
<th>Equivalent of 40 mm plywood</th>
<th>Equivalent of 50 mm plywood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative mass, %</td>
<td>47.8</td>
<td>40.9</td>
<td>32.3</td>
</tr>
<tr>
<td>Relative thermal conductivity, %</td>
<td>28.3</td>
<td>25.1</td>
<td>21.4</td>
</tr>
</tbody>
</table>

Analysing results summarised in Table 3 it could be stated that advantage of sandwich panels increases gradually by increasing thickness. Due to exploitation considerations surface thickness of the sandwich panel with 33 mm section height has been raised to 5 layer. For all sandwich panels types the most efficient strategy to increase stiffness is by increasing the section height using 3-layer stiffeners and foam filler with low density. In case of the sandwich panel with the largest section height, variables P3 and P4 reached the boundaries of design space. Therefore it has been considered useful to run the same optimisation task for sandwich panels with foam core only (without stiffeners). Results of this optimisation are shown in Table 4. From both types of sandwich structures it is clearly seen that increasing section thickness is more efficient than raising density and thus mechanical properties of the foam. In the last column of Table 4 foam properties were increased due to the reason that section height variable reached upper boundary.

Table 4. Optimised sandwich panels (without stiffeners) in comparison with solid plywood

<table>
<thead>
<tr>
<th>Cross-section parameter values</th>
<th>Equivalent to 30 mm plywood</th>
<th>Equivalent to 40 mm plywood</th>
<th>Equivalent to 50 mm plywood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative mass, %</td>
<td>47.1</td>
<td>34.1</td>
<td>35.5</td>
</tr>
<tr>
<td>Relative thermal conductivity, %</td>
<td>25.3</td>
<td>21.7</td>
<td>24.7</td>
</tr>
</tbody>
</table>
Pareto optimality front

Overall efficiency of plywood sandwich panels has been demonstrated by formulating 3D Pareto optimization problem where maximization of relative stiffness is done simultaneously by minimizing the self-weight and cost per 1 square meter and relative thermal conductivity of the panel. An example of 3 different designs are given in table 5. Where Pareto optimality front is shown in Figure 3 and 4.

Table 5. Optimised sandwich panels – example of three optimal designs for 4 m long panel.

<table>
<thead>
<tr>
<th></th>
<th>(P_1)</th>
<th>(P_2)</th>
<th>(P_3)</th>
<th>(P_4)</th>
<th>(P_5)</th>
<th>Self-weight per 1 m(^2), kg</th>
<th>Price of materials per 1 m(^2), EUR</th>
<th>U-value, (\frac{W}{(m^2K)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design I</td>
<td>3</td>
<td>3</td>
<td>250</td>
<td>190</td>
<td>75</td>
<td>8.9</td>
<td>19.6</td>
<td>0.11</td>
</tr>
<tr>
<td>Design II</td>
<td>5</td>
<td>5</td>
<td>250</td>
<td>160</td>
<td>75</td>
<td>9.6</td>
<td>20.7</td>
<td>0.12</td>
</tr>
<tr>
<td>Design III</td>
<td>7</td>
<td>5</td>
<td>250</td>
<td>140</td>
<td>75</td>
<td>10.3</td>
<td>21.2</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Fig.3. Pareto optimality fronts for a) stiffness height and b) foam stiffness versus cost and self-weight.

Fig.4. Pareto optimality fronts for a) number of plies in stiffeners b) number of plies in skin versus cost and self-weight.
From Figures 3 one may learn that PU core filler tend to be reach a minimum condition, thus restriction on minimum adhesion strength should be incorporated for further study. An overall height of the panel not necessarily tend to maximum cross section height as it delivers both cost and weight penalty. There is sufficient evidence that optimum solution tend to 5 to 7 ply plywood panels, which by industrial standard are most frequently and widely manufactured panels. Therefore Pareto optimality found solution have a sole potential to be integrated in further manufacturing process.

CONCLUSIONS

Performing parametrical optimisation on sandwich panels with plywood surfaces and PU foam core the optimal combinations of the variables granting the same stiffness as for conventional plywood reference panel have been found. The largest mass and thermal conductivity benefits has sandwich structures with highest cross-section thickness. Solid plywood board with thickness of 50 mm could be successfully replaced by the same stiffness sandwich panel with 63 mm thickness, but possessing only 32.3 % of the reference panel’s mass and approximately 5-fold decreased effective thermal conductivity. Due to the fact that PU foam, made of renewable components, has linear modulus/density ratio increment of sandwich thickness is more efficient than use of higher density foam core.

Pareto optimality front for self-weight/cost/thermal conductivity numerical responses has been constructed to assess field of possible optimisation outputs. General trend observed in Pareto front shows that sandwich panels with foam core filler outperform panels with additional stiffeners especially comparing they effective thermal conductivity.

ACKNOWLEDGEMENTS

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IMPACT OF LAMINATE DIRECTIONS ON IN-PLANE SHEAR STIFFNESS OF CROSS-LAMINATED TIMBER

Turesson, J.¹ & Ekevad, M.²

ABSTRACT

Twenty-three finite element models of cross-laminated timber (CLT) with different laminate directions were studied. Simulations with quadratic orthotropic linear elastic finite elements were conducted. One goal was to compare in-plane shear stiffnesses for CLT blocks made up from Norway Spruce (Picea abies) boards. 3- and 5-layer CLT were studied with board sizes 25x150x1200 mm. Bloc sizes were 75x1200x1200 and 125x1200x1200 mm for 3-layer and 5-layer blocs, respectively. The first and last layers laminate directions were assumed to be in direction 0°. The second and fourth layers laminate directions for 5-layer models were assumed equal and were 5°, 10°, 15°, 30°, 45°, 60°, 75° and 90°. The middle layer was in direction 0° or 90°. For 3-layer models the middle layers laminate directions were 5°, 10°, 15°, 30°, 45°, 60°, 75° and 90°. No edge gluing was assumed and thus all side edges were allowed to separate or overlap. Glued contact surfaces were assumed to be perfectly glued with rigid glue. The results for 5-layer models showed that all models with angled second and fourth layers were stiffer than the models with 90° layers. Stiffnesses for models with angled second and fourth layers were higher when the middle layer laminate direction was 90° compared to 0°. The stiffest 5-layer model was the one with laminate directions 0/45/90/45/0. This stiffness was 1.5 times the shear stiffness of a reference block with 1-layer and solid timber shear stiffness. The stiffest 3-layer model was the one with laminate directions 0/30/0. This stiffness was 0.99 times the shear stiffness of the reference bloc.

Keywords: Cross laminated timber, CLT, shear stiffness, finite element, FEM

INTRODUCTION

Wood is commonly judged as orthotropic with three material directions: longitudinal, radial and tangential. Shear stress and strain can occur in different directions on surfaces with different directions and shear stiffness is commonly described by three shear moduli. Of those the weakest shear modulus is called the rolling shear modulus. (Wood Handbook, 2010).

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Panels of cross laminated timber (CLT) are built up from cross-wise oriented layers of wood boards. Normally the layers are oriented in only 0 or 90 degree directions mainly from reasons of ease of manufacturing. Two advantages with CLT are the homogenized mechanical and physical properties, which make CLT suitable to be used for instance as shear walls. CLT is a rather recent and innovative engineered wood product with properties that can be improved and which still requires research. The research needs to quantify some of the materials properties. The benefits of using wood in buildings and constructions are far from being maximized (Saavedra Flores et al., 2015).

Timber constructions have increased the latest years mainly because of the use in multi-storey buildings. A problem, which occurs when technology used for one- and two-storeys house is used for higher buildings, is the magnification of previous small and acceptable movements. It can create discomfort for the buildings occupants. (Reynolds, Casagrande, & Tomasi, 2016). Finding stiffer wall designs made of CLT could solve this problem and a way used in this report is to find a theoretical stiffer construction by conducting finite element computer simulations. This study focuses on how shear stiffnesses in 3- and 5-layer CLT blocs changes when the laminate direction is changed.

MATERIAL AND METHODS

In this study 3- and 5-layer blocs were analysed via linear finite element analysis. The boards’ dimensions were kept constant in all models. The changing variable was the angle of the laminate direction. To reduce model size and calculation time a symmetry plane was used, see Fig. 1. and Table 1.

**Fig. 1.** A 5-layer CLT bloc where the second/fourth layer is rotated 30° degrees and the third layer (white marked) was changed between 0° and 90° degrees (figure shows 0°). View 1 shows a section of all five layers and view 2 shows a detail of first three layers. View 2 shows the symmetry plane for the 5-layer models.
The symmetry plane was set in layer two in a 3-layer bloc and layer three in a 5-layer bloc. A summary of all models can be seen in Table 1.

Table 1. A summary of all models and the direction of each layer.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Board dimension: length x width x thickness [m]</th>
<th>Laminate direction in layer:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0/90/0</td>
<td>1,2x0,15x0,025</td>
<td>0°</td>
</tr>
<tr>
<td>0/75/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/60/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/45/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/30/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/15/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/10/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/5/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/75/0/75/0</td>
<td>1,2x0,15x0,025</td>
<td>0°</td>
</tr>
<tr>
<td>0/60/0/60/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/45/0/45/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/30/0/30/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/15/0/15/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/10/0/15/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/5/0/5/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/90/0/90/0</td>
<td>1,2x0,15x0,025</td>
<td>0°</td>
</tr>
<tr>
<td>0/75/0/75/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/60/0/60/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/45/0/45/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/30/0/30/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/15/0/15/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/10/0/10/0</td>
<td>“</td>
<td>0°</td>
</tr>
<tr>
<td>0/5/0/5/0</td>
<td>“</td>
<td>0°</td>
</tr>
</tbody>
</table>

The dimensions were 0.075x1.2x1.2 and 0.125x1.2x1.2 m for 3-layer and 5-layer blocs, respectively. Glue was not used between the side edges, only the flat side between layers were glued. The contact property between two layers was set as a tied connection with rough friction, i.e. no sliding was possible and separation was not allowed. Master surfaces were almost every time chosen to be the layers angled 0° or 90°. No contact condition was set between the side edges and thus overlapping or separating was possible.

Fig. 2. shows the load application on the model. A surface shear stress was applied on all 4 side surfaces and was set to 0.05 MPa. A symmetry plane was applied in the Z-direction in the middle of the thickness and two corner nodes (marked with red circle and yellow diamond in Fig. 2.) were partly fixed to avoid displacement
in X- and Y-direction and rotation in Z-direction. Displacement was then measured in the Y-direction in the corner node marked with a green cross.

**Fig. 2.** Load application with surface shear force $F$ which corresponds to shear stress 0.05 MPa. Figure shows Y-deformation (mm) of a 0/30/0 bloc where the deformation scale factor is 1000.

The modulus of elasticity was set to: 430, 430 and 13000 MPa in the material directions 1, 2 and 3 (equal to radial, tangential and fiber direction, respectively) in a cylindrical coordinate system. The modulus of shear was set to: 121.5, 810 and 810 MPa in the directions 12 (rolling shear), 13 and 23. All Poisson’s ratios were set to zero.

The global mesh seed was chosen to 1 cm for all models. All $0^\circ$ or $90^\circ$ layers were meshed with a structured mapped mesh technique. The angled layers were meshed with a sweep technique. Quadratic reduced order elements C3D20R elements in commercial code Abaqus (Abaqus 6.14. 2016.) were used.

A nondimensional shear value $G_{trans}$ for the CLT bloc in question was calculated from simulation result by using equation 1. $G_{shear}$ is the reference value 810 MPa in the 13 and 23 shear directions. The $k$-value is the number of layers in the simulated model.

$$G_{trans} = \frac{\tau}{\varphi \cdot G_{shear}} = \frac{F}{k \cdot t_{layer} \cdot D_y \cdot G_{shear}}, \quad k = 3 \text{ or } 5 \text{ layers.} \quad \text{Eq. 1}$$

**RESULTS**

In the 3-layer models the number of degrees of freedom was between 1.6 to 4.2 million depending on the laminate direction. In the 5-layer models the number of degrees of freedom varied between 2.8 to 7.8 million. In general, a lower angle gave less degree of freedom.
Fig. 2. shows a deformed CLT bloc with colours showing the displacement in Y direction. Diagramme in Fig. 3. shows $G_{\text{trans}}$ for the 3-layer and 5-layer models.

**Fig. 3.** Relative shear modulus $G_{\text{trans}}$ for in-plane shear for 3-layer CLT bloc (grey line) and for 5-layer bloc (blue and orange line) as a function of laminate direction X in intermediate layers.

The stiffest 3-layer model (grey line) was 0/30/0 with $G_{\text{trans}} = 0.99$ which can be compared to the 0/90/0 model which has $G_{\text{trans}} = 0.76$. For 5-layer models the one with 3$^{\text{rd}}$ layer in 0$^{\circ}$-direction gave results which were about the same as for the 3-layer model but slightly higher (orange line).

The stiffest results were obtained for the 5-layer model with the 3$^{\text{rd}}$ layer in 90$^{\circ}$-direction. Here all results were higher compared to the model with the 3$^{\text{rd}}$ layer in 0$^{\circ}$-direction. Highest value $G_{\text{trans}} = 1.5$ was obtained for the 0/45/90/45/0 model.

**DISCUSSION**

All models were stiffer than the models with only 0$^{\circ}$ and 90$^{\circ}$ laminate directions. In all models 0/X/0/X/0 was stiffer than 0/X/0 which can be because of the higher percentage of angled layers in the 0/X/0/X/0 model. Why models with 30$^{\circ}$ for 3-layer models were stiffest cannot be answered in this study. One explanation could be: when the laminate direction is changing from 90$^{\circ}$ to 0$^{\circ}$, the contact surfaces in the connection points between boards increase. And the stiffness could be a relation between the area of the glued contact surface in one connection point and the percentage of angled layers in the bloc. The results from these simulations don’t take into account for contact between side edges. In reality over closure cannot occur, so in these cases the practical stiffness would be higher than the calculated value.

Important to remember, results in this study were only for simulations of shear and not for other loading cases such as bending. Practical tests of the simulated pure shear load cases are difficult to conduct but would be interesting.
CONCLUSIONS

Based on the above result and discussion these four conclusions can be made:

• The stiffest 3-layer model was not 0/45/0 but instead 0/30/0.
• The stiffest construction was the 0/45/90/45/0 model where the $G_{\text{trans}}$ value was 1,5.
• The stiffness in a 5-layer model increased by changing laminate direction of the third layer from 0° to 90°.
• It was enough to use a mesh size of 0,01 meter.

As future work it would be interesting to find how the stiffness changes in a bloc by the relation between the area of the connection surface and the percentage of angled layers.

REFERENCE

FIBRE DAMAGE IN WPC FOR TWO DIFFERENT COMPOUNDING PROCESSES

Frisk, O.¹, Segerholm, B.K.² & Wålinder, M.E.P.³

ABSTRACT

During compounding of wood plastic composites (WPC) there is a need for high shear mixing to ensure a good dispersion of the fibres in the thermoplastic matrix, however, a too extensive mixing will result in fibre damage and thus will reduce the reinforcing capability of the fibres. A well dispersed fibre component with low fibre damage could enhance the mechanical properties of the final WPC product. In this study two vastly different compounding technologies were used to assess possible differences in the mixing results. The equipments used were two laboratory sized equipments, one co-rotating twin screw extruder and one batch type mixer.

The material used was thermo-mechanical pulp fibres, HDPE matrix and a MAPE coupling agent. The fibre content was 40% by weight. The compounds were extracted from its matrix material to free the fibres for further analysis. The fibres were analysed before and after the processing procedures in order to determine degree of fibre damage during the process and average fibre length. This paper will present initial findings of the study.

Keywords: compounding, extraction, fibre, wood plastic composite

INTRODUCTION

Feeding of a thermo-mechanical pulp (TMP) or any other natural fibres (NF) into an extruder is a well known problem. Not only is the feeding but also to disperse the fibre in the compound without mechanical or thermal damage of the fibre is a challenge. The compounding process have tendency to damage the fibre by shortening the fibre with a reduced aspect ratio as a result and consequently reduced mechanical properties of the compound. Another problem with a tense mixing process is that the fibre will be damaged by a to high temperature exposure, often caused by friction in the extruder, leading to discolorations and odor problems on the final product. The challenge of using TMP or other NF in composites as alternatives to WPC is of outmost interest whereas the TMP have a much greater aspect ratio than wood flour. Typically L/D greater than 30 compared to less than 5.

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Alternative compounding methods that makes feeding more easily has been found in the rubber compounding industry by a so called internal batch-mixer. An advantage with this method is that it makes feeding possible by accurate batch mixing and compounding with a very high process control of the temperature. The batch mixer also allows higher fibre filling rates. Trials with fibre rates up to 80% have been made in this study. Most important though is the possibility with this compounding method for upscaling to production rates with automatic batch feeding.

To establish whether internal batch mixing is comparable or even superior to traditional compounding with a co-rotating twin screw extruder, mechanical properties will be measured. Fibre measurements of the TMP before and after compounding will take place to determine the fibre breakdown in the process, with the batch mixer also with two different filling rates.

**MATERIAL AND METHODS**

**TMP**

A commercially TMP, Rottneros CS 770, was used. The TMP was delivered in pre-dried 10 cm thick sheets. The sheets was sawn into 1 dm³ blocks. The blocks used for compounding in the extruder was mildly grinded in a Bezner grinder to a fluff, enabling manual feeding. Initial measurements of the fibre, ungrinded and grinded was made in an Eurocon PulpEye Analyzer.

**Matrix and additives**

A standard HDPE, MG9641 from Borealis was used together with MAPE coupling agent, Fusabond E100 from DuPont.

**Compounding**

Compounds with 40% TMP, 57% HDPE and 3% MAPE was first produced in a standard corotating 26 mm twin screw laboratory compounder, Coperion ZSK 26K, 10.6, 2009, 10 heating zones at SWERA IVF (Mölndal, Sweden). HDPE and MAPE was gravimetrically fed into the hopper. TMP was manually fed into the side feeder of the extruder. Afterwards strand pelletizing without water cooling. Fig. 1

Secondly the same formulation was compounded in a 5 l lab mixer at HF Mixing Group (Freudenberg, Germany). The TMP blocks could be fed directly into the mixer. First TMP alone to let dry and shortly afterwards by adding the HDPE and MAPE. Pelletizing was not possible with the lab mixer. Thus the outcome was grinded before using. Fig. 2 and Fig 3. Compounding at HF was made with 40%, 60%, 70% and 80% fibre fillings.
Compounds from both compounding methods with 40% fibre have been injection moulded into tensile test bars for mechanical testing. Moulding with higher filling rates has not been done due to very high melt pressure. Note that it is more difficult to injection mould compounds with NF than with wood flour such as in WPC due to much higher melt viscosity.

**Extraction**

To remove the matrix from the compound and to free the fibre, enabling fibre measurements, Soxtech extraction in boiling Xylene is being performed. This is ongoing at the time of writing this paper and thus not fully accomplished. Target is to extract PE from fibre including PE in lumen of the fibres. The result should be a free fibre, able to be dispersed in water for further fibre measurement. Different trials are carried out to secure a method. For the extraction a Soxtec System HT6 is being used. To determine the extraction methods influence on the fibre, the original fibre, which not have been involved in any compounding process, will be extracted according to the same method. Initial trials has found that the extraction has to be ongoing for 24 h, 2 or more times with frequently stirring and renewing the xylene. Temperature set between 160-180 °C. In all four set of fibres is being extracted. Bezner 40%, HF 40%, HF 70% and CS 770 as an extraction reference.

**Fibre measurements**

Each fibre measurement in the PulpEye Eurocon Analyzer, alternative in a Fibrelab, involves one gram of fibre mixed in water. At least 3 measurements on each fibre will be performed. To secure more significant results and determine small differences 6 measurements are planned. 10 gram of each fibre is being extracted.

**PRELIMINARY RESULTS**

No results will be published in this paper. Full paper with results will be published late 2016 as a part of a licentiate study at KTH, Stockholm
SURFACE CHANGES OF ARTIFICIALLY WEATHERED POLYPROPYLENE-THERMALLY MODIFIED WOOD FLOUR COMPOSITES

Kuka, E.¹,², Cirule, D.¹, Kajaks, J.², Andersone, I.¹ & Andersons, B.¹

ABSTRACT

Wood plastic composites are mainly used in outdoor applications: decking, railing, window profiles, fencing and outdoor furniture. Therefore it is important to determine their behavior in UV exposure. In this work some of the surface properties of wood plastic composites made with thermally modified wood flour were investigated. Measurements of surface color after artificial UV weathering showed a significant change for these composites where ΔE_ab values were in the interval between 30 and 34 units depending on thermal modification regime of wood. Reflected light microscope pictures showed that for all of the wood plastic composite that were tested the surface was shattered after 280 h of artificial weathering. However, there was an important benefit for wood plastic composites with thermally modified wood flour: the erosion effect was less noticeable.

Keywords: Wood plastic composites, Thermally modified wood, Artificial weathering, UV degradation, Color change.

INTRODUCTION

Wood plastic composites (WPC) quite recently have become well-known and highly demanded materials worldwide. In Europe 260 000 tonnes of WPC were produced in the year 2012 – that is around 10 % of the total European composite market. A rapid WPC market growth is observed nowadays and the growth is still expected in the near future. By the year 2020 it is forecasted that the WPC production in Europe will reach around 1 million tonnes of WPC per year. Market growth in China and USA is expected to be even more significant for these materials (Carus et al. 2014). WPC are mainly used in outdoor applications (decking, railing, fencing, outdoor furniture etc.), therefore durability against weathering should be considered. UV radiation initiated photodegradation is one of the main concerns for WPC, because wood and polymer are both susceptible to UV radiation. Photodegradation in most cases lead to material discoloration, loss in mechanical properties and lower surface quality (Muasher and Sain 2006). Therefore, all of

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the commercial WPC that are intended for outdoor usage contain UV absorbers, quenchers or hindered amine light stabilizers (HALS).

Theoretically polyolefins should be durable against UV radiation, because photodegradation can only occur when the polymer contains chromophores which absorb wavelengths of the solar radiation. However, because of the end product impurities, chromophores are present in the polyolefins. These impurities can be internal in-chain impurities such as hydroperoxides or carbonyls and external impurities such as polymerisation catalyst residues, additives, residual monomer, metal traces from processing equipment and pollutants from atmosphere (Gijsman et al. 1999). Therefore polyolefins are susceptible to UV radiation. Photodegradation is due to radical based autooxidative process, where in the initiation step free radicals are generated in presence of UV radiation. Afterwards these free radicals attack the polymer, which leads to termination via cross linking or chain scission reactions. Chains scission reactions decrease the molecular weight and increase the crystallinity of the polyolefin which leads to material embrittlement (Gijsman et al. 1999). UV radiation has an effect on wood and its main polymeric components as well. The most susceptible component in wood is lignin, which absorbs 80 to 95 % of the total amount of UV radiation absorbed by wood (Morrell et al. 2009). Lignin undergoes photodegradation via different pathways, however they all lead to formation of chromophoric functional groups such as carboxylic acid, quinones and hydroperoxy radicals. These free radicals may then cause photooxidation of hemicelluloses and cellulose, which leads to depolymerisation (Muasher and Sain 2006). Overall, photodegradation of WPC involves several factors, which makes this system even more complex.

Thermally modified wood has experienced a significant commercial growth in last few years. Based on ThermoWood® production statistics 2015 data, the production of thermally modified wood has increased by 70 % in last five years. Thermally modified wood compared to unmodified wood has improved water resistance, enhanced biodurability and reduced discoloration due to UV radiation (Cirule et al. 2016). Our previous research showed that thermally modified wood residues can be used in production of WPC. These composites had an improvement in most of the tested properties partly due to enhanced compatibility between wood flour and polymer matrix (Kuka et al. 2015). For WPC with thermally modified wood residues most of the mechanical, physical and biological properties have been tested (Segerholm 2012, Kuka et al. 2015), however little information is available about UV degradation for these materials.

The objective of this work was to investigate the surface properties of artificially weathered WPC with thermally modified wood flour and compare it to WPC with unmodified wood flour.
MATERIAL AND METHODS

Thermal modification of wood and preparation of wood plastic composites

Wood Treatment Technology (WTT) multifunctional pilot device was used to perform thermo-hydro treatment (THT) for five birch (*Betula* spp.) boards for each THT regime. The boards with dimensions 25×100×1000 mm were placed in an autoclave, where thermal modification in water vapor medium under pressure (6-8 bars) was performed. Three THT regimes were chosen: 160°C/1h, 170°C/1h and 170°C/3h (peak temperature of the modification/ holding time at this temperature).

To obtain wood residue like products, the wood boards were milled in a Retsch Heavy-Duty Mill to a flour size that passes through a 1 mm sieve. As a polymer matrix commercial polypropylene (PP) Mosten MA-712 was used. Before compounding, the wood flour was dried in an oven at 103±2°C for 24 h. WPC were made with a two-roll mill. Roll temperatures were 180°C and 185°C. Four different types of WPC were prepared. All of them consisted of 50 wt% wood flour, 50 wt% PP. The only difference was in the wood flour which was used (unmodified (UM), 160/1, 170/1, 170/3). Compression moulding (T=180°C, P=2 MPa) was used to prepare 1.5 mm thick sheets for an artificial weathering test.

Artificial weathering

Artificial weathering test was performed in a QUV accelerated weathering tester, which is equipped with UVA-340 type fluorescent lamps. The lamps provide a good simulation of sunlight in the short wavelength region from 365 nm to 295 nm with a peak emission at 340 nm. The UV radiation flux density at 340 nm was 0.68 W·m⁻² and the chamber temperature throughout the test was 60°C. The artificial weathering test was stopped at the specific period of time (10 h, 50 h and 120 h) to measure color of the specimens. The total exposure time of specimens was 280 h. Artificial weathering test involved only UV radiation and temperature, therefore water spray cycle was not used.

Color of two replicate specimens (5 marked locations for each replicate) was measured with a Konica Minolta CM-2500d Spectrophotometer and expressed according to the CIELAB three dimensional color system. L* is a lightness parameter, a* is a chromacity parameter which represent red-green coordinates and b* is a chromacity parameter which represent yellow-blue coordinates. The total color change ∆Eab was calculated according to the Eq. 1:

\[ \Delta E_{ab} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \] (1)
When the measurements were taken of polypropylene black surface was put under the light translucent polypropylene sheet.

Reflected light microscope Leica MZ6 was used to examine the surface of non-weathered and artificially weathered specimens.

RESULTS AND DISCUSSION

Color change

Aesthetic properties are the ones that attract customers and add value to the product. Color and its stability is one of the cornerstones for aesthetic properties. If a long-term color stability is ensured then that is a major advantage for these type of outdoor materials. Significant discoloration of WPC because of the UV radiation is well known, therefore these materials without any additional UV stabilizers or/and absorbers are unusable in direct contact with solar radiation (Muasher and Sain 2006). Similar situation is observed in case of WPC with thermally modified wood flour (Fig. 1), where the color change (ΔEab) after 280 h of exposure is 30 to 34 units depending on regime, that is approximately 2.5 times larger color change than for WPC with unmodified wood flour. The large increase in color change is discussed later in the publication. These results approve that UV stabilizers or/and absorbers are necessary also for WPC with thermally modified wood flour.

![Graph](image)

**Fig. 1.** Color change (ΔEab) of artificially weathered WPC with unmodified and thermally modified birch wood flour. UM – unmodified; THT – thermo-hydro treatment; 160/1, 170/1 and 170/3 – modification regimes.

The results in Fig. 1 and Table. 1. show that for both types of WPC there is a different color change kinetics. For WPC with unmodified wood flour the fastest color change is occurring in the interval between 0 and 10 h of exposure time, where the discoloration speed is 0.28 units/h. However for the WPC with thermally modified wood flour the fastest color change is occurring in the interval between 50 and 120 h of exposure time. In this interval the discoloration speed is 0.20 to 0.27 units/h depending on regime. The results suggest that for WPC with thermally modified wood flour there is some kind of an induction period before the photodegradation
can reach its sufficient level. There is no such thing noticeable in case of unmodified wood flour. Wood modification regimes most likely have an influence on induction period as well, however more detailed research is necessary to make this statement.

Table 1. Discoloration speed of WPC during different exposure time intervals of artificial UV weathering.

<table>
<thead>
<tr>
<th>Interval</th>
<th>0-10 h</th>
<th>10-50 h</th>
<th>50-120 h</th>
<th>120-280 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM</td>
<td>0.28</td>
<td>0.15</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>THT 160/1</td>
<td>0.07</td>
<td>0.13</td>
<td>0.27</td>
<td>0.21</td>
</tr>
<tr>
<td>THT 170/1</td>
<td>0.07</td>
<td>0.10</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>THT 170/3</td>
<td>0.06</td>
<td>0.08</td>
<td>0.20</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Changes in CIELAB color parameters after 280 h of artificial UV weathering are shown in Fig. 2. An increase in \( L^* \) parameter is related to increase in specimen lightness. A positive change (\( \Delta a \)) of parameter \( a^* \) is related to a color shift towards red, but negative – towards green. A positive change (\( \Delta b \)) of parameter \( b^* \) is related to a color shift towards yellow, but negative – towards blue. In the Fig. 2 it is shown that all of the tested WPC are becoming lighter because of the UV exposure. However polypropylene (PP) is just becoming less translucent (measurements were taken while PP sheet was placed on black surface). This is because of the formation of photodegradation products in result of scission reactions, which have shorter chains and therefore these substances are more mobile and more capable of crystallization (Muasher and Sain 2006). Another sign of crystallization is surface embrittlement, which is shown in Fig. 3. For PP there is also a slight positive shift in \( a^* \) parameter and more significant positive shift in \( b^* \) parameter, which indicates yellowing of the specimen. For WPC with unmodified wood flour the change in \( L^* \) is the smallest, which makes the smallest change in the total color change. This could be mainly because of the surface erosion (Fig. 3), therefore most of the wood flour close to the surface is exposed, which decrease the lightness. Also unmodified wood should become darker when exposed to UV radiation (Cirule et al. 2016). Changes in parameters \( a^* \) and \( b^* \) show that the composite color has shifted away from the red and yellow towards more gray. These shifts most likely are due to PP, which reduce the positive \( a^* \) and \( b^* \) parameter of non-weathered composite closer to its value for weathered PP. For WPC with thermally modified wood the situation is different where changes in lightness parameter \( L^* \) are more significant and that is mainly because of the dark color of non-weathered WPC and a lot less noticeable surface erosion for weathered WPC (Fig. 3). Also small increase in lightness is because thermally modified wood exposed to UV radiation becomes lighter (Cirule et al. 2016). From the \( a^* \) and \( b^* \) parameters it is noticeable that the composite color has become less red and more yellow, respectively. Overall the total color changes \( \Delta E_{ab} \) mostly depend on the changes in lightness parameter \( L^* \).
Fig. 2. Changes in CIELAB color parameters ($L^*$, $a^*$, $b^*$) and the total change ($\Delta E_{ab}$) for WPC with unmodified and thermally modified birch wood flour after 280 h of artificial UV weathering. 

PP – polypropylene; UM – unmodified; THT – thermo-hydro treatment; 160/1, 170/1 and 170/3 – modification regimes.

Surface imaging of artificially weathered WPC

Reflected light microscope pictures with 50× magnification (Fig. 3) show that the surface is shattered for both types of WPC after 280 h of artificial UV weathering. Surface shattering as previously mentioned is a sign of chain scission reactions that have occur because of the photodegradation. Surface shattering leads to surface erosion which is a serious problem for both plastics and composites, because this exposes the fillers and additives where in time these substances are lost (Jones 2002). There is an important benefit for WPC with thermally modified wood flour that regards surface erosion – the effect is less noticeable comparing to WPC with unmodified wood flour where most of the wood flour that is near the surface is exposed due to surface erosion. In case of the strongest thermally modified wood regime there are only minimal erosion traces noticeable. Because of the reduced surface erosion, WPC with thermally modified wood flour could have an advantage over WPC with unmodified wood flour if additives, for example, UV absorbers, were used. That is because these additives would not be exposed and eventually lost as quickly.

Fig. 3. Reflected light microscope pictures of WPC before and after artificial weathering.
CONCLUSIONS

The results of the research show that UV absorbers or UV stabilizers are necessary also for WPC with thermally modified wood flour. For these composites the color change was significantly larger, although the surface was less subjected to erosion comparing to WPC with unmodified wood flour.

ACKNOWLEDGEMENT

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REFERENCES

REACTION-TO-FIRE PERFORMANCE OF FIRE RETARDANT TREATED WOOD AFTER LEACHING TEST

Kim, I.1, Larnøy, E.2 & Militz. H3

ABSTRACT

It is important to enhance the fire retardant properties of wood. Although it was mentioned in several literature that the phosphate based fire retardants (FR) leaches out from wood easily, it was difficult to find the exact leaching properties. In this study, Scots pine sapwood (Pinus sylvestris L.) and Maple (Acer platanoides L.) were impregnated with FR and leached as described in EN84. The specimens were tested with a mass loss cone calorimeter to observe the fire performance. The FR leached out easily from both species, but more from Scots pine than maple. Furthermore, the FR treated specimens showed better results with delayed time to ignition, lower maximum average rate of heat emission, peak heat release rate and calculated fire growth rate.

Keywords: fire behaviour, fire retardant, leaching test, Norway maple, Scots pine

INTRODUCTION

Wood is a sustainable and renewable material which has been preferred as a building material in the Nordic countries. However, its fire retardancy needs to be improved. Most common fire retardants (FR), such as phosphate salts and sulphate salts, are stated to act as acidic salts through a dehydration mechanism during thermal decomposition, increasing combustion temperature of materials, decreasing maximum weight loss rates and directing the degradation pathway toward more residues or char production and fewer volatiles (Levan 1984). Although these FR can be applied on wood, they leach out from wood easily due to its water solubility (Stevens et al. 2006).

The leaching of salt-based FR has been mentioned in many literature studies and is known for long time. However, it is not known how fast these FR leach out from wood and to which extension. Also, it was not known how the different wood species react to fire after leaching test.

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In this study, the leaching of phosphate based FR according to EN84 and the fire behaviour of FR impregnated Scots pine sapwood (*Pinus sylvestris* L.) and Maple (*Acer platanoides* L.) was investigated.

**MATERIAL AND METHODS**

**Preparation of Specimens**

Scots pine sapwood (*Pinus sylvestris* L.) and Maple (*Acer platanoides* L.) with specific gravity of 0.52 and 0.71, respectively, (20°C, 65%RH) were prepared in dimensions of 100 x100 x18mm. A 15% solution of a commercial FR was used. The FR was phosphorus based and can be applied on timber and plywood. The uptake of FR was 840.6 kg/m³ in pine and 697.0 kg/m³ in maple.

Forty specimens of each species were prepared and divided into two groups: untreated and FR treated specimens. The specimens treated with FR, was impregnated in 15% (w/w) solution of FR by applying a vacuum of 4 kPa for 30 minutes followed by applying pressure at 800 kPa for 2 hours. The specimens were dried at room temperature for a day and stored in climate chamber (20°C, 65%RH) until stable weight was obtained.

The oven-dried weight (103°C, 24h) of specimens was measured to calculate weight percentage gain (WPG) as follows:

\[
\text{Weight Percentage Gain (WPG)}(\%) = \left[\frac{W_c - W_i}{W_i}\right] \times 100
\]

Where \(W_c\) is the oven-dried weight of specimens after impregnation, while \(W_i\) is oven dried weight of specimen before the treatment.

**Leaching Test**

Ten specimens from each group were subjected to leaching as described in EN84 (1997). The weight and dimension of specimens were measured. The test was done for 10 days and the water samples were taken 10 times from every vessel during the test.

The specimens were dried in a vacuum chamber (4kPa, 40°C) for 20h to accelerate drying process. The oven dried weight (103°C, 24h) of specimens was measured to calculate WPG after the leaching test.

**Analysis of Leachate**

The leachate, which was collected during the leaching test, was analysed by ion-chromatography (IC) to detect leached fire retardant which contains
chloride and phosphate. The samples were analysed by a Dionex Ion chromatograph DX100. The anions were separated on an ion exchange column with the mobile phase (solution of 1.8mM Na₂CO₃ and 1.7mM NaHCO₃). A flow rate of the mobile phase was 2.0mL/min and the injection volume of sample was 50µL.

**Reaction-to-Fire Test**

The specimens were tested with a mass loss cone calorimeter according to ISO 5660-1. The specimens were tested under an external heat flux of 25 kW/m² for 1800s. Fire growth rate (FIGRA) (W/s) was calculated in two different ways: the maximum of Heat release rate (HRR) to time and the peak HRR (pHRR) to time.

**RESULTS AND DISCUSSION**

The WPG of FR was higher in pine (26.1%) than maple (12.4%) after impregnation. However, the WPG after leaching test was higher in maple (2.3%) than in pine (1.1%) (Figure 1).

![Figure 1](image)

**Figure 1** Weight percentage gain (WPG) (%) of fire retardant

According to the analysis of leachate by IC, more phosphate and chloride were leached out from the FR treated specimens than untreated ones. Considering that the FR contains phosphate and ammonium chloride and the decrease of WPG after leaching test, it is reasonable to conclude that the FR leached out from wood (Table 1).
Table 1 The analysis result of leachate by ion chromatography

<table>
<thead>
<tr>
<th></th>
<th>Phosphate (mg/L)</th>
<th>Chloride (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated</td>
<td>Fr</td>
</tr>
<tr>
<td>Pine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>2.2</td>
<td>5.6</td>
</tr>
<tr>
<td>FR</td>
<td>3068.2</td>
<td>1355.4</td>
</tr>
<tr>
<td>Maple</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>12.1</td>
<td>11.1</td>
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<tr>
<td>FR</td>
<td>1848.5</td>
<td>1047.1</td>
</tr>
</tbody>
</table>

The unleached FR treated specimens did not ignite, while the leached FR treated specimens were ignited. The leaching test did not have a large effect on the mass loss (ML) (%) of untreated specimens. Among FR treated specimens, however, the leached specimens showed higher ML (%) and maximum average rate of heat emission (MARHE) compared to non-leached specimens due to loss of FR during the leaching test (Table 2).

Although most of the FR was leached out during the leaching test, they showed delayed time to ignition and lower mass loss compared to untreated specimens (Table 2).

The FIGRA calculated as maximum of HRR/t was higher than that calculated at pHRR between untreated specimens, while the FR treated specimens did not show as large a difference as untreated specimens. This can be related to the curve of HRR. The HRR of untreated specimens showed the typical curve of thick charring materials described in the study of Schartel and Hull (2007) but the first peak was lower than the last peak. However, the HRR curve of FR treated and leached specimens showed similar shape to non-charing materials. Therefore, the two FIGRA were calculated at the nearby or same test time (Figure 2).

Table 2 Result of cone calorimeter test, mass loss (ML) (%), time to ignition (TTI) (s), effective heat of combustion (EHC) (MJ/kg), peak heat release rate (pHRR) (kW/m²) and maximum of average rate of heat mission (MARHE) (kW/m²)

<table>
<thead>
<tr>
<th>Species</th>
<th>Treatment</th>
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<th>ML (%)</th>
<th>TTI (s)</th>
<th>EHC (MJ/kg)</th>
<th>pHRR (kW/m²)</th>
<th>MARHE (kW/m²)</th>
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<td>160.3</td>
<td>46.9</td>
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REFERENCES


ROLE OF EXTRACTIVES AND LIGNIN FOR THE DURABILITY OF THREE HARDWOOD SPECIES FROM MOZAMBIQUE

Sitone, E.¹, Uetimane, E.¹, Jebrane, M.², Terziev, N.² & Daniel, G.²

ABSTRACT

The study assessed the distinct role of extractives and lignin content in the natural durability of three tropical hardwoods growing in Mozambique namely ntholo (*Pseudolachnostylis maprounaefolia* Pax), metil (*Sterculia appendiculata* K. Schum) and neem (*Azadirachta indica*). The experiment consisted of exposing control, extracted and delignified wood samples to fungal attack caused by brown rot- (*Postia placenta* and *Gloeophyllum trabeum*), white rot- (*Trametes versicolor* and *Pycnoporus sanguineus*) and soft rot fungi (*Chaetomium globosum* and *Phialophora mutabilis*) in controlled environment.

Ntholo had the highest extractive content (4.0%) followed by metil (1.1%) and neem (1.0%). The results show that control wood samples of ntholo are characterised as very durable showing negligible mass loss (1.0-2.5%) against all tested fungi. Neem is moderately durable wood species with mass loss of 15.8% against white rot *T. versicolor*. The most perishable wood species was metil, which is very sensitive to white rot fungi that caused mass loss of 24.3-29.8%.

After removal of water- and solvent-soluble extractives, ntholo was still very durable, but demonstrated an increased mass loss of 3.9-4.2% caused by the white rot *T. versicolor*. The decay rate also slightly increased for neem (*T. versicolor* caused 18.2% mass loss). Since metil is perishable wood species with low content of extractives no significant change in the mass loss after extraction was noted.

Delignification of all species had significantly more pronounced effect on the natural durability of tested species compared to removal of extractives. The white rot fungi were most destructive for ntholo and neem leading to mass loss higher than 40%. *P. placenta* was found to be the main degrader for metil with mass loss of 51.6%. Results confirm the synergy between lignin and extractives for playing key roles for the natural durability of wood.

Keywords: Basidiomycetes, Extractives, Lignin, Natural durability, Soft rot fungi

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INTRODUCTION

Mozambique is a country rich in wood species of high natural durability. There are more than 120 species in Mozambique that can be of interest for the wood-working industry; the timber species divided in precious, 1st, 2nd, 3rd and 4th classes. However, the wood market in the country is concentrated over only a few species, e.g. pau-preto (*Dalbergia melanoxylon*), umbila (*Pterocarpus angolensis*), chan-futa (*Afzelia quanzensis*) and jambirre (*Milletia stuhlmannii*). The overuse of these naturally durable timbers has emerged the utilisation of lesser-used species that have moderate to low resistance against wood-destroying organisms. Such a scenario would be very positive and needed to release the pressure on the well-known timbers, diversify and expand the market options (Mackenzie 2006; EIA 2013).

In wood of high natural durability, extractives are the main source of resistance to bio-deterioration by acting as natural wood preservatives but not all wood species contain extractives with biocide ingredients to resist deterioration agents. Knowledge of the natural durability of wood is very important to recommend a more suitable use, avoid unnecessary spending on replacement of damaged parts and reduce the impact on the remaining forests (Syofuna et al. 2012; Santos 2010). The objectives of the present study were to assess the role of extractives and lignin on the natural durability of 3 lesser-used hardwood species from Mozambique against fungal degradation.

MATERIAL AND METHODS

Collection and sample preparation

Samples of *Pseudolachnostylis maprounaefolia* (ntholo), *Sterculia appendiculata* (metil) and *Azadirachta indica* (neem) were collected at Pemba, Montepuez and Nicoadala districts located in North Mozambique. Bottom logs were cut from native forests and transported to a sawmill where they were converted into blocks of 60 × 60 × 600 mm. Only heartwood samples were taken from ntholo and neem; sapwood was excluded due to its insignificant volume in the studied species. The blocks were frozen to prevent accidental drying before transportation to the laboratory.

Extractive removal and quantification

Wood specimens (5 × 15 × 40 mm) were cut from the blocks, oven-dried at 103°C until constant weight was gained and then placed in Soxhlet apparatus with 150 mL of toluene, 50 mL of ethanol and 50 mL of acetone (3:1:1) for 24 h (Scan-CM 49:03, 2003). After removal of the extractives, the specimens of each wood species (4 replicates) were oven-dried again at 103°C until constant weight was achieved, conditioned at 20°C and RH of 70% and exposed to brown, white and soft rot fungi for 24 weeks.
After removing the extractives by a Soxhlet apparatus, the mixtures of toluene, ethanol, acetone and extractives of each species were placed in a rotary evaporator to evaporate the solvents. The flask was left to dry at 103°C in an oven and then weighed to calculate the amount of extractives for each species. The content of the extractives was calculated according to Scan-CM 49:03, 2003.

Delignification of wood and decay test

Thirty specimens were dried in oven at 103°C until constant weight. They were placed in oven at 60°C for 18 h in an Erlenmeyer flask with 200 mL of acetone and hydrogen peroxide (1:1). After delignification the specimens were triple-washed in distilled water, dried, reweighed and exposed to the test fungi. A modified screening test, similar to the standard European test EN 113, was employed in the study. Four specimens of each wood species and reference samples (birch) were placed in Petri dishes with the test fungus inoculated on agar (EN 113) and left to decay for 24 weeks. The specimens were exposed to the brown rot fungi *Postia placenta* and *Gloeophyllum trabeum*, the white rot fungi *Trametes versicolor* and *Pycnoporus sanguineus* and the soft rot fungi *Chaetomium globosum* and *Phialophora mutabilis*.

RESULTS AND DISCUSSION

Durability of untreated and extracted wood

The performance of the untreated wood samples of all species against fungal attack is presented graphically below (Fig. 1 left).

![Figure 1. Mass loss of untreated (left) and extracted wood samples (right)](image)

The white rot fungi were more active compared to the two other rot types. Untreated ntholo wood was the most durable against all tested fungi. This species has high proportion of fiber tissue and low amount of parenchyma cells, making it least preferred for the tested decay fungi (Uetimane et al. 2009). Metil showed the largest mass loss (Fig. 1 left), particularly when tested with the white rot fungi *T. versicolor* (29.8%) and *P. sanguineus* (24.3%) followed by the soft rot *C. globosum* (18.4%) and *P. mutabilis* (12.0%) and brown rot fungi *P. placenta* (8.4%)
and *G. trabeum* (9.0%). According to Uetimane et al. (2009), this species contains 53% parenchyma cells which are responsible for storing nutrients as starch and sugars and thus, contributing to the high mass loss (Bessa 2009). Neem is more resistant to decay than metil (*T. versicolor*-15.8% and *P. sanguineus*-4.9% mass loss) followed by soft rot (*C. globosum*-5.6% and *P. mutabilis*-0.7%) and insignificant mass loss against the brown rot fungi. Neem results are in line with the findings of Koyani and Rajput (2015) who found the mass loss of neem caused by the white rot fungi *Irpex lacteus* and *Phanerochaete chrysosporium* to be in the range of 15-19% after 90 days of exposure. It was concluded that although lignin is somewhat resistant to decay, white rot fungi are extremely efficient lignin degraders.

The analysis found that ntholo has the largest amount of extractives (4%), metil and neem had 1.1% and 1.0% respectively. Extractives removal increased slightly the incidence of attack by wood-destroying fungi (Fig. 1 right). In general, all three species maintained the resistance pattern displayed for untreated wood (Fig. 1 left).

Analysing the natural durability of wood species demands understanding of the availability, quantity and chemical composition of extractives (Taylor et al. 2002). Microscopy observations (not shown here) confirmed that both ntholo and neem still contained some extractives in the parenchyma cells after the extraction. It seems the extractives are extremely well integrated in the cell wall, particularly for neem wood which has initially only 1.0% extractives. Metil did not have extractives remaining in its structure after chemical removal and thus, the mass loss was unchanged, i.e. the extractives played insignificant role for the natural durability of metil wood.

**Durability of delignified wood**

As expected delignification had more pronounced effect on wood durability than the removal of extractives. The three wood species were significantly more attacked, particularly by the white rot fungi *T. versicolor* and *P. sanguineus* causing mass loss higher than 20% even for ntholo and neem and the brown rot *P. placenta* which was very active on all wood species (Fig. 2 left).

![Figure 2. Mass loss of delignified wood samples (left) and least significant difference (LSD) between overall mass loss means per treatment (right)](image)
The resistance against fungal attack for the tested procedures is compiled in Table 1. The classification terms of the European standard EN 350-1 (1994) are used. In general, all species suffered severe decay when extractives and lignin were removed. Uetimane et al. (2009) described anatomical features of ntholo and predicted that it is a very durable due the presence of extractives and thick-walled fibres. Ali (2011) performed a natural durability test using laboratory EN 113 test with basidiomycetes and found ntholo classified as very durable wood. Neem has been recommended in pest management thanks to its leaves, roots and wood toxicity against xylophages agents (Soares et al. 2009; Paes et al. 2012). Paes et al. (2007) also determined the natural durability of neem to brown (*P. placenta*) and white (*P. fumosus*) rot fungi and classified it as a durable wood. The role of extractives and lignin in the overall durability of the three species has been depicted through analysis of variance at 5% confidence interval. A Fisher pair-wise comparison using the least significant difference (LSD) statistical test (Fig. 2 right) was performed to prove the differences between the treatments. There are no statistical differences between mass loss of untreated and extracted wood of ntholo and neem. Mass loss of metil showed no statistical difference between the untreated, extracted and delignified samples (Fig. 2 right). The above confirm the findings of Pereira et al. (2009) who stated that the wood extractives together with the phenolic nature of lignin offer protection to wood by inhibiting the enzymatic activity in fungi and insects.

**Table 1.** Durability classes according to standard EN 350-1 for all treatments and wood species.

<table>
<thead>
<tr>
<th>Decay type</th>
<th>Untreated wood/natural durability</th>
<th>After extractive removal</th>
<th>Delignified wood</th>
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<tr>
<td></td>
<td>Ntholo</td>
<td>Neem</td>
<td>Metil</td>
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<tr>
<td>Brown rot</td>
<td>Very durable</td>
<td>Very durable</td>
<td>Durable</td>
</tr>
<tr>
<td>White rot</td>
<td>Very durable</td>
<td>Moderately durable</td>
<td>Slightly durable</td>
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<tr>
<td>Soft rot</td>
<td>Moderately durable</td>
<td>Moderately durable</td>
<td>Non-durable</td>
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<tr>
<td>Type of fungal attack/species</td>
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<td>Neem</td>
<td>Metil</td>
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<tr>
<td>Brown rot</td>
<td>Slightly durable</td>
<td>Slightly durable</td>
<td>Non-durable</td>
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<tr>
<td>White rot</td>
<td>Very durable</td>
<td>Moderately durable</td>
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<tr>
<td>Soft rot</td>
<td>Non-durable</td>
<td>Non-durable</td>
<td>Non-durable</td>
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</table>

LSD test between the three types of fungal attack (Fig. 2 right) showed that ntholo and neem have similar behaviour against fungal attack. The attack of brown-,
white- and soft rot fungi are not significantly different for untreated and extracted wood. Delignification has strongest effect on wood durability despite native differences in the tested wood species.

CONCLUSIONS

This study was aimed at assessing the role of lignin and extractives in the overall performance of lesser-used timbers (ntholo, metil and neem) against fungal attack, namely, brown, white and soft rot fungi based on a screening laboratory test.

White rot fungi caused more decay for all species for the untreated wood, after removing extractives and delignification. In terms of extractives, ntholo showed the highest content (4.0%) followed by metil (1.1%) and neem (1.0%) but the amount of extractives was not directly related to wood durability. An example is the wood of metil which is a perishable wood species while neem, with similar extractive content is moderately durable. Ntholo wood showed high durability and was the most durable among the tested species. Delignified samples of the three species demonstrated more decay compared to untreated and extracted samples. Both extractives and lignin play important role in the resistance against wood destroying fungi.

ACKNOWLEDGEMENTS

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INvolvement of antioxidant enzymes in the response of Quercus robur leaves to Erysiphe alphitoides infection

Skwarek, M.1, Witczak, A.2 & Patykowski, J.3

Abstract

In recent years, the increase in infestation of trees by pathogens has been reported. In Polish forests, oak powdery mildew is most commonly caused by a species of fungus Erysiphe alphitoides. Fungi which cause powdery mildew belong to the subdivision Ascomycetes (Ascomycotina). Oak powdery mildew is responsible for significant damage in nurseries.

The development of the infection caused by the fungus Erysiphe alphitoides in cells of oak leaves triggers many processes which involve enzymes and non-enzymatic compounds. One of the first reactions at the beginning of the infection is generation of excessive amounts of reactive oxygen species (ROS). Generation of ROS, often called oxidative burst, can lead to irreversible changes in cell structures and molecules, for example by oxidation of protein thiol groups. The plant features enzymatic repair systems reducing excessive amounts of ROS. Catalase, peroxidase and enzymes which are involved in ascorbate-glutathione cycle belong to the defense system.

The aim of the study was to determine the selected antioxidant enzyme activities including peroxidase (POX) and catalase (CAT), elements of ascorbate-glutathione cycle such as ascorbate peroxidase activity (APX) and dehydroascorbate reductase activity (DHAR) and the concentrations of ascorbate (AA) and dehydroascorbate (DHA) in the Quercus robur leaves infected with powdery mildew. Additionally, the lignin decomposition as an extra mechanical barrier against pathogen attack was visualised by confocal microscopy.

As material to investigation one-year-old seedlings of pedunculate oak were obtained, in three times long period, from container nursery of the Forest District Gidle, Poland. For analysis we used leaves with different size of infection area (<5%, 12-15%, 25%).

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2 PhD student, Department of Forest Protection and Ecology, Warsaw University of Life Science – SGGW, Nowoursynowska Street 159, 02-776 Warsaw, E-mail: adrian_witczak@sggw.pl
3 Associate Professor, Department of Plant Physiology and Biochemistry, University of Lodz, Banacha Street 12/16, 90-237 Lodz, E-mail: jacpat@biol.uni.lodz.pl
The results showed the changes in the APX and DHAR activity and in AA and DHA concentrations after pathogen infection which is associated with regeneration of the reduced form of ascorbate. The high activities of antioxidant enzymes in powdery mildew-infected leaves may indicate activation of additional mechanisms that protect cells from oxidative stress.

**Keywords**: antioxidant enzymes, oak powdery mildew, biotrophic pathogen
FUNGAL MOISTURE DEMANDS FOR COLONIZATION AND DECAY OF WOOD

Höpken, M., Schmidt, O. & Huckfeldt, T.

ABSTRACT

Regarding wood decay by fungi there are still open questions, like their ability to transport water, to produce it by their metabolism and to infect and decay dry wood. Few laboratory investigations were already done using piled wood samples. The aim of this study was to get data on three common indoor wood decay basidiomycetes on different wood substrates regarding growth, moisture demands and wood decay. Small wood blocks from Scots pine sapwood (Pinus sylvestris) and English oak sapwood and heartwood (Quercus robur) were piled in Erlenmeyer flasks. Metal rings between the samples inhibited the capillary water diffusion from sample to sample. The flasks were supplied with nutrient agar and were inoculated with the brown-rot fungi Coniophora puteana, Serpula lacrymans and the white-rot species Donkioporia expansa. Different harvest times were used according to the different colonization time of the piles. Results revealed that the fungi were able to transport water from the agar to the piles and within them and to colonize wood even from 15.1 % to 21.8 % moisture content. Regarding minimum moisture for decay, e.g. D. expansa degraded the oak heartwood at even 17.9 % moisture. Depending on wood species and distance between the samples the fungi showed different growth behaviour.

Keywords: wood decay fungi, wood moisture, lab test, Quercus robur, Pinus sylvestris

INTRODUCTION

The wood water content is the most important influence parameter for fungal wood decay (Liese 1928, Willeitner 1981, Schmidt 2006). It is widely believed that the fibre saturation point (FSP) is the limiting factor (e.g. Grosser et al. 2013). However, there are hints that fungi colonize and degrade wood also below FSP. Early studies were done with small incised wooden boards (Theden 1941, Ammer 1963). Wälchli (1980) tried to demonstrate water transport by Serpula lacrymans from one wood sample to the next. The first use of piled wood to measure the moisture

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influence on decay was by Schmidt et al. (1996). Huckfeldt and Schmidt (2005) modified the technique to investigate the minimum moisture demand for growth of *S. lacrymans* and Stienen et al. (2014) for data on the temperature influence. Meyer and Brischke (2015) used it with different European woods. Besides moisture and temperature, growth of wood decay fungi is influenced by the specific characteristics of the wood species (Eaton and Hale 1993, Huckfeldt and Schmidt 2015). For those information and data on further wood decay fungi, *Pinus sylvestris* sapwood and *Quercus robur* sapwood and heartwood were subjected to *Coniophora puteana*, *S. lacrymans* and *Donkioporia expansa*.

**MATERIAL AND METHODS**

For the pile tests, wood samples (30 mm × 30 mm × 5 mm cross to fibre direction) from *Pinus sylvestris* L. sapwood and *Quercus robur* L. sapwood and heartwood with a hole of 4 mm in the centre of the broad surface, were dried at 103 °C for 24 h and weighted for initial dry weight. 84 piles with 20 or 10 samples were arranged on a wire of stainless steel with 1 or 5 separation rings for distances of 3 or 8 mm between the samples. At pile basis, an additional wood block avoided contact of the lowest sample with the agar. As indoor wood decay fungi, the brown-rot species *Coniophora puteana* (Schum.: Fr.) P. Karsten, strain 167, *Serpula lacrymans* (Wulfen: Fr.) Schroeter, strain 7, and the white-rot fungus *Donkioporia expansa* (Desm.) Kotl. & Pouzar, strain 188 from the Schmidt strain collection were pre-cultured in petri dishes on malt agar (2 % malt extract, 1.5 % agar, Oxoid). 2-litre Erlenmeyer flasks with 200 ml malt agar and a pile placed on the wood block at bottom were autoclaved at 121 °C for 25 min. After inoculation of the agar surface with 6 to 8 mycelial agar plugs, cultures were incubated at 21 °C and 70 % RH. Fungal growth was regularly recorded with a marker on the flask outside. For control, 12 flasks remained uninoculated. First harvest was done when the piles were overgrown by 2/3, a second harvest using parallel piles 3 to 4 times later, depending on the specific growth. Wood samples were cleaned from mycelium, weighed for wet weight, dried as above and weighed again for mass loss determination.

**RESULTS AND DISCUSSION**

Figure 1 shows as an example for the growth rate on the piles the colonisation by *Serpula lacrymans*.

The mycelium of *S. lacrymans* needed about 20 days to reach the first wood sample and on oak heartwood further 20 days. After this, fungi needed once more the same time for reaching the upper pile part regardless of substrate.

Altogether, the fungi showed species-specific characteristics regarding mycelium, strands and fruit bodies, however influenced by the wood substrate. For example, *Donkioporia expansa* formed strand-like mycelium on oak heartwood and air my-
celium on sapwood, *Coniophora puteana* showed a fluffy shape of air mycelium at the front line which wandered from bottom to top.

Figure 2 shows as an example for the colonization and degradation of pile samples, the results obtained with *Donkioporia expansa* on *Quercus robur* sapwood.

The data regarding the minimum moisture content for all fungi and woods are summarized in Table 1.

![Figure 1. Growth of *Serpula lacrymans* on piles of *Pinus sylvestris* sapwood and *Quercus robur* sapwood and heartwood; piles with 20 wood samples and 3 mm distance (example picture on right).](image1.png)

![Figure 2. Moisture content (MC) and mass loss (ML) of oak sapwood colonized for three weeks with *Donkioporia expansa*, sample distance 3 mm, stripy columns: mycelium growth border](image2.png)
Table 1. Minimum moisture content for growth and decay of Pinus sylvestris sapwood and Quercus robur sapwood and heartwood by Coniophora puteana, Serpula lacrymans and Donkioporia expansa after short (2–4 weeks) and long (7–11 weeks) incubation

<table>
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<tr>
<th>Fungus</th>
<th>Parameter</th>
<th>Minimum moisture content [%]</th>
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<td></td>
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<td>Scots Pine sapwood</td>
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<td></td>
<td></td>
<td>Incubation period</td>
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<td></td>
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<td></td>
<td>Decay</td>
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<td>Serpula lacrymans</td>
<td>Growth</td>
<td>20 – 29</td>
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<td></td>
<td>Decay</td>
<td>31 – 37</td>
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<tr>
<td></td>
<td>Decay</td>
<td>-</td>
</tr>
</tbody>
</table>

No data given: mass loss remained below 2%

All fungi were able to colonize the three woods already around 20 % MC. Regarding the minimum moisture demands for wood decay, C. puteana and S. lacrymans even degraded the three woods slightly below the fibre saturation point. There was no significant difference between pine and oak sapwood. The high data of D. expansa may be caused by its behaviour to overgrow the flask cotton plug with mycelium which yielded high RH. Our results resemble and complete earlier studies mentioned above.

Fungi also increased the wood moisture content (see Fig. 2). Our first studies using cultures without agar to investigate if fungi produce water from the degradation of wood carbohydrates revealed promising but uncertain results. Corresponding studies are running because culture experiments without agar would be more practically orientated. Furthermore, it shall be investigated if an initial decay of sapwood favours degradation of heartwood.

CONCLUSION

The important indoor wood-decay fungi Coniophora puteana, Serpula lacrymans and Donkioporia expansa are able to colonize and degrade woods below the fibre saturation point. Our results are important in view of the environmental conditions in buildings and the repair of fungal wood damages.
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LOMAS: VISI BRIEZI
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GAISMU OPERATORS: PILNMĒNESS
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