Proceedings of the 5th meeting of the nordic-baltic network in wood material science and engineering (WSE)
Copenhagen, Denmark

Bergstedt, Andreas Christian E

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The Nordic-Baltic Network in Wood Material Science and Engineering

Proceedings of the 5th Meeting
October 1-2, 2009
Copenhagen, Denmark

Andreas Bergstedt (Editor)

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Wood Material Science and Engineering

PREFACE

For several decades, wood science research in Nordic countries has benefited from a close co-operation, supported financially by The Nordic Forest Research Co-operation Committee (SNS) under the Nordic Council of Ministers. The annual meetings of university researchers have served as a forum for exchanging results and ideas, and as a valuable breeding ground for new research projects.

The overall purpose of the SNS is to promote research into the diverse functions of the forests in sustainable forestry, as well as to advise the Nordic Council of Ministers on questions concerning forests and forestry research.

Because wood products and wood industry are important parts of the forestry sector in the Nordic countries, it has been a logical development to include wood materials and structural use of wood in the research efforts. Simultaneously, the growing internationalisation of research has called for a widening of the view beyond the original Nordic horizon.

In 2004 this was successfully accomplished by establishing The Nordic-Baltic Network in Wood Material Science and Engineering, including the Baltic countries in the co-operation, and extending the network to technical universities and research organisations in order to cover the whole forestry-products-reuse value chain of wood.

During the past five years the network has been growing steadily, making the 2009 meeting attract 60 researchers from nine countries. The present publication contains 25 papers presented at this fifth annual meeting of the network, and it demonstrates the active and diversified wood research going on in the Nordic-Baltic region.

Forest & Landscape Denmark is proud to host the meeting in 2009. We wish to thank the speakers for their contribution, and the SNS for financial support to make this event possible.

Copenhagen, September 2009

Andreas Bergstedt

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POSTERS

HARDENING OF WOOD

Rowell, R. M. [1]

ABSTRACT

Wood is a very versatile biomaterial. It is used in construction because of its availability, sustainability, cost and strength and in furniture because of its warmth and beauty. For many applications, wood is used without any modification. In some cases, however, there is a need to improve its performance properties to compete with other higher performing and more expensive materials. When wood is used where hardness is a requirement (such as in flooring), there are several ways to increase hardness. A wood that is naturally hard is the first choice and the hardness of wood varies greatly. If additional hardness is desired and wood is the selected resource for the application, there are methods to make softer woods harder. There are two major methods that have been used to increase the hardness of wood: compression and impregnation of chemicals.

Key words: Hardening, wood, physical properties, compressing, phenolics, acrylics.

INTRODUCTION

Hardness is, for the most part, a function of density, i.e. the more dense the wood, the harder it is. The density of dry wood varies widely based on the volume of void (lumens and vessels) space in the wood. For example, the density of dry balsa wood ranges from $100–200 kg/m^3$ with a typical density of about 140 to 170 kg/m^3 (about one third the density of other hard woods) while a wood like lignum vitae has a density of 1280 - 1370 kg/m^3 (this wood does not float). The Janka Scale of Hardness measures the force required to embed a 1.11 cm (0.444 inch) steel ball to half its diameter in wood. It is the industry standard for determining the ability of various species to resist denting and wear. The Janka hardness of eastern white pine is 380 lbf or 1.7 kN, for Douglas fir 660 lbf, 2.9 kN, Red oak 1290 lbf 5.7 kN, Birch 1470 lbf, 6.5 kN, Ebony 3220 lbf, 14.3 kN and lignum vitae ranks highest of the trade woods, with a Janka hardness of 4500 lbs or 20 kN (Wood Handbook 1999). It is not surprising that oak, maple and hickory are species of choice for lower cost, available, domestic flooring materials. Some of the Brazilian hardwoods are also used for flooring but they are much more expensive.

Wood can be compressed under very high pressure to give a product where the hardness is nearly doubled and the scratch-resistance improved by over 200%. One method of compressing wood involves softening the wood at high temperature and high water vapor temperature and then compressing the wood to reduce it one half to one third of its original thickness. The compression is fixed by maintaining wood in a compressed state for a predetermined period of time. An early application of this technology was the production of a product known as Staypak. By compressing the wood under conditions

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that cause the cell wall lignin (the cementing material between fibers) to flow, the cell wall lignin (the cementing material between fibers) to flow, the internal stresses resulting from the compression relax and the wood takes on a new structure in its new compressed state. A temperature range of 150 to 170°C is used and the wood is compressed while heated. The density is increased by 25 to 40%, there is an increase in tensile and flexural strength proportional to the increase in density, an increase in impact strength and toughness and the hardness is 10 to 18 times that of the non-compressed wood (Inoue et al.1993).

Wood can also be impregnated with various chemicals to improve hardness (Rowell and Konkol 1987). In older technology, a solution of phenol-formaldehyde can be impregnated into wood and cured resulting in an increase of 15 to 25% in density, an increase in compressive strength in proportion to the increase in density and an increase in hardness that is more than proportional to the increase in density (Wood Handbook 1999). More recent technology involves treating wood with acrylic monomers and the monomers polymerized in the wood voids to increase hardness. For example, some industrial flooring is treated with acrylics to reduce damage done by high traffic.

MATERIAL AND METHODS

Impregnation using phenolic

Wood can be impregnated with various chemicals to improve hardness. A solution of phenol-formaldehyde can be impregnated into wood and cured resulting in an increase of 15 to 25% in density, an increase in compressive strength in proportion to the increase in density and an increase in hardness that is more than proportional to the increase in density. This product is called Impreg.

The phenol-formaldehyde polymers are the oldest commercial synthetic polymers, first introduced around 100 years ago. Their inventor, Leo Bakeland, worked out conditions to produce a tough, light, rigid, chemically resistant solid from two inexpensive ingredients. The actual chemistry is complicated, and still not competely understood. The polymers are thermosetting (cannot be melted or dissolved) and the main reaction is the production of methylene bridges between aromatic rings, as shown (Wood Handbook 1999). Many side reactions also occur, and some of these give phenol-formaldehyde polymer its dark color.

The phenol-formaldehyde impregnated wood can be compressed making one of the hardest woods known. This product is called Compreg where the density is increased by 40% and the hardness is increased 10 to 20 times that of the starting wood. Master automotive dies were made of Compreg as well as laminated airplane propellers used during the second world war. Wood sawdust mixed with a phenol-formaldehyde polymer is known as Bakelite and was one of the very early plastics used in the United States (Wood Handbook 1999).

Impregnation using acrylics

The technology used today to increase the hardness of wood is to use acrylic monomers and the monomers are polymerized in the wood voids (Meyer 1981, 1982, Schneider and. Witt 2004, Ibach and Ellis 2005). For example, some industrial flooring is treated with

acrylics to reduce damage done by high traffic. There several brands of acrylic impregnated flooring sold under the names of Wearmaster, Permagrain, Hartco, and Gammapar. The major monomer used in these flooring products is methyl methacrylate.

Methyl methacrylate (MMA) (CAS number 80-62-6, IUPAC name methyl 2-methylprop-2-enoate) is a colorless liquid and is the methyl ester of methacrylic acid. Methyl methacrylate polymers and co-polymers are used for waterborne coatings, such as latex house paint, in plates that keep light spread evenly across LCD computer and TV screens, and also used to prepare corrosion casts of anatomical organs, such as coronary arteries of the heart. The principal application of methyl methacrylate is the manufacture of transparent polymethyl methacrylate acrylic plastics (plexiglas). Methyl methacrylate is also used for the production of the co-polymer methyl methacrylate-butadiene-styrene (MBS), used as a modifier for PVC. Other acrylic monomers are also used but they are more expensive.

In the wood industry, methyl methacrylate polymers are not only used in hardened engineered wood flooring but it has also been used to produce furniture (desk writing surfaces, tabletops), decorative products (knife handles, clock faces, plaques), musical instruments (bagpipe chanters, finger boards for stringed instruments boards, instrument bodies, mouthpieces for flutes, trumpets) and sports equipment (gold club heads, baseball bats, hockey sticks, laminated skis, gun stocks).
The treating procedure is rather simple. The wood is placed in a stainless steel reactor and weighted down with a stainless steel weight (so the wood does not float in the monomer). A vacuum is applied to remove the air from the wood and the monomer is introduced under vacuum with nitrogen gas into the reaction chamber. A nitrogen pressure can be applied depending on the thickness of the wood to be treated. Usually, only a thin veneer is treated that will be laminated on top of a sub-bass of plywood, particle board or a high density fiber board.

The monomer solution can contain a few percent of a cross linking agent such as trimethylol propane trimethacrylate. The free radical reaction is catalyzed using either a Cobalt 60 source, peroxides or a vazo (Meyer 1965).

The Cobalt 60 procedure uses a deep water pool with the gamma radiation source near the bottom. The container of wood is placed close to the radiation source. After receiving 1 to 2 MeV of radiation, curing has taken place. The rate of free radical generation is constant depending on the radiation flux. There is no residual radiation from the Gamma radiation treatment.
Several peroxide catalyst have been used in this reaction including t-butyl hydroperoxide, methyl ethyl ketone peroxide, lauroyl peroxide, isopropyl hydroperoxide, cyclohexanone peroxide, hydrogen peroxide and benzyl peroxide. Each of these generate free radicals with the phenyl radical the most reactive. Benzoyl peroxide is the most commonly used initiator and the peroxide concentration usually ranges from 0.2 to 3% by weight of monomer.

Vazo® is a registered trade name of nitriales that are used to cure acrylics. Vazo® 67 is 2,2'-azobis-(2-methylbutyronitrile) and is a heat catalyzed free radical catalyst. Other Vazo® catalysts are also available. When a Vazo® catalyst is used, it is included in the solution of monomer and cross linking agent so that this mixture must be kept cool so polymerization does not take place in the storage container. The concentration usually

used in between 0.5 and 1%. This catalyst generates free radicals that initiate the polymerization reaction shown below.
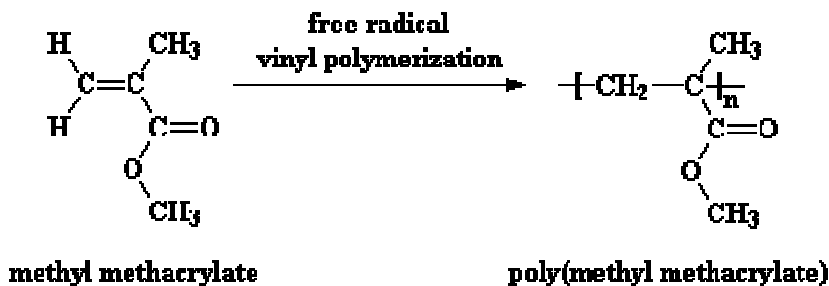
Fig. 1. The Vazo[®] catalyst generates free radicals that initiate the polymerization reaction.

Polymerization of MMA is exothermic and a lot of heat is generated during the polymerization that must be controlled. After the curing is complete, either by Cobalt 60, peroxide or Vazo®, the reactor is drained, flushed with nitrogen, cooled and the treated wood removed. There may be residual polymer on the surface that must be removed. Not all woods treat the same so the time of monomer impregnation, vacuum, pressure, level of loading and cure time will vary depending on the species.

As with all polymerization reaction, the volume of the monomer shrinks upon polymerization. In the case of MMA to PMMA, the shrinkage is about 20%. Figure 2 (left) shows the open structure of oak before MMA-PMMA treatment and the figure on the right shows the polymer in the lumens after treatment. It is easy to see the polymer in the void structure of the wood. Figure 3 shows that extreme shrinkage can also occur in some acrylic systems.
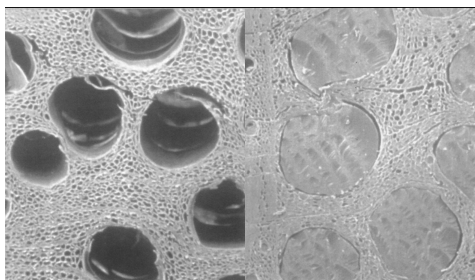
Fig. 2. (*Left*) The open structure of oak before MMA-PMMA treatment, (right) polymer in the lumens after treatment.
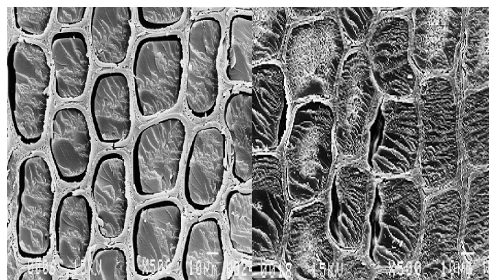
Fig 3. Extensive shrinkage (left) away from the cell wall and (right) within the polymer itself.

The hardness of the PMMA treated wood is increased from 70 -200% depending on the wood treated (Moisuk, 1978 Table 2). Indentation resistance is increased 50 to 70% and the static bending properties of the PMMA treated wood are greatly improved. The diffusion coefficient is reduced by 75% with very little dimensional stability gained by the MMA treatment.

Table 1 - Physical properties of polymethyl methacrylate treated wood (62% weight gain)*

Sample Maple	Modulus of Elasticity (psi)	Percent Change	Modulus of Rupture (psi)	Percent Change (%)
Control	1,905,797		18,280	
62.6% MMA	1,998,692	+5	21,620	+18

Sample Maple	Radial Hardness (lbs)	Percent Change	Tangential Hardness (lbs)	Percent Change	Longitudinal Hardness (lbs)	Percent Change (%)
Control	308		403		825	
62.6% MMA	944	+207	1154	+186	1458	+76

Sample Maple	Diffusion Coefficient (10^{-6} cm^2/sec)	Percent Change	Maximum Crushing Strength (psi)	Percent Change	Fiber Stress at Proportional Limit (psi)	Percent Change (%)
Control	6.27		9,420		9,017	
62.6% MMA	1.7	-73	12,338	+31	10,106	+12

Sample Maple	Swelling due to Treatment (%)	Antishrink efficiency (%)
Control	---	---
62.6% MMA	1.27	13

* The original units from the author were used without conversion to metric units.
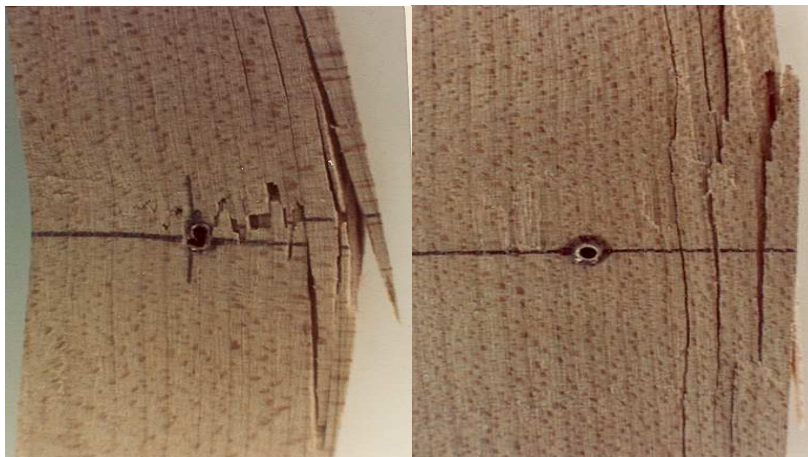
Fig 4. Failure in bending of control (left) and MMA treated (right).

The fracture pattern between control and MMA treated wood are very different (Figure 4). The control samples break deep within the sample and it looks more like a brittle failure (Figure 4 left). In the case of the MMA treated wood, the break is confined to the outer surface and failure is more in the longitudinal direction (Fig 4 right). This indicates that the MMA polymer is acting as a reinforcing element in the longitudinal direction.

Dyes can be added to change the color of the impregnated wood with the darker browns the most popular (see Figure 4). Oak and maple are often dyed to resemble walnut. The

PMMA is resistant to aliphatic hydrocarbons, cycloaliphatic compounds, fats and oils, and also to weak acids and bases at temperatures of up to 60 ºC. The resistance to weathering of PMMA is very good. PMMA ignites very quickly and burns with a blue glow, even outside the flame, and crackles with white spurts. PMMA has good insulating properties, a high dielectric strength and high tracking resistance. PMMA is naturally transparent and colorless. The transmission for visible light is 92%. The refractive index is 1.492 for PMMA. There are types that transmit UV rays, and types that absorb it almost completely, as a result of which sensitive dyes on painted surfaces behind are protected from fading.

Fig. 4. Various dyes can be added to change the color of the impregnated wood.

Hobbyists are also using the Vazo® system to treat wood laminates to be used for knife handles. Veneers are treated with MMA and a dye to give veneers of different colors which are laminated into custom knife handles (see Figure 5).

Fig.5. Veneers can be treated with MMA and a dye in order to obtain various colors that are laminated into custom knife handles.

CONCLUSION

There will always be a need to harden wood for some speciality applications such as floors used for heavy equipment, truck beds, commercial flooring, scratch resistant furniture and recreational equipment. The technology used today to accomplish this is the use of acrylic monomers.

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A BETTER UNDERSTANDING OF THE MODE OF ACTION OF FURFURYLATED WOOD

Pilgård, A.[1], Alfredsen, G.[2]

ABSTRACT

A range of studies the last decade has shown that modified wood can provide excellent protection against a range of wood deteriorating organisms, including decay fungi. However, we still lack information about *why* the modified wood is protected from microbial attack. An understanding of the mechanisms utilized by decay fungi when exposed to modified wood is important for further optimisation of new modified wood products. Several hypotheses have been put forward, but they still need testing.

The aim of this study was to summarize our earlier studies using molecular methods as a tool for better understanding of the mode of action of decay fungi in furfurylated wood. The studies include laboratory and field evaluations of decay colonisation patterns and gene expression.

For studying growth dynamics in furfurylated, CCA, Cu-HDO and untreated Scots pine sapwood the white-rot fungus *Trametes versicolor* qPCR was used. Incubation time was 2, 4, 6, 8 and 10 weeks. While the fungal colonisation in untreated control samples showed a continuous increase during the experimental period, the amount of fungal DNA in the treated samples had an initial peek after two weeks, followed by a gradual decline.

Stakes run for 6 years according to EN 252 were used for colonisation pattern studies. Results from chemical- and molecular methods together with microscopy analysis were compared. The results from the different evaluation methods indicated that the qPCR method is more sensitive than the other methods tested.

Gene expressions of the brown rot fungus *Postia placenta* after 2, 4 and 8 weeks were studied in furfurylated and untreated Scots pine sapwood under laboratory conditions. The main finding was that genes related to oxidative metabolic activity was higher in furfurylated wood compared to untreated Scots pine, and that carbohydrate metabolism related expression was lower in furfurylated wood compared to untreated control.

Also other studies revealing knowledge of the mode of action of furfurylated wood are discussed.

Key words: Fungal colonization, furfurylation, gene expression, mode of action, quantitative real-time PCR.

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INTRODUCTION

The area of wood protection is in a period of change. New wood protection systems have been developed while their mode of action remains insufficiently understood. The development of molecular methods provides potential tools to investigate the interaction between modified wood and decay fungi. An understanding of the mechanisms utilized by decay fungi when exposed to modified wood is important for further optimisation of new modified wood products. The fungal mode of action in wood preserved with heavy metals and fungicides is completely different than in modified wood. The traditional preservatives were working because they were toxic, while e.g. modified wood per definition is non-toxic. A range of studies the last decade has shown that modified wood can provide excellent protection against a range of wood deteriorating organisms, including decay fungi. However, we still lack information about *why* the modified wood is protected from microbial attack. Some general theories of mode of action in modified wood have been put forward (Hill 2006): The equilibrium moisture content (EMC) is lowered, physical blocking of the entrance of decay fungi to e.g. micropores of cell walls and inhibition of action of specific enzymes.

Furfurylated wood is wood modified by reacting furfuryl alcohol (FA) inside the wood structure. Since early 2000s, commercial products based on furfurylation have been on the market, and the need for better understanding of the process is still warranted (Lande 2008). Venås (2008) showed that a dose response relationship in decay resistance can be obtained. It is still unclear if chemical bonds can be formed between the FA polymer and the wood as hypnotized by Lande *et al.* (2004). Nordstierna et al. (2008) supports the theory of a chemical bound of FA to lignin. Thygesen *et al.* (2009) showed that a higher amount of FA was located in the lignin-rich parts of the cell wall. Experiments by Venås (2008) indicated that an analytical method based on enzymatic hydrolysis and high-performance anion exchange chromatography (HPAEC) may be a viable tool for further investigations regarding decay protection mechanisms in modified wood. However, there are still considerable knowledge gaps with regard to the mode of action of modified wood.

The aim of this study was to summarize our earlier studies using molecular methods as a tool for better understanding of the mode of action of decay fungi in furfurylated wood.

MATERIAL AND METHODS

Early stages of fungal colonization (Alfredsen *et al.* 2008)

Miniblock sized samples (Bravery 1979) were prepared from furfurylated, thermally modified and acetylated Scots pine (*Pinus sylvestris* L.). As reference and control Cu-HDO and untreated samples were used. The samples were inoculated with the *Trametes versicolor* (synonym *Coriolus versicolor*). Replicates were harvested after 2, 4, 8 and 10 weeks of incubation. Fungal biomass was quantified using real-time Polymerase Chain Reaction (qPCR) as described in Eikenes *et al.* (2005) with slight modifications.

Colonization pattern in EN 252 stakes after 6 years (Pilgård et al. 2009)

EN 252 stakes were harvested after six years. All wood samples were from Scots pine; furfurylated with two different treatment levels (both were lower than 25 WPG), Cu-HDO and Scots pine heartwood.

All stakes were visually rated according to the EN 252 standard. Samples were taken from three different parts of the EN 252 stakes; 1 cm from the bottom (below ground level), from the soil-surface region and 3 cm from the top (above ground level) (Fig.1). Each of these three parts was then divided, vertically, into three segments for further analysis. A lamella of 1 cm was taken out from the middle part of each of these three samples in horizontal direction.
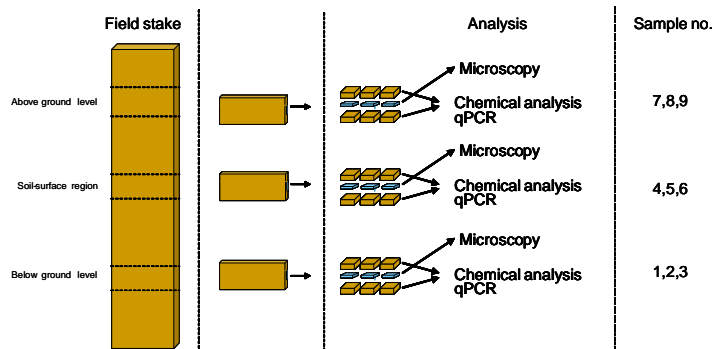
Figure 1. Preparation of wood samples

Results from one sample below ground level (sample 2) and one sample from the soil-surface level (sample 5) are presented in this paper. To assess the degradation level, all samples were analysed with qPCR, ergosterol and chitin and TGA assays. Copper analysis were preformed on the two stakes impregnated with a copper organic preservative. The lamella samples were evaluated in a light microscope.

Postia placenta gene expression (Alfredsen _et al._ 2009)

Miniblock samples were prepared from furfurylated Scots pine sapwood and Scots pine sapwood as control. The samples were inoculated with _Postia placenta_. The incubation time was 2, 4 and 8 weeks. RNA was extracted, reversely transcribed and quantified. Seven target genes with different functions in the fungal metabolism and 2 endogenous control genes were tested.

RESULTS

Early stages of fungal colonization (Alfredsen _et al._ 2008)

The fungal colonisation in untreated Scots pine control samples increased during incubation. Among the included wood modifications thermally treated wood showed the highest and furfurylated wood the lowest amount of _T. versicolor_ DNA throughout the test. The trend among the wood modifications was a decrease in fungal DNA after a peak at week 2. In the following weeks the DNA amount declined to a level that was roughly half of the amount observed after two weeks of incubation. In traditional wood

preservation systems (Cu-HDO, CCA) the fungal colonisation trend was quite similar to that observed in modified wood, except that the amount of fungal DNA declined more drastically in these copper-based treatments than in modified wood.

Colonization pattern in EN 252 stakes after 6 years (Pilgård et al. 2009)

After 6 years in the field, the EN252 (1989) stakes were rated according to the EN 252 standard (Table 1).

Table 1. Rating of EN 252 stakes (according to EN 252 standard) after 6 years in field, using a scale from 0-4, where 0 is no visible attack and 4 is failure.

Wood material	Rating after 6 years in EN252
Modified wood material	
Furfurylated Scots pine (low treatment level) sample 17	3
Furfurylated Scots pine (low treatment level) sample 18	2
Furfurylated Scots pine (medium treatment level) sample 18	1
Furfurylated Scots pine (medium treatment level) sample 28	1
Reference Use class 3 retention	
Copper organic wood preservative sample 5	0
Copper organic wood preservative sample 10	4
Control	
Scots pine heartwood (medium level of pinosylvin) sample 154	3
Scots pine heartwood (high level of pinosylvin) sample 10	1

The highest amount of fungal DNA, ergosterol and chitin was found in the sample rated as 4 (Cu-HDO sample 10). As expected, a lower amount of DNA was found in the samples rated as 3 and 2 and even lower in the ones rated as 1 and 0. Generally the samples rated as 3 and 2 had low amounts of ergosterol and chitin. The results from the TGA showed that the below ground sample rated as 4 (Cu-HDO sample 10) had the lowest cellulose content. For the samples rated 4, 3 and 2, a clear difference could be seen in the amount of fungal DNA detected in below ground samples of the stakes as compared to the soil-surface samples. This difference could not be detected with the ergosterol and chitin assays which may indicate that the qPCR method is more sensitive.

Postia placenta gene expression (Alfredsen *et al.* 2009)

Based on gene expression changes observed in this pilot study, oxidative metabolic activity is likely *higher* in samples of furfurylated wood compared to untreated control after 2 and 4 weeks. Carbohydrate metabolism is likely *lower* in mini block samples of furfurylated wood compared to untreated control after 2 and 4 weeks. After 8 weeks of inoculation the metabolic activity in untreated samples seemed to drop.

DISCUSSION

In a TMC (modified ENV 807) trial with three different soil types Westin and Alfredsen (2007) found that FA modifications had the highest mass loss in forest soil even though this soil generally was the least virulent soil. This soil had the highest water holding capacity, the lowest pH and was dominated by white rot fungi. Pilgård *et al.* (2009) found that qPCR was the most sensitive method for detection of wood decaying fungi also in field trials. Both visual evaluation and biochemical methods found an effect of

treatment level and FA, the highest treatment level had lowest fungal colonization. All six sub-samples from the two stakes that were furfurylated to a low treatment level were degraded by mainly soft rot fungi, but also white rot fungi and tunnelling bacteria were present in some of the samples. Only one of the six samples from the two stakes that were furfurylated to a medium treatment level had a slight visible biological degradation. The remaining 5 samples had no visible degradation. Brown rot were found both in the Cu-HDO treated samples and in Scots pine heartwood, but not in the furfurylated samples.

The hypothesis put forward by Hill (2006) regarding the mode of action of modified wood is also valid with regard to furfurylation. The equilibrium moisture content (EMC) is lowered in modified wood, and hence it is more difficult for fungi to get the moisture required for decay. This theory has gained a lot of support and seems to be valid for all the most established wood modification methods. EMC is reported to be lowered by 30-50% with moderate FA-treatment intensities (Epmeier *et al.* 2004) although some variability is observed in different trials (Epmeier *et al.* 2007). Westin (2004) found dimensional stability in furfurylated wood to be significantly improved (30-70 % ASE). Goldstein (1955) reported the anti-swelling efficiency (ASE) of furfurylated Idaho white pine to be in the range from 41 to 70 % when the weight percent gain (WPG) varied from 17 to 120 %. Lande *et al.* (2004) found similar tendencies, when the WPG varied from 15 to 125 % the ASE ranged from about 30 % to about 75 %. Hence, these findings seem to be consistent even though chemical formulations and wood species varied. Venås (2008) indicated that furfurylation levels about 25 WPG might represent some sort of threshold value for furfurylated wood with regard to decay resistance and moisture balance. This threshold is supported by the findings in Alfredsen and Westin (2009). They found no obvious effect of increasing WPG (treatment levels were from WPG 20 and higher) in lab and field trials.

The second mode of action hypothesis is related to inhibition of action of specific enzymes. The hydroxyl groups in the cell wall and/or in the lumen could, according to this theory, be substituted with other groups in modified wood. This may lead to the fact that the enzymes no longer recognize the substrate. It is still unclear if chemical bonds can be formed between the FA polymer and the wood. Lande *et al.* (2004) suggested that lignin and polymerized FA are covalently bond in furfurylated wood, and this theory was supported by Nordstierna et al. (2008) using NMR on lignin model compounds. Thygesen et al. (2009) found that a higher amount of FA was located in the lignin-rich parts of the cell wall and that the molecular weight was higher at these parts. This might support grafting of the FA polymer to lignin. Venås (2008) indicated that moderately furfurylated wood was recognized as a substrate by hydrolytic enzymes with activities resembling those of wood destroying fungi thereby establishing that if adequate moisture is present the substrate will be hydrolysed. He further stated that the accessibility of carbohydrates was reduced markedly which offers a protective effect. He also found that leachates from furfurylated wood were substrates for laccase-catalysed oxidation. Results from the gene expression pilot study (Alfredsen *et al.* 2009) indicate that *P. placenta* changes its metabolism in furfurylated wood compared to untreated Scots pine. The oxidative metabolic activity (laccase-like, peroxidise-like and alcohol oxidase) was higher in furfurylated wood compared to untreated control while carbohydrate metabolism (endoglucanase, β-glucosidase) was lower in furfurylated wood compared to untreated control. This supports the findings by Venås (2008). If this is due to chemical change of the wood or change of carbon source is still unrevealed. Venås (2008)

hypothesised that the reduced accessibility of carbohydrates most likely is mainly due to cell wall bulking. It could also be explained by inhibition of action specific enzymes.

The third hypothesis is that wood modification results in physical blocking of the entrance of decay fungi to e.g. micropores of cell walls. This theory can contribute to explain the mode of action for e.g. lumen filling modifications, but cannot explain methods like acetylation or thermal modification. In Alfredsen *et al.* (2008) the low amount of fungal DNA in furfurylated wood, compared to the other modifications, might be due to the polymerisation of the furfuryl alcohol in the wood. This polymerisation might result in a physical blocking in the wood cell wall. The polymerization might also encapsulate the wood polymers, making them less accessible for *T. versicolor*. These two assumptions would be compatible with the normal growth modus of white rot fungi which involves enzymatic degradation of the cell wall by hyphae attached to the S3 wall within cell lumen. As mentioned above, Venås (2008) hypothesise that the reduced accessibility of carbohydrates in his experiment most likely was due to cell wall bulking, but this remains to be investigated.

It is of great importance to remember that the three above mentioned hypotheses do not exclude each other. All can be true for one modification. However, there are still considerable knowledge gaps with regard to the mode of action of modified wood.

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ALTERNATIVE SYSTEMS FOR WOOD PRESERVATION, BASED ON TREATMENT WITH SILANES

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ABSTRACT

One of the biggest drawbacks of using European native wood species as a construction material is its tendency to degrade by fungal attack. This has lead to the development of different systems for wood preservation. Many of these systems suffer the disadvantage that they contain biocides, which can leach from the wood into the environment and damage organisms.

In this project ten silanes, 3-(2-Aminoethylamino)propyltrimethoxysilane, 3-[2-(2-aminoethylamino)ethylamino]propyltrimethoxysilane, 3-Aminopropyltrimethoxysilane, Diethoxydimethylsilane, Dodecyltriethoxysilane, Hexadecyltrimethoxysilane, N-Trimethoxysilylpropyl-N,N,N-trimethylammoniumchloride, Octyltriethoxysilane, Octyltrimethoxysilane and Phenyltrimethoxysilane, have been investigated for their ability to increase the hydrophobicity of wood and decrease shrinking and swelling, and thus increase its ability to withstand attack by fungi. In the initial phase of the project two solvents, ethanol and water were investigated to find out which of these that gave the best result for surface modification with silanes. The results showed that water as solvent gave a surface with higher hydrofobicity than when ethanol was used as solvent.

The samples treated with water as the solvent gave better surface modification, Therefore, only water was used for pressure impregnation.

It has been shown by FT-IR-spectroscopy that the silanes binds to hydroxyl groups in the wood structure.

The systems which have given the best indications to be suitable as wood preservatives after measuring of contact angles are octyltrethoxysilane, 3-(2-aminoethylamino)-propyltrimethoxysilane, 3-[2-(2-aminoethylamino)ethylamino]propyltrimethoxysilane and 3-aminopropyl-trimethoxysilane. The three last systems contain amine groups, which acts as a biocide and may be able to stop the fungi.

Key words: Contact angles, FT-IR-spectroscopy, silanes, wood preservation.

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INTRODUCTION

There has been developed a variety of systems for wood preservation to cope with the tendency of European native wood to degrade by fungal attack when it is used as a construction material. Traditional systems for wood preservation have lately been based on copper compounds. The effectiveness of these systems is due to the fact that copper is a biocide and will therefore kill the fungi. The main drawback with these systems is that the compounds are able to leach out from wood and pollute the environment and kill other organisms. Because of this it has been suggested that these systems shall be phased out. It is therefore necessary to develop other systems that can protect wood from attack by fungi.

For wood to be attacked by fungi three factors must be present, water, oxygen and nutrients. To prevent attack by fungi it is necessary to remove one of these factors. Access to oxygen will in most cases be difficult to do anything with, while the access to water and nutrients is possible to reduce (Hill 2006). The approach chosen in this study is to make the wood hydrophobic to reduce the access to water.

The systems investigated here are based on silanes functionalized with different side groups. Silanes have earlier been used with success for making glass hydrophobic (Mørk 2004), they have also been used on textiles. Based on the similarities between cotton in textiles and cellulose in wood, it is reasonable to assume that silanes can be used to make wood hydrophobic (Weigenand 2006).

Silanes are unstable in water, they will be hydrolyzed to silanoles which in turn will condensate into three dimensional structures (Donath et al. 2006). The general reactions for the hydrolysis and condensations for silanes are shown in the following equations.

Hydrolysis:

$$\equiv SiOR + H_2O \rightarrow \; \equiv Si\text{-}OH \; + \; ROH \tag{1}$$

Water condensation:

$$\equiv Si\text{-}OH \; + \; \equiv Si\text{-}OH \; \rightarrow \; \equiv Si\text{-}O\text{-}Si \equiv \; + \; H_2O \tag{2}$$
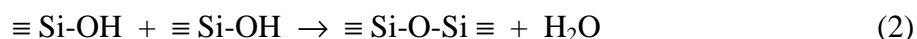
Alcohol condensation:

$$\equiv Si\text{-}OR \; + \; \equiv Si\text{-}OH \; \rightarrow \; \equiv Si\text{-}O\text{-}Si \equiv \; + ROH \tag{3}$$
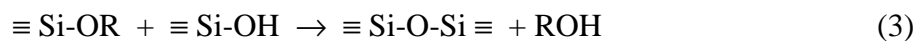
R is here an alkyl group on the form C_xH_{2x+1}.

The silanes used here are di- and tri-functional, which means that one or two of the Si-OR bonds are replaced by Si-X bonds where X is a functional group with desired properties.

MATERIAL AND METHODS

The treatment of the wood samples was preformed in two rounds, one was a surface treatment and the other was as a pressure impregnation. The surface treatment was done to investigate which solvent gave the largest increase in contact angles. The solvents used were water and ethanol, with a concentration of silanes of respectively 0.25 M and 0.025 M. The wood samples were fastened in a test tube and submerged in the solution. The test tube was then placed in a sealed plastic bottle which was placed in a hot box for 20 hours at 100°C for water as solvent and 80°C for ethanol as solvent. After the heat treatment the samples were washed with pure solvent to remove any remnants. They were then air dried over night.

For the pressure impregnation only water was used as solvent (since ethanol as solvent did not give as good results as when water was used). The same concentration as for the surface treatment was used. The samples was placed in plastic beakers and submerged in the solution. The beakers were filled with an excess of solution to allow for the samples to stay submerged as the solution penetrated into the samples. The beakers were placed in an autoclave where they first were exposed to vacuum (4 kPa) for an hour and then pressure (0.8 MPa) for 2 hours. After this treatment the samples with the solutions were transferred to plastic beakers which were sealed with lids. They were then placed in a heating chamber for 20 hours at 100°C.

After the treatment the contact angle between the sample and water was measured for all the samples. This was done with a "CAM 200 Optical Angle Meter". The contact angle was measured by the goniometer method, where a drop of fluid is placed on a surface and the contact angle is determined as the angle between the surface and the tangent of the drop surface (Mørk 2004). The contact angle was also measured for untreated samples.

It was also performed FT-IR-spectroscopy on all the treated samples and on untreated samples. The FT-IR-spectrophotometer used was "Bruker Tensor 27", with a D316/B MCT detector. The software was supplied by OPUS.

A list of the silanes used is given in table 1.

Table 1. Silanes used for treatment of the wood samples

Compound	Name
1	3-(2-Aminoethylamino)propyltrimethoxysilane
2	3-[2-(2-Aminoethylamino)ethylamino]propyltrimethoxysilane
3	3-Aminopropyltrimethoxysilane
4	Diethoxydimethylsilane
5	Dodecyltriethoxysilane
6	Hexadecyltrimethoxysilane
7	N-Trimethoxysilylpropyl-N,N,N-trimethylammoniumchloride
8	Octyltriethoxysilane
9	Octyltrimethoxysilane
10	Phenyltrimethoxysilane

RESULTS AND DISCUSION

The first part of this study was to determine which silanes and solvents that gave the largest increase in contact angles. The contact angel was used as a measurement to determine whether the treatment had made the samples more hydrophobic. The results from these measurements can be seen in table 2.

It is a trend that water as solvent gives a larger increase in contact angle than when ethanol is used. The results from the FT-IR-spectroscopy, given i table 3, showed a reduction in the area indicating C-O stretch compared to a untreated sample as the only indication of silanes bonding to the wood structure when ethanol was used as solvent. The results from when water was used showed new peaks in the area indicating alkanes for the 9 first compounds and in the area indicating aromatics for compound 10. For compounds 5, 6, 8, 9 and 10 new peaks in the area indicating Si-O bonds were also detected. New peaks indicating Si-C bonds were detected for compounds 5, 6, 8 and 10. Based on these results it was decided only to use water as solvent for the pressure impregnation.

Table 2. Results from measurements of contact angles

Compound	Surface treatment		Pressure impregnation
	Ethanol	Water	
1	106.9 ± 11.8	116.2 ± 6.0	135.5 ± 11.0
2	-	121.2 ± 13.0	140.1 ± 14.0
3	-	106.1 ± 6.3	148.6 ± 10.5
4	106.6 ± 9.8	127.8 ± 15.7	135.9 ± 12.4
5	118.2 ± 16.8	134.9 ± 14.3	129.8 ± 16.1
6	122.7 ± 5.7	132.9 ± 5.6	129.2 ± 11.3
7	103.4 ± 3.2	123.1 ± 5.0	136.6 ± 13.6
8	122.5 ± 13.0	135.0 ± 15.4	141.5 ± 11.0
9	113.7 ± 6.4	127.7 ± 6.0	134.1 ± 10.7
10	109.1 ± 8.7	98.7 ± 14.0	103.2 ± 9.9
Untreated		90.4 ± 14.5	

The pressure impregnated samples showed the same pattern for increased contact angles as for the surface treated samples, they are however somewhat higher. This can possibly be explained by the fact that the pressure treatment has made the silanes penetrate deeper into the wood matrix and thus enabling them to bind to more hydroxyl groups. The relatively large standard deviations can be ascribed to the heterogenic nature of the wood surface.

Three of the systems used here contain amines, these compounds act as biocides. Considering the incentives for developing new systems for wood preservations that do not harm the environment, the use of these compounds can seem contradictory. However the idea behind these systems is that they bind directly to the wood structure which may prevent that they leach into the environment, and thus show no biocidal effect. In addition these systems are among the systems with the largest increase in contact angles after the pressure impregnation.

Table 3. Summary of the changes found with FT-IR-spectroscopy for the treated samples compared to untreated

Compound	Treatment	Wave number [cm⁻¹]							
		1040-1150	1200-1450	2850-2970	1340-1470	900-1300	600-900	700-850	~1600
1	Surface EtOH	Reduction							
	Surface water	Reduction							
	Pressure impregnation	Reduction		2850 2915					
2	Surface EtOH	-	-	-	-	-	-	-	-
	Surface water	Reduction							
	Pressure impregnation	Reduction		2850 2915					
3	Surface EtOH	-	-	-	-	-	-	-	-
	Surface water	Reduction							
	Pressure impregnation	Reduction		2850 2915					
4	Surface EtOH	Reduction							
	Surface water	Reduction							
	Pressure impregnation	Reduction	1255	2850 2915 2950		1255	790	790	
5	Surface EtOH	Reduction							
	Surface water	Reduction		2850 2915			720	720	
	Pressure impregnation	Reduction		2850 2915			720	720	
6	Surface EtOH	Reduction							
	Surface water	Reduction		2850 2915	1460		720	720	
	Pressure impregnation	Reduction		2850 2915	1460		720	720	
7	Surface EtOH	Reduction							
	Surface water	Reduction		2850 2915					
	Pressure impregnation	Reduction		2850 2915					
8	Surface EtOH	Reduction							
	Surface water			2850 2915			720	720	
	Pressure impregnation	Reduction		2850 2915			720	720	
9	Surface EtOH	Reduction							
	Surface water			2850 2915	1455		680		
	Pressure impregnation	Reduction		2850 2915			680		
10	Surface EtOH	Reduction							
	Surface water	Reduction			1430		693 720	720	1590
	Pressure impregnation	Reduction			1430		693 720	720	1590
Indication of:		C-O stretch	OH-bend	Alkane	Alkane	C-O stretch	Si-O	Si-C	Aromates

The systems containing ethoxy groups instead of methoxy groups do not seem to be sterically hindered because of the increased molecular size. This can be seen from the FT-IR-results as well as from the measurements of the contact angles.

Octyltriethoxysilane is among the systems with the highest contact angles after the pressure impregnation.

The systems that look the most promising are octyltriethoxysilane, 3-(2-aminoethylamino)propyltrimethoxysilane, 3-[2-(2-aminoethylamino)ethylamino]propyl-trimethoxysilane and 3-aminopropyltrimethoxysilane. Octyltriethoxysilane has in the entire test been among the systems with the highest contact angles, and has been proven bound to the wood structure by FT-IR-spectroscopy. The three last systems are biocidic which means that they may be able to stop the fungi. They are also proven bound by FT-IR-spectroscopy and they are among the systems with the highest contact angles after the pressure impregnation. Since they are bound to the structure they may be prevented from leaching out into the environment.

Compared to earlier studies (Donath et al. 2006) silanes with longer hydrocarbon chains have been used in this study. The results have shown the same tendency to make wood more hydrophobic.

Further test that will be done is to investigate the degree of decay by fungi for samples treated with the different silanes, for both leached and unleached samples. The leaching of the samples will be used to investigate whether the silanes can leach out into the environment.

CONCLUSIONS

The preliminary tests showed that water was better suited as solvent for the modification procedure than ethanol, as it gave larger increase in contact angles. This was also evident from the results obtained by the FT-IR-spectroscopy, showing clearer indications of silanes bound to the wood structure.

The results from the pressure impregnation followed the same pattern as the preliminary test, but with an even bigger increase in contact angles, probably due to deeper penetration of the silanes into the wood matrix allowing them access to more hydroxyl groups to bind to.

The results from the different treatments showed that silanes can be used for making wood more hydrophobic. This happens as silanes bind to hydroxyl groups in the wood structure, which was proven by FT-IR-spectroscopy.

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DRYING OF SOFT- AND HARDWOODS IN OIL UNDER VACUUM

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ABSTRACT

Plant oils have significantly higher thermal conductivity than air, thus conducting heat more effectively to the surface and into wood. Although known for long time, drying in oil under vacuum is underestimated and the information on this type of drying is scarce. The objective of this study was to investigate the suitability of oil drying under vacuum for three wood species using cheap and available plant oil.

Boards of Scots pine, Norway spruce and oak wood with thickness of 26 mm and high initial moisture content (100-130%) were dried in rapeseed oil at temperature of 60-90ºC and under permanently or alternately applied vacuum. Final moisture content, distribution of moisture along the thickness of samples, internal stress, modulus of elasticity (MOE) and oil uptake were measured for the studied wood species. Scots pine and spruce boards were dried to 12% moisture content with negligible degradation for 12 h. The drying dynamic differs significantly from that of conventional kiln drying, e.g. the drying curves show only constant drying rate. The drying times were compared to that calculated by a drying model and it was concluded that drying in oil under vacuum is 4-5 times faster. MOE of the oil dried samples was measured by a static method and compared to air dried control samples. Oil drying had no negative effect on the MOE. The uptake of oil was in the range of 40-90 kg/m^3. The tests showed that drying in oil is a promising process for softwood timber providing short drying time and insignificant degradation.

Use of oils as water repellent impregnation agents has industrial potential and is an environmentally friendly alternative to the traditionally employed chemical wood protection. The method facilitates further impregnation of wood with modified oils.

Key words: drying quality, Norway spruce, oak, rapeseed oil, Scots pine

INTRODUCTION

Development of faster and better methods for drying of wood is a continuous activity. Only several of the existing methods are of industrial importance, e.g. conventional kiln drying, high temperature and vacuum drying. Kiln drying is the most common drying

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method to commercially dry timber at present time. It is a fast and economical way but it can take many weeks up to months to ensure a good drying quality. Limited interest from the industry has slowed down the development of new methods. Nevertheless, one drying approach with great potential is drying of wood by boiling it in oily liquids. Wood can be dried rapidly by immersing into a water-repelling liquid which has a boiling point considerably above that of water and which is maintained at a temperature high enough to vaporize water (Kollmann and Côté, 1984).

The first process based on the above mentioned method was so-called Boulton process patented in England in 1879 and in the USA in 1881. Boulton (1881) developed the drying process as a part of treating wood with preservative formulation. Heat has been applied by immersing timber in hot oily liquid. Boulton applied a constant vacuum to efficiently evaporate water from timber at significantly lower temperature compared to normal atmospheric pressure that was common in conventional drying kilns. The US Forest Products Laboratory reported one commercial test with green southern pine timber which was dried by boiling-in-oil process. The timber was dried from an average moisture content of 77 to 22% in 16 h. The report also presented a few problems like checking, honeycombs and casehardening after drying (Mc Millen, 1961). Analogously Hager (1971) presented a wood treatment method (Royal process) consisting of boiling-in-oil drying process for impregnated timber. After the impregnation treatment when the solution has been pumped out from the cylinder, a high-boiling liquid (oil) has been introduced. Today, the boiling-in-oil process is limitedly used in combination with preservative treatments and still known as Royal process. Grothe (2007, unpublished material) dried green wood by immersion in oil under vacuum. His study has shown very interesting results, especially for drying pine and spruce. Samples of pine, spruce and oak have been dried in a closed cylinder under vacuum and a temperature of 80°C. The samples of pine and spruce have been shortly dried without severe degradation to moisture content below 20%. The oak samples were severely degraded and insufficiently dried. The present study is a continuation and altered parameters, e.g. samples dimensions, process temperature and oscillation of vacuum were targeted to investigate their effect on the timber drying quality. The maim objective of the study was to deeply investigate oil drying under vacuum and to gain more practical experience.

MATERIAL AND METHODS

Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* Karst.) boards were purchased as fresh as possible from local sawmills near of Uppsala. Oak (*Quercus robur* L.) boards were purchased earlier and stored in a freezer (-20°C). Four samples with dimensions $26 \times 100 \times 320$ mm for pine and spruce and $28 \times 100 \times 320$ mm for oak were cut from each board. Two of the samples were selected for oil drying test while the other two samples were air-dried in room climate (20 °C, 65% RH) to serve as controls. The samples intended for drying were end-coated with a commercial polyurethane glue to avoid moisture losses from the ends and to simulate longer boards during drying. The samples were stored in a freezer to avoid moisture losses. The pine and spruce samples consisted mainly of sapwood and the oak samples of heartwood. Some samples had small knots and resin pockets. Some spruce samples had insect holes as well. The initial moisture content was calculated according to standard DIN 52183 and the density according to DIN 52182. The samples were dried in a cold-pressed rapeseed oil.

The drying was performed in a small test plant at the Swedish University of Agricultural Sciences, Department of Forest Products. The test plant consists of two cylinders, equipped with heating elements and connected through numerous pipes and valves. A vacuum pump was attached to the system. A flask was connected between the upper cylinder and the vacuum pump. The flask was placed on a balance and cooled with ice to condense and collect the evaporated water. The temperature during the drying process was measured by a data logger (Intab Interface AAC-2) and four thermo-couples. One couple was placed in the upper cylinder to measure the temperature of the heating oil. The second couple was placed in the lower cylinder for measuring the temperature of oil during drying. The other two couples were placed in drilled openings in one of the wood sample; one couple was placed approximately 1mm underneath the flat wood surface at depth of 1.5 cm while the other one was placed in the wood core at depth of 3.0 cm. The target moisture content was 12%. For each sample, the amount of water which had to be evaporated was calculated by the initial moisture content and the dry weight measured by two slices taken close to the ends of samples. The samples were placed in a cache of mesh wire in the lower cylinder. The lower cylinder was closed and heated up. The upper cylinder was filled with oil which was heated up to 80°C. When the temperature in the wood core compassed 10-20°C the oil was sent to the lower cylinder to initiate the drying process. Vacuum was applied after the oil had filled the lower cylinder. The oil temperature was gradually increased from 60-65°C up to 85-90°C. The temperature in the upper cylinder was kept up to 90-120°C to facilitate the removal of the evaporated water. The evaporated water was weighed at equal intervals to calculate the wood moisture content. After the target moisture content was achieved or when no water bubbles came out of the wood, the oil was discharged. A final vacuum was applied for 20 min to recover oil from the sample surface. In some tests, final conditioning was performed in a laboratory kiln (85°C, 94% RH, 2 h). After drying and conditioning samples for measuring the final moisture content, moisture content distribution along the thickness and internal stress were cut. The internal stress was measured according to standard ENV 14464. Two types of drying were studied, i.e. one with constant function of the vacuum pump and one with alternate function (Table 1.). During alternate function the pump was switched on and off at 10 min intervals. The system was closed when the pump was switched off to avoid interruption of the drying. The oil uptake was calculated by the difference between the amount of the initial oil and the recovered oil corrected by 10 g (the amount of oil remaining in the cylinder and pipes). After drying the samples were stored in room climate (20°C, 65% RH) for four weeks and the module of elasticity (MOE) was measured. Pairs of one control and one oil dried sample from the same board were chosen to compare the MOE that was measured by the three-point-bending method according to standard ISO 3349.

RESULTS AND DISCUSSION

Scots pine and spruce samples were dried below the target of 12% moisture content in an impressively short time in all tests (Table 1.). Due to severe internal stress the drying of oak was stopped after a certain time (8.5 h). The reason for this occurrence might be the long storage of oak wood in the freezer. The alternate working of the vacuum pump showed better results than the constant working. The alternate schedule decreased the drying time and the oil uptake as well (Table 1. and Fig. 1.). Due to the alternate working, the vacuum pump worked only half of the time, which is an important cost aspect.

Table 1. Drying time, moisture content (MC) and oil uptake

Test nr.	Wood species	Vacuum pump	Conditioning	Average initial MC, %	Average final MC, %	Drying time, h	Oil uptake, kg/m³
1	Pine	constant	-	114	6	12.3	84.5
2	Pine	constant	-	91	5	11.3	90.4
3	Pine	alternate	-	107	10	10.8	41.2
4	Pine	alternate	-	108	12	10.2	83.6
5	Pine	alternate	+	133	10	13.5	52.9
6	Pine	alternate	+	108	9	10.5	52.6
7	Spruce	alternate	+	94	8	8.5	59.5
8	Spruce	alternate	+	103	8	9.2	75.9
9	Oak	alternate	-	55	26	8.5	-

The oil uptake was over 50 kg/m³ for all tests with one exception (test 3). This is not consistent with the data of Hager (1971) who reported an oil uptake of less than 40 kg/m³. The explanation for the high oil uptake might be the low moisture content and the recovery of the oil without vacuum, which was not possible for technical reasons. The low relative humidity and thickness of the vapour layer that surrounded the wood cannot protect the wood at the end of oil drying (Kollmann and Côté, 1984). This facilitates the penetration of the oil into the wood. The oil uptake was observed only at depth of 1-2 mm at the surfaces of samples.

The drying curves for all tests showed a constant drying rate (Fig. 1.a). This is typical for this study and differs significantly from the modelled drying curves of conventional kiln drying (Fig. 1.b). A conventional kiln drying schedules was simulated by the computer programme widely used at the Swedish sawmills (Trätek, TRÄTORK vers. 2.4). The model calculated 54 drying h from 100 to 12% final MC. The drying terms were similar to the parameters of the oil drying with one exception, i.e. the maximal drying temperature was limited to 80°C. The results showed that the time for oil drying was approximately 5 times shorter than for the simulated conventional kiln drying (Fig. 1.a and Fig. 1.b).

All samples showed casehardening after drying, which was measured according to standard ENV 14464. Moisture content distribution along the thickness showed significant gradient which is one of the reasons for casehardening (Fig.2.a and 2.b). After final conditioning (85 °C, 94% RH, 2 h), no casehardening was detected (Table 2. and Fig. 2.a and 2.b).
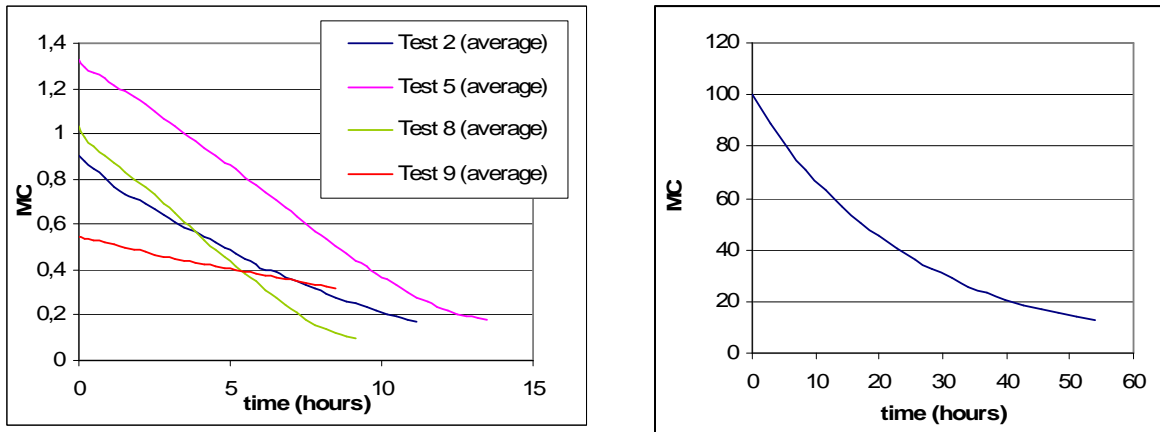
Fig. 1. Comparison of drying rates oil drying (Fig. 1a, right) and simulated conventional kiln drying (Fig. 1b, left).
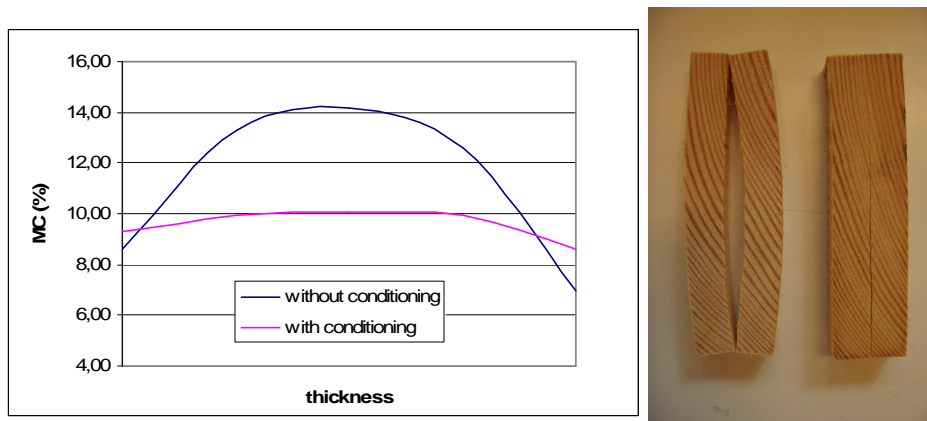
Fig. 2. Moisture content distributions along the thickness (Fig. 2a, right) and internal stress (Fig. 2b, left) before (right) and after (left) conditioning (test 6).

Table 2. Measured gap in mm after drying (average of 4 samples)

Test	1	2	3	4	5	6	7	8	9
without conditioning	2.5	2.0	4.4	4.3	3.0	4.3	3.6	2.7	4.1
with conditioning	-	-	-	-	0.0	0.0	0.0	0.0	-

Only one spruce sample showed radial checks on the ends after drying. The reason might be an incorrect end coating. All other pine and spruce samples were without any checking or honeycombs. This proves that drying in oil is not only a fast drying method but also a method that ensures very good drying quality after conditioning. Due to technical reasons it was not possible to carry out conditioning in the test cylinders but it should not be difficult to combine these two processes. The modulus of elasticity (MOE) was measured to analyse the properties of the samples after drying. No difference between control and oil dried samples were measured. This means that oil drying has no negative effect on the MOE.

CONCLUSION

The present study revealed a number of advantages of the oil drying under vacuum. Both Scots pine and Norway spruce samples with high initial moisture content (100-130%) were dried below the target of 12% moisture content in an impressive time in all tests. Although the casehardening occurred after drying responded to standard drying quality (according to ENV 14464). It was shown that the internal stress could be eliminated by conditioning after drying. It is recommendable that the both methods should be combined to decrease drying time and production cost. In general no checks or honeycombs were observed after drying; only one spruce sample showed radial checks. No valid conclusion could be drawn for the oak samples because they were insufficiently dried and showed severe degradations. Apparently drying of hardwoods in oil under vacuum needs further investigation and definitely another drying schedule. The uptake of oil was in the range of 40-90 kg/m^3 but this consequence is debatable and can depend on the further use of the dried timber. The high oil uptake could also be explained by the fact that too little amount is presumed (not measured) to be left in the drying equipment. A high oil uptake might be good for further impregnation and exterior purposes and a low oil uptake for interior purposes. The results suggested that drying in oil under vacuum has no negative effect on the module of elasticity because the temperature never exceeds 90°C. The drying time in oil under vacuum was approximately 5 times shorter than for the simulated conventional kiln drying. The results confirm the method to be fast and promising; it ensures very good drying quality after conditioning. The alternate working of the vacuum pump showed better results than the constant working. It decreases drying time, oil uptake and eventually costs at commercial use of this method. It is possible that other time ratio of the alternate work of the vacuum pump can lead to a better result, i.e. there is further need for optimisation. This study reveals new data about distribution of moisture along the thickness of the samples, internal stress, modulus of elasticity and drying rates.

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LEACHING OF NEW ENVIRONMENTAL FRIENDLY WOOD PROTECTION AGENTS

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ABSTRACT

New environmental benign wood protection agents often come from natural resources, and are sometimes a waste product. Chitosan, a derivative from chitin which is among other sources a by-product from the shellfish industry, is tested as well as known wood protection agents and their synergetic effect with chitosan.
The objective of the research presented in this paper, is to describe the leaching properties of the following compounds: Chitosan, chitosan/copper, chitosan/boron and chitosan/ScanImp (a commercial wood preservative). A leaching procedure was performed on treated Scots pine sapwood samples. The four solutions have also been tested with and without post treatment. A new effective fire preservative has been included in the test. Common wood preservatives have been tested as references.
The combination with chitosan did improve the fixation of the wood protection agent ScanImp. Furthermore, the post treatment of the chitosan treated samples did significantly reduce the leaching of glucosamine and to some extend also the leaching of boron.

Key words: Leaching, boron, chitosan, copper, Scots pine sapwood.

INTRODUCTION

One of the challenges in wood material sciences is the topic of natural durability and protection of wood. One of the greatest problems in the utilization of most types of wood as construction material is the low resistance against biotic factors. Most European and northern American softwoods in outdoor or humid conditioned applications need to be protected against wood-deteriorating microorganisms such as fungi or bacteria, for example by pressure-impregnating with chemicals or by modifying the wooden matrix. The wood protecting agents developed since the restriction of CCA are copper-organic mixtures, such as ammonium copper quat (ACQ), copper azole mixtures, with or without boron and copper systems (Green III and Schultz, 2003; Schultz and Nicholas, 2003).
Copper is the primary active agent and the lack of chromium and arsenic requires higher concentrations. Since copper itself diluted in water is toxic to aquatic organisms, the new

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agents have only changed the environmental problem, which is not yet solved. Another issue is the disposal of treated wood in general. There is a need to develop non or less toxic wood preservatives which still allow conveying treated wood into energetic processes whenever it is out of use.

This study will try to find ways to improve the fixation of chitosan in wood and to detect possible synergy effects with other protection agents.

Chitosan, a natural polymer, is a nontoxic, edible, and biodegradable deacetylated product of chitin. It is a naturally occurring polysaccharide which has been found in a wide range of natural sources (crustaceans, fungi, insects, annelids, mollusks, coelenterate etc.) (Muzzarelli, 1990). Chitosan is normally manufactured from crustaceans (shrimp, crab, krill and crayfish), primarily because a large amount of the crustacean exoskeleton is available as a by-product of the food processing industries (Brine et al., 1991). Chitosan consists of β-1.4-linked D-glucosamine residues with a variable number of randomly located N-acetyl-glucosamine groups. Chitin is the most abundant natural nitrogen containing polysaccharide, and its annual bio-production is estimated to be almost as much as that of cellulose (Kumar, 2000), at a level of up to 1 – 10 billion tons per year (Ratajska et al., 1997).

Recently chitosan has received much attention as a potential polysaccharide resource owing to its specific structure and properties and it has been studied extensively for industrial applications. Chitosan has proven to minimize fungal attack, however, only a few studies have been conducted on the application of chitosan to wood (Alfredsen et al., 2004; Chittenden et al., 2004; Eikenes et al., 2005; Kobayashi and Furukawa 1995a,b; 1996, Larnøy, 2006, Lee et al., 1992; 1993; Maoz and Morrell, 2004, Raiser et al. 2008). Investigations on the anti fungal behavior related to this research have been published by Raiser et al. (2008).

MATERIAL AND METHODS

Scots pine *(Pinus sylvestris L.)* sapwood from stands in southern Norway was used to produce samples with dimensions 5 x 10 x 30 mm³.

A 5 % chitosan solution was prepared by adding acetic acid until a pH-value of 5.6 was reached. This solution was also used as basis for the other chitosan solutions.

Table 1: Overview over wood protection chemicals used in this research

Solution	description	pH	Concentration (%)
Chitosan (I)	polysaccharide composed of randomly distributed β-(1-4)-linked D-glucosamine and N-acetyl-D-glucosamine	5.6	5.4
Chitosan + Boric acid (II)	Boric acid CAS 10043-35-3	5.4	5.5
Chitosan+Cu (III)	Copper(II)chloride dihydrate (CAS 10125-13-0)	4.6	5.5
Chitosan+ScanImp (IV)		5.6	1.73
ScanImp (V)	Propiconazole-based wood preservative	3.9	1.42
Wolmanit® CX-8 (VI)	Copper-based wood preservative	8.5	4
Fire protection-1 (VII)	Fire protection agent + crossbinder	3.2	-
Fire protection-2 (IX)	Fire protection agent	3.2	-

The Chitosan + Boric acid solution was produced equally to the basic chitosan solution as described above. Additionally, 5 g boric acid (CAS 10043-35-3) was added.
Solution III was produced by adding copper(II)chloride dihydrate (CAS 10125-13-0) to the basic chitosan solution.
Solution IV was produced by mixing diluted solutions of chitosan and ScanImp. ScanImp, a product of Jotun, is a water soluble micro emulsion based on organic biocides. The composition is not official, but the main ingredient is propiconazole.

Wolmanit® CX-8 is a chromium free, copper- and boron-based wood preservative consisting of the 2.80 % Bis-(N-cyclohexyldiazeniumdioxy)-Copper (Cu-HDO), 13.04 % Copper (II) hydroxide carbonate and 4 % boric acid.
Fire protection-1 (VII) and Fire protection-2 (IX) are both developed for fire protection in which their effectiveness has been proven already. Due to fixation problems in former trials (unpublished results) the Fire protection-1 solution was mixed with 2.2'-Azobis (2-methylpropionamidine) dihydrochloride, 97% (CAS 2997-92-4), which was expected to function as a crossbinder. The Fire protection-2 solution is an enhanced version of the Fire protection-1 solution, and was used as supplied by the company.

Impregnation

All solutions were impregnated into the wood samples by using vacuum of 0.004 MPa for 1 h, and pressure of 0.8 MPa (1h).

Post Treatment

Directly after the impregnation, half of all samples impregnated with a Chitosan-solution were wrapped in small plastic bags, sealed and post treated at 85 °C for 20 h. The other half remained in ambient temperature. The samples treated with Fire protection-1 were post-treated at 65 °C for 12 h.

Leaching Procedure

Half of the post treated samples as well as half of the non-post treated sample were subjected to a leaching procedure according to EN 84. They were exposed to a vacuum of 0.004 MPa for 20 min and maintained in the water for 2 hours, before the water was changed the first time. 20 ml of the leaching water was collected from each of the vessels every day for chemical analysis.

Chemical Analysis of the Leaching water

The amount of Glucosamine in the leaching water was determined by high performance liquid chromatography (HPLC) as described by Eikenes et al. (2005).
An Agilent 1100 series liquid chromatograph equipped with a Shimadzu RF-551 fluorescence detector was used for separation at 50 °C on a Zorbax Eclipse XDB-C8 (4.6 x 75 mm, 3.5 µm particle size) with an analytical guard column Eclipse XDB-C8 (4.6 x 12.5 mm, Agilent technologies).
Additionally, the propiconazole of the ScanImp-treated samples was analyzed according to AWPA A 28-99 (1999).

The determination was performed by a simultaneous ICP-AES technique with axial or radial viewing of plasma (Skoog et al. 1998) on a Thermo Jarell Ash ICP-IRIS HR Duo. For sample preservation 0.05 ml of HCL were added to 7 ml sample. The following elements were determined in all leaching water samples: Al, As, B, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si and Zn.

RESULTS AND DISCUSSION

From Table 2 it can be seen that the post treatment of chitosan treated wood samples reduces to a large extent the leaching of glucosamine which is the main component of chitosan. Combining chitosan with boric acid or ScanImp reduces significantly the leaching of glucosamine.

Table 2: Amount of glucosamine in leaching water [µmol/L] of different chitosan treated wood samples after different leaching time (PT = post-treated, NPT= non post-treated)

hours	*Chitosan*		*Chitosan+Boric acid*		*Chitosan+Cu*		*Chitosan+ScanImp*	
	PT	**NPT**	**PT**	**NPT**	**PT**	**NPT**	**PT**	**NPT**
2	1247	6259	61	1175	1058	2892	329	1250
21	2602	6071	314	1493	1557	5815	281	836
47	2289	5070	248	1013	1851	4306	243	880
71	1243	2339	133	450	882	1820	137	385
119	1140	1944	141	476	701	1621	129	356
246	472	574	128	243	200	486	64	117
314	113	109	45	72	45	109	23	32
Sum*	9902	23604	1247	5295	6722	18047	1317	4076

*The sum is calculated by the accumulated amount of glucosamine of 10 leaching water samples. Here are only 7 shown.

Untreated Scots pine sapwood samples leach the elements K, Ca and Mg during 14 days of leaching in water (see figure 4).
The post-treatment of chitosan treated samples had no influence on the leaching of the elements Na, Mg and Ca (only values > 1 mg/l are shown in the graphs). In contrary, the post treatment was effective in order to significantly reduce the leaching of glucosamine (see table 2).

Table 3: Amount of Propiconazole in leaching water [ppm] of different treated wood samples after different leaching time (PT = post-treated, NPT= non post-treated)

hours	ScanImp	Chitosan+ScanImp NPT	Chitosan+ScanImp PT
2	26	12.9	< 1
21	11,3	4.4	< 1
47	15	6.6	< 1
71	10,8	3.7	< 1
119	11,7	3.8	< 1
246	6,3	2.6	< 1
314	3,7	1.9	< 1
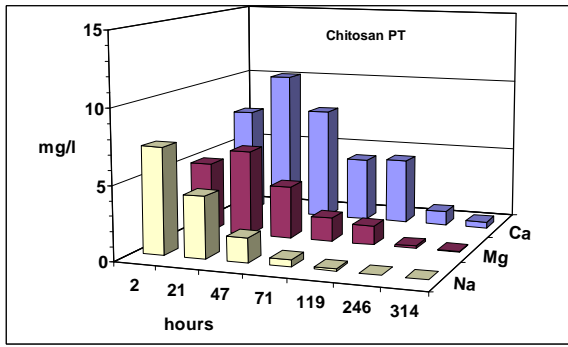
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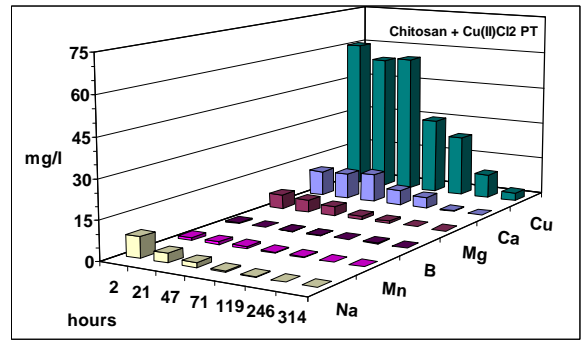
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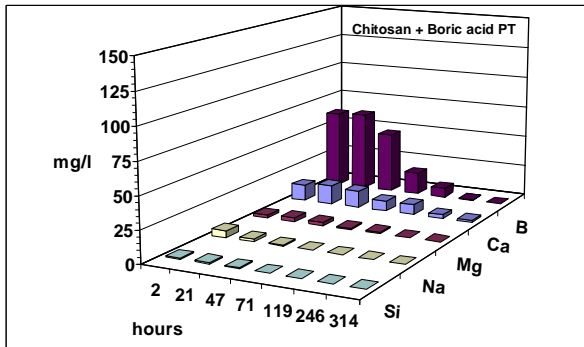
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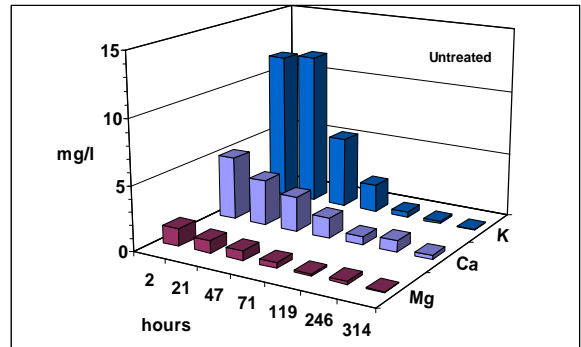
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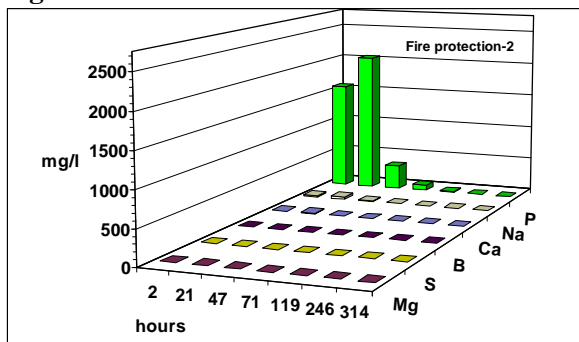
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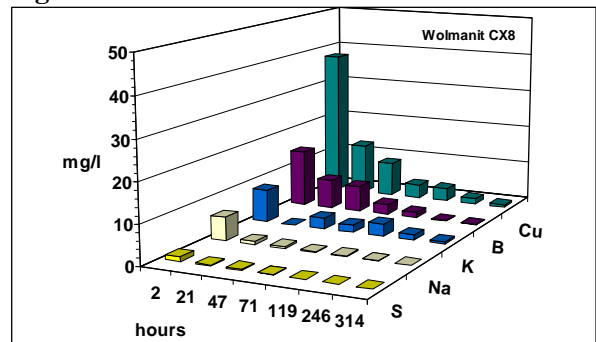
Figure 6

Figure 1-6: Amount of different elements in leaching water during 14 days leaching of different treated wood samples, values < 1 mg/l are not shown in the graphs, figure 1: chitosan treated samples, figure 2: chitosan combined with copper (II) chloride dehydrate, figure 3: chitosan combined with boric acid, figure 4: untreated wood samples, figure 5: fire protection-2-treated wood samples, figure 6: CX8-treated wood samples

The leaching of boron in combination with chitosan is reduced when post- treatment is applied. However, boron is still leached out to a large extend. Nevertheless, in subsequent laboratory fungi trials with the leached wood samples it can be seen that

there is still a reduced mass loss after 9 weeks of exposure to *Coniophora puteana* and even more pronounced for *Trametes versicolor* compared to untreated control samples. The leaching of copper could only be reduced slightly when applied in combination with chitosan (see figure 2, no figure is shown for the non post-treated samples). The leaching of these elements out of non post-treated samples was not significantly different. The anti fungal effectiveness after a 9 weeks fungi test was comparable to the fungi results of chitosan and boric acid treated samples (Raiser et al. 2008).

The combination of ScanImp and chitosan significantly reduced the leaching of Cu, and P; however, the post treatment had no influence on the leaching of these elements. ScanImp treated wood samples leached Cu, Na, Ca and P to small amounts. The analysis of propiconazole shows the positive effect that chitosan has on the leaching of propiconazole. The post treatment of the treated samples further increased the fixation of propiconazole (see table 3).
The fire protection agent 1 and 2 (see figure 5, only fire protection 2 is shown here) showed similar results in leaching. The amount of P in the leaching water is for both substances very high and could not be reduced by the cross binder. However, a high fungal effectiveness can be seen in subsequent trials on fungal decay of the treated samples for both, leached and non-leached as well as post-treated and non post-treated samples.

CONCLUSIONS

- The synergetic effect of chitosan and ScanImp reduces the leaching of propiconazole
- With an additional post treatment of chitosan and ScanImp the amount of propiconazole in the leachate is negligible
- The addition of boron and ScanImp to chitosan reduces significantly the leaching of glucosamine
- An additional post treatment increases the fixation of glucosamine in all tested chitosan solutions
- An addition of a cross binder to the fire protection agent could not reduce the leaching of P, although it gave a significantly better protection against fungal decay

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CHANGES IN THE CHEMICAL COMPOSITION OF SOFT DECIDOUOUS WOOD AFTER THERMAL TREATMENT

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ABSTRACT

Thermal treatment is one of the most promising methods for upgrading wood durability properties. In the hydrothermal modification process, not only the chemical properties and structure of wood are changed, but also physical properties such as colour, mass, volume and mechanical strength. The heating of wood in the water vapour medium influences mainly the three basic components of wood - cellulose, hemicelluloses and lignin. As a result of the thermal treatment, the content of hydrophilic groups in wood decreases dramatically. Hence, the thermally modified wood binds much less water than untreated wood. The hygroscopicity of thermally modified wood is affected mostly by the hemicelluloses degradation, some break-up of the amorphous part of cellulose and changes in the lignocarbohydrate complex.

In the present study, the chemical changes in soft deciduous wood – aspen, grey alder and birch as a result of hydrothermal treatment were investigated. For modification, an experimental laboratory modification device was used. Wood boards under pressure in water vapour medium were subjected to the treatment at 140, 160 and 180ºC. Holding time at the maximum temperature was 1 h. With increasing treatment temperature, density decreases, mass losses grow, which can be explained by the evaporation of more volatile components, wood dehydration and hemicelluloses decomposition to low-molecular compounds, with the formation of CO_2, formic acid, acetic acid, furfural, etc. With increasing temperature, the amount of acids, esters, sugars and tannins in the condensates grows. The Kürchner-Hoffer method was applied for cellulose determination, the Klason method for lignin but the hemicelluloses content was determined indirectly. For assessing the changes in the functional groups of wood, FTIR spectroscopy was used. With increasing treatment temperature, as a result of the degradation of less ordered carbohydrate (hemicelluloses), the degree of crystallisation of cellulose increases; the amount of the acetone extractable compounds in wood also grows. Applying the water vapour sorption method, the specific surface accessible for water vapours was determined. It has been found that the obtained wood hydrophobicity is partially reversible and decreases in elevated moisture conditions.

Key words: aspen, birch, grey alder, hydrothermal modification

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INTRODUCTION

The total forest stock in the territory of the Republic of Latvia in 2006 was 577.6 million m^3 wood. Among deciduous trees, the most widespread species in Latvia is birch (24% from the total forest area) with a 62 million m^3 stock; the prevalence of grey alder is 5.3% (31.33 million m^3 of wood), and that of aspen is 3.6% (24.23 million m^3 of wood). The wide prevalence and great stock make them the most applicable deciduous tree species in the national economy of Latvia. The natural resistance of these tree species against biological actions, UV radiation, moisture and other factors is limited. To improve these properties, urgent is the study of modification methods, which, similarly to the elucidation of durability principles, embrace the changes in individual main components of wood. Up to now, it has been regarded that the main property of wood – hygroscopicity – is connected only with the destruction of hemicelluloses. Various studies show that also the chemical changes in lignin influence the cell wall properties, because lignin and hemicelluloses are closely interconnected. The hemicelluloses degradation can change both the structure of the lignocarbohydrate complex and the cell wall, changing also the wood hygroscopicity, mechanical strength and durability properties. Hence, the studies on the chemical changes in wood components are essential for finding sustainable technological parameters.

MATERIAL AND METHODS

Birch (*Betula* spp.), aspen (*Populus tremula*) and grey alder (*Alnus incana*) boards without visible defects were chosen for modification. Samples sizes were: length 1000 ± 2 mm, width 75 ± 0,5 mm, thickness 25 ± 0,5 mm for aspen; length 1000 ± 2 mm, width 75 ± 0,5 mm, thickness 32 ± 0,5 mm for grey alder; length 970 ± 2 mm, width 99 ± 0.5 mm, thickness 12 ± 0.5 mm for birch. The average density of wood at the absolute moisture content 12% was 546 kg/m^3, 524 kg/m^3 and 719 kg/m^3 for grey alder, aspen and birch, respectively. Absolute moisture content of the wood before modification was 6-8%.

The thermal modification was carried out in a multifunctional wood modification pilot device. Aspen, grey alder and birch boards were thermally modified in the water vapour medium for 1 h at 3 different temperatures: 140ºC, 160ºC and 180ºC. The material was placed in an autoclave, in which 0.67 ml of water was supplied per 1 g of air dry wood.

Chemical analyses were performed for both non-treated wood and the modified samples. 8-12 g of air dry chips of each sample were extracted in a Soxhlet apparatus with acetone for 8-10 h for extractives determination. After extraction from the solution, the excess of acetone was distilled, and the extract was dried under a vacuum and a temperature of 40ºC.

Cellulose was determined applying the Kürchner-Hoffer method, for determination, the Klason 72% sulphuric acid method was applied [1].

Sorption-desorption isotherms were obtained on the so-called Macben vacuum balance with a quartz spiral as the sensitive element at a temperature of 22 ± 0.1°C. The vacuum treatment residual pressure was 1 Pa. The time necessary for reaching the equilibrium at each point of the isotherms was 20-24 h. The isotherms are characterised by the comparative method in combination with the BET method [2]. The following values were determined: specific surface accessible for water vapours (A, m^2/g), mass concentration of hydrophilic centres (a$_m$, mMol/g) and concentration at the surface (α, groups/nm^2), where $\alpha = a_m/A$. Measurements of sorption – desorption isotherms in one

or several cycles make it possible to evaluate the stability of the hydrophobic properties obtained in the modification process in high moisture conditions and to forecast the material's behaviour under the circumstances.

Infrared spectra were obtained using a Perkin-Elmer Spectrum One FTIR spectrometer with a LiTaO$_3$ detector and the resolution 4 cm^{-1}. Absorption was measured at the wavelength from 4000 to 450 cm^{-1}. Spectrum v5.0.1 software was used. The samples were analysed as KBr tablets. For each sample, 2 tablets were produced, and 32 scannings were performed, from which the computer calculated and represented the spectra average results. The average result was calculated also from the average spectra data of both the samples. Employing the program's potentialities, the FTIR spectra basic lines were corrected and normalised.

RESULTS AND DISCUSSION

Chemical changes

Table 1. Changes in the chemical composition of aspen, grey alder and birch wood depending on the modification temperature

Treatment temperature °C	Wood components content (%)				Cellulose/ lignin ratio
	Extractives	Cellulose	Lignin	Hemicelluloses*	
Aspen					
Non-treated	1.8	53.7	19.6	26.6	2.73
140	2.6	54.5	19.2	26.4	2.84
160	10.4	61.3	21.1	17.6	2.90
180	12.8	62.0	30.4	8.6	2.01
Grey alder					
Non-treated	4.0	47.2	24.7	28.1	1.91
140	3.4	48.4	25.5	26.0	1.90
160	9.2	48.2	28.9	22.9	1.67
180	12.8	50.5	37.7	11.9	1.34
Birch					
Non-treated	1.7	51.9	20.1	27.9	2.59
140	2.0	52.8	20.2	27.0	2.61
160	13.2	63.2	22.5	14.3	2.81
180	14.3	61.7	34.3	4.1	1.80

*Hemicelluloses = 100 – (Cel+Lig)

The Table 1 shows that, for the wood of all 3 species modified at 160ºC, the amount of the extractives grows 4-6 times, and the hemicelluloses amounts for birch and aspen are almost half-decreased. The major part of the extractives is decomposed during thermal treatment. Extracting the thermally modified wood, not the extractives concentrate, but new products are obtained, which are formed as a result of the thermal destruction of cell wall components [3]. For grey alder, the components changes are more uniform, and the greatest changes are observed at 180ºC. The decrease of hemicelluloses can be explained by their disintegration to easier volatile compounds [4]. Aspen and birch have a dramatic

increase in the relative amount of cellulose at 160ºC, while changes are minor for grey alder. The amount of lignin for all species gradually grows, and a considerable increase is observed at 180ºC, probably, at the expense of hemicelluloses degradation. It is proven that lignin is a thermally most stable wood cell wall component, but its changes are observed at lower temperatures, as a result of which different products are formed, as the lignin forming elementary units (phenyl propane units) are split out [5]. For aspen and birch, the cellulose/lignin ratio passes through the maximum at 160ºC and then decreases dramatically. For grey alder, the ratio decreases with increasing treatment temperature.

Analyses of Fourier Transformed Infrared spectroscopy (FTIR)

FTIR spectra for deciduous wood are similar, but differ quantitatively by the aromatic compounds (lignin) and polysaccharides ratio. The lignin content decreases in the row: alder > birch > aspen. This is testified also by the chemical analysis for the non-treated wood. After the thermal treatment at 180°C, hemicelluloses acetate groups are split out, and the absorption maximum disappears at 1740 cm^{-1} in FTIR spectra. As a result of oxidation processes, a new absorption maximum appears at 1710 cm^{-1}, which corresponds to the C=O groups. The higher is the wood treatment temperature, the more acetate groups (variations in the range 1750-1735 cm^{-1}) are split out and the more wood is oxidised – oxidation products such as ketones and aldehydes are formed [6]. As a result of hydrothermal modification, double bond configurations change – different oxidation products are formed, or also splitting out of some groups and the formation of new double bonds occur. The content of isolated double bonds (1680-1620 cm^{-1}) in wood decreases. Hence, conjugated double bond systems are possibly formed. The wood of different deciduous tree species reacts variously to the thermal treatment. Comparing the ratio of aromatic rings C=C fluctuations (1515 cm^{-1}) against the C=O groups fluctuations (1709 cm^{-1}), the following row can be formed: alder > birch > aspen, which characterises the oxidative changes. Probably, the increased lignin content protects the wood from oxidation during the thermal treatment. The -CH$_2$- groups fluctuations are in the range 2940-2915cm^{-1} and 2870-2845cm^{-1}. As the initial wood is compared with thermally modified wood, the appearance of the second peak is observed, which testifies the changes in the arrangement of the -CH$_2$-groups. Greater vibrations of the aromatic ring at 1600 cm^{-1} and 1505 cm^{-1}, and the shift to 1510 cm^{-1} testify the splitting out of the lignin aliphatic side chains or condensation reactions. The presence of higher condensed structures is testified by the greater intensity at 1330 cm^{-1}, as well as a shift at 1245-1220 cm^{-1}. The peak fluctuations typical for lignin are in the range from 1520 to 1505 cm^{-1}, where they are somewhat shifted and become sharper, with increasing treatment temperature. Hence, minor changes occur in lignin, and its relative content increases, which is demonstrated also by the chemical analysis. Probably, the lignin relative content increases as a result of decomposition less thermally stable compounds. In the region 1200-900 cm^{-1}, all peaks correspond to the functional groups typical for oligosaccharides. With increasing treatment temperature, an increase in the peak's sharpness is observed. Hence, the carbohydrate (cellulose) degree of crystallinity increases. This occurs as a result of the degradation of the less ordered carbohydrates (hemicelluloses), which can be observed as changes in the second alcohol groups absorption range from 1200 to 1000 cm^{-1}.

Water vapour test

Water vapour sorption-desorption isotherms in two cycles were taken, and microstructure characteristics for modified birch wood were calculated: **A** – specific surface accessible for water vapours, m^2/g; $\mathbf{a_m}$ – mass concentration of hydrophilic centres, mMol/g; α - concentration of hydrophilic centres on the surface, groups/nm^2; **W** – pore volume, cm^3/g (Table 2).

Table 2. Changes in the grey alder, birch and aspen wood microstructure characteristics depending on the treatment temperature

Parameter	A, m^2/g		a_m, mMol/g		α, groups/ nm^2		Ws, cm^3/g	
Cycle of sorption **Treatment,**°C	I	II	I	II	I	II	I	II
Grey alder								
Non-treated	274	326	2.5	2.9	5.4	4.2	0.27	0.29
140	216	259	2.2	2.1	6.2	4.9	0.21	0.24
160	175	211	1.4	1.8	5.4	5.0	0.20	0.31
180	119	179	0.8	1.5	5.3	5.0	0.09	0.12
Birch								
Non-treated	315	300	2.80	2.51	5.3	5.1	0.32	0.32
140	180	245	1.77	2.06	5.8	5.1	0.21	0.25
160	135	215	1.48	1.77	6.6	5.0	0.21	0.27
180	110	170	1.09	1.43	6.2	5.1	0.16	0.16
Aspen								
Non-treated	280	280	2.41	2.35	5.2	5.1	0.23	0.27
140	245	305	2.10	2.81	5.2	5.5	0.18	0.22
160	175	240	1.66	2.04	5.7	5.2	0.15	0.20
180	190	205	1.62	1.75	5.1	5.1	0.10	0.11

With increasing modification temperature, the specific surface accessible for water vapours, the concentration of hydrophilic centres as well as pore volume decrease. The changes in the surface hydrophilic centres concentration have an accidental character; determined by the summary oxidation, degradation and new hydrogen bonds formation processes. The results of the second sorption cycle II show that, after staying in the saturated water vapour medium, the material is relaxed, in comparison with the results of the cycle I; the specific surface grows by 35-55%, and the concentration of hydrophilic centres increases by 15-30%. It has been found in the third sorption-desorption cycle that, after the second cycle, the hydrophobic properties become irreversible, and the material's structure becomes stabilised, retaining the hydrophobicity gained in the cycle II (these results are not shown in Tables). In the literature, the reversibility of hydrophobicity is explained by the decrease in the polymer chains mobility under the action of heat, the increase of mobility in high relative moisture conditions and, correspondingly, the renewal of water absorption. The irreversible effect is caused by the material's chemical changes [7].

Condensate analysis

After the accomplishment of the grey alder and aspen thermal modification process, condensate samples were taken and analysed (Table 3).

Table 3. Chemical composition of the grey alder and aspen condensate depending on the modification temperature

Parameter	Acids, mg/g		Esters, mg/g		Sugars, mg/g		Tannins, mg/g	
Measurement Treatment, °C	I	II	I	II	I	II	I	II
Grey alder								
140	4.17	11.75	0.39	0.64	0.09	0.73	0.89	4.00
160	29.20	24.40	0.59	0.58	0.83	0.81	13.12	16.51
180	56.14	31.45	1.11	0.93	1.81	1.14	18.11	19.19
Aspen								
140	5.36	3.86	1.37	2.43	0.14	0.14	0.78	1.33
160	28.22	16.89	0.62	1.11	0.58	0.48	8.80	8.35
180	53.60	36.51	1.84	2.39	1.43	1.26	24.59	22.83

The results testify that, with increasing hydrothermal treatment temperature, the concentration of both acids and esters, both sugars and tannins in the condensate grows. The only exception is the aspen esters concentration, which declines at 160ºC and then grows again at 180ºC. Acids, esters, sugars and tannins are hemicelluloses destruction products. These results testify again the weak stability of hemicelluloses as a result of hydrothermal treatment.

CONCLUSIONS

1. For birch, alder and aspen wood, with increasing hydrothermal treatment temperature, the amount of extractives and the relative content of lignin in wood grow, which occurs at the expense of hemicelluloses destruction. Except the case of grey alder, the relative cellulose amount grows dramatically at 160ºC. The chemical analysis shows similar tendencies in the case of aspen and birch.

2. FTIR spectra for investigated deciduous wood are similar and differ only quantitatively. The changes are in the range 1750 - 1700 cm^{-1}, which is caused by the formation of oxidation products (ketones, aldehydes). The configuration of double bonds changes (1680 - 1600 cm^{-1}). Minor changes occur also in lignin (1520 - 1505 cm^{-1}), and their relative content somewhat increases. The changes in the region 1200 - 900 cm^{-1} testify the growth in the cellulose degree of crystallinity.

3. With increasing modification temperature, the specific surface accessible for water vapours, the concentration of hydrophilic centres as well as the pore volume decrease. Hence, the changes in cell wall and lignin, occurring during the thermal modification, enhance the hydrophobic properties of wood. The hydrophobicity gained in the modification process is to a certain extent reversible.

4. The increase in the acids, esters, sugars and tannins concentration in the condensates, with increasing the treatment temperature, testifies a considerable destruction of hemicelluloses.

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OPTIMISING HYDROGEN BONDING IN SOLID WOOD

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ABSTRACT

The chemical bonds of wood are both covalent bonds within the wood polymers and hydrogen bonds within and between the polymers. Both types of bonds are responsible for the coherence, strength and stiffness of the material. The hydrogen bonds are more easily modified by changes in load, moisture and temperature distorting the internal bonding state. A problem arises when studying hydrogen bonding in wood since matched wood specimens of the same species will have very different internal bonding states. Thus, possible changes in the bonding state due to some applied treatment such as conditioning or mechanical stress might be difficult to detect due to a large variation between the specimens.

In this study, the modifications by all past external impacts such as climate and mechanical history were sought erased. This was done by heating specimens of pine (*Pinus sylvestris* L.) to 80 °C about 24 h while maintaining 100 % moisture content of the wood. The hypothesis was that this would enable a fast stress relaxation as a result of reorganization of bonds, since moisture plasticizes the material and temperature promotes faster kinetics. Hereby, all past bond distortions caused by various moisture, temperature, and load histories were assumed to be erased by this treatment. Thus, all specimens would be given a common starting point for further experiments. After the first treatment, the specimens were subjected to different climate histories in order to examine the impact of variations in air humidity and temperature.

The distribution of bond lengths was examined using infrared spectroscopy (ATR-FTIR) both prior to treatments and after. The results show that the absorbance bands of the spectra related to the hydroxyl and carboxyl stretching vibrations were changed by the treatments. Apparently, the first treatment mostly caused an extension of the short hydrogen bonds. This extension decreased after the second treatment either as a result of changes in air humidity and temperature or merely as a function of time.

Key words: Hydrogen bonds, ATR-FTIR, mechanical relaxation

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INTRODUCTION

This study attempts to narrow the variation between specimens by allowing a fast relaxation of internal stresses. Since the hydrophilic hemicelluloses and also the lignin of wood are amorphous (Struik 1987), their rheological behaviour changes with temperature and also with the moisture content (Kelley et al. 1987). Water plasticizes the wood polymers by lowering the glass transition temperature, whereas a high temperature promotes fast kinetics enabling a faster change in hydrogen bonding into a more favourable bonding state. Thus, the variation should be lowered between specimens with different climate and mechanical histories when exposed to high moisture content and temperature. That was at least what a previous and very simple experiment indicated. The results showed that it was possible to get a more homogenous hydrogen bonding state between and within samples of softwood. This study attempts to verify the first results and examine if it is possible to create distortions in the hydrogen bonding state by exposing different samples of specimens to different climate histories. Changes in the bonding state are examined using infrared spectroscopy, focusing especially on changes in hydroxyl stretching vibrations.

MATERIAL AND METHODS

All specimens used in this study were cut out of six different pieces of wood taken from stems of pine (*Pinus sylvestris* L.) planted in 1917 in West Zealand, Denmark. Specimens (R-T-L: 0.25 x 5 x 30 mm) were cut with a microtome from the earlywood of different annual rings and sorted into 4 samples of 18 specimens in such way that each sample contained three specimens from each slab of wood. This was to ensure an even distribution of properties among the four different samples.

Cut samples were dried in an oven (103 °C) for 22 h and were cooled over silica gel before the dry mass of each sample was recorded. Hereafter, the samples were conditioned to room climate (30-40 %RH and 30 °C) for 20 days to ensure equilibrium. The room climate was fairly stable yielding moisture fluctuations within 0.5 %MC. This condition is in the following referred to as the "PRE"-condition. An infrared spectrum was obtained for each specimen using infrared spectroscopy (ATR-FTIR) equipment at Forest & Landscape, University of Copenhagen located in the room used for conditioning. This ensured stable conditions also during recording of spectra. The spectrum for each specimen was obtained in similar manner by pushing the specimen on to the ATR-crystal with a preset load and recording 128 spectra with a resolution of 4 cm^{-1} which was then automatically averaged. The run order of specimens was statistically determined to avoid systemic error.

In the first of two treatments the specimens were subjected to high moisture contents (about 100 %) and left in an oven at 80 °C for about 24 h. Each sample of specimens was wrapped in aluminium foil along with added demineralised water. The wrapped samples were placed in sealed glass bottles which contained 3 mL demineralised water. Hereby, the vapour pressure around the wrapped samples would prevent drying of the samples during the heating period.

After the treatment, the samples were dried out over silica gel and were then conditioned to room climate before the infrared spectra were obtained again. This condition is in the

following referred to as the "1ST"-condition. To see if moisture and temperature changes can induce changes in the bonding state, four of the samples were subjected to different climate histories A, B, C, and D depicted in Figure 1. After the samples were in equilibrium with the dry silica gel atmosphere at the end of each climate history, the samples were conditioned at room climate and the infrared spectra were obtained for the last time. This condition is in the following referred to as the "2ND"-condition.
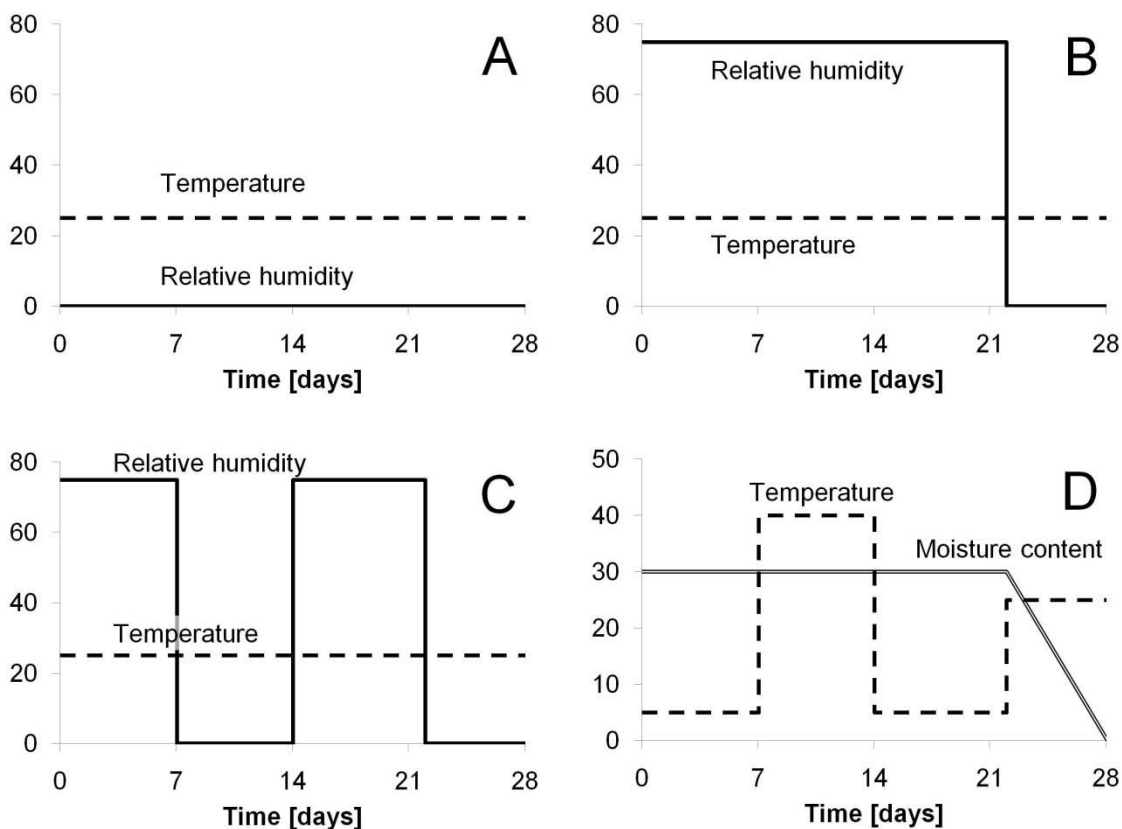
Fig. 1. Climate history of the four different samples.

All recorded spectra were normalized with the standard deviation of each spectrum. For studying changes in the hydrogen bonding state, the infrared range for the OH-stretching and CH-stretching vibrations (2600-3700 cm^{-1}) were baseline corrected.

RESULTS AND DISCUSSION

Illustration of spectra obtained from one sample of 18 specimens is shown in Fig. 2. Also shown is a zoom of the region of the hydroxyl and carboxyl stretching vibrations. Four different values from the latter, describing the shape of the OH-peak, are obtained. These include the position of the peak, the peak height, i.e. the intensity at the peak position and the width of the peak both left and right of the peak position. The width is determined from the wave numbers associated with the half intensity of the peak.
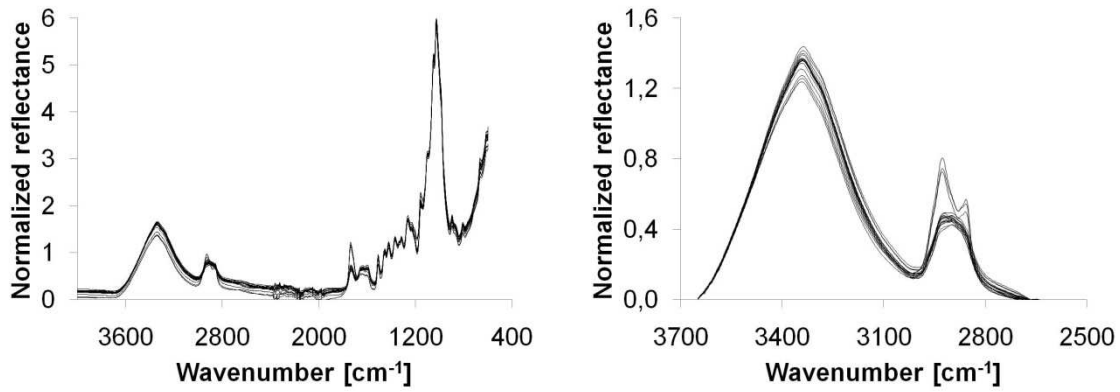
Fig. 2. Infrared spectra for one of the samples of 18 specimens (left) and zoom on the region of the OH- and CH-stretching vibrations (right).

In Fig. 3-6 the four descriptive values are shown for all samples in the PRE- and 2ND-conditions. It is clear that the four samples are statistically equivalent whish was also seen for the samples in the 1ST-condition. Thus, the different climate histories did not create any apparent differences in the hydrogen bonding states between the samples.
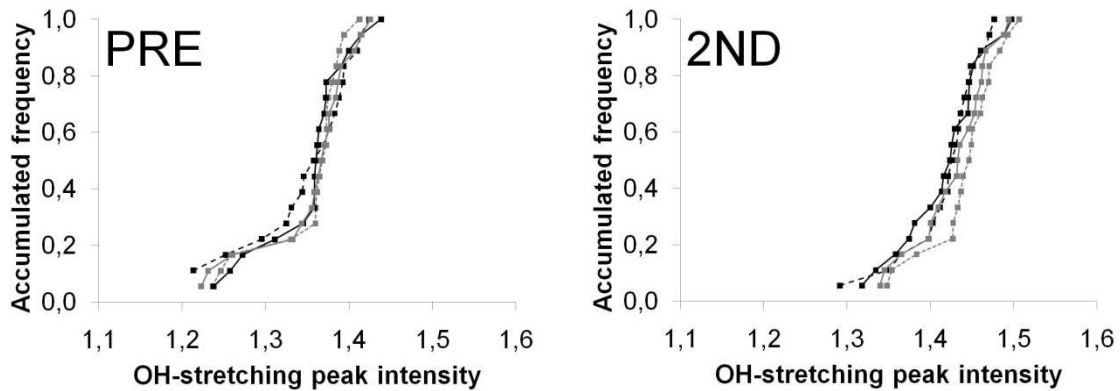
Fig. 3. Distribution of peak intensity of the OH-stretching peak before and after the second treatment. Curves for all four samples are shown.
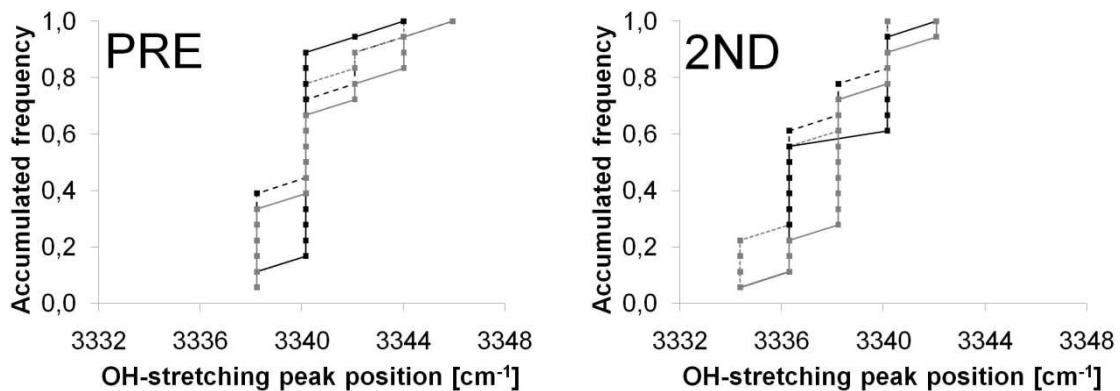
Fig. 4. Distribution of peak position of the OH-stretching peak before and after the second treatment. Curves for all four samples are shown.
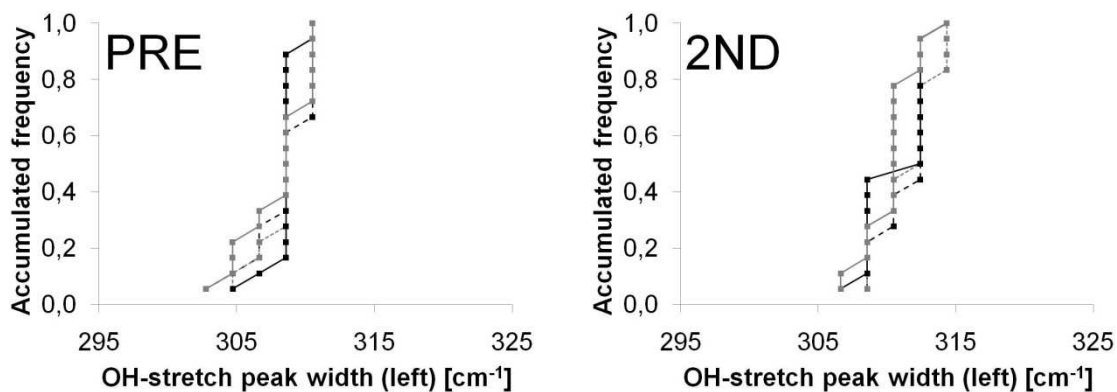
Fig. 5. Distribution of peak width toward higher wavenumbers at half intensity of the OH-peak in the PRE- and 2ND-conditions. Curves for all four samples are shown.
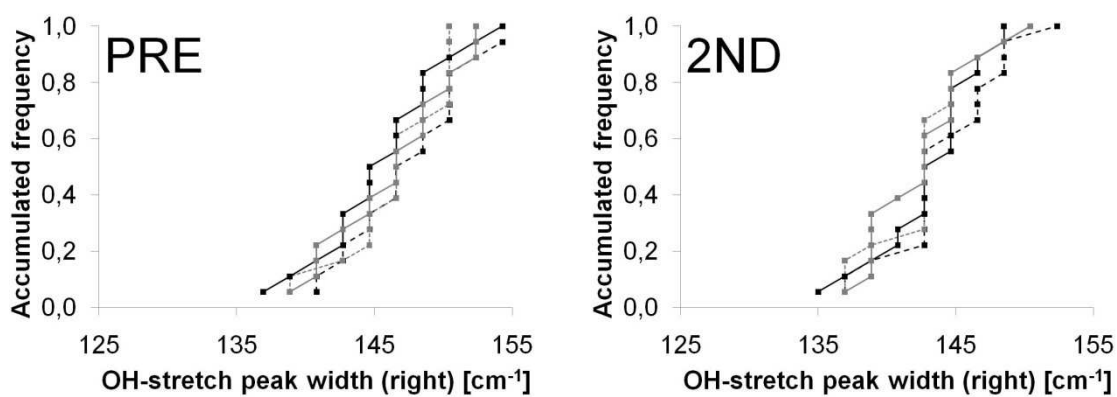
Fig. 6. Distribution of peak width toward lower wave numbers at half intensity of the OH-stretching peak before and after the second treatment. Curves for all four samples are shown.

Therefore, in the following average values for the four samples are used to examine possible differences between the three conditions; PRE, 1ST, and 2ND. In Fig. 7 and 8, the peak intensity, position and width are shown.
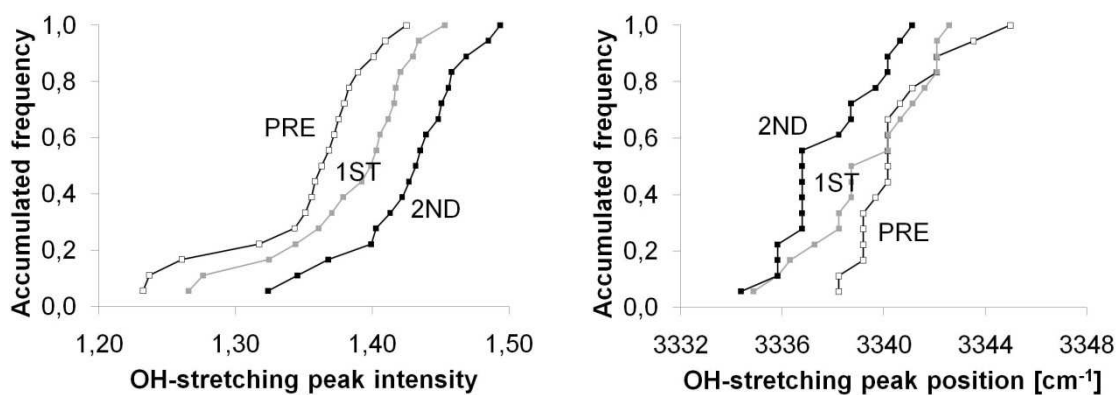
Fig. 7. Distribution of peak intensity and position of the OH-stretching peak before and after the first and second treatment. The curves represent average values for the four samples.

In Fig. 7 it can be seen that lower tail of the three distributions is unusually stretched. The outliers are in general the three lowest points of the distribution. A closer examination of the data behind Fig. 7 shows that the three lowest values of the peak intensity are all based on spectra with a double carboxyl peak such as the one shown in Fig. 2. Thus, the low hydroxyl intensity seems related to the splitting of the CH-vibrations into two distinct peaks. Also, the splitting seems related to the intensity of the peak around 1730 cm^{-1} which is due to vibrations of C=O. Since the phenomenon is seen for three specimens in each sample, it seems as if one of the six pieces of wood involved in this study significantly differ from the five others. However, a closer examination of the data is needed in order to determine the cause of the split.
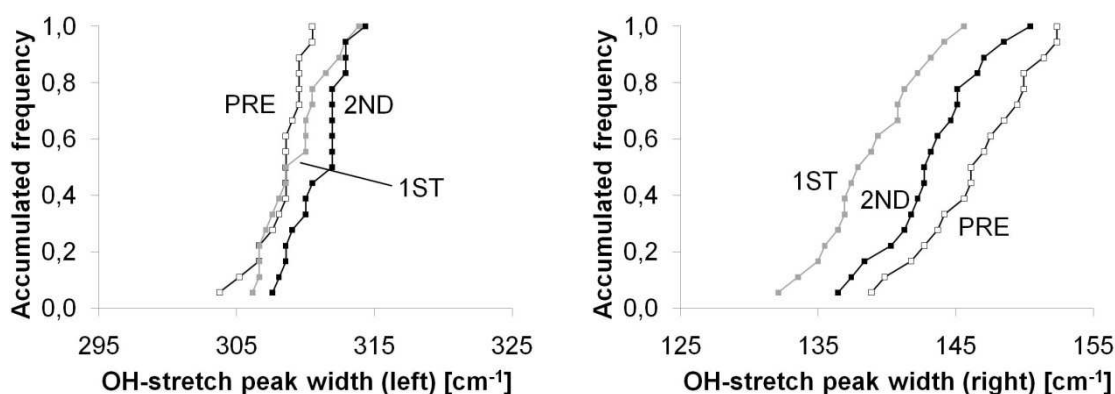
Fig. 8. Distribution of peak width of the OH-stretching peak before and after the first and second treatment. The curves represent average values for the four samples.

In general, the peak position and peak width toward higher wave numbers are not significantly different between the three conditions. The peak position is in the range of 3340 cm^{-1} which corresponds to a hydrogen bond length H···O of 0.187 nm (Rozenberg et al. 2000). This value is typical for hydrogen bonded hydroxyl groups on carbohydrates, whereas a free hydroxyl group on carbohydrates vibrates at a wave number of 3640 cm^{-1} (Rozenberg et al. 2000). Thus, the stronger the hydrogen bond is, the greater is the red shift, i.e. the peak shift toward lower wave numbers.

The peak intensity and width toward lower wave numbers is slightly different between the three conditions. The peak intensity is significant for $\alpha = 5$ % except for PRE vs. 1ST. However, if the three low outliers are removed from the statistics, the three conditions are all significantly different for $\alpha = 1$ %. Thus, the hydrogen bonding state is different in the three conditions. Statistical analysis of the peak width towards lower wave numbers show that all conditions are different from each other at a significance level of 5 %, whereas the PRE- and 2ND-conditions are not significantly different for $\alpha = 1$ %. The change in peak width toward lower wavenumbers indicates a change in the stronger bonded hydroxyl groups. In the right diagram of Fig. 8 it seems as if the first treatment extends some of the short bonded hydroxyl groups, whereas the bonds in the 2ND-conditions are in an intermediate position between the initial bonding state in the PRE-condition and the extended state in the 1ST-condition.

In general, the measurements did not follow the results from a previous and simpler experiment. The first treatment did not create a more homogenous distribution of

bonding states within the samples by relaxation of build-in stresses from bond distortion. It therefore seems that the wood in the PRE-condition was in a more favourable bonding state compared with the 1ST- and 2ND-conditions. Also, tt appears that the bonding state slowly return to the initial conditions during and after the second treatment. Whether this is a result of the changes in air humidity and temperature or just a time dependant response is unclear. However, it may be speculated that the climate variations promote a faster return to the initial conditions. The measurement method itself might also influence the results in that the wood is under mechanical load when the spectra are obtained. This gives a better signal-to-noise ratio but may also change the bond lengths of the hydrogen bonds. The impact of this has not yet been investigated.

CONCLUSIONS

Measurable changes in the bonding state of the specimens were observed after the extreme conditions in the first treatment in which the specimens were subjected to high moisture content and heat. This was observed as an extension of some of the short hydrogen bonds of the hydroxyl groups. The second treatment consisting of different climate histories with varying air humidity and temperature decreased the extension. Seemingly, the bonding state approached the initial conditions prior to any treatment. The infrared spectroscopic method did not detect any measurable difference in the bonding state between the different climate histories. Thus, whether the bond length decrease is a result of the climate variations or merely a time dependant response remains unsolved. However, it can be speculated that the climate variations promote a faster return to initial conditions.

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BIOLOGICAL DURABILITY AND MECHANICAL PROPERTIES OF HYDROTHERMALLY MODIFIED DECIDUOUS WOOD

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ABSTRACT

In the moderate climatic zone, in which also Latvia is located, mainly coniferous wood is used in construction, whose properties are more appropriate for load-carrying and bearing structures. The stock of the main deciduous tree species (birch, grey alder, aspen and black alder) in Latvia's forests is about 229.2 million m^3. From soft deciduous wood (grey alder, aspen), mainly small-size assortment is currently produced, for example, box boards, pallets, bath-house facing boards. To extend the applicability potentialities of deciduous wood by improving its biological durability and hydrophobicity, thermal treatment was investigated.

In the present study, birch (*Betula* spp.), aspen (*Populus tremula*) and grey alder (*Alnus incana*) wood samples were used. The task was to elucidate the effect of the hydrothermal treatment process on the biological durability and mechanical properties of wood, and to find optimal treatment parameters so that to compromise between the improved biological durability and the declined mechanical strength. Modification was carried out in a multi-functional pilot device WTT in elevated water vapour pressure conditions at five different treatments (temperature, ˚C/duration, h): 140/1; 160/1; 160/3; 170/1 and 180/1.

The modification at 140˚C does not improve the durability of the modified soft deciduous wood against rot test fungi, white rot (*Coriolus versicolor*) and brown rot (*Coniophora puteana*); mass losses are similar and even greater than those for the control wood, which could be explained by the presence of easily usable thermal degradation products. The treatment temperature 160˚C improves the durability against brown rot fungi (mass losses decrease by 30-40%), to a lesser extent- against white rot fungi (mass losses decrease by 6 -15%). Protection against fungi is reached, when modifying wood at 180˚C.
Modification for 1 h at 140˚C and 160˚C increases the bending strength of birch wood by 31-34% and 8-10%, respectively, in comparison with the bending strength of untreated wood. Extending the treatment time up to 3 at 160˚C, bending strength decreases dramatically (by 26-28%) and is similar to that for wood modified at 170°C/1 h. Thermal modification for 1 h at 180°C decreases the bending strength by 50-55% and is not suitable for producing high-quality material.

Key words: hydrothermal treatment, grey alder, aspen, birch, mechanical and biological durability

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INTRODUCTION

During the last decades, researchers worldwide have developed and investigated new treatment techniques to improve intrinsic wood properties. Because of environmental concerns, the pressure on the wood industry is higher than ever before to find alternatives to tropical hardwoods and preservative treated wood. This is the reason why some new modification technologies such as furfurylation, acetylation, resin treatment and heat treatments have been introduced to the market [1]. In recent years, heat treatment industrial processes have been developed successfully in Europe. These processes use air steam, nitrogen or oil as the heat transfer. The Finnish ThermoWood and Dutch PlatoWood using steam, French Rectification using nitrogen, the German OHT-process using oil are the most investigated technologies [2]. Referring to publications of many authors, it is known that, performing thermal modification, wood becomes more hydrophobic, form stability is improved, and resistance against rot fungi is increased; at the same time, the mechanical properties (bending strength) decline, especially dramatically at temperatures higher than 180-190°C, certainly also depending on the environment in which the thermal modification occurs [3].

As the objects of our study, three deciduous tree species such as birch, aspen and alder were chosen for the following reasons:

- Sufficient amount of the raw material (the amount of the produced high-quality wood is increased, both from grey alder and aspen wood).
- The low price of the raw material, especially for grey alder (20-23 EUR/m^3) and aspen (23-26 EUR/m^3), birch veneer logs (about 31-37 EUR/m^3).
- There are no data in the literature concerning the hydrothermal modification of grey alder wood. There are some publications, in which the data obtained as a result of the hydrothermal treatment of aspen and birch wood are considered [8.], although the flow diagram and parameters of the process are know-how.
- Interest of the local woodworking enterprises or timber producers in thermal modification has increased.

To improve the deciduous wood properties, we have chosen the thermal modification method, employing Wood Treatment Technology equipment (WTT), because it is a simple, easily realisable process, in comparison with Rectification (nitrogen is necessary) or OHT (oil is necessary). It has distinctions from other hydrothermal treatment technologies. In Thermowood production, convection type drying is used, in which the water vapour flow rate in the autoclave is no less than 10 m/s [4]. The Plato process is multistage, and the heat carrier (water vapour or superheated steam) is introduced from outside [2]. In our case, the vapour medium is conventionally static; on the contrary, in the Plato and Thermowood processes, the vapour medium has a known flow speed. Besides, in our treatment, water vapour is formed in the thermal treatment time, as a result of which pressure is formed in the autoclave, which is not typical for the above-mentioned processes.

MATERIALS AND METHODS

For modification, we have chosen birch (*Betula* spp.), grey alder (*Alnus incana*) and aspen (*Populus tremula*) wood boards without any visible defects. Moisture content before the treatment was 6-8%, after the treatment it was within a range of 3.5-5.5%, and after conditioning it was 5-6%. The initial wood average densities (at W 12%) were 546 kg/m^3, 524 kg/m^3 and 719 kg/m^3 for grey alder, aspen and birch, respectively. The boards average sizes were: length 1000 ± 2 mm, width 75 ± 2 mm, and thickness 25 ± 2 mm for aspen; length 1000 ± 2 mm, width 75 ± 0,5 mm, and thickness 32 ± 0,5 mm for grey alder; and length 970 ± 0,5 mm, width 99 ± 0,5 mm, and thickness 12 ± 1 mm for birch.

Treatment of materials

The material was placed in an autoclave, and 0.6 ml of water per 1 g oven dry material was pumped in it. The thermal modification process can be divided in three stages. The first stage: temperature rise from room temperature to the maximum final temperature of the process (140°C, 160°C, 170°C, 180°C). The second stage of the process: holding of the maximum final temperature (1 or 3 h). The third stage: cooling stage. Pressure in the autoclave, depending on temperature, reached 4 to 9 bar.

Decay test

Two fungal strains were used in this study: brown rot fungi *Coniophora puteana* BAM Ebw.15 and white rot fungi *Coriolus versicolor* CTB 863 A. Grey alder, birch and aspen untreated and thermally modified wood blocks (20 x 20 x 5 mm) were exposed to the fungi for 6 or 10 weeks at 22°C and a relative humidity of 70%. Test procedures were carried out according to modified EN 113 [5] and EN 84 [6] standards. Three replicates for each fungus and each treatment temperature were tested. Percentage of weight loss was calculated from the weights before and after decay testing.

Mechanical properties

Bending properties of birch wood were determined according to the EN 310 standard [7]. Birch samples sizes: 12 x 50 x 300 mm. The properties of aspen and grey alder wood samples in bending were determined according to the DIN 52186 requirements [8]. Sample sizes: 20 x 20 x 360 mm. Samples were without wood defects, with their fibres parallel to the sample's longitudinal axis. After sawing, the samples were placed in a conditioning room for levelling the moisture in wood according to the DIN 50014 requirements (air temperature 20 ± 2°C, moisture 65 ± 3%) [9]. 20 samples from each treatment were taken for the tests, and the results were compared to the bending properties of the untreated samples of the corresponding species.

RESULTS AND DISCUSSION

Mass loss of wood is one of the most important features in heat treatment and is commonly referred to as an indication of quality. Several authors studied mass loss with heat treatment and concluded that is depends on the wood species, heating

medium, temperature, and treatment time. Most of the data are difficult to compare because different treatment processes temperatures, time of treatment, species, and initial moisture contents were used [10].

Initially, the following modification regimes were chosen: 1 h treatment at 140, 160 or 180°C. With increasing treatment temperature, mass losses and density changes for all three tree species grow (Table 1). The analysis of modified wood has shown that, at 180°C, in comparison with the case of the treatment at 160°C, the sample's mass and density decrease 3-3.5 times and 1.5-2 times, respectively. At the same time, reaching of wood durability class 1 against rot fungi according to EN 350-1 [11] is ensured by the treatment 180/1 (Table 2). To optimise the treatment parameters, modification was carried out for 3 h at 160°C and for 1 h at 170°C. Initial wood average densities, kg/m^3: 546, 524 and 719 for grey alder, aspen and birch, respectively.

Table 1: Effect of the chosen treatment process parameters on the wood mass and density changes

Treatment, °C/h	Mass losses, %			Decrease in density,%		
	Birch	Aspen	Grey alder	Birch	Aspen	Grey alder
140/1	0.6	0.8	1.9	1.2	1.4	4.5
160/1	5.2	5.0	6.3	4.7	5.2	8.1
160/3	9.9	9.6	11.2	7.1	7.3	11.2
170/1	11.9	11.3	13.6	8.6	8.9	12.8
180/1	18.0	14.2	14.7	11.4	11.0	13.0

With increasing holding time at a temperature of 160°C from 1 h to 3 h, mass losses grow twice for all tree species, reaching about 10%, but the wood density decreases 1.4-1.5 times. The decrease in mass and density at the treatment 170°C/1 h, in comparison with the case of 160°C/3 h, is still greater by 15-20%. The birch and aspen changes are similar, while the grey alder samples are somewhat more sensitive against the thermal action. The exception is the comparatively high birch wood mass losses at the treatment 180°C/1 h. After extraction of modified samples, only 4% of non-cellulose and non-lignin compounds remain in wood [12]. Already at the treatment 140°C/1 h, minor mass losses are observed, which are connected with the release of bound water and easily volatile extractives. Analysing the chemical composition of the wood, it has been found that, with increasing treatment temperature, mainly the degradation of thermally more unstable wood components – hemicelluloses grows [12].

The samples density changes are connected with the mass and volume changes. Grey alder, in comparison with aspen and birch, has the greatest decrease of wood density because of the greater mass losses and lower changes in the samples' volume (geometrical parameters).

Durability

Fig. 1 shows mass losses for thermally modified and untreated wood samples as a result of the action of white (*Coriolus versicolor*) and brown (*Coniophora puteana*) rot fungi. The mass losses of the control samples tested with *C. puteana* (pine wood) and *C. versicolor* (control wood of the corresponding hardwood species) are in the range 37-53% and 24-37%, respectively. With increasing treatment temperature, wood mass losses decrease. The modification at 140°C/1 h does not improve the

durability of the modified wood against rot test fungi; mass losses are similar and even greater than those for the control wood, which could be explained by the presence of easily usable thermal degradation products. The treatment temperature 160˚C/1 h improves the durability against brown rot fungi (mass losses decrease by 30-40%), to a lesser extent - against white rot fungi (mass losses decrease by 6 -15%). Full protection against fungi is reached, when modifying wood at 180˚C/1 h.

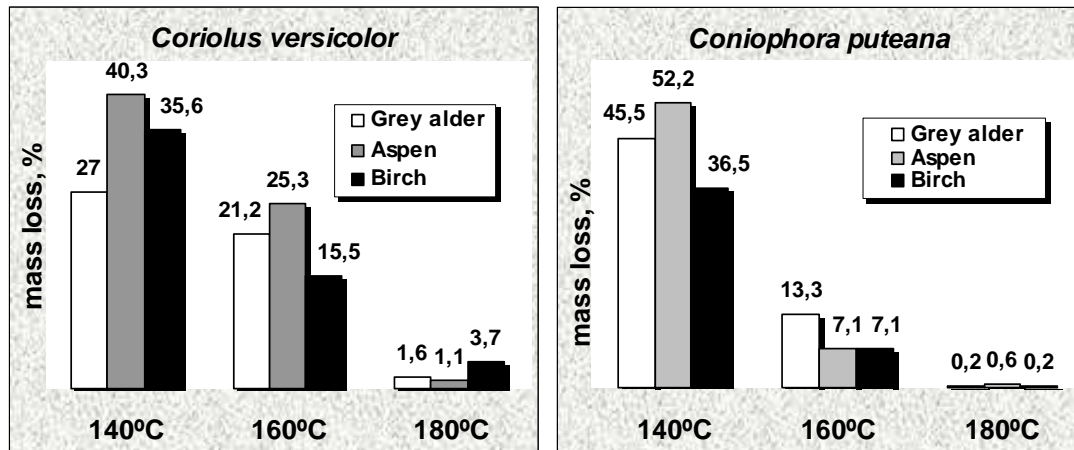**Fig. 1**. Modified grey alder, aspen and birch wood mass losses as a result of the action of white (*Coriolus versicolor*) and brown (*Coniophora puteana*) rot fungi (EN 113).
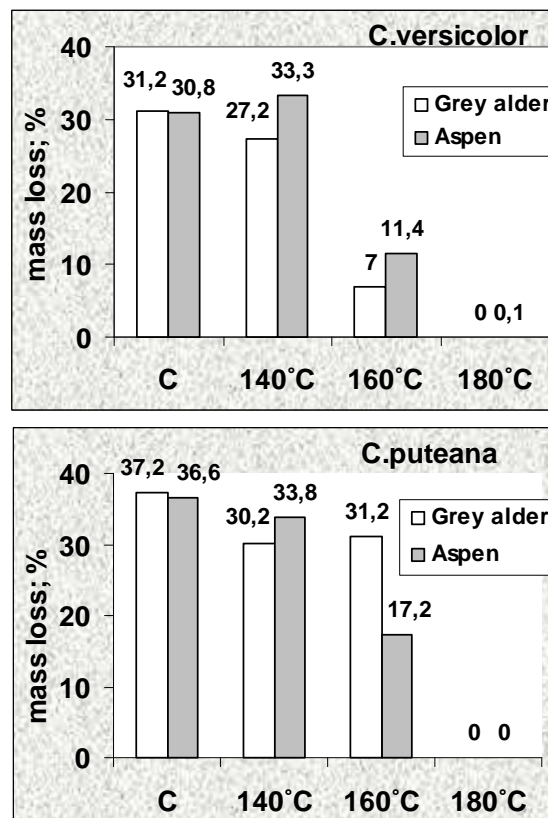

Fig. 2. Mass losses for modified grey alder and aspen wood as a result of the action of white (*Coriolus versicolor*) and brown (*Coniophora puteana*) rot fungi after washing the samples with water (EN 84, EN 113).

Also after washing, the resistance against rot fungi is retained for the grey alder and aspen wood modified at 180°C/1 h (Fig. 2).

It is interesting to note that, after washing with water, mass losses after the action of brown rot fungi grow at 140°C and 160°C for modified wood. On the contrary, the wood becomes more resistant against the most typical deciduous wood degrading agent – white rot fungus. In the case of *C. versicolor,* this is possibly explained by the washing with water of the easily taken up degradation products (sugars, etc.), necessary for the fungi growth. In contrast, the *C. puteana* activity is probably stimulated by the leaching of thermal degradation and hydrolysis products, which have acted as fungi growth inhibitors during the EN 113 test.

Mechanical properties

The results of wood bending properties depending on the treatment temperature are listed in Table 2.

Table 2: Effect of the chosen treatment process parameters on the wood bending strength properties

Tree species	Treatment temperature and time, °C/h	Density at W_{12}%, kg/m^3	Moisture content, %	Bending strength, N/mm^2	Changes against the control, %
Birch (*Betula* spp.)	Control	604	8.4	124	0
	140/1	719	7.0	166	+34
	160/1	652	6.4	136	+10
	160/3	543	5.5	97	-22
	170/1	644	5.7	94	-24
	180/1	606	5.4	61	-51
Aspen (*Populus tremula*)	Control	506	8.8	79	0
	140/1	539	6.1	95	+21
	160/1	502	5.5	67	-14
	160/3	526	5.2	59	-24
	170/1	483	5.3	60	-24
	180/1	528	5.2	37	-53
Grey alder (*Alnus incana*)	Control	608	9.3	82	0
	140/1	548	8.5	80	-3
	160/1	533	7.1	56	-33
	160/3	512	6.1	60	-27
	170/1	499	6.3	48	-41
	180/1	488	5.9	53	-36

With increasing treatment temperature, the wood bending strength changes; in this case, there are distinctions among the tree species. Bending strength for birch at the treatment 140°C/1 h and 160°C/1 h grows, but the increase in the modification time or temperature decreases the bending strength by more than 20%, even up to 50% at 180°C/1 h. For aspen, bending strength grows only at 140°C/1 h, but gradually decreases at higher temperatures. For grey alder, bending strength decreases already at lower modification temperatures. There are no essential distinctions between the bending strength indices at 160°C/3 and 170°C/1 for modified birch and aspen wood.

In contrast, alder is the most sensitive against the temperature increase – the strength at the modification $170^{\circ}C/1$ is lower by ~20% than at $160^{\circ}C/3$. Taking into account those results, the resistance of the investigated species' wood against rot fungi will be decisive for choosing the optimum conditions.

CONCLUSIONS

1. 1-h hydrothermal modification in the temperature range from 160˚C to 180˚C is sufficient to ensure the durability of birch, aspen and grey alder wood against brown and white rot fungi.
2. The thermal treatment carried out at 180˚C/1 h essentially decreases the statical bending strength (even to 50 %); the wood becomes brittle, which decreases its applicability and processability. The acceptable (< 30%) decrease in bending strength is reached in the case of the modification regime 160/3 h.
3. The obtained results testify the principal possibility to improve the properties of grey alder, aspen and birch wood by way of thermal modification and to expand its application fields.

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NATURAL DURABILITY OF DIFFERENT WOOD SPECIES – RESULTS AFTER FIVE YEARS TESTING IN GROUND CONTACT

Flæte, P.O. [1], Evans, F.G. [2] & Alfredsen, G. [3]

ABSTRACT

Information given in EN 350-2 on natural durability of different wood species against wood destroying fungi is mainly based on heartwood tested in ground contact. The objective of this study was to test and compare durability of many different wood species in a field test in ground contact. The material consisted of Norwegian wood species able to give sufficient sawn wood dimensions (commercial and less utilised species, indigenous and introduced species) and imported species (Larch from Russia; Oak, Douglas fir and Western Red Cedar from North America; Merbau and Teak from Asia). Additionally, modified wood (thermally modified and tall oil treated) and preservative treated wood (CCA- and Cu-preservative) were included in the test.

The wood types, 31 in total, were tested according to EN 252 and EN 350-1 at NTIs test site in Sørkedalen, Norway. Results after five years exposure show that most of the Norwegian grown wood species have low durability. This study also provides information on durability of four species not included in EN 350-2: *Juniperus communis*, *Salix caprea*, *Sorbus aucuparia* and *Populus tremula*.

Key words: Natural durability, ground contact, decay

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INTRODUCTION

Wood is used in a broad range of applications and environmental conditions that can influence the service life of wooden structures. One of the most severe applications is when wood is exposed in ground contact because of the favorable conditions for wood-destroying microorganisms.

EN 460 (CEN 1994a) gives guidance on requirements for natural durability of wood against wood destroying organisms in different use classes. The use classes are defined in EN 335-1 (CEN 2006). According to EN 460, only wood with high durability against wood-destroying fungi (durability class 1 and 2 in EN 350-1 (CEN 1994b)) can be used in use class 4 (soil contact/fresh water) without treatment.

Documentation to increase the knowledge base on natural durability of wood in different use classes is therefore an important task for a proper utilisation of wood. A study, recently reported by Brischke *et al*. (2009), on in-ground and above-ground natural durability of European oak heartwood, strongly indicate that the natural durability of oak given in EN 350-2 (CEN 1994c) is overestimated. Additionally, EN 350-2 does not cover all commercially available wood species.

The objective of this study was to test and compare durability of many different wood species in a ground contact field test.

The results reported here is part of a larger project, focusing on testing natural durability of wood in different applications (Flæte *et al*. 2006, 2008, Evans *et al*. 2008).

MATERIAL AND METHODS

The material consisted of Norwegian wood species able to give sufficient sawn wood dimensions (commercial and less utilised species, indigenous and introduced species) and some imported species. Additionally, modified wood (thermally modified and tall oil treated) and preservative treated wood (CCA- and Cu-preservative) were included in the test.

Ten test stakes (25 x 50 x 500 mm^3) were prepared from each of the 31 wood types listed in Table 2.

Field testing was performed at the accredited test field of Norsk Treteknisk Institutt (NTI) in Sørkedalen (Fig. 1) in accordance with EN 252 (CEN 1989).

Fig. 1. EN 252 - field testing in ground contact (Sørkedalen, Norway).

Evaluation of the decay rate was performed annually, following the grading system of EN 252 (Table 1).

Table 1. Classes of decay

Rating of decay	Classification
0	No attack
1	Slight attack
2	Moderate attack
3	Severe attack
4	Failure

RESULTS AND DISCUSSION

Mean decay rating for each of the 31 wood types after five years exposure, and mean life time of wood types where all test stakes have failed (rating 4) are listed in Table 2.

The EN 350-1 natural durability classification system for wood against fungal attack based on EN 252, uses the ratio between mean life time of stakes of the tested wood species and mean life time of stakes of a reference species (*Pinus sylvestris* sapwood for softwoods and *Fagus sylvatica* for hardwoods). Hence, calculating natural durability of a wood species in agreement with EN 350-1 requires that all test stakes of the wood species have failed. Therefore, after five years it is only possible to calculate natural durability for Alder, European birch, European lime, European silver fir, Norway spruce, Sitka spruce and Norwegian grown Western Red Cedar. All these species are classified as Not durable (durability class 5) in this test. For Alder, European birch and European lime the results are in accordance with the natural durability classification given in EN 350-2.

There are only three Norwegian grown wood species that have a mean decay rating lower than 2 after five years exposure, namely European oak, Common juniper and European larch. European oak is classified after EN 350-2 as durable (durability class 2). However, Brischke *et al*. (2009) have recently tested in-ground durability of European oak at different test-sites in Germany. Based on these tests, oak was classified as not durable (durability class 5), indicating that the durability classification given for this species in EN 350-2 is overestimated. European larch, as well as Siberian larch, has been found to belong to durability class 3-4, and are therefore not suitable for use in class 4 applications without treatment. Common juniper can potentially fulfil the natural durability requirements in EN 460 for use in class 4 applications, but the test has to continue over a longer time scale before conclusions may be drawn. It has to be pinpointed that Common juniper has a limited commercial potential due to its limited availability and small dimensioned timber.

For all other Norwegian grown species tested in the present study, the mean decay rating after five years exposure is higher than 3, implying that these species are not suited for use in in-ground applications when used without protective treatments.

Western Red Cedar (WRC) was expected to perform better than revealed through these test results. The mean life time of the test stakes of the Norwegian grown WRC was only 2.6 years and 60% of the test stakes of the imported North American grown WRC failed after five years exposure. One factor that partly can explain the low durability is the low strength of this species.

Thermal modification reduces strength properties of wood. This is probably the reason why mean life time for thermally modified Scots pine was shorter than for untreated Scots pine sapwood.

The tall oil treated test stakes perform well after 5 years exposure (all test stakes have decay rating 1). This complies with the results reported by Jermer *et al*. (1993), who found good efficacy of tall oil treatment of wood in ground contact after 11 years exposure in Sweden when using very high retentions.

It must be emphasised that in-ground field testing of wood is affected by several sources of variance, e.g. the occurrence of wood-destroying organisms in the soil. Results from testing durability of wood in ground contact can therefore vary between test sites (Edlund *et al.* 2006). In the test field in Sørkedalen soft rot is regarded as the dominant decay type. The reported results and future results from this field test should therefore be regarded as one of many contributions to the classification of natural durability of wood in ground contact.

Although no final classification can be made for many of the tested wood species, the results indicate that the potential of utilising untreated wood from the tested Norwegian grown wood species for constructions in ground contact is very limited if a long service life is needed.

Table 2. Wood types used in the project, scientific name, common name, mean decay rating after 5 years, mean life time and EN 350-2 classification. Class 1: Very durable, class 2: Durable, class 3: Moderately durable, class 4: Slightly durable, class 5: Not durable, n/a: data not available.

Scientific name	Common name	Rating	Life	EN 350-2
Norwegian grown hardwoods			(y)	
Acer platanoides	Norway Maple	3.8		5
Alnus glutinosa/ Alnus incana	Alder	4.0	2.6	5
Betula pendula/ Betula pubescens	European birch	4.0	2.5	5
Fagus sylvatica	European beech	4.0	2.9	5
Fraxinus excelsior	European ash	3.6		5
Populus tremula	Aspen	3.8		n/a
Quercus petraea/ Quercus robur	European oak	1.6		2
Salix caprea	Goat Willow	3.3		n/a
Sorbus aucuparia	Rowan	3.9		n/a
Tilia cordata	European lime	4.0	3.1	5
Ulmus glabra	Wych Elm	3.3		4
Norwegian grown softwoods				
Abies alba	European silver fir	4.0	3.3	4
Juniperus communis	Common juniper	1.5		n/a
Larix decidua	European larch	1.1		3-4
Picea abies	Norway spruce (ring width ≈ 1 mm)	3.7		4
Picea abies	Norway spruce (ring width ≈ 3 mm)	4.0	2.9	4
Picea abies	Norway spruce (ring width ≈ 6 mm)	4.0	3.0	4
Picea sitchensis	Sitka spruce	4.0	2.9	4-5
Pinus sylvestris	Scots pine heartwood	3.1		3-4
Pinus sylvestris	Scots pine sapwood	4.0	4.6	5
Thuja plicata	Western Red Cedar	4.0	2.6	n/a
Imported wood species				
Intsia bijuga	Merbau (Asia)	1.0		1-2
Quercus sp.	Oak (North America)	1.5		
	American White Oak			2-3
	American Red Oak			4
Tectona grandis	Teak (Asia)	0.9		1
Larix sibirica	Siberian larch (Russia)	2.0		3-4
Pseudotsuga menziesii	Douglas fir (North America)	1.1		3
Thuja plicata	Western Red Cedar (N. America)	3.3		2
Treated/modified wood				
Pinus sylvestris	Thermally modified (commercial)	4.0	2.8	
Pinus sylvestris sapwood	Crude tall oil (high retention)	1.0		
Pinus sylvestris sapwood	Cu (Wolmanit CX-8, 11 kg/m3)	0.8		
Pinus sylvestris sapwood	CCA (Kemwood K33, 5 kg/m3)	0.4		

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NATURAL WOOD WEATHERING AS DESIGN OPTION

Hirche, M.[1]

ABSTRACT

Rather than an undesirable consequence of climate exposure, color changes of wooden surfaces may be regarded an interesting and unexploited architectural potential for using climate to produce desired weathering colors on untreated wooden claddings.

This paper describes an experimental study aiming at facilitating the climate as an active parameter in building design with exterior use of untreated wood.

A series of 10 different cladding types was designed using untreated, quartersawn heartwood of Scots pine (*Pinus sylvestris* L.). Each design was produced in four samples and placed in an aboveground vertical position on walls facing approximately cardinal compass directions.

After 18 months of weathering, coloration of the claddings was recorded and correlated with visualisations of climate angular distribution as obtained from available meteorological data.

Results of the study suggest the possibility of predicting potential color changes from climate observations.

Key words: Weathering, color change, wooden cladding design.

INTRODUCTION

Untreated wooden surfaces exposed to outdoor climate change color by a variety of processes commonly known as weathering. The initial mono-color of fresh wood changes to colors of brown and grey nuances.

Knowing what to anticipate in terms of color development of a wooden facade is crucial, when designing buildings with exterior use of untreated wood. Further, realistic expectations regarding the development over time of the look of a building is important to the relationship between architect and client.

Most of the existing studies of weathered wood are designed to investigate material deterioration. This implies studies under extreme conditions (accelerated testing) such as surfaces facing south at 45˚ inclination, continued exposure to water and direct contact with soil. Data from such studies is less relevant to understanding the results of natural climate exposures of typical vertical facades.

Hence, the need to study the matter under conditions combining experimental research methodology with conditions comparable to real facades. Two dominant

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climate sources are responsible for processes leading to color changes of wooden surfaces: Precipitation and solar radiation. The grey color is attributed to surface growth of microfungi activated by wetting of wood surface. The microfungi hypha contain black color (melanin) in the cell walls and the black hyphae coverage makes the wood surface appear grey to the human eye. Precipitation (possibly wind driven) directed onto a wooden surface may raise moisture levels of the outmost wood cells above the fiber saturation point resulting in fungal growth (Eaton & Hale 1993).

The brown color is attributed to the effect of solar radiation. Both visible light and UV- radiation can produce a brown surface through various chemical reactions. Due to its high photon energy, UV- radiation can break down the lignin wood component with products that are generally loosely attached to the wooden surface and easily washed out from the surface when the radiation is combined with precipitation. (Kollmann & Cotè 1968)

MATERIAL AND METHODS

Since the understanding of the relationship between climate and coloring requires detailed knowledge of climate exposure, a controlled experimental approach was chosen for this study rather than the acquisition of data from existing buildings with untreated wooden facades.

Figure 1. Voll research fields. In front the Southern experimental wall and the automatic weather station to the left.

A series of 10 different cladding types was designed in order to investigate the relationship between cladding geometry and climate exposure. The claddings were prepared from untreated quatersawn heartwood of Scots pine (*Pinus sylvestris* L.). Each cladding covers 60 cm by 90 cm and is mounted in a plywood box to provide constructive protection corresponding to typical building conditions. Effects from mounting materials e.g. corroding metal parts have been avoided by applying all mounting from the back side of the cladding. The designs were produced in four samples and placed in an aboveground vertical position on walls facing app. North, South, West and East, Figure 3. The experiment was carried out at Byggforsk-SINTEF research fields at Voll in Trondheim, Norway.

2S. Vertical relief cladding   *1S. Vertical plane cladding*
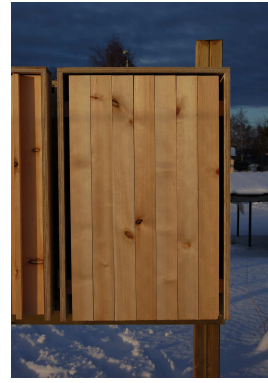
Figure 2. Two examples of board cladding design

Following 18 months of weathering, from February 2006 to October 2007, claddings were demounted, dried and disassembled. Board faces were scanned in a flatbed scanner. No cleaning or other preparation was applied to the board faces prior to scanning.

In this paper two south-facing designs are discussed. 1S is a vertical plane cladding and 2S is a vertical relief cladding (Fig. 2). Depth of relief from front edge to back is 37 mm.

Diagrams have been constructed to show the angular distribution of wind driven rain (WDR) as based on data from an automatic weather station placed at the experimental site, and of solar UV-radiation as estimated from calculations of sun positions and atmospheric attenuation.

RESULTS

Figure 3 shows the climate facing the experimental walls with a highly uneven distribution of WDR and radiation towards the directions of the walls. The South Wall is accessible to climate from Azimuth 84˚ - 264˚. Within this sector there is a highly asymmetrical distribution of WDR with a significant contribution coming from app 180˚ - 264˚ only. From 84˚ to app 180˚ the sector hardly contains any WDR. In contrast to this the angular distribution of UV is nearly symmetric.
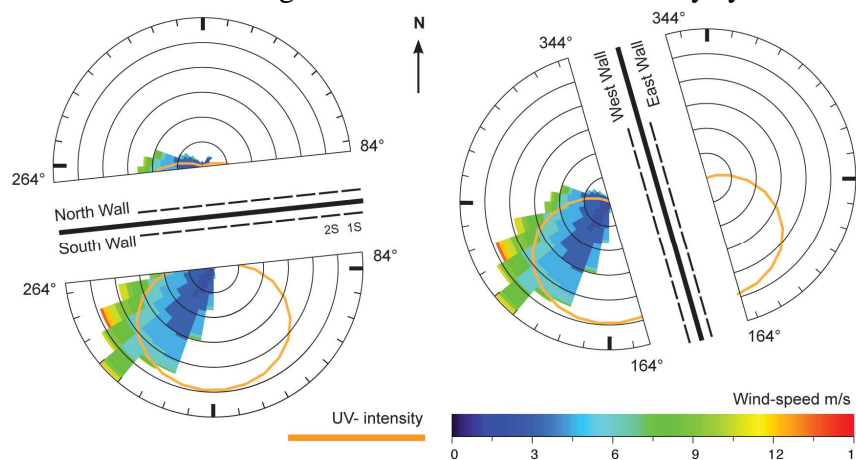
Figure 3. Angular distribution of exposure to experimental walls. UV-radiation intensity and amount of wind driven rain (WDR) are shown in arbitrary units.

Board faces	Accessible sector	Angular distribution of exposure

1S

264° ⎯ 84°

174°

Board face 1 has a 180° opening.

1

264° — 84°

2S

264° — 84°

174° · 174°

Board face 1 has a 180° opening.

1

264° — 84°

174°

84°

174° · 174° — 111°

Board face 2 has a max of 90° opening at the front
that gradually narrows to 63° at the rear corner.

2

84°

111°

174°

174° — 111° · 219° — 129° · 237° — 174°

Board face 3 has a max of 90° opening at the middle of the
board that gradually narrows to 63° at the right and left corner.

3

237° · 111°

219° · 129°

174°

264° — · 237° — 174°

174°

Board face 4 has a max of 90° opening at the front
that gradually narrows to 63° at the rear corner.

4

264°

237°

174°

Figure 4. Relation between cladding surfaces and climate affecting 1S and 2S

Figure 5. Scanned images of board faces from cladding 1S and 2S

Figure 4 shows board faces of claddings 1S and 2S with respective climate angular sectors.

Front faces of 1S and 2S both face climate from the full 180˚ sector. For the remaining board faces of case 2S it is seen how the geometry of the cladding narrows the accessible sector thus differentiating the climate contributing to the weathering of the different board faces.

Figure 5 shows weathering colors of 1S and 2S. 1S has developed a grey monocolor covering the whole surface area and 2S has developed a multicolor pattern of grey and brown.

The color patterns may be described as sequences of rhythms with 1S as |: G :| (repeated grey boards) and 2S as |: G-B-GB-G:| (repeated pattern of boards of grey, brown, combined grey and brown, grey). The vertical color distribution on board face 2S-3 is ascribed to shading effects of the plywood enclosure.

The apparent correlation between the weathering colors of 1S and 2S and the angular distribution of climate suggest a relation between climate and color development. In the case of face 2S-2 amounts of water have been too low to allow the growth of fungi on the surface. For this board surface, radiation has been the dominant contribution resulting in a brown surface. For the other surfaces of both cladding designs the WDR has contributed sufficient water to a greying of the surfaces.
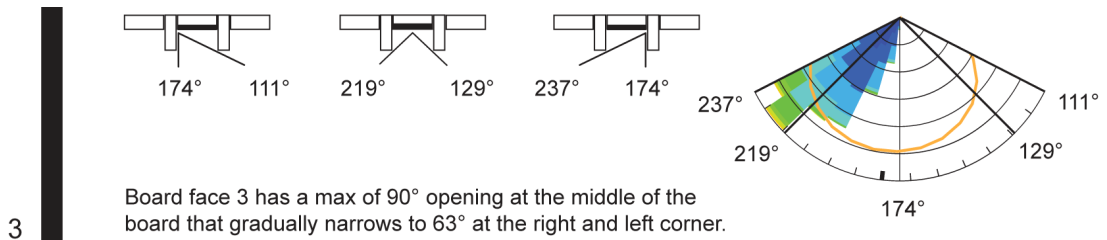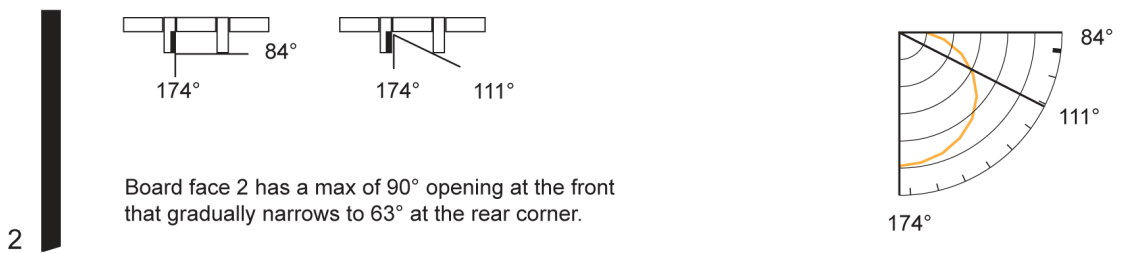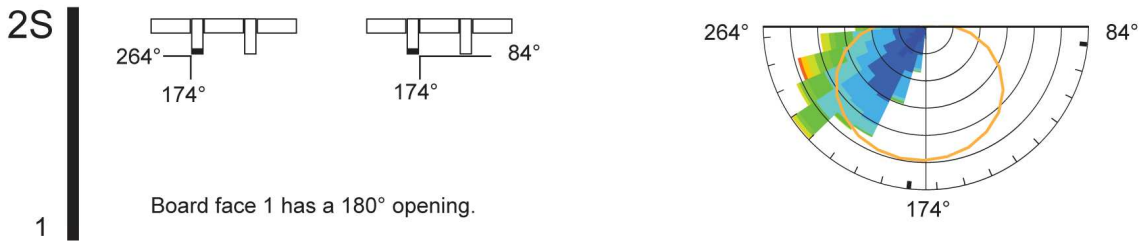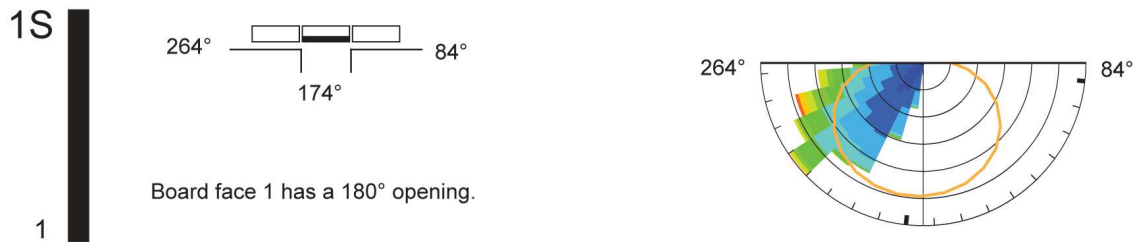

DISCUSSION

Much of the guidelines available to architects and clients recommend facade designs with homogenous access to climate in order to achieve monocolored surfaces. This desire for monocolor appearance of a surface may be seen as the result of lack of predictability of color changes. The results of the present study suggest a development of a controlled pattern of varying weathering color could be regarded a valuable design option.

In addition to the effect of a relief geometry discussed in this paper, one may consider varying the vertical angle of the surface. For instance, in the present study the East facing claddings were subject to very little water exposure due to the predominantly South-westerly wind direction. Even a slight inclination of the board surface away from the vertical orientation would dramatically increase water exposure on the East facing claddings.

Yet another parameter is the quality of the wood tissue as this generally affects the weathering processes. One such source of variation is the woods content of toxic extractives known to retard the surface growth of fungi.

It is common practice in building construction always to select materials with maximum durability properties for all parts of the building regardless of exposure. A detailed understanding of the angular distribution of climate exposure as established in this study allows for a more differentiated choice of materials opening a broader spectrum of design options. For instance, the use of material qualities normally regarded inferior for external use could be desirable in dry sections of a cladding.

The mathematical modeling applied to the angular distribution of climate exposure presented in this paper is subject to a number of severe limitations. This includes the lack of account for variations in atmospheric composition, cloud coverage and the application of a pure free-field approach to the treatment of WDR.

However, more advanced modeling could be done as research in the field is rapidly progressing (Blocken & Carmeliet 2005).

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ASSOCIATION OF GROWTH WITH HIGH HEARTWOOD QUALITY IN SCOTS PINE

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ABSTRACT

The natural durability of wooden structures subjected to decay has become more important along with increasing concern about the ecological impacts of wood preservation chemicals. The fact that wood is highly variable in its characteristics offers a real challenge for its optimal use in various applications.

The possibility of increasing the quality and quantity of Scots pine heartwood timber by means of forest tree breeding was studied by estimating phenotypic and genetic parameters for stem diameter, the amount of heartwood and the concentration of total phenolics in the heartwood. The concentration of total phenolics has proven to be a good predictor of the resistance to decay of Scots pine heartwood, which can be regarded as an important wood quality characteristic. The estimated genetic parameters comprised heritability, additive genetic coefficient of variation, and genetic correlation. The purpose was to describe the distribution of the studied characteristics and to evaluate the outcome of selection.

The phenotypic variation in all the traits was wide. In the concentration of total phenolics, a large part of the variation was attributed to genetic differences among the families. For the variation in the stem diameter and the amount of heartwood the environmental effect was more pronounced. The phenotypic and genetic correlations between the studied characteristics varied between –0.24 – 0.04 and –0.26 – 0.04, respectively.

In a breeding program, target traits may be improved by combining them into a single selection index, or by selecting for each trait separately.

Based on this preliminary study on a single progeny test, we conclude that it is possible to select for trees with a larger proportion of heartwood and better decay resistance without a loss in volume growth.

Key words: Heartwood, durability, quantity, growth, forest tree breeding

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INTRODUCTION

The interest on the natural durability of Scots pine (*Pinus Sylvestris* L.) heartwood has increased due to the legal restrictions on the use of wood preservation chemicals. The natural durability of Scots pine heartwood is known to be dependent on the extractives (Rudman 1966, Scheffer & Cowling 1966), which are unavoidably produced during the heartwood formation. However, due to the developmental, environmental and genetic causes, wood material is highly variable in its characteristics, which offers a real challenge for its optimal use in various applications.

The efficiency of the exploitation of the good durability properties of Scots pine heartwood is strongly dependent on the amount of heartwood as well as on the uniformity of the quality offered to the end-users. It would be possible to reduce the variation in the quantity and quality of heartwood by technological applications to grade timber during and after the harvest, by the forest management practices as well as by selection of the forest regeneration material.

The aim of our study was to investigate the possibility to combine high heartwood content and high extractive concentration with fast volume growth by means of selective breeding. The aim of such breeding line would be to produce timber with good natural decay resistance and dimensional stability, traits that are important in construction use.

MATERIAL AND METHODS

The study population consisted of 520 trees belonging to 53 half-sib families in a 38-year-old Scots pine progeny test (Harju & Venäläinen 2006). We estimated genetic parameters i.e. the genetic correlation, heritability and additive genetic coefficient of variation for the stem diameter, for the amount of heartwood, and for the concentration of total phenolics within the annual rings 3-6 counted from the pith. The concentration of total phenolics, which was measured by Folin-Ciocalteu assay (Prior 2005, Harju & Venäläinen 2006) describes the decay resistance of Scots pine heartwood against cellar fungus, *Coniophora puteana* (Schum. Ex Fr.) Karst. (strain BAM Ebv 15) (Harju & Venäläinen 2006).

Diameter ($D_{1.30}$)

Total phenolics (TP)

Heartwood (HW) radius
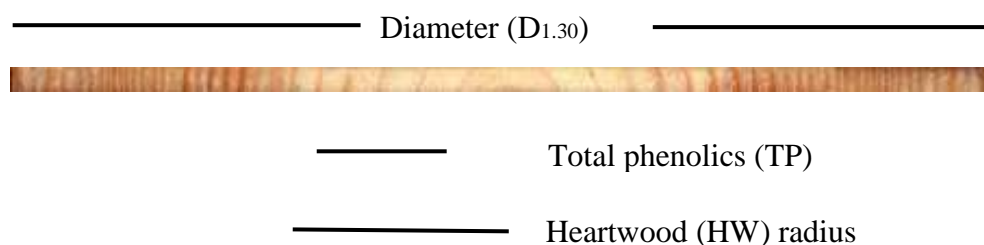
HW proportion =100 x HW area/Stem cross-section area ($D_{1.30}$)

Figure 1. The variables that were measured.

The estimates of the genetic parameters together with phenotypic variation parameters were applied in estimating the gain to be achieved by selective seed harvesting from existing seed orchards using progeny test data, or by establishment of a new seed orchard with trees obtained by novel phenotypic selection from natural stands.

RESULTS AND DISCUSSION

Description of the variation

Both phenotypic and genetic variation was the largest for the concentration of total phenolics. Phenotypic and genetic variation was larger for the proportion of heartwood than for the stem diameter. Regarding the heritable variation, the order of the characteristics was similar (Table 1.).

Table 1. Description of the phenotypic and the genetic variation of the studied characteristics. Coefficient of variation = CV (%)= (100×SD/Mean). Proportion of heritable variation of the total phenotypic variation = h^2 (%). Coefficient of additive genetic variation = CV_A (%).

	Phenotype			Genotype	
	Range	Mean	CV (%)	h^2 (%)	CV_A (%)
$D_{1.3}$, mm	85 - 257	185	14	17	6
HW proportion, %	3 - 38	15	33	28	18
TP, mg TAE/g	2 - 21	9	39	71	33

Heartwood proportion and the concentration of total phenolics were independent from the stem diameter. However, there was a slight negative correlation between the concentration of total phenolics and the proportion of heartwood. Thus, the larger the proportion of heartwood was, the less it contained the extractives within the annual rings 3-6 counted from the pith. (Table 2.).

Table 2. Phenotypic (r_P, n = 520) and genetic (r_G, n = 53) correlation between the studied characteristics. Standard deviation = SD.

r_P, p\r_G, (SD)	$D_{1.3}$, mm	HW proportion, %	TP, mg TAE/g
$D_{1.3}$, mm		0.03 (0.391)	0.04 (0.309)
HW proportion, %	0.04 0.411		-0.26 (0.243)
TP, mg TAE/g	0.04 0.309	-0.23 <0.000	

Breeding for the decay resistance of heartwood timber

Breeding programs usually aim at simultaneously improving multiple traits. A selection index is a technique used to integrate information on many traits for an optimal result. In the selection index approach, the trait-wise values on individuals are weighted with estimates of economic values and genetic and phenotypic variation parameters.

Genetic gains are commonly delivered to forestry by means of seed orchards (sexual propagation). We predicted the genetic gain for two reproduction scenarios that differed with respect to the intensity of selection (proportion of selected trees = P) and the estimate of pollen contamination (= CONT):

1) Selective cone harvesting from existing seed orchards using progeny test data (P = 25 %, BP = 100 %), and
2) Establishment of a new seed orchard with trees obtained by mass selection (phenotypic selection from natural stands) (P = 1 %, CONT = 50 %).

Fig. 2 A demonstrates the genetic gain that could be achieved by selecting for any single trait, irrespective of changes in other traits.

The results for index selection (Fig. 2 B, next page) show the predicted improvement when diameter as well as heartwood quantity and quality were selected for. The concentration of total phenolics dominates the gain due to its high heritability and large phenotypic variation in relation to the two other traits in the index. One example of restriction is given to show the breeder's possibilities to balance the end result (C).
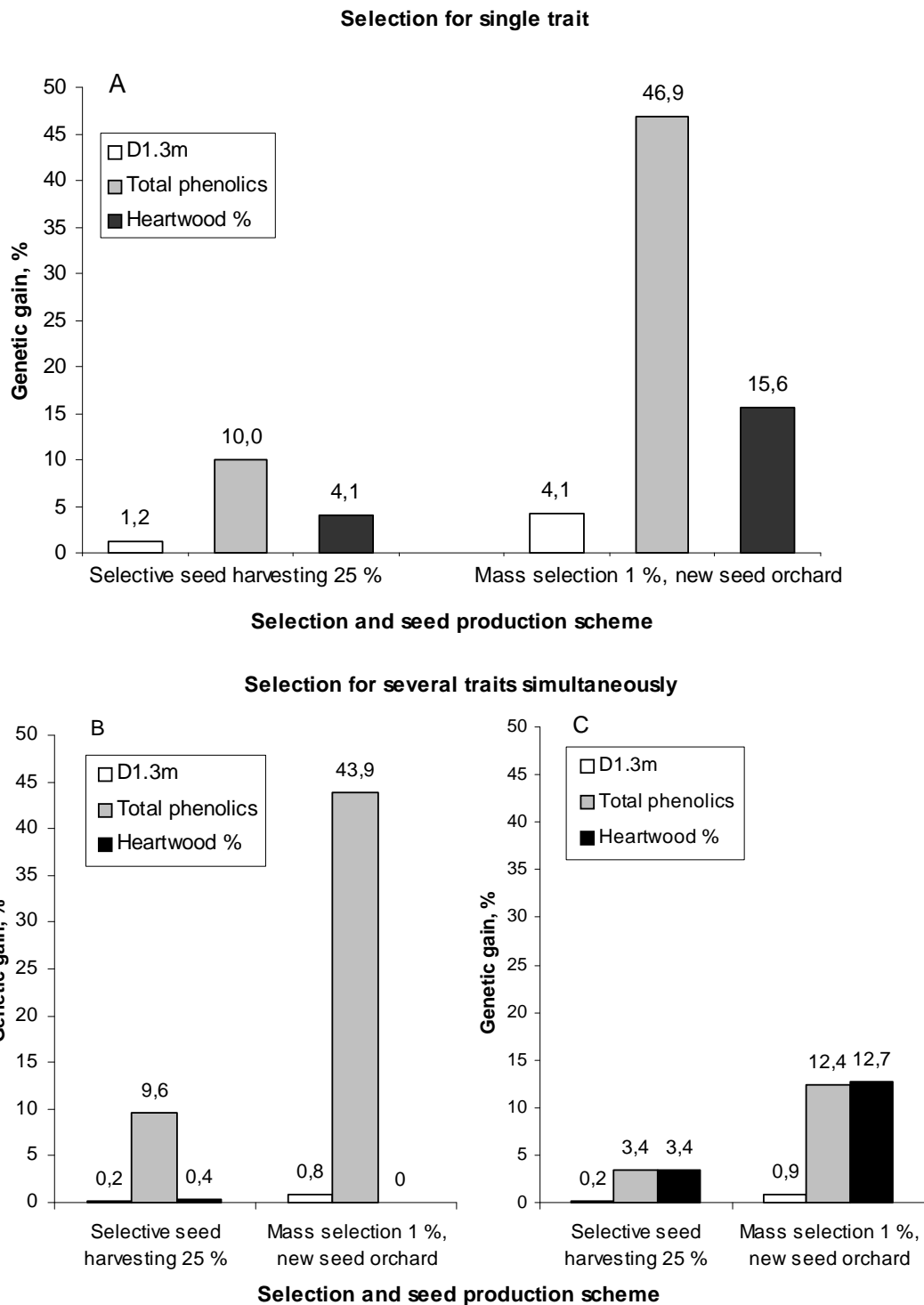
Fig. 2. The genetic gain in stem diameter, heartwood percentage, and the concentration of total phenolics obtained in different selection and seed production schemes. A) selection of one trait at a time, B) Selection for all the traits simultaneously using Smith-Hazel selection index with equal economic weights among the traits (the same percentage change in each trait was considered to be of equal value), C) Selection index with restrictions: equal gain in total phenolics and heartwood percentage with maximised gain in $D_{1.3}$ desired.

CONCLUSIONS

We conclude that it is possible to select for trees with a larger proportion of heartwood and better decay resistance without a loss in volume growth. The gain to be achieved by selective seed harvesting is substantially lower than that of mass selection. However, it would take more than 20 years after the mass selection until a new seed orchard will attain the full seed production. When a mass selection is carried out, an index with restriction is needed to balance the genetic gain in the heartwood volume and the concentration of total phenolics.

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COMPARISON BETWEEN DIFFERENT DECAY ASSESSMENT METHODS

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ABSTRACT

The durability of wood in exterior use is limited by to climatic factors and wood deteriorating organisms. The natural durability of the Nordic wood species is generally regarded as low, and for e.g. decking and use in soil contact wood protection is needed. Within the last years, new non-biocidal treatments, like wood modification systems, have been developed to improve the biological resistance of wood. For information about the decay resistance of untreated and modified wood, natural outside exposure is necessary. European standard EN 252 is the main field test method for use class 4. In use class 3 the need of new or improved test setups has been put forward. Traditionally evaluation of field trials has mainly been based on visual evaluation and pick-test. However, to get in depth knowledge about: 1) different field trial methods and 2) fungal colonization of new wood protection systems, additional assessment methods can be used. Hence, comparative studies are needed.

In this study, two outdoor test-procedures, the block-test for use class 3 and the EN 252 standard for use class 4, were used as model methods for comparison between different decay assessment methods. Untreated Scots pine (*Pinus sylvestris*) samples were exposed in field for 4 years (2004 to 2008). A range of different methods were used to evaluate decay. The following methods for detecting early decay gave significant correlation with mass loss: MOEdyn, chitin- and ergosterol assays, lignin content using TGA and EMC. For severe decay, only lignin and cellulose gave significant correlation with mass loss.

Key words: Assessment methods, block-test, EN 252, Scots pine sapwood, wood decay

INTRODUCTION

Wooden building and construction materials are continuously exposed to fungi, which under suitable conditions are able to colonize and degrade wood using enzymatic processes. In the Nordic countries there is a tradition for the use of wood (mainly conifers) as construction materials, even though the natural inhabiting wood species

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are generally not regarded as very durable. Within the last years, new non-biocidal treatments, like wood modification systems, have been developed to improve the biological resistance of wood.

European standard EN 252 (1989) is the main field test method for new wood protection systems in ground contact. However, most applications for untreated and modified wood are without ground contact in use class 3 situations. For above ground testing there is a range of standard and non-standard methods available. Lap-joint (ENV 12037 1996) and L-joint (EN 330 1993) are standard tests, but there are some dissent about whether or not they are really accelerated test methods (Grinda et al. 2001, Grinda and Carey 2004). The test setups bears some disadvantages: the samples are complicated to prepare, sample size is too large particularly if the samples have to be prepared from sapwood (Sailer et al. 1999) and the sample size is not optimised for evaluations with e.g. dynamic modulus of elasticity (Pfeffer et al. 2008). Some new accelerated non-standard above ground tests are the block test (Pfeffer et al. 2008), double layer (Rapp and Augusta 2004) and close to ground test (Westin et al. 2002). The block test was developed to expose the wood close to the ground, hence to an environment with high humidity and high biological activity (Pfeffer et al. 2008). The objectives of the test were: 1) fast colonisation by fungi based on the positioning of the samples, 2) non-destructive evaluation while the test runs, 3) significant results after a relatively short time (5 years), simple preparation of the samples and test setup.

Visual inspection combined with a pick-test is the most common method applied to assess wood decay in field trials. It is a subjective method and under estimate early internal decay (Grinda and Göller 2005). Field tests need many years before any conclusions can be drawn. How many depends on the site and climate. Neither mass loss nor visual inspection methods are sufficiently sensitive to detect early stages of decay. The interpretation from test rating to estimation of service life is also a topic that needs further work. "Accurate, quantitative, sensitive and species-specific": these are according to Eikenes et al. (2005) the main qualities that an ideal technique for evaluation of fungal wood deterioration should have. However, this ideal wood decay assessment method has not yet been found. As a supplement to the traditional wood decay evaluation, both mechanical and biochemical assessment methods can provide new and useful information in the testing of new wood protection systems.

The aim of this study was to compare and evaluate a range of different decay quantification methods after exposure in use class 3 and 4.

MATERIAL AND METHODS

For this study two field test procedures were used: 1) the European standard EN 252 (1989) for evaluation of specimens in soil contact (use class 4), 2) the block-test (Pfeffer et al. 2008) for above ground (use class 3). The samples were exposed from 2004 to 2008 in Göttingen, Germany. A subset of 12 replicates was harvested for analyses each year in addition to the samples failing each year. In this paper, only results from untreated Scots pine (*Pinus sylvestris* L.) sapwood will be presented. The mass loss were calculated gravimetrically for each sample.

Wood samples: Samples of Scots pine sapwood without faults were used. The block test samples were 20 x 20 x 300 mm, and the EN 252 samples were 25 x 50 x 500 mm.

Evaluation and analyses: The methods used to quantify fungal colonization and determine the change in wood properties are given in Table 1.

Table 1. Methods used for determining the change in wood properties.

Method	Reference
Ergosterol assay	Eikenes et al. 2005
Chitin assay	Eikenes et al. 2005
Quantitative real-time polymerase chain reaction (qPCR)	Eikenes et al. 2005
Calorimetric value (Bomb Calorimeter)	SIS-CEN/TS 14918:2005
Dyn MOE Vibration (Grindosonic)	Machek et al. 1998
Dyn MOE Ultrasound (Pundit)	Alfredsen et al. 2006
Visual evaluation of surface moulds	ASTM E24-06
Visual evaluation of decay	EN 252 1989
Thermo gravimetric analyses (TGA)	Grønli et al. 2002
Equilibrium moisture content (EMC)	Gravimetric

Statistical methods: JMP software V.8.0 was used for statistical analysis. The screening was performed by using a multivariate correlation. The comparison between different test methods was performed using bivariate fit with ANOVA.

RESULTS

The traditional evaluation of EN 252 gave a decay index of 97 after two years and all samples had failed after three years. After four years of exposure none of the block test specimens failed, and the mean decay index was 40. All specimens in the block test were totally covered with surface moulds already after one year. Mass loss in the two test setups are given in Fig. 1 and Fig. 2.

ANOVA was used to analyse the effect of the different quantitative evaluation methods compared to percent mass loss (Table 2). In the EN 252 specimens, change in cellulose ($r^2 = 0.495$) and lignin content ($r^2 = 0.330$) were the only parameters that significantly correlated with mass loss. Also some other interesting significant ($p < 0.05$) correlations were found. TGA results showed that when cellulose content decreased from initial value in unexposed samples the relative lignin content increased, ($r^2 = 0.862$). When the cellulose content decreased the amount of ergosterol increased ($r^2 = 0.373$). The qPCR gave very low or no result due to lack of optimal storage, therefore no statistical analyses were performed.
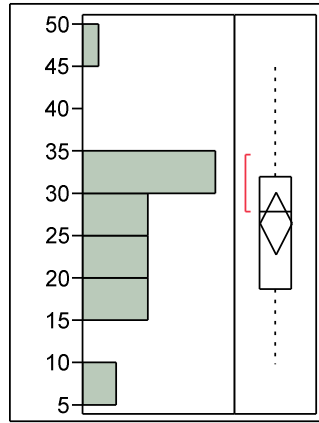
Figure 1. Mass loss distribution in EN 252 after failure.
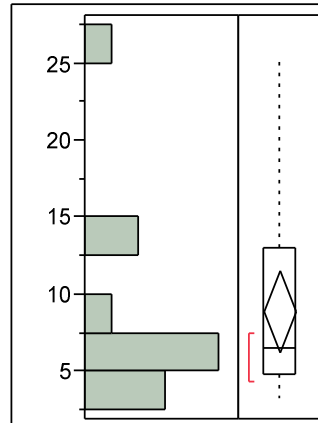
Figure 2. Mass loss distribution in block test after four years.

In the block test all the following parameters significantly correlated with mass loss (Table 2): ergosterol ($r^2 = 0.307$), chitin ($r^2 = 0.730$), MOEdyn ultrasound $20C°/65\%RH$ ($r^2 = 0.974$), MOEdyn ultrasound water saturated ($r^2 = 0.672$), MOEdyn vibration water saturated ($r^2 = 0.922$), lignin content ($r^2 = 0.348$) and EMC ($r^2 = 0.391$). Also some other interesting significant ($p < 0.05$) correlations were found. The amount of chitin increased when the change in MOEdyn ultrasound 20/65 compared to unexposed specimens increased ($r^2 = 0.695$), and the same trend was found for MOEdyn vibration versus chitin ($r^2 = 0.714$). MOEdyn ultrasound 20/65 versus MOEdyn vibration was found to be strongly correlated ($r^2 = 0.947$).

Table 2. The effect of the different evaluation methods compared to percent mass loss using ANOVA.

Method	EN 252		Block test	
	p-value	r^2	p-value	r^2
Ergosterol	0.351	0.045	<0.05	0.307
Chitin	0.759	0.005	<0.05	0.730
Bomb calorimeter	0.132	0.097	0.535	0.018
Dyn MOE ultrasound (20C°/65%RH)	-	-	<0.05	0.974
Dyn MOE ultrasound (water saturated)	-	-	<0.05	0.672
Dyn MOE vibration (water saturated)	-	-	<0.05	0.922
TGA; change in cellulose content	<0.05	0.495	0.348	0.040
TGA; change in hemicellulose content	0.979	0.000	0.531	0.018
TGA; change in lignin content	<0.05	0.330	<0.05	0.348
TGA; change in extractives content	0.308	0.050	0.547	0.017
Equilibrium moisture content (EMC)	0.502	0.022	<0.05	0.391
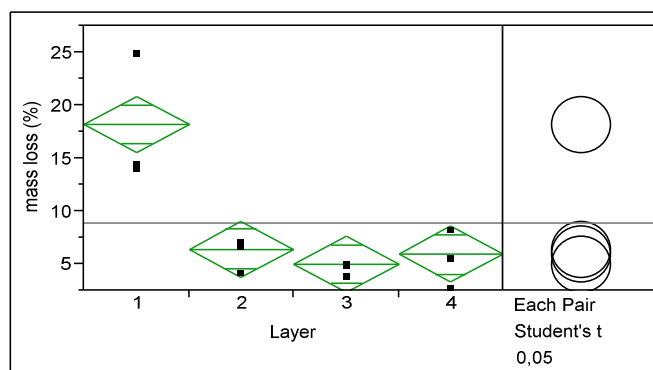
Figure 3. The bottom layer (1) had higher mass loss than the other layers and no significant differences were found between layer 2, 3 and 4.

The samples in the bottom of the block test had much higher mass loss than layer 2, 3 and 4, with did not differ between themselves (Figure 3). In the block test, samples were taken from both the centre and edge of each test stake. In the EN 252 test, samples were taken from the bottom end in soil (edge) and in the transition zone (centre). No significant difference in mass loss was found, neither for EN 252 or the block test specimens.

DISCUSSION

The German test site for EN 252 showed high biological activity. In the EN 252 test, the only factors significantly correlating with the mass loss was cellulose and lignin content. This show that cellulose is faster deteriorated than lignin at this EN 252 test site. This might indicate that brown rot is the most dominant decay fungi. The correlation between ergosterol and cellulose indicate that both can be used as quantitative measurements for decay. Decay fungi break down cellulose and the higher the fungal activity (more fungal biomass), the higher the amount of ergosterol. The specimens from EN 252 were severely deteriorated and sensitive measurements of fungal colonization using chitin and ergosterol was not optimal at this late stage of decay. The results from the quantitative real-time PCR method showed undetermined results. The storage of the samples was not optimal for qPCR analyses and samples for further studies should immediately be stored in a freezer.

For the above ground test (block test) the decay rate was slower than in the EN 252 samples. As the samples were not heavily decayed, the more sensitive evaluation methods provided interesting information. The methods that gave significant values with mass loss were chitin and ergosterol assays, MOEdyn methods, change in lignin content and EMC. The chitin and ergosterol is a sensitive, quantitative measure of fungal biomass, where chitin corresponds to living and dead fungal mycelia, and ergosterol is a method for living fungal mycelia. The results of this study show that chitin and ergosterol assays are convenient tools for determination of early decay. This concurs with the laboratory experiment by Eikenes et al (2005). The correlation between increased chitin values and increased strength loss (MOEdyn ultrasound 20C°/65%RH) indicates that higher fungal colonization gives higher strength loss in the block test samples. It was a strong correlation between MOEdyn ultrasound (20C°/65%RH), and MOEdyn vibration (water saturated). The correlation was lower between MOEdyn ultrasound (water saturated), and MOEdyn vibration (water

saturated). This shows that MOEdyn ultrasound below fibre saturation is a reliable tool for early detection of strength loss. Above the fibre saturation calculation of MOE needs further optimisation, or alternatively, only transit time might be used. The result from this study shows that the EMC of wood powder increase with increasing mass loss. This illustrates that acclimatized deteriorated wood not necessarily has uniform moisture content, and is important to keep in mind when performing physical and chemical analysis.

CONCLUSIONS

- The following methods for detection of early decay gave significant correlation with mass loss: MOEdyn, chitin- and ergosterol assays, lignin content using TGA and EMC. For severe decay, only lignin and cellulose gave significant correlation with mass loss.
- The bottom layer in the block test had the highest mass loss. The remaining layers had lower mass loss and no significant difference in mass loss was found between them.

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ULTRASOUND – A FEASIBLE TOOL FOR DECAY DETECTION?

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ABSTRACT

Mechanical strength properties are the most important feature of wood in constructions. In decaying wood strength loss can precede mass loss. Hence, both in laboratory and outdoor applications non-destructive measurement methods for early decay detection are in demand. The aim of this study was to evaluate the applicability of ultrasonic pulse propagation as a tool for decay detection in different laboratory setups. A dynamic MOE (MOE_{dyn}) strength test device based on measurement of ultrasonic pulse propagation was used for non-destructive strength evaluation in different exposure situations for Scots pine sapwood. Two different test setups were used.

In the first test MOE_{dyn} was measured above fibre saturation. A range of different wood protection treatments were tested according to the terrestrial microcosms (TMC) test, a modified ENV 807. Three different soil types were used: forest soil dominated by white rot, Simlångsdalen test field soil dominated by brown rot and compost soil characterised by a mixture of bacteria and soft rot. Before strength testing the samples were water saturated and MOE_{dyn} was measured above the fibre saturation point at time intervals (0, 8, 16, 24, 32 and 40 weeks) using ultrasound. Comparisons of strength loss were performed between treatments in the different soil types, and strength loss was also compared with mass loss.

In the second test MOE_{dyn} were measured below fibre saturation. Ultrasound measurements were performed on 0.5 m pine logs sampled from five trees from the same stand in central Southern Norway. Logs from two of the trees had varying amounts of discoloration due to an incipient attack by the white rot fungus *Phlebiopsis gigantea* during storage. Amount of visible discoloration had effect on MOE_{dyn} values from measurements on log ends. Transversal measurement of MOE_{dyn} was not successful. In a subsequent water uptake test, logs with discoloration absorbed substantially more water than the rest of the sample.

The conclusion of this study was that the use of ultrasonic MOE is applicable as an evaluation tool in early decay detection.

Key words: ultrasound, early decay detection, dynamic MOE

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INTRODUCTION

Mechanical properties, usually the most important characteristics of wood for use in structural applications, are highly influenced by microbial deterioration. In order to assess the degree of decay in wood in laboratory tests and in use, non-destructive tests are in demand. Modulus of elasticity (MOE) is highly correlated to the ultimate strength in bending (Kollmann & Côté 1968), and a high correlation between static MOE and dynamic MOE has been reported (e.g. Gerhards 1975; Pellerin 1965). The determination of dynamic MOE (MOE_{dyn}) is non-destructive even on decayed wood, and these methods are particularly interesting for evaluation of wood decay. Ultrasound is one of the main methods of determining MOE_{dyn}, and this method has been shown to give satisfactory results (Bauer & Kilbertus 1991; Faraji et al. 2004).

When evaluating ongoing decay tests, drying of the specimens is not feasible because it will affect the biological activity in the wood in a negative manner. All mechanical properties of wood stay more or less constant above the fibre saturation point (e.g. Kelsey 1956; Skaar 1984; Tiemann 1906). This makes it feasible to test wood specimens at moisture contents above the fibre saturation point (FSP). However, earlier studies have reported some problems with ultrasound measurements above FSP (Alfredsen et al. 2006; Larnøy et al. 2006).

The permeability of wood is known to increase in very early stages of decay (Behrendt & Blanchette 1997; Lindgren 1952), paving the ground for further decomposition of the wood. Early detection of decay in wood in outdoor use is therefore of great importance. MOE_{dyn} testing has mainly been done on small dimension specimens prepared for durability tests (e.g. Machek et al. 1998; Alfredsen et al. 2006). Possible utilisation of the method on the larger dimensions used in wooden constructions would be practical in early decay detection on wood in use.

The aim of this study was to evaluate the applicability of ultrasonic pulse propagation as a tool for decay detection in different laboratory setups.

MATERIAL AND METHODS

Terrestrial microcosms (TMC)

The wood modifications, reference treatments and control samples used in this part of the study are given in Table 1. Scots pine sapwood (*Pinus sylvestris* L.) was used for the different wood modifications and preservative treated reference. The specimens had the dimensions specified in ENV 807 (2001), 5 x 10 x 100 mm, and were leached according to EN 84 prior to decay testing. The decay study was a terrestrial microcosms (TMC) test (Edlund 1998), a modified ENV 807 (2001). Three different types of soil were used: soil from Scandinavian coniferous forest, garden compost from Sweden and soil from the Swedish test field in Simlångsdalen. The forest soil is dominated by white rot fungi, Simlångsdalen soil by brown rot and compost soil by soft rot and bacteria. Further soil characteristics are given in Westin and Alfredsen (2007). MOE_{dyn} was measured above the fibre saturation point at time intervals (0, 8, 16, 24, 32 and 40 weeks) using ultrasound. The specimens were water saturated for one hour prior to the strength testing. Twelve replicates of each treatment were tested

in each of the three soil types. Six specimens of each treatment were harvested and oven dried after 24 and 40 weeks.

Table 1. Wood treatments in the terrestrial microcosms experiments (TMC).

	Treatment	Treatment levels (abbreviations)
Wood modifications:	*Furfurylation*	25 WPG (FA 25)
	Thermal modification	212°C, (TM)
	Acetylation	23 WPG (Ac 23)
	Linseed oil*	150 kg/m³ ret. (Linseed)
References:	*Copper chromium based*	10 kg/m^3 (CC 10)
	Semi-durable hardwood	*Robinia pseudoacacia* heartwood (Robinia)
Control:		*Pinus sylvestris* sapwood (Control)

* wood modification according to the manufacturer due to grafting compound.

Coated log sections

Five Scots pine trees from a single stratus in a single stand in the central part of southern Norway were sampled in such a way as to minimise between-tree and within-tree variation. The specimens for the experiment were taken from the second log of each tree, between 5 and 10 m from the tree stump. The logs were pre-cut along two sides to obtain two distinct cracks during drying, debarked manually and dried naturally outdoors for 12 months. Each log was cut into nine test specimens of 0.5 m in length.

During drying two logs were attacked by a rot fungus (determined to the white rot fungus *Phlebiopsis gigantea* (Fr.)). The attack caused brown staining of the wood (up to 35 % of the slice area) in all specimens from log III and in some specimens from log II (up to 8% of the slice area) (Figure 1; Table 2). Annual increment and brown stain were determined by visual inspection of slices cut from the butt end of the specimens.
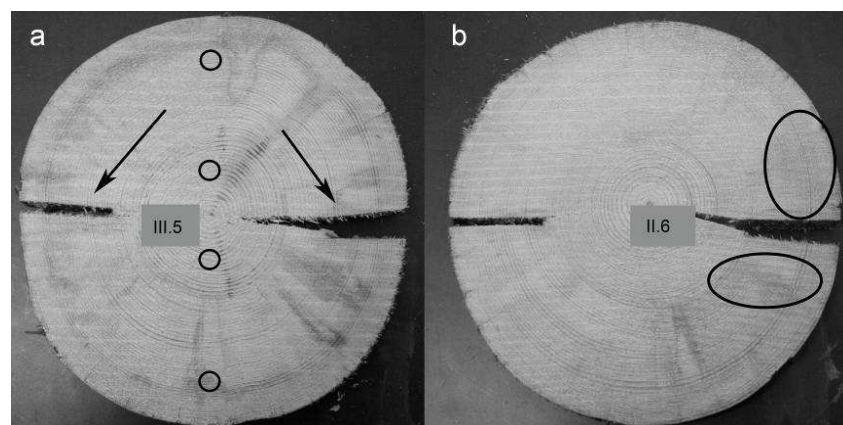

Figure 1. a: Slice from log III showing extensive brown stain. Arrows indicate pre-cut cracks. Measurement points for MOE$_{dyn}$ (3 cm from the pith and outer edge) is indicated with circles. **b:** Slice from log II showing only minor brown stain (rings) and some blue stain.

Table 2. Annual increment width and brown stain. Means for each tree, n = 9 specimens. Max values for area of brown stain due to the white rot fungus *Phlebiopsis gigantea* are listed.

Tree no.	Annual increm. (mm)		Brown stain (% area)	
	Mean	**StDev**	**Mean**	**Max**
I	1.3	0.03	0	0
II	1.4	0.03	3.06	8.42
III	1.5	0.13	10.30	35.07
IV	1.4	0.04	0	0
V	1.3	0.03	0	0

After 6 months of conditioning in lab climate (20 °C, 65 % relative humidity) the end surfaces of the specimens were sealed using a two-component epoxy sealant. Three different surface coatings (alkyd, acrylic and untreated) and two crack directions (up/down) were used, and the experiment was designed to give two full replicates from the brown stained part of the sample. The test logs were put through 6 wetting and drying cycles, and ultrasonic MOE_{dyn} measurements were done on the specimens prior to the first wetting cycle. Measurement points on the end faces are shown in Figure 1 a. Transversal measurements were done on the midpoint and 10 cm from each end on the same axis as measurements on end faces.

Ultrasound

In both parts of the experiment, dynamic MOE (MOE_{dyn}) was measured using Pundit Plus, an ultrasonic pulse exitation device. The transducers used had resonant frequencies of 200 kHz. The MOE_{dyn} was calculated from the measured transit times using the following formula:

$$MOE_{dyn} = (l / t)2 \cdot m / v \qquad (1)$$

where l = length of specimen (mm), t = measured transit time, m = mass at measurement moisture level (kg) and v = volume at measurement moisture level (m^3). In the TMC experiment calculation of MOE_{dyn} gave illogical results. Therefore, transit time was used for analyses in this part of the experiment.

RESULTS

Terrestrial microcosms (TMC)

In Table 3, percent mass loss and percent strength loss (measured as transit time) compared to initial measured values are shown. The strength evaluation using ultrasound gave the same general trends between treatments as mass loss for all soil types. Interestingly, Simlångsdalen soil gave the highest strength loss, while compost soil gave the highest mass loss. Forest soil generally gave the lowest mass and the lowest strength loss. However, for FA 25 strength loss was highest in forest soil. Mass loss after 40 weeks was equal in compost and forest soil and higher in forest soil than in Simlångsdalen soil. In compost soil several specimens failed (fell apart) from week 32.

Table 3. For the three soil types: percent change in dry weight mass loss (ML) at 24 and 40 weeks and percent change in ultrasound transit time at 8, 16, 24, 32 and 40 weeks.

	Compost soil							Simlångsdalen soil							Forest soil						
	ML		Transit time					ML		Transit time					ML		Transit time				
	24	40	8	16	24	32	40	24	40	8	16	24	32	40	24	40	8	16	24	32	40
FA 25	1	4	3	3	3	1	1	0	3	3	5	4	5	4	0	4	5	6	6	10	10
TM	1	3	4	5	5	5	5	1	2	3	5	5	6	4	1	5	5	5	6	7	8
AC 23	1	1	1	2	1	2	2	0	1	0	0	0	1	1	0	1	3	3	2	3	3
Linseed	11	26	5	5	5	7	5	2	4	6	5	4	9	6	4	9	4	3	2	8	6
CC 10	7	20	0	1	3	6	8	5	7	1	1	1	2	2	3	6	1	1	0	2	2
Robinia	28	45	7	11	12	14	17	5	12	6	7	10	13	14	6	10	7	8	8	10	9
Control	36	74	9	14	19	15*	9*	33	50	20	23	30	50	83	8	27	4	4	4	2	4

* Decrease in ultrasound transit time occurred due to failure of specimens.

Coated log sections

In an ANCOVA test on the whole sample, both amount of brown stain and log number (between-tree effect) had significant effect on MOE_{dyn}. Brown stain had negative effect on MOE_{dyn}, while the sign of the tree effect varied between logs (Table 3). Analysis including only specimens with more than 2.5 % brown stain (n=11) yielded even higher R^2 (0.64) (p brown stain = 0.0171, no tree effect). If transit time was analysed directly, brown stain was the only significant effect (p<0.0001, estimate positive).

Table 4. Results from ANCOVA tests, effect on MOE_{dyn} and transit time.

Sample	Effect	R2	Sign of estimate	p value
All sp., n=35	Log no.	0.79	+(I, III)/-(II, IV, V)	0.0110
	Brown stain		-	<0.0001
All sp., n=35	Brown stain		+	<0.0001

Transversal measurements gave substantially lower MOE_{dyn} than longitudinal measurements. There was a statistically significant correlation between longitudinal and transversal measurements (p = 0.0362). The correlation was clearer in analysis on specimens with no brown stain (p = 0.0084), and disappeared if logs with no brown stain were excluded.

Brown stain had a large influence on water uptake, and effects of coating and crack orientation became important only when brown stained specimens were excluded from the analysis. Detailed description of the results regarding moisture uptake in specimens with different treatments and degrees of brown stain will be reported in an article presently in preparation.

DISCUSSION

The use of ultrasound to measure strength in small soil exposed samples was shown to be useful in detecting early stages of decay. An interesting result was that the highest strength loss was found in Simlångsdalen soil while the highest mass loss was found in compost soil. This is most likely due to differences in species composition of deteriorating fungi in the different soil types. The Simlångsdalen soil is dominated by

brown rot. Brown rot is known to cause more rapid strength loss at lower mass losses than white rot fungi. Even though the highest general mass loss was found in compost soil and the highest strength loss was found in Simlångsdalen soil, the furfurylated samples were most affected by the forest soil. The forest soil is dominated by white rot fungi and had the highest water holding capacity and the lowest pH. This result will be of interest for further investigations on the mode of action of furfurylated wood.

The correlation between MOE_{dyn} and brown stain due to *Phlebiopsis gigantea* was less clear in samples with very minor brown stain. MOE_{dyn} was measured in one point at a time, and as the brown stained areas in these specimens were small the MOE_{dyn} measurements may have missed them entirely. The moisture data include the whole log cross sections, including the highly permeable brown stained areas. This might explain why these small areas of brown stain gave little effect on measured MOE_{dyn}, even if they were highly influential on water absorption.

The lack of a significant tree effect on the measured transit time in the coated logs indicates that the tree effect on MOE_{dyn} was caused by the relationship between mass and volume of the samples. On this background the influence by mass loss can be the reason why calculated MOE gave illogical results in the TMC experiment.

The much higher transversal than longitudinal transit time can be explained by the fact that the ultrasound must cross a lot more cell walls in the transversal direction. The significant correlation between longitudinal and transversal transit time indicates that transversal decay detection should be possible. The lack of success in detecting early fungal colonization by transversal transit time might be explained by the fact that the brown stain is caused by *Phlebiopsis gigantea,* a white rot fungus which leaves the cellulose fibres more intact than brown rot. This should be given further study, which should include wood in different stages of decay and brown rot versus white rot.

The conclusion of this study was that the use of ultrasonic MOE is applicable as an evaluation tool in early decay detection, but that it is important to take moisture and temperature into consideration in experimental planning. Ultrasound measurements during decay give supplemental information to mass loss measurements and visual evaluation, illustrating the influence by different deterioration organisms. The direct link to strength properties makes ultrasound a potentially useful tool in technical service life prediction.

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ULTRASOUND AND VIBRANT RESPONDS OF MODIFIED OAK WOOD: A COMPARATIVE ANALYSIS

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ABSTRACT

Understanding and modeling links and relations between wood micro-scale characteristics and behavior of real timber elements requires scaling-up sizes of specimens as well as testing methods and instrumentation corresponding to the sophisticated diversity of wood structure.

Methods of non-destructive wood testing are getting more and more popular due to the possibility to evaluate mechanical properties of wood. However concerning to wood anisotropy and un-homogeneity in some cases it is difficult enough to get reliable results.

In this work for the experiments two testing devices were used – portable timber grader MTG and special ultrasonic strength meter, developed at Kaunas University of Technology. To explore and compare applicability of this specific testing equipment based on ultrasonic and amplitude-resonant inspection ammonia-modified and unmodified oak wood samples are used. Variable physical-mechanical and size factors of specimens were focused on comparative specification the measurement accuracy and validation of applicability for testing specific wood properties.

Keywords: ultrasonic, amplitude, resonance, wood modification, dynamic Young's modulus.

INTRODUCTION

Non-destructive testing methods (NDT) for investigation of wood especially large-scale dimensions specimens become more and more popular. Non-destructive methods allow enhancing species and grade populations for structural timber though requiring permanent and adequate control measures. Critical condition for scientific and industrial NDT applications is measuring uncertainties and overall accuracy [1]. Being anisotropic biological material wood marks wide spectrum and variation of physical and

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mechanical properties. Internal structural formations as knots, fissures, spiral grain, early/late wood ratio, etc. make characterization of certain properties even more difficult [2]. Detecting and evaluation of such formations could be equivalently sophisticated as tested substance and structure itself. At the same time, those methods have to be accurate, reliable, productive and cost efficient. Ultrasonic wood examination was universally acceptant as corresponding above-mentioned requirements especially for evaluation mean values of wood elastic constants such as Young`s modulus (MOE) and indirectly strength [3-5].

Large databases are nowadays available for characterization of ultrasound velocity in wood depending on species, grain direction, moisture content and temperature [6-11].

Changes of wood properties under heat treatment and modification were open for careful studies for more than 50 years. However, even well known wood ammonia modification remain many questions on plasticization proportions, colorings, extent of structural changes influencing physical-mechanical properties. Emerging new testing methods focused on wood characterization on micro and nanoscales seems to be revolutionary in understanding breaking by ammonia treatment intra-molecular hydrogen links [12]. For practical applications of such a modified timber, e.g. wood flooring key interest is monitoring, targeted correction of resonant behavior and grading and batching during production factory control.

Concerning to wood anisotropy and un-homogeneity in some cases it is difficult enough to get reliable results. Considerable differences of measure values recorded in even negligible changes of testing position and specimen sizes makes problematic determining mechanical and physical properties for even externally identical specimen. Even more confusions appear when applying different NDT testing methods and devices.

As indicated above, there are many reports on the research about nondestructive testing of wood. However, few investigations have been concerned with comparative nondestructive testing of wood-based on usage of different methods and instrumentation. To complement existing data validation of NDT using portable timber grader MTG (Holland) and special ultrasonic strength meter developed at Kaunas University of Technology was performed [13]. The aim of the work focuses on comparative specification the measurement accuracy and validation of applicability for testing specific wood properties.

MATERIAL AND METHODS

For the study, oak timber was cut into samples with 751 mm length, 75 mm width and 24 mm thickness respectively. The average specimen wood density was 658.3 kg/m^3 and initial average moisture content for unmodified oak wood was 9% while that for the ammonia-modified wood was 12%.

Resonance frequency, modulus of elasticity (MOE) and coefficient of damping of all samples initially were estimated using measurement instrument „Timber Grader MTG". The measurement system consists of the „Timber Grader MTG", weighing device, wireless communication device bluetooth and PC with „Timber Grader"software. The measuring principle of the MTG is the measurement of the natural frequency of wooden specimen. The stress waves are introduced with an integrated electric hammer and measured with an integrated sensor. Vibrations that are brought into the wood are converted into a digital value and sent via the wireless connection bluetooth to the computer.

Parallel to the above mentioned were accomplished measurements using acoustic stiffness-strength meter developed at KTU. A technique is based on excitation of acoustic Lamb waves in wood and measurement time-of-flight between fixed at 380 mm transmitter and adapter. Later on series of MOE experiments using KTU stiffness meter were carried out for evaluation size factor and wood anisotropy in changing specimen widths and thicknesses.

Measurements were performed on four specimen planes denominated Side 1 (S1), Side 2 (S2), Edge 1 (E1) ir Edge 2 (E2). Specimen width was changed by planing repeatedly every 6 mm on edges and that for changing thickness was successive 3 mm on sides. Longitudinal ultrasound scanning was performed gradually on every particular specimen plane at 10 steps (zones). Scanning data on planed and sawn specimen surfaces was also compared. Comparative format of our research focused on distinctions of treated-untreated wood characteristics and measurement method accuracy and uncertainties allowed to narrow testing procedure with the specimens having near-longitudinal grain direction.

Modulus of elasticity was calculated after measuring sound velocity (time-of-flight) using simplified Eq. 1:

$$MOE = C^2 \rho \qquad (1)$$

where C – sound velocity, m/s; ρ – wood density, kg/m^3

For evaluation of wood plastic properties, another amplitude-frequency characteristic – coefficient of damping - is used Eq. 2 [14]:

$$tg\,\delta \approx \eta = \frac{f_2 - f_1}{f_{rez}} \qquad (2)$$

where tg δ – tangent of loss angle; η – coefficient of damping.

RESULTS

Received format of resonance frequencies for modified and non-modified oak wood was similar yet careful evaluation of vibration extinction time and coefficient of damping character emerged substantial differences. Those are seen from Fig. 1 showing time-to-flat graph and Fast Furier Transform (FFT) graph on Fig. 2. Excitations in modified wood fade away 1.2 times faster (Fig. 1, b) than in unmodified one.
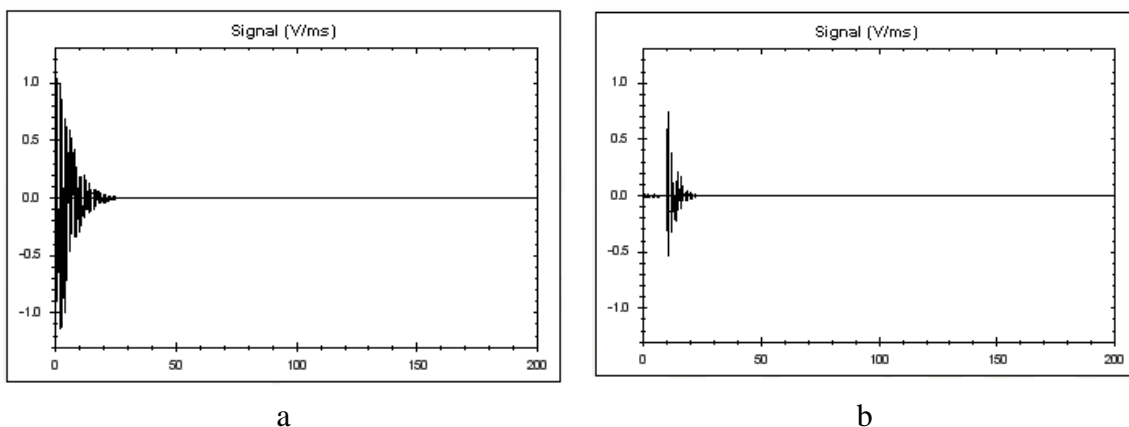

a   b

Fig. 1. Pattern of vibration fading in time: a – unmodified oak; b – modified oak

a   b
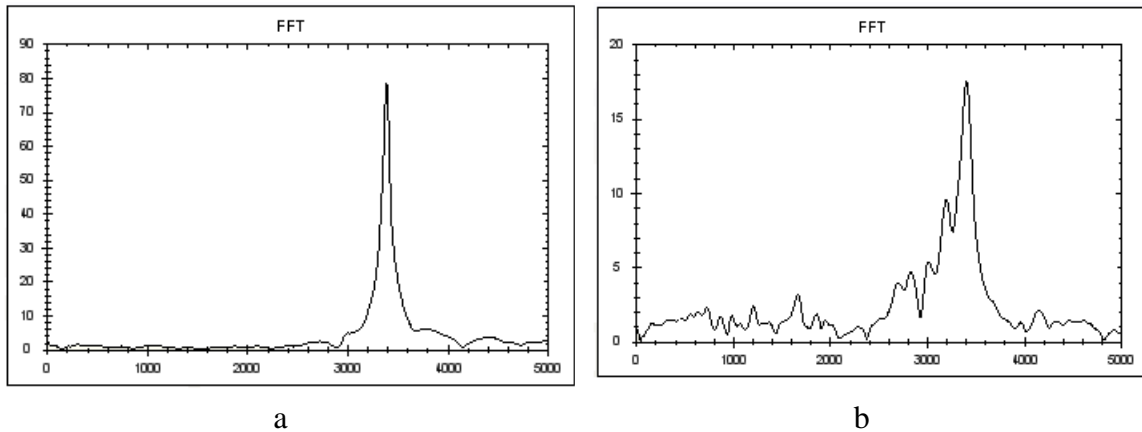
Fig. 2. Fast Fourier Transform data: a – unmodified oak; b – modified oak

Resonant amplitudes in ammonia-modified oak are by 4.47 times lower than those in unmodified. For illustrated case, average coefficient of damping in unmodified wood (0.01228) was by 1.5 times higher than of modified oak. For all tested specimens vibration fading for ammonia-modified oak was on average by 1.2-1.4 faster than that in unmodified; coefficients of damping were in turn higher by 1.4—1.9 times.

MOE values obtained using KTU stiffness meter were up to 29 percent different from those measured with Timber Grader MTG. Supposedly end-to-end measuring with MTG gives lengthwise-generalized MOE values while on-plane positioning of KTU stiffness meter reflect localized within 380 mm zone stiffness properties.

Fig. 3 presents differences in MOE values measured with Timber Grader (MTG) and KTU ultrasound tester US (KTU).

a   b
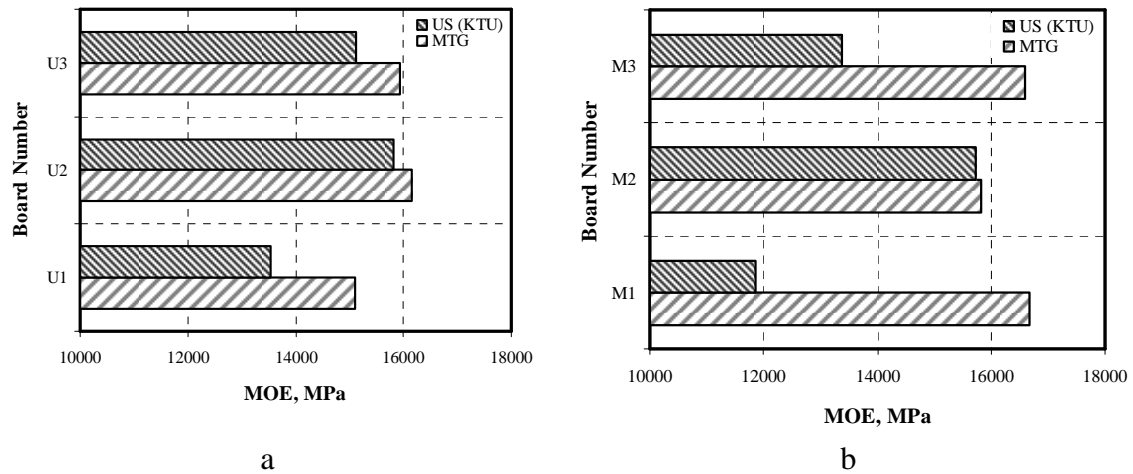
Fig. 3. Comparison of MOE values obtained with tested devices MTG (Timber Grader) and KTU ultrasonic stiffness tester US (KTU); a – unmodified oak samples U1-U3; b-ammonia-modified oak wood samples M1-M3

On average values obtained with MTG for unmodified wood are by 2-10% than those received with US (KTU). For ammonia modified wood differences were even larger – 0.5-29%. Whether wood modification and resulting structural changes influences in measuring principle (eg. Lamb wave propagation peculiarities) or it is matter of measuring uncertainties it is still not clear. Special experiments are planned to be focused on clearing-up latter questions.

Next series of experiments dealt with size factor effects on measuring results and accuracy. All specimens have been successively planed on the same edge by 6 mm for width changing. Ultrasound velocities on new surfaces were measured with US (KTU) tester and recalculation of them into dynamic MOE performed. Longitudinal lengthwise specimen scanning on 10 zones (points) allowed to sense local structural variations. Fig. 4 presents MOE variation lengthwise specimen measured on successively planed surfaces.
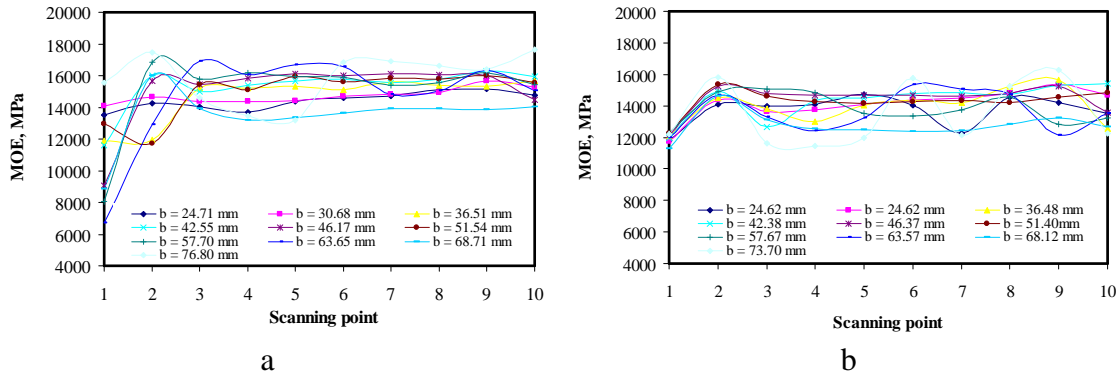
Fig.4. MOE variation lengthwise specimen for changing width: a – unmodified oak wood; b – modified oak wood

For unmodified (Fig. 4, a) wood specimen width diminishing causes MOE decrease by 4.1-18.6% (respective ultrasound velocities fall by 3.8-9.7%). Near-surface structure of modified wood appear to become more homogenous and less related to the width changes and thus size factor effects on measurement accuracy. Illustrated example, Fig.4, b, indicates that 60% of MOE values increased from 1 to 23%; remaining 40% of MOE values decreased by 3.4-12%. Still measurements are sensitive to the localization of the ultrasonic tester closer to the specimen ends: MOE values decreases in some cases by 25-35 % when scanning at both ends.

Similar series of experiments examined dependencies of specimen thickness and lengthwise variation of structure anisotropy on resulting MOE values. By nature Lamb wave propagation is not sensitive to the specimen thickness, therefore fluctuation of MOE measures is clearly dependent on tester position (scanning point) and responds the spatial singularities of wood within ultrasound propagation path. For unmodified oak, the decrease of specimen thickness from 24.6 mm to 9.8 mm results in MOE increase by 1.5-25.7%; coherent (computational) ultrasound velocity increases by 0.7-13.8%. Lengthwise MOE variation of modified oak shows larger local anisotropy (Fig. 5, b).

Fig.5. Variation of ultrasound velocity (a) and MOE (b) for different thickness unmodified specimen

For the same as above mentioned unmodified specimen thickness range MOE increases by 13.7-44.8% (ultrasound velocity increases respectively by 3.5-25.7%). Indirectly those figures indicate that no-homogeneity of tested modified specimen by 1.74 times higher than that of unmodified.

Comparative testing of nondestructive instruments for examining wood stiffness-strength properties allowed evaluating measurin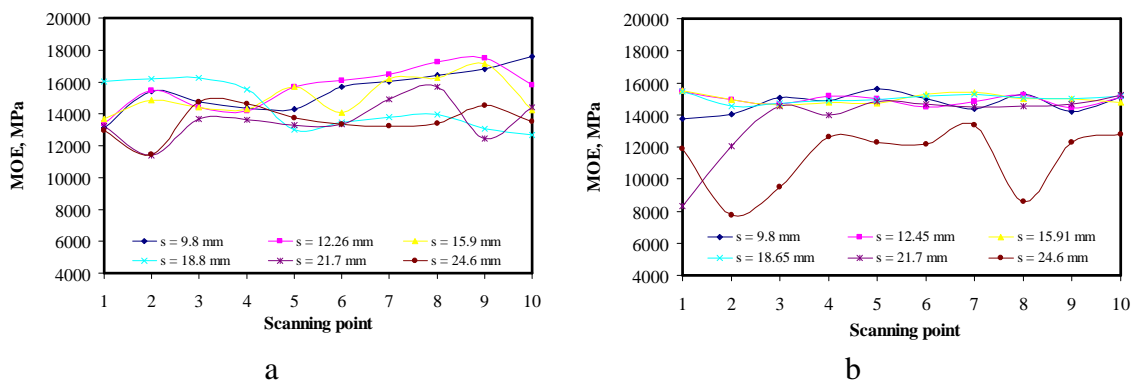g accuracy and uncertainties and judging the optimal scope of application. Experimental validation of end-to-end tester MTG Timber Grader and on-plane Lamb wave stiffness tester unfolded significant differences of nominal values when testing identical specimen and also measuring accuracy and uncertainties.

CONCLUSIONS

1. Ammonia-modification of oak wood results in notable beneficial accomplishments compared with the natural solid oak. Oscillation amplitude decrease up to 4.47 times and vibration fades by 1.2-1.4 times faster, coefficient of damping is on 1.45-1.90 times higher compared with the untreated oak wood.
2. Comparative stiffness values determined with tested vibrant-acoustic instruments differed up to 29% when measuring identical specimens. Regarding resonant behaviour of the whole specimen end-to-end vibrant-acoustic examining gives somehow generalized lengthwise stiffness values; significant local anisotropy, especially critical as regards strength, remains unidentified.
3. Lengthwise ultrasonic Lamb wave scanning of timber pieces allows localization of hazardous positions with the unacceptable viscous-elastic performance. Together with the end-to-end scanning it could be recommended for in-line out-grading timber with the predictable vibrant-resonant behaviour.
4. Ultrasound velocity is dependent on specimen dimensions. Width size factor controversially affects Lamb wave propagation velocity in wood: reduction of specimen width follows ultrasound velocity decrease by 4-10 % in unmodified oak while width diminishing reveal tendency to ultrasound velocity growth for modified.
5. Theoretically, Lamb wave propagation velocity is not sensitive to specimen thickness in tested range. Increase of ultrasound velocity in decreasing specimen thickness respond changing anisotropy, early-late wood configuration and hence variant stiffness. Resulting variable modulus of elasticity for tested thicknesses changed by 1.5-25.7% for unmodified and by 13.7-44.8% for modified wood.

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RFID TAGS APPLIED FOR TRACING TIMBER IN THE FOREST PRODUCTS CHAIN

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ABSTRACT

Wood products are typically produced in 'break-down and sorting' processes: stems are cross-cut and sorted into saw-, pulp- and energy-logs; sawlogs are sawn to boards and sorted according to quality, then split again and applied in various ways. Through the sorting processes, the 'group traits' become increasingly more homogeneous, but any individual identity or origin is lost after each process. 'Group identity' is even the method for the popular and much applied timber certification systems. 'Individual identity' should be an option, however, if the industry wants e.g. to send some specific information together with the wood pieces to subsequent processes, or the answer to questions like 'what was the outcome of products and profitability of a given lot of raw material?' Pursuing efforts from the Indisputable Key project, this paper discusses some experiences and commercial opportunities for tracing wood pieces by applying the RFID (radio frequency ID) technique. A rather standardised system has been set up for the forestry chain tracing system: reading/adding and transferring information from various sources like a harvester, a log scanner and sawing machines, and joining this information in databases to be retrieved in subsequent stages. Dissolvable tags that can be accepted in chips for the pulp industry, and other tags tolerable to the harsh conditions in a creosote preservation plant, have been identified. Models are developed that add reliability to the prognoses for quality outcome from stems and logs based on stored information. The option of calculating environmental, wood quality and profitability indicators is incorporated. A case study in tracing preservation treated transmission poles is presented. However, so far the tags appear quite expensive, up to one euro, and there are additional costs to set up and run the system, so the commercial benefit should be indisputable before venturing into a RFID project.

Key words: Wood industry, tracing cost, information exchange, profitability

INTRODUCTION

Wood is generally acknowledged as a natural material with a certain degree of unpredictable variability in traits. A producer of wood products – from logs through sawn timber and chips to furniture or paper – will, to his best ability, do a pre-process quality assessment and sorting. Nevertheless, some variability will always remain in the end product. It has been assumed that better knowledge of wood origin should facilitate the quality assessment and increase the efficiency of the forest products chain. This has

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been one of the driving forces for establishing the Indisputable key, IKey, project; a brief presentation of the project is given as appendix.

However, it has also been assumed that tracing technology might be used in the wood industry for a wider variety of purposes, like keeping control with consignment lots ("what has been the outcome of a given roundwood lot?"), location of products in stock, or calculating environmental impact of individual wood products.

The objective of this paper is to give an overview of the tracing technology and illustrate a few applications, based on activities in the IKey project. Other tracing systems than RFID are considered in the project, but will not be dealt with in this paper.

TRACING TECHNOLOGY

RFID, radio frequency identifier, is a general electronic technology, commercially applied already for some decades. A tag consists of a small chip connected to an antenna (Fig. 1). A unique identification number is stored in the chip, and might be transmitted to a reader through the antenna by electromagnetic waves. The chip and antenna are encapsulated for protection and to ease the application, and might be supplied with additional information, e.g. by printing the ID number. The cost of a tag is to a large degree depending on the quality of the encapsulation.

In IKey a particular tag has been developed, suitable for automated application directly from the harvester head into a log and with a casing dissolvable during pulp processing.
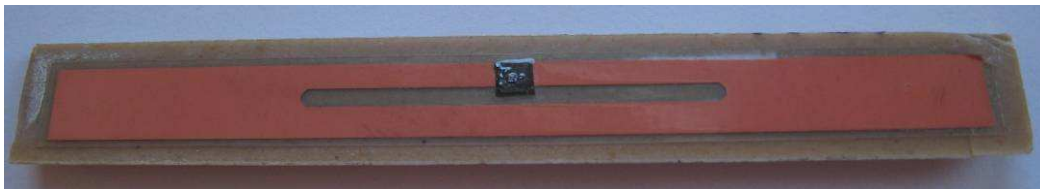

Fig. 1 An open RFID; CPU (black square on top, centre) connected to the antenna

Fig. 2 Various tag types encapsulated in paper (left), glass (right, down) and plastic

The only way to communicate with the RFID tag is through a reader. The reader consists of an antenna, a computer and software for interpretation, filtering e.g. to avoid repeatedly reading, and typically also providing an interface to the company's commercial databases. Even for the readers a variety of technical solutions are available (Fig. 3).

Fig. 3 Left: Hand-held reader operates only at very short distances
Right: Experimental setup of antenna (top right) and computer for reading distances up to a few meters

Transponders might come with a power supply, allowing them to actively and continuously submitting radio waves, which might increase reading distance. Such tags are, however, too expensive to have been considered for the wood industry.

For a passive tag, the reader antenna emits radio waves that are received in the tag, which accumulates enough energy to return a radio signal, giving away its identity. RFID tags are produced with varying frequency, or wavelength, specifications. Tags and reader must be compatible, i.e. of identical frequency, to communicate. Also, emitted energy from both tags and antennae will typically be inhomogeneous in different directions. Thus, a proper alignment is mandatory to get a maximum reading signal and reading distance. Even vicinity to water or metals might cause distortion in the radio waves.

Setting up a RFID tracing system is rather laborious, and consequently most appropriate for applications that will be used as routine for a prolonged period.

APPLICATION IDEAS

The IKey idea: Added value by adding info on wood origin

The idea of IKey is to establish an operational technology. This is to be achieved in the forest products chain: An RFID tag is automatically applied to the chosen logs during harvest, giving the log a unique ID that will be maintained until the breakdown process in the sawmill. Information related to each log will be stored in a database, i.e. site, stand and harvest information. New information might be added during hauling, transport and scanning at the log sorting plant. After breakdown each board will be

given a new ID number directly connected to the old one. Additional information from the breakdown, green sorting, kiln drying, strength grading etc. will be added to the database, and so on during secondary manufacturing. Standardised internet data communication and database structure have been defined, and example procedures and software for wood quality modelling, performance indicators, environmental issues and information exchange between commercial partners have been given and will be demonstrated during the project. Once the technology is established, the hope is that commercial pluralism will identify new and profitable applications.

However, the profitability should be carefully analysed before venturing into a full tracing system. Considerable information is already available, or can be easily achieved, on request and at low cost without RFID tags. One will expect increasing marginal cost and decreasing revenue when transferring towards full ID tracing for all logs (Fig.4).
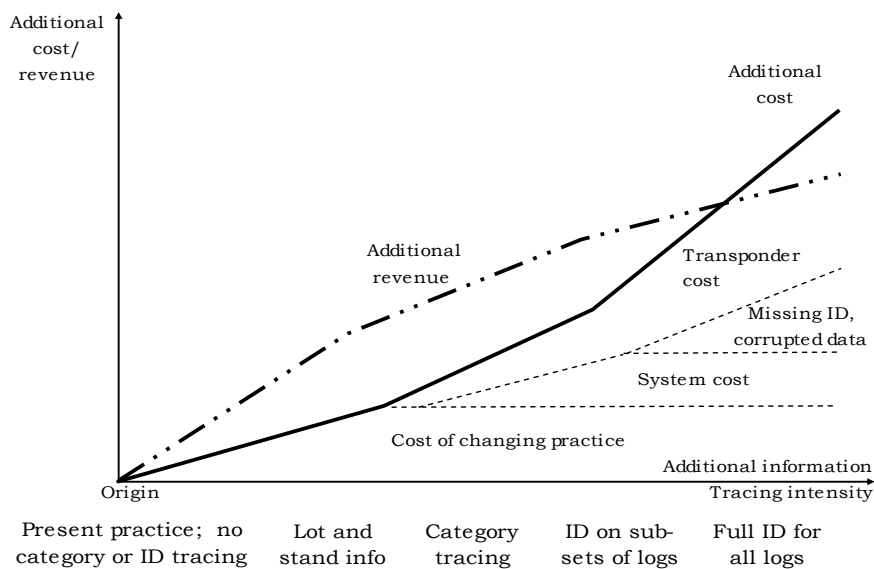
Fig. 4: Sketch illustrating decreasing profitability at increasing tracing intensity

Idea: Posterior verification of profit from specific sawlog lots

In the sawmill industry, acquiring proper raw material, i.e. sawlogs, is by far the heaviest expense. Nevertheless, most major sawmills, those with a log sorting system, have only a faint and qualitative impression of the outcome of single sawlog lots. Even if reliable info is available at the time of arrival in the sawmill, the traceability is lost once several lots are mixed in the log sorting, and further confused during the breakdown process. Consequently, a sawmill rarely has the opportunity of identifying the sawn timber outcome of a lot and thus is deprived the chance of calculating the revenue. With RFID, only tracing within the company is needed, and thus simpler than tracing between two or more independent commercial partners. Improved knowledge of lot profitability will stimulate the buyer to pay more correctly for suitable wood.

Idea: Consignment lot control for transmission poles

At least two approaches apply: Control of impregnated pole truck-load weight, and invoice control for shipped poles. Poles are rather bulky and heavy, and transport cost substantial. Poles are classified according to size and sold by the number. Volume and

weight vary considerably between poles in the same class. To have full control of load weight, individual data are needed. Further, the shipping documents and invoice state the number of poles delivered. Counting the number of poles (or logs) might seem straightforward – but it is not; missing by one or two in one hundred is not unusual. So we wanted to identify every loaded pole to be shipped (Fig. 5). So far, however, there are a few challenges: Reading reliability must be improved, transponder casing must be tolerable to creosote, and revenue so far does not balance system cost. However, we hope to come to better solutions in the subsequent tests.

Fig. 5 Four antennae mounted in each corner of the container for reading RFID transponders on transmission poles during loading

COST FOR A SAWMILL RFID TRACING SYSTEM

For any commercial company, the verification of profitability of new procedures and applications is a prerequisite. RFID technology has been at hand for a couple of decades or more, and has found application in various industries. Newer technology versions offer better value for money, so it is easy to assume, or hope, that even our industry should benefit from the same tools. However, it must be acknowledged that, despite that the technology was introduced to the sawmill industry in a first project fifteen years ago, no company has so far ventured into a permanent application on a commercial basis. Certainly, the costs are not preventive – provided a manifest revenue increase. But costs are not negligible neither, so no company will afford until this increased revenue is readily at hand.

It is very hard for a researcher to estimate revenue in a commercial business, and this task will be omitted here. Contrarily, the estimation of cost elements is much easier and some rough information will be given (Tab. 1). The figures are based on unpublished materials from the project, and must be considered as preliminary. The illustrative use of figures, e.g. by calculating annual cost for a sawmill of given size, is mine.

A few comments should be given. The standards (item 1), e.g. for data transfer, are produced inside IKey, and will be free for use with no cost. A certain effort will be needed to establish info and routines for calculating key performance indicators, KPI.

The same for process and wood quality models, but for these (item 3), even an annual fee will apply. The main annual fee, however, is related to the use of the IKey database and the software – IK adapters – to connect to the various RFID readers and the sawmill's ICT system (item 5). All these items end up to an annual cost, irrespective of how many tags will be used. Finally, tags are assumed to cost 35 eurocent each (item 4, the price will have to be verified), for at total of 350 thousand Euro if a medium-sized company sawing a million logs a year should tag all their logs. Even a small sawmill, or a medium-sized tagging a fraction of the log, might end up with a total annual cost of several hundred thousand Euros.

Table 1. Estimated annual cost for a sawmill applying the RFID technology based on IKey ideas

| No | Item | Estimated annually, k€ | | | | Total annual cost, k€ | |
		Depri-ciation [a]	Time-dependent	per 10^5 tags [b]	per 10^6 tags [c]	Total, 10^5 tags [b]	Total 10^6 tags [c]
1	Standards	0				0	0
2	KPI ninventory and configuration	11.1				11	11
3	Process & wood quality models [d]	22.2	5			27	27
4	RFID tags, applicator & reader/antenna	11.47		35	350	46	361
5	Services, IK adapters, tools	3.7	102			106	106
6	Pacing system in sawmill	1.85	2			4	4
7	Training	1.85				2	2
	TOTAL					**196**	**511**

[a] 3 years incl. 8% interest, i.e 37% p.a.

[b] equivalent to 10% subset of sawmill producing 200 000 m3 sawn timber annually

[c] equivalent to all logs of sawmill producing 200 000 m3 sawn timber annually

[d] wide variation depending on the model ambition

Appendix – the IKey project

Full project name: Intelligent distributed process utilization and blazing environmental key.

A EU-FP6 project running from autumn 2006 through 2009 with 30 partners from Norway, Sweden, Finland, Estonia and France, and representing forestry, harvesting, sawmilling, pole production, ICT industry: electronics and data processing, and teaching. Public demonstrations of the achievements are planned in the last quarter of 2009 and first quarter of 2010.

Objective: "The main proposal objective is to initiate and stimulate an industrial breakthrough in tracing systems for biological raw materials, specifically wood, leading to substantial economical and environmental improvements in the wood processing chain" (cited from the description of work.)

For further information, see www.indisputablekey.com

CHANGES OF THE PHYSICO-MECHANICAL PROPERTIES IN THE STEM LONGITUDINAL AND TRANSVERSE DIRECTIONS FOR WILD CHERRY WOOD

Gunars Pavlovics[1], Janis Dolacis[1], Mudrite Daugaviete[2], Dace Circule[1], Anda Alksne[1], Ilzite Lavnikovica[1], Andis Antons[2]

ABSTRACT

During recent years, interest in wild cherry wood (*Prunus avium* L.) has grown dramatically in Europe and worldwide owing to its unique decorative, technical, and physico-mechanical properties. Wild cherry wood is used in production of furniture and flooring, in yacht interior finishing, motorcar construction, civil engineering as well as in woodcarving. Wood is easy-to-process and easy-to-polish, it can be etched and lacquered - it is as if specially designed for the furniture industry. In Germany, wild cherry wood is more expensive than oak, ash and mahogany.

Since the demand for wild cherry wood grows on the world's market and in Latvia, its cultivation for wood production was started, and studies to elucidate the anatomical and physico-mechanical properties of wild cherry wood grown in Latvia were carried out. Density (ρ_{12}), swelling (K_α), shrinkage (K_β) and shearing strength (τ_{12}) were studied. The average characteristics in the stem's periphery and central parts (wood density at 12% moisture ρ_{12} - kg/m^3; volume shrinkage coefficient K_β - %/%; shearing strength at 12% moisture τ_{12} - MPa, compressive strength - MPa,) were obtained. The results gained make it possible to forecast that the wild cherry wood grown in Latvia is competitive on the world's market.

It has been found that the values of the physico-mechanical properties of wild cherry wood have minor distinctions among the stem's transverse, central and outer periphery parts.

Key words: cherry wood, mechanical and physical properties

INTRODUCTION

In the future, wild cherry may substitute the hardwood of tropical origin for the manufacture of different wood articles so that to decrease the consumption of tropical tree species wood. This is one of the possible solutions to decrease the cutting intensity of tropical forests, which is a global problem today. The wild cherry species is selected and cultivated mainly for fruit production. However, not long ago, it became a valuable tree species directly from the timber production viewpoint. In many European countries,

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wild cherry is cultivated in plantations, including also in Latvia, at the Latvian State Forestry Research Institute "Silava" [1, 9, 10]. Hence, it can be forecasted that wild cherry wood will become increasingly promising in the furniture and civil engineering – in finishing works.

Wild cherry has a bright red or red-brown colour and a fine, straight fibre. In stands, the height of wild cherry, depending on the soil fertility, ranges from 15-20 m to 30-35 m, and the stem diameter from 40 to 70 cm. Up to 40 years, the wild cherry growth is very fast, but, reaching the 50-60-year age, its annual increment decreases. Therefore, the maximum cutting age does not reach 60-80 years. For the time being, no regular studies on the anatomical, morphological, chemical, physical, mechanical, technological, optical, thermo-physical and other properties have been carried out.

It is important that at the end of the 20th century, wild cherry plantations had been established in many regions of Latvia and, until they reach the necessary felling cycle, the main proposals and technologies for practical utilisation and application of the new material should be ready. The following studies have been carried out on the anatomical and physico-mechanical properties of wild cherry wood, as well as the introduction in Latvia [1, 6-8, 11]. However, the versatile elucidation of the properties of wild cherry wood requires profound studies on such innovative and promising material, which would enable to forecast the properties of the wild cherry wood grown in Latvia.

MATERIALS AND METHODS

With changing climatic conditions and looking for „economical" tree species for providing the forest owners with a high-quality wood that can be produced within a relatively short term, profound studies on the provenance selection and reproduction of wild cherry (*Prunus avium* L.) have been carried out in Latvia.

Wild cherry samples were taken from two Latvia's stands: from Šķēde, Talsi region (height 20.5 m, stem diameter at the the height 1.3 m is 32.0 cm, and the age 31 years), and From Jaunlutriņi, Saldus region (height 19.7 m, stem diameter is 27.5 cm at the height 1.3 m, and the age 43 years). The studies were carried out for samples from four stem heights – butt-end, ¼, ½, ¾ , in the periphery and central parts.

The samples' preparation is schematically represented in Fig. 1.
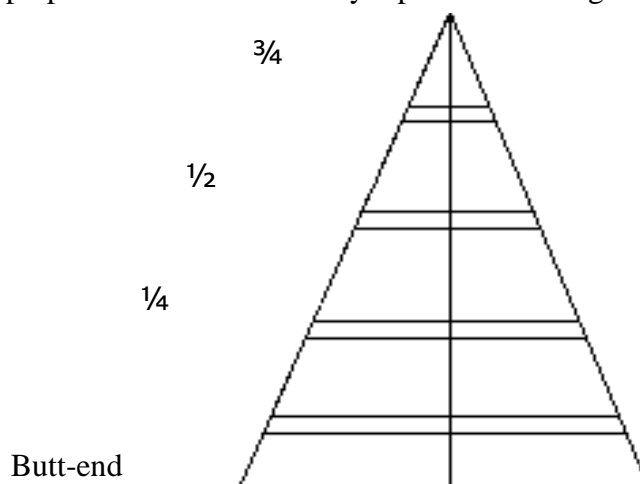
Fig. 1. Schematic representation of the samples' location in the stem.

The physico-mechanical properties were investigated in compliance with DIN and GOST standards. Density was determined according to DIN 52 182 [2]. Swelling and shrinkage were determined according to DIN 52 184 [3]. Water absorbance was determined according to GOST 16483.20-72 [13]. Shearing strength was determined according to GOST 16483.13-72 [12]. Compression strength was determined according to DIN 52 185 [4]. Bending strength was determined according to DIN 52 189 [5]. Ultimate shearing strength was determined according to GOST 16483.5-73 [15]. Tensile strength was determined according to GOST 16483.23-73 [14]. Ultimate strength in cutting was determined according to GOST 16 483.13-72 [12].

Oven dry wood density (ρ_o), radial, tangential, and volume swelling were determined for all samples. The wood density at the moisture W = 12% - ρ_{12} was calculated.

RESULTS AND DISCUSSION

Table 1 shows the physical indices of wild cherry wood at different stem heights.

Table 1. Physical indices of wild cherry wood at different stem heights

Properties	Height of the stem part	Wild cherry	
		Sapwood	Heartwood
Density, kg/m^3			
ρ_o	B	660	682
	¼	574	574
	½	692	602
ρ_{12}	B	692	714
	¼	607	607
	½	723	635
Swelling, % / K_α			
Tangential	B	13.6/0.45	13.0/0.43
	¼	12.9/0.43	10.6/0.35
	½	12.6/0.43	9.9/033
	¾	11.8/0.39	-
Radial	B	5.7/0.19	5.8/0.19
	¼	5.6/0.18	4.6/0.16
	½	6.0/0.20	4.9/016
	¾	5.9/0.19	-
Volume	B	18.8/0.62	19.4/0.64
	¼	19.2/0.64	5.2/0.60
	½	18.9/0.63	15.4/0.18
	¾	17.9/0.59	-

Table 1 (continued). Physical indices of wild cherry wood at different stem heights

Property	Height of the stem part	Sapwood	Heartwood
Shrinkage, % / K$_\beta$ Tangential	B	12.0/0.4	11.5/0.38
	¼	11.4/0.38	9.9/0.33
	½	11.2/0.37	9.0/0.30
Radial	¾	10.5/0.35	-
	B	5.4/018	5.5/0.18
	¼	5.3/0.17	5.7/0.19
	½	5.7/0.19	4.7/0.15
Volume	¾	5.6/0.18	-
	B	15.8/0.52	16.2/0.54
	¼	16.3/0.54	13.1/0.43
	½	15.7/0.52	13.1/0.43
	¾	15.8/0.52	-
Moisture Content, % Green	B	51	50
	¼	52	55
	½	53	54
Maximal, %	¾	52	-
	B	105	103
	¼	109	127
	½	114	117
	¾	110	-

Notes: B = butt-end; ¼; ½; ¾ = part of the stem, refer to Fig. 1.
Designations: R- radial; T- tangential; V- volume; K$_\beta$ –shrinkage coefficient; Kα –swelling coefficient.

The density of the central part of the stem, in comparison with the density of the outer part, is lower by 4.3%. Greater linear changes in wood, with varying wood moisture, which is characterised by swelling (K$_\alpha$) and shrinkage (K$_\beta$) coefficients, are observed in the outer part of wild cherry wood. This applies to both the changes in the radial direction and also the tangential direction. Water absorbance for wild cherry wood is higher by 9 % in the stem's central part, in comparison with the outer part.

Regarding the mechanical properties of wild cherry wood, studies on ultimate compression, tensile, bending, shearing, cutting strength, and hardness were carried out during the work. The results are shown in Table 2.
In general, the mechanical properties of wild cherry wood are demonstrated to be higher than those of other hardwoods. Hence, wild cherry wood is suitable for wide application.

Table 2. Average mechanical indices of wild cherry wood

Properties	Values, MPa
Compression strength	53.9 ± 1.8
Tensile strength	141.1 ± 20.8
Bending strength	116.2 ± 19.6
Modulus of elasticity in bending	8650 ± 1130
Cutting strength	35.6 ± 2.1
Shearing strength	16.1 ± 0.4
Hardness	54.00

As can be seen from Table 3, the ultimate compression, tensile, bending, cutting, shearing strengths are highest at the butt-end, which is the most valuable part of this wood, and decrease slightly towards the top end of the stem.

Table 3. Mechanical indices of wild cherry wood at different stem heights

Properties	Height of the stem part	Ultimate strength, MPa
Compression strength	B	55.16
	¼	54.01
	½	53.55
	¾	52.94
Cutting strength	B	39.1
	¼	35.1
	½	33.7
	¾	34.8
Shearing strength	B	17.0
	¼	15.8
	½	15.6
Bending strength	B	119.3
	¼	113.1
Tensile strength	B	141.1

Notes: B= butt-end; ¼; ½; ¾ - part of the stem, refer to Fig. 1.

CONCLUSIONS

1. It has been shown that the indices of the physico-mechanical properties of wild cherry have some distinctions in the stem's cross section central and outer periphery parts. Hence, it is suitable for fabricating both parquet and flooring boards, as well as the manufacture of different articles and souvenirs from both the central and outer parts.
2. The physical indices – density, swelling and shrinkage are greater in the stem's outer part than those in the central one.

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WOOD PRODUCT MANUFACTURE POTENTIAL OF EUROPEAN AND HYBRID ASPEN IN FINLAND

Heräjärvi, H.[1]

ABSTRACT

Aspen species cover ca. 1.5% (ca. 30 Mill. m^3) of the total growing stock in Finland. Their principal end use is in papermaking currently, however, increasing proportion of logs is expected to be obtained from planted hybrid aspen stands in the future. The purpose of this study was to compare the technical properties of European and hybrid aspen (*Populus tremula* L., *Populus tremula x tremuloides*) stems in Southern Finland. Material consisted of five European aspen stands and seven hybrid aspen stands between 20 and 60 years of age. Routine measurements on the characteristics of the stands were done from 100 m^2 circular sample plots, 6–7 of them per stand. The sample plots were located around one randomly selected, but sawlog-quality aspen that was then more comprehensively measured as a sample tree. Finally, altogether 75 of these sample trees were felled, bucked and cut into logs. The logs were graded and their technical quality characteristics were assessed in detail. The most common external quality defects included curves, sweep, and branchiness. European aspen trees showed better quality in terms of branchiness and stem form. Fast growing hybrid aspen trees had even 1.5 metre long clear distances between the whorls, which is an interesting possibility considering wood product manufacture. Both European and hybrid aspen suffered from diverse rot and surface defects. Based on the evaluation of logs, heart rot turned out to be more common than could be expected based on the evaluation of standing trees. Therefore, the overall quality of the logs was relatively poor compared to the impression obtained by pre-harvest measurements of the stands. As a conclusion, it turned out that planted hybrid aspen that is originally meant for pulpwood, has considerable potential to produce saw or veneer logs within significantly shorter rotation time than European aspen.

Key words: European aspen, hybrid aspen, timber grade distribution, branchiness, stem form.

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INTRODUCTION

European aspen (*Populus tremula* L.) is the fifth common tree species in Finland. In the entire country, aspen species are dominant on an area representing 0.3% of the total forest area, whereas in southern Finland the respective proportion is 0.5%. Aspen species make up ca. 1.5% (30 Mill. m^3) of the total volume of Finland's growing stock of 2000 Mill. m^3 (Peltola 2008). There are ca. 54,000 hectares of aspen-dominated forests in southern Finland, however, most of the aspen grows in stands dominated by conifers or birch. Lots of aspen grows also in fragmented small stands along the agricultural lands and roads. Therefore, aspen harvesting is difficult and expensive.

Breeding trials of European and North American aspen (*P. tremuloides* Michx.) during the 1950's led up to finding an exceptionally fast growing tree for boreal conditions, *i.e.*, hybrid aspen (*P. tremula x tremuloides*). It can yield as much as 20 m^3/ha/a in southern Finnish fertile soils. Hybrid aspen is basically the only tree species that can be grown in a manner of agroforestry in boreal conditions. Most of the annual aspen wood consumption goes for production of high-quality papers in Finland. Finnish wood product industries use some 3000–5000 m^3 of aspen logs annually.

In timber purchase, the most severe problem has been that the aspen supply is so fragmented and the harvesting removals per hectare are, subsequently, small. Only seldom pure aspen stands are harvested, mostly timber is obtained in small amounts as a secondary assortment of harvesting spruce or birch dominated stands. There is a countrywide buyer for aspen pulpwood, but only adventitious buyers for aspen logs. Thus, the small amounts of sawable or veneerable logs often end up to the pulp or paper mills. Due to a company-driven campaign started at the end of the 1990's, ca. 1000 hectares of *P. tremula x tremuloides* has been planted in Finland. Their principal aim is to fulfil the needs of paper industries, but it can be supposed that in ca. ten years some timber will be also available for the wood product industries. The wood technological properties of *Populus* species in Finland have been studied, *e.g.*, by Jalava (1945), Kärkkäinen & Salmi (1978), Heräjärvi & Junkkonen (2006), Heräjärvi *et al.* (2006), Junkkonen & Heräjärvi (2008), Borrega *et al.* (2009), and Heräjärvi (2009). The objective of this study was to determine the differences between the external quality of European and hybrid aspen stems and logs.

MATERIAL AND METHODS

The material comprised of 12 stands located in southern and central Finland. When selecting the sample stands, criteria were set for the area and soil fertility of the stand, as well as for the size and quality of the trees. Five of the stands were *P. tremula* stands; two of them mixed stands of aspen and conifers. One of the *P. tremula* stands was planted and four of them were of natural origin. The rest of the stands, 7 of them, were cultivated single-species *P. tremula x tremuloides* stands. One of those represented "second generation", i.e., it was regenerated by root suckers. All stands were located on medium-fertile to fertile mineral soils, either on forestland or on former agricultural land. The average age of the *P. tremula* stands was 44 years and that of *P. tremula x tremuloides* stands was 32 years.

Altogether 6 to 7 circular sample plots with an area of one hundred square metres were measured from each stand to determine the average growing conditions and tree characteristics (Table 1). The tree in the centre of each sample plot was selected as a sample tree that was measured in more detailed manner. Heräjärvi et al. (2006) described the exact measurements made in sample stand, sample plot and sample tree levels. Further measurements for stem form, branchiness, etc. were done for logs after the felling of sample trees. The 2-m-long logs were graded into A,B,C and D (reject) classes according to the quality requirements presented Keinänen & Tahvanainen (1995)(Table 1). The log material consisted of 256 European aspen logs (mean log volume 90 dm^3) and 348 hybrid aspen logs (84 dm^3).

Table 1. Quality grading rules for aspen logs (Keinänen & Tahvanainen 1995).

LOG CHARACTER-ISTICS	GRADE		
	A	B	C
TOP DIAMETER	MIN. 23 CM	MIN. 15 CM	MIN. 15 CM
LENGTH *	31-55 DM	31-55 DM	31-55 DM
LENGTH	±3 CM	±3 CM	±3 CM
GROWTH	UNIFORM	NO	NO
SWEEP	MAX. 2 CM/M	MAX. 2 CM/M	MAX. 3 CM/M
BRANCHES, NUMBER PER M OR MAX DIAMETER			
BRANCHES	NOT ALLOWED	4 BRANCHES	6 BRANCHES
GREEN	NOT ALLOWED	2 BRANCHES / 4	3 BRANCHES / 8 CM
DRY BRANCH	NOT ALLOWED	2 BRANCHES / 2	3 BRANCHES / 4 CM
SOFT ROT	NOT ALLOWED	NOT ALLOWED	2 BRANCHES / 3 CM
SPLITS	NOT ALLOWED	NOT ALLOWED	NO RESTRICTIONS
DISCOLOURATI	NOT ALLOWED	SOME ALLOWED	50% OF DIAMETER
HEART ROT	MAX 1 CM	MAX 5 CM	MAX 50% OF

* Not applied in this study.

RESULTS AND DISCUSSION

All sample stands were located on fertile sites. There were only minor differences in the basal areas of the stands. Numbers of stems per hectare, on the other hand, differed between the stands since hybrid aspen stands were planted, whereas European aspen stands were mostly of natural origin. In case of planted stands, saplings had occupied the stands very efficiently. Table 2 presents some technical characteristics of the sample stands, based on sample plot measurements. Although the European aspen trees were on average 12 years older and 18 mm thicker than the hybrid aspen trees, the latter ones were slightly taller, and thus, more slender. However, the slenderness is more likely related to the origin by planting and age than to the aspen species. Between 1.3 and 6-metre heights, the stems tapered only slightly, which is a positive feature considering the sawing or veneering processes.

European aspens were more efficiently self pruned than the hybrid aspens. This is related to the more wide spacing in the planted hybrid aspen stands at young age. Generally, if young aspen tree grows thick branches, they self prune inefficiently later. Large hybrid aspen trees (> 35 cm Dbh) appeared to contain whorls of dead branches all

the way down to the stump height. Also water sprouts originating from adventitious buds were common in hybrid aspen trees. European aspen stands provided some knot free butt logs, but hybrid aspens trees were totally knotty. The lowest living branches were approximately three metres higher in planted trees than in trees of seed origin. The average saw log reductions (percentage of log sized stem that cannot be log due to quality reasons) in European and hybrid aspens stems were 21.0% and 21.8%, respectively. However, the variations in saw log reduction were extensive between the stands and, especially, between the trees. Most often the saw log reduction was increased by curves, sweep, heart rot or oversized branches.

Table 2. Selected technical properties of aspen trees representing the dominant crown layers of the stands.

STAND	AGE	DBH	STEM TAPER	LENGTH	SAW LOG REDUC	HEIGHT OF THE LOWEST	HEIGHT OF THE LOWEST
	A	MM	MM/	M	%	M	M
EUROPEAN ASPEN							
1[1]	52	325	8.7	24.2	16.7	4.4	9.3
2	38	279	9.6	23.7	21.1	3.7	11.2
3	34	244	11.5	19.0	18.2	3.9	7.0
4[1]	57	326	8.9	24.8	8.3	3.8	10.0
5[2]	42	267	6.2	29.2	16.3	1.4	16.5
HYBRID ASPEN							
6	29	263	6.8	26.6	23.5	1.1	10.4
7	42	296	5.3	29.6	24.0	3.3	14.8
8[3]	33	241	7.6	22.8	23.6	3.8	9.9
9[4]	23	248	6.8	24.4	13.7	2.9	9.8
10	34	312	7.1	25.8	25.3	1.6	13.3
11	33	290	6.2	26.0	8.7	2.8	11.6
12	32	238	6.2	23.5	12.3	0.7	10.5
EUROPEAN ASPEN	**44**	**288**	**9.0**	**24.2**	**16.1**	**3.4**	**10.8**
HYBRID ASPEN	**32**	**270**	**6.6**	**25.5**	**18.7**	**2.1[5]**	**11.5**
SEED ORIGIN	**41**	**284**	**9.1**	**23.2**	**15.6**	**3.7**	**9.5**
PLANTED	**35**	**272**	**6.5**	**26.2**	**19.1**	**1.8[5]**	**12.4**
ENTIRE	**37**	**277**	**7.6**	**25.0**	**17.6**	**2.7**	**11.2**

[1] Mixed stand.
[2] Planted European aspen stand.
[3] Pruned up to 4 m in 1986.
[4] 2nd generation hybrid aspen stand regenerated by root suckers.
[5] Calculated without the pruned stand number 8.

The percentages of stems with form defects in European and hybrid aspen stands were 26 and 45, respectively. Hybrid aspens had curves in butt logs, probably caused by improper planting. Only 2–5 percent of the trees contained some kind of surface defects, such as fungal (*Neofabrea populi*) or mechanical defects. The internal quality of the logs was poor in comparison to the relatively good external quality. Almost every log had more or less discolouration, decay or wetwood. As much as 42% of European aspen trees and 26% of hybrid aspen trees contained larval tunnels of Large poplar longhorn (*Saperda carcharias*). These tunnels, usually located near to the stump height, cause discolouration of the most valuable part of stem.

Figure 1 shows the size distribution of the largest dead and sound knots in different parts of aspen stems. Logs obtained from felled trees were graded according to the quality requirements suggested by Keinänen & Tahvanainen (1995) (Fig. 2). Overall quality was poor due to discolourations, decay, or too many or too big branches. Grade D (reject) made up to 40% of all logs. Upper logs from hybrid aspen trees actually represented rather good quality due to long, even 1.5 metres branch free stem sections.
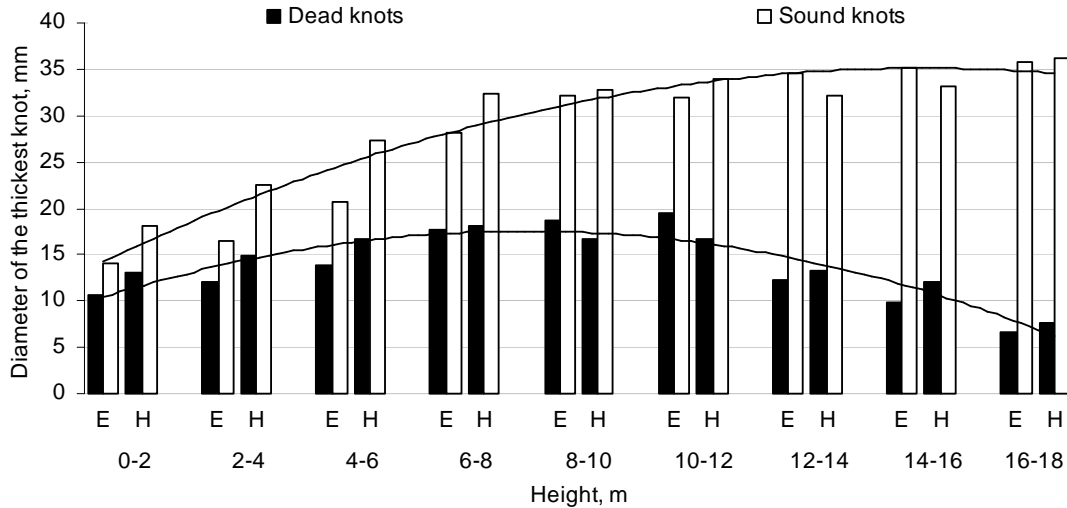

Figure 1. Mean diameters of the largest dead and sound knots on log surfaces at different heights in European (E) and hybrid (H) aspen stems (pruned stand nr. 8 excluded). Measurements up to the height of 12 cm diameter.
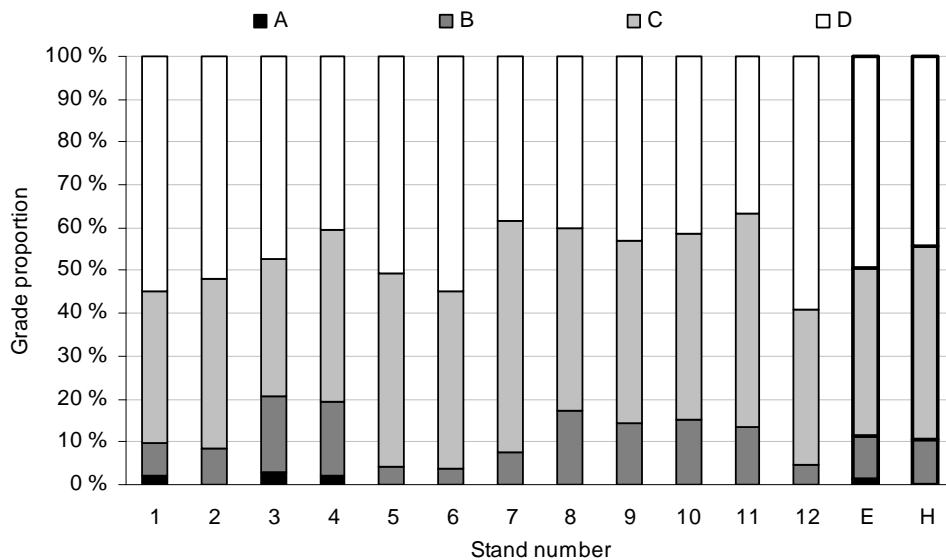

Figure 2. Grade distributions of logs obtained from sample stands accroding to the grading system by Keinänen & Tahvanainen (1995). E stands for the average European aspen, and H for average hybrid aspen.

CONCLUSIONS

Consumption of aspen in pulp and paper industries has decreased, partly as a result of the global economic downturn. Apparently, the demand of aspen pulpwood will not return into its highest level within the next couple of years. The plantations of the late 1990's and early 2000's will, however, reach their final felling size in 5–10 years. At that time, there will preferably be buyers and users for the timber, including saw and veneer logs. From the quality point of view, the problems related to discolouration and decay in the wood material make up a substantial challenge to the utilisation of aspen timber in wood products. The current technologies, such as finger jointing, gluing and mechanical or chemical modifications, however, enable profitable end uses for this beautiful, light coloured, low density, uniform and easy-to-machine wood.

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VARIATION IN WOOD PROPERTIES OF PINE PULPWOOD FROM THINNING STANDS AND FINAL FELLINGS ON PEATLAND

Rikala, J.[1], Rissanen, A.[2] & Sipi, M.[3]

ABSTRACT

Drained peatlands are a characteristic specific to Finnish forestry; almost five million hectares of peatlands have been drained for forestry. Most of that area was drained during the 1960s and 70s, and the stands have already reached the thinning stage. Thinning stands on peatlands are dominated by Scots pine (*Pinus sylvestris* L.), which is widely used both in wood product and pulp and paper industries in Finland.

The aim of the study was to examine the variation of wood properties of Scots pine in typical thinning stands on peatlands, and to compare the results to those of mineral soil sites. Results concerning top pulpwood from mature peatland pines were used as a reference material. The idea was to get a better understanding about the variation in the wood properties of the pulpwood flow to be able to evaluate the need for pulpwood sorting according to its origin.

The thinning stand material was collected from two sample plots representing site types generally managed for pine. Altogether, eight sample trees were felled. Sample discs were taken at two meter intervals from the stump to the top diameter of 5–7 cm. The properties studied were age, growth rate, basic density, latewood content, heartwood content, moisture content, extractive content and fibre length.

Ring width, basic density and heartwood content varied a lot both within and among the trees in the thinning stands. Trees containing pre-drainage wood showed an extremely high variation in the properties. There are some differences in wood properties between peatland thinning stands and upland first thinning stands. Since the harvesting removals are quite low in peatland thinnings, roundwood sorting within stands is not reasonable. Steering pulpwood stand-wise to different uses might be reasonable. However, this does not eliminate the large variation in certain properties.

Key words: Scots pine, pulpwood, wood properties, drained peatlands

INTRODUCTION

Up to five million hectares of peatlands have been drained for forestry. Most of that area was drained during the 1960s and 70s, and the stands have already reached the thinning stage providing a great harvesting potential. Thinning stands on peatlands are

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dominated by Scots pine (*Pinus sylvestris* L.), which is widely used both in wood product and pulp and paper industries in Finland.

Peatland forests are characteristically uneven-structured. They contain uneven-aged and -sized trees born before drainage. Furthermore, drainage with cleaning-thinning promotes natural ingrowth and birth of new trees. This means that structural inequality may even increase for several decades after drainage. (Sarkkola et al. 2005)

Pulpwood is very seldom sorted according to its origin but wood from mineral soil sites and peatlands are mixed together. The aim of the study was to examine the variation of wood properties of Scots pine in typical thinning stands on peatlands, and to compare the results to those of mineral soil sites. Results concerning top pulpwood from final fellings on peatland were used as a reference material. The idea was to get a better understanding of the variation in the wood properties of the pulpwood flow to be able to evaluate the need and means for pulpwood sorting according to its origin.

MATERIAL AND METHODS

The thinning stand material was collected from two sample plots representing site types generally managed for pine: Mannila (*Vaccinium vitis idaea* type, VT) and Ahvenräme (Dwarf-shrub type, DsT). In both sample plots, trees were divided into groups according to the breast height diameter (dbh) and drainage effect in growth rings (yes/no). Altogether, eight sample trees were felled. Sample discs were taken at two meter intervals from the stump to the top diameter of 5–7 cm. The material consisted of 47 sample discs. The properties studied were age, growth rate, basic density, latewood content, heartwood content and moisture content. Ring number, ring width and latewood proportion of a ring were measured with an incremental measuring device and microscope. Heartwood and latewood contents were determined as a proportion of a disc cross-section. Basic density and moisture content were first determined from pith to bark and then calculated to disc-wise by weighing each piece by its volume proportion. In the thinning stand material, stem-wise values were achieved by weighing each disc by its volume proportion. The basic tree characteristics are presented in Table 1.

Table 1. Characteristics of the thinning stand material.

Stand	Site type	Tree no.	Height m	Dbh cm	Age at stump height, years	Clear drainage effect visible in growth rings
Ahvenräme (1)						
	DsT	1	14.1	18.7	75	Yes
	DsT	2	16.5	20.0	75	No
	DsT	3	14.0	15.1	69	Yes
	DsT	4	12.6	12.2	62	No
Mannila (2)						
	VT	1	16.4	18.9	82	Yes
	VT	2	15.7	18.1	87	No
	VT	3	11.2	11.6	83	Yes
	VT	4	14.1	11.0	71	No

The reference material from final fellings consisted of 335 sample discs taken from pulpwood section (stem diameter 5–15 cm) of mature peatland pines. The trees (100) were felled on ten old drainage areas in southern Finland representing *Vaccinium vitis idaea* and dwarf-shrub types. Average stand ages (determined from the stump height) varied from 81 to 146 years. The mean diameter of trees weighted by the basal area

varied from 22.1 to 29.4 cm and the mean height of all sample trees from 16.8 m to 24.9 m. The disc sampling in the pulpwood section followed the procedure presented above. In contrast to the thinning stand material, the results are given disc-wise. Fibre length or extractive content were not determined. Detailed description of the study material is given in Rikala (2003). Location of the sample plots is shown in Fig. 1.
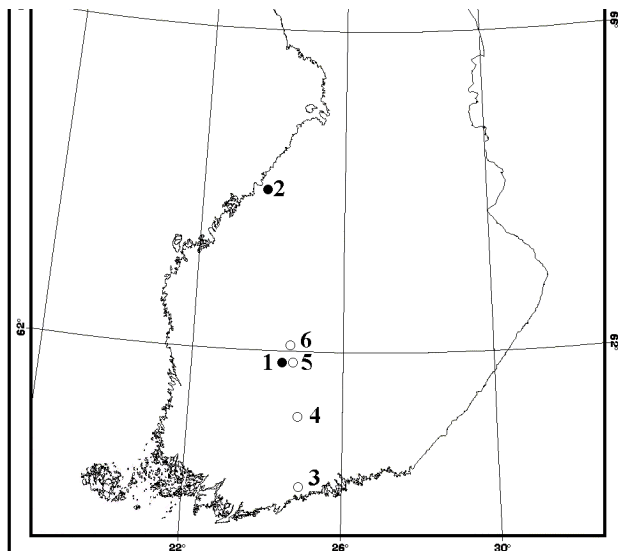

Fig. 1. Location of sample plots. Numbers 1 and 2 (black circles) refer to the thinning stands and numbers 3–6 (white circles) to the final felling stands.

RESULTS

Thinning stands on peatland

Ring width

Mean annual ring width of the stems ranged from 0.8 to 1.6 mm. The narrowest rings were found in the wood formed before drainage and the widest rings at the lower parts of the stems in the wood formed after drainage and near the pith in the top of the trees.

Basic density

The average basic density of stems varied from 382 to 478 kg/m^3 being higher in the wood formed before drainage (397–648 kg/m^3) and somewhat lower in the wood formed after drainage (317–558 kg/m^3). Thus, variation in basic density was very high both within and among the trees.

Latewood content

Latewood proportion of the stems ranged from 26 to 35%. There was no significant difference in latewood proportion between the wood formed before drainage and after drainage.

Heartwood content

Heartwood proportion of the stems varied from 4 to 20%. In the site representing DsT, the heartwood proportion was stable (from 7 to 9%), but in the site representing VT, the variation was high. Age or growth rate did not explain the high variation.

Moisture content

Moisture content of wood varied from 18% to 29% of green weight in heartwood and from 46% to 65% in sapwood. Variations in the moisture content between the trees were quite small.

Fibre length

Fibre length varied from 1.65 mm to 2.05 mm. Increased growth rate due to drainage did not affect the fibre length.

Extractive content

Acetone-soluble extractive content varied from 3.0 to 5.0% being higher in heartwood than sapwood (3.0–13.5% vs. 2.5–5.2%).

Final felling stands on peatland

Ring width

Mean annual ring width of the discs ranged from 0.5 to 3.0 mm (mean 1.8 mm, SD 0.4 mm). Extremely slow growth (mean ring width less than 1 mm) was only found in three discs originating from a tree which contained pre-drainage wood (age 170 years).

Basic density

Basic density of the sample discs averaged 385.8 kg/m^3 (SD 26.6 kg/m^3, min. 325.6 kg/m^3, max 489.8 kg/m^3). Basic density was on average about 12 kg/m^3 higher in the more fertile site type (392 kg/m^3 in VT vs. 380 kg/m^3 in DsT).

Latewood content

Latewood content was on average 19.1% (SD 4.3%, min. 9.8%, max 33.9%) determined as a proportion of the sample disc cross-section. Latewood content was on average 20.0% in VT and 18.2% in DsT. This is in line with the basic density figures.

Heartwood content

Variation in the heartwood proportion was high between the discs (stems). For example at a relative height of 50%, the heartwood proportion varied from 10 to 40%. Relative height accounted about 64% of the variation in heartwood proportion. In old peatland pines, heartwood was observed up to 95% of tree height.

Moisture content

Moisture content was not determined separately for heartwood and sapwood but for the whole sample discs. Moisture content varied from 42% to 65% of green weight (mean 56%, SD 4.2%) increasing towards the top of the tree where heartwood proportion is lowest.

DISCUSSION

Results from the thinning stands on peatlands were compared to those of typical first thinning stands on mineral soil sites in southern Finland (Hakkila 1968; Hakkila et al. 1995; Hakkila et al. 2002). Results from final fellings on peatlands were used as a reference material. Comparisons are presented in table 2.

Table 2. Comparison of pulpwood properties in thinning stands and final fellings on peatlands (top pulpwood) and first thinning stands on mineral soil sites. Range, mean and standard deviation (SD) of wood properties are given if available.

Wood properties	Thinning stands on peatland[1]		Final fellings on peatland[2]		First thinning stands on mineral soil sites[1]	
	Range (mean)	SD	Range (mean)	SD	Range (mean)	SD
Ring width, mm	0.8–1.6	0.28	0.5–3.0 (1.8)	0.4	(2.6)	Not given
Basic density, kg/m^3	382–478	32.5	326–490 (386)	26.6	(398)	26.3
Latewood content, %	26–35	3.0	10–34 (19)	4.3	25.9–27.1	2.0
Heartwood content, %	4–20	4.7	1–45 (11)	9.5	0–10	Not given
Moisture content of green mass, %	50–56	1.8	42–65 (56)	4.2	(59)	Not given
Fibre length, mm	1.7–2.1 (1.9)	0.13	Not given	Not given	2.3	0.22
Extractive content, %	3.0–5.0 (3.9)	0.74	Not given	Not given	3.3	0.49

[1] Stem-wise values

[2] Disc-wise values

The most evident differences in wood properties between thinning stands on peatland and first thinning stands on mineral soil sites can be observed in ring width (growth rate), basic density and heartwood content. At the (first) thinning stage, peatland trees are usually much older – due to slow growth rate – than first commercial thinning stands on mineral soil sites. Since the peatland stands are typically uneven-age structured, some trees contain narrow-ringed wood formed before drainage while others emerged after drainage in better growing conditions. This increases the variation especially in ring width and basic density both within and among the trees in stands. In peatland trees, higher tree age appears in higher heartwood content and somewhat lower moisture content. Also latewood content may be slightly higher in peatland trees.

Top pulpwood from final felling stands on peatland showed large variation in wood properties. One reason for that is that the results were given disc-wise not stem-wise

bringing clearly out the naturally high longitudinal variation in stems. In general, the properties do not seem to differ markedly from those of top pulpwood in mineral soil sites.

CONCLUSIONS

This study focused on exploring the variation in wood properties of pulpwood originating from thinning stands and final fellings on peatland and comparing the results to those of mineral soil sites. There are some differences in wood properties between peatland thinning stands and first thinning stands on mineral soil sites. Since the harvesting removals are quite low in peatland thinnings, roundwood sorting within stands is not reasonable. Instead, steering pulpwood stand-wise to different uses might be possible. This does not eliminate, however, the large variation in certain properties. Even though some wood properties in thinning stands on peatland and mineral soil sites may be on a different level, the differences should not essentially hamper the main use object, i.e., pulp production (Varhimo et al. 2003).

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VARIATION IN THE MOISTURE CONTENT WITHIN PULP LOGS OF NORWAY SPRUCE

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ABSTRACT

The moisture content (mc) of wood is of great importance to several processes in mechanical pulp mills. Debarking, chipping, refining and indirect bleaching are factors that are affected by the mc of the wood. The mc varies within a log, mainly between heartwood and sapwood, but also within the sapwood, where mc often varies significantly. This study aims to describe the variation in the mc of pulp logs of Norway spruce (*Picea abies*) arriving at Braviken paper mill in southern Sweden. 574 discs from 82 logs were sampled in April, June and October, respectively. Of the sampled discs, 164 were divided into 8 equal pieces, and the heartwood content of each piece was determined. Mc values were determined for all discs. The results showed a high variation in the mc values, with up to a 25 % difference in mc within a single disc. The average difference in mc within a single disc varied between the different sampling periods, from 7.2 % in October up to 11.0 % in June.

Key words: moisture content, pulpwood, Norway spruce, *Picea abies*, disc

INTRODUCTION

The wet based moisture content (mc) in wood is of great importance to several processes in mechanical pulp mills. Debarking, chipping and pulp production are typically affected by the mc of the wood (Bjurulf 1993, Sundholm 1999). The mc is also a good indicator of the freshness of the wood (Wilhelmsson et al. 2005). Mc is particularly important for mechanical pulp mills that primarily use spruce as a raw material because the wood quality and mc strongly affect these processes (Persson et al. 2001). The mc also varies within logs, especially between the drier heartwood and the sapwood, but also within the sapwood (Tamminen 1964). These differences in mc often increase when the wood is stored and is able to dry. The variation in mc within a log also depends on the time of year, with a higher variation in the mc occurring during the summer than during the winter (Björklund 1988). When the tree is cut, the water supply to the wood is cut off, and the wood begins to dry. The drying process is affected by several parameters, such as time of the year, whether the wood is placed in a sunny or shadowed location, weather, the duration of storage, etc. These factors are correlated with the variation in mc that occurs in pulpwood. When the mc in the harvested roundwood decreases and reaches a mc value of approximately 50 %, it can be attacked

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by fungi, which makes it harder to bleach the pulp. When the mc drops below 40 %, the wood becomes harder to debark and the fibers become harder to separate during processing. When the wood reaches the fiber saturation point (approximately 23 % for spruce), the wood starts to crack, which has a negative influence on the processability, both for the pulp industry and for the sawmills (Persson et al. 2002). Having a deeper knowledge of the variation in mc values could improve several processes in the pulp industry. Efforts to develop a tool to take samples from roundwood for mc determination created interest in determining how the mc varies within individual pulpwood logs. Thus, this pilot study was initiated with the aim of describing the variation in mc within spruce pulpwood logs when they arrive at the mill.

MATERIALS AND METHODS

The study was performed at the Braviken paper mill (Holmen) in Norrköping on spruce *(Picea abies)* pulpwood logs during three sampling intervals (15-16 April, 25 June and 10-11 October) during 2008. Thirty logs were sampled during the two first intervals, while only 22 logs were sampled during the third sampling interval due to bad weather conditions and technical problems with the equipment. A summary of the sampling effort is presented in Table 1. The logs were taken randomly from the first truck with roundwood that arrived at the wood measuring station. Five discs, 20 – 30 mm thick, were taken from each log (Fig 1). These discs were used to describe the variation in mc along the logs, in order to describe the relationship between mc and the diameter of the logs and to describe the ratio of mc to the percentage of heartwood. Mc was determined by weighing the discs and drying them in an oven at $103 \pm 2°$ C until a constant weight was achieved, after which they were weighed again, and the mc was calculated with the formula presented below:

$$mc = \frac{Weight\ of\ raw\ wood\ -\ weight\ of\ dry\ wood}{Weight\ of\ raw\ wood} \tag{1}$$

At two positions on each log, additional discs were taken and were divided into eight pieces (Fig 1). Mc and heartwood were determined for each piece.

Table 1. Summary of the three sampling intervals

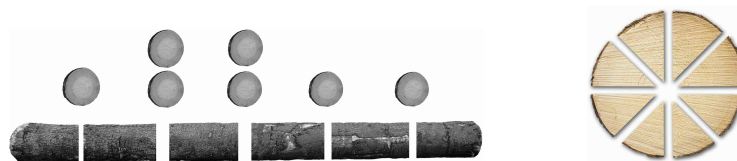| Date	Number of logs	Number of single cut disc/log	Number of double cut disc/log	Average log diameter (cm)
0804	30	5	2	21.3
0806	30	5	2	19.2
0810	22	5	2	11.3
Total	82	410	164	17.9

Fig 1. Schematic of one of the sampled logs where five discs were removed for mc determination to describe the mc variation along the log. Two extra discs were taken and were divided into eight pieces to describe the mc variation within a disc.

The mc variation within a disc was calculated as the difference between the highest and the lowest recorded mc value from the eight pieces. The standard deviation (SD) presented in Table 2 is the average SD within a disc and was calculated as follows:

$$SD = \frac{\sum ((n_i - 1) * s_i^2)}{\sum (n_i - 1)}$$

(2)

RESULTS

Variation within a disc

A relatively high variation in mc values within a single disc was observed with an average variation of 8.3 %, which differs over the year (Table 2). The highest and lowest average values of variation in the mc were observed in June and April, respectively. The maximum and minimum values of mc variation in a single disc were also found in June and April, respectively.

Table 2. Average difference, expressed in percentages, between the maximum and minimum mc within a disc for the three different occasions and the maximum and minimum difference in mc within a single disc. The SD is the mean SD for the difference within a disc.

	0804	0806	0810	Total
Average diff. (%)	7.1	11.0	6.9	8.3
Max diff. (%)	22.1	25.6	16.6	25.6
Min diff. (%)	1.9	2.8	2.1	1.9
SD (%)	2.9	4.1	2.7	3.3

Mc variation along a log

The mc was relatively evenly distributed along the log with a tendency for the log to be drier at the ends of the logs during the first sampling interval. At the second and third sampling intervals, the butt end of the logs was drier, and the mc increased after this point with increasing height. The mc was highest in October and lowest in June. In Table 3, the average mc is presented for the five different positions along the log, where the first location was at the butt end of the log, and the fifth location was at the top of the log.

Table 3. Average mc values along the log at the five sampling positions

Sampling place	0804 mc (%)	SD (%)	0806 mc (%)	SD (%)	0810 mc (%)	SD (%)
1	48.1	6.6	42.8	7.4	58.7	4.3
2	50.2	5.2	45.1	8.4	60.9	5.1
3	50.5	5.7	43.3	10.0	61.6	5.8
4	51.0	6.6	45.1	8.2	63.1	5.2
5	49.0	5.7	45.0	7.6	62.7	4.2

Mc versus diameter

For April, the mc decreased steadily with increasing diameter (Fig. 3). The highest mc value in a single disc (60.8 %) was found in the 201-250 mm diameter class, while the lowest mc value in April (37.4 %) was also found in the same diameter class. In June, the mc decreased with increasing diameter for logs up to 200 mm thick, after which the mc increased with increasing diameter. However, only six and two logs were included in the two last diameter classes which make the statistics very uncertain. The highest mc value observed in June was 62.0 %, which occurred in the 201-250 mm diameter class. The disc with the lowest mc value observed (21.2 %) occurred in the 151-200 mm class. In October, the mc initially decreased slightly up to a log diameter of approximately 100 mm, after which it increased slightly. The highest and lowest mc values recorded in October (62.9 % and 48.1 %) were both found in the 151-200 mm class.
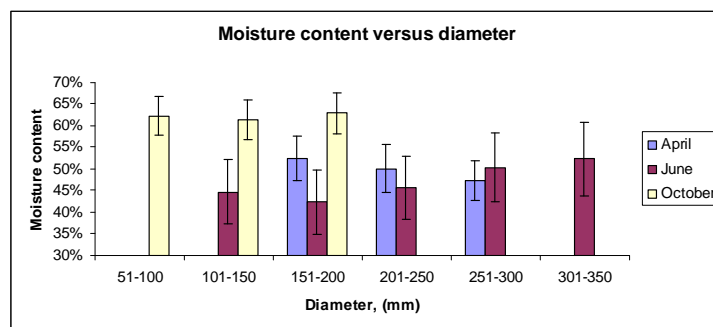

Fig 3. The relationship between diameter and mc for the three sampling locations. Mean values ±SD are shown

Mc versus heartwood content

The general trend observed in this analysis was that the mc value decreased with increasing heartwood content (Fig. 4). In April, the mc value decreased with increasing heartwood content. The first class was only represented by four discs. In June, the mc value increased with increasing heartwood content up to a value of 20 % heartwood and then decreased with increasing heartwood content up to 50 % of heartwood, whereafter it slightly increase again. In October, the trend was the same as in April with the mc decreasing when the amount of heartwood increased. The last bar for October only consisted of one disc, and conclusions from this period should be made cautiously given the single sample unit.
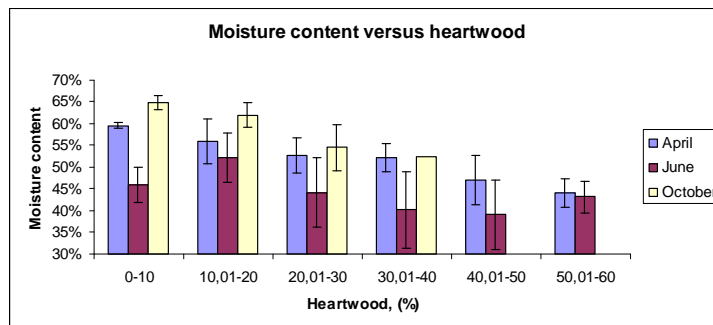

Fig 4. The relationship between heartwood and mc for the three sampling intervals. The mean value ±SD is shown

Diameter versus heartwood

Fig. 5 shows the amount of heartwood in comparison to the log diameter. There was a clear trend of increasing heartwood content with increasing diameter. However, there was a dip in the heartwood content in the last diameter class. This class only included two discs, thus large-scale conclusions should not be drawn from this class.
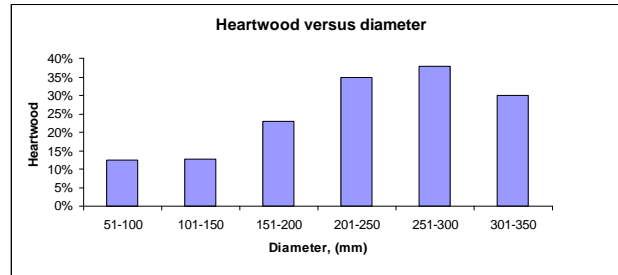

Fig 5. Amount of heartwood versus log diameter

DISCUSSION

The results from this study show that there can be a surprisingly high degree of variation in the mc values within a single disc, amounting to more than 25 %, when the wood arrives at the mill. An even mc in the logs is of great importance for the pulp industry; if the mc drops too low, problems are likely to arise. For example, problems can arise when debarking the logs, which then lead to a higher energy consumption, a higher loss of fibers, more bark left on the logs, etc. Ekenstedt et al. (2002) showed with computed tomography that logs dry unevenly in the radial direction; however the difference in mc was not quantified. In addition, earlier studies showed that the mc varies naturally in the living tree both between the heartwood and sapwood and also within the sapwood (Tamminen 1964).

One explanation for the large variation within the discs is that the bark was damaged during harvesting. The bark prevents the logs from drying. Logs without any bark have been shown to dry more than ten times as quickly as logs with all of their bark remaining, and logs showing injuries in the bark after harvesting dry two to three times as fast as logs without any damaged bark (Ekenstedt et al. 2002). Also, Filipsson (1999) found that thin logs with a lot of damaged bark dry faster than thicker logs without any bark injuries. If the bark is damaged at some places along the log, these places are likely to dry faster and cause high variation in the mc values. Filipsson (1999) pointed out that the drying of logs is mainly affected by three factors: storage place, storage time and local climate. Logs that are exposed to the sun can dry up to 1 % a day (Persson et al. 2001, Persson et al. 2002). Filipsson (1999) found that logs that were not forwarded from the harvested area dried four times faster than if they were placed in piles that were exposed to the sun. Furthermore, piles placed in the sun dried 11 times faster than piles placed in shadows. Persson (2002) reported that logs placed in the upper part of the piles dried faster than logs in the middle and lower parts of the pile. Local climate also affects how fast the logs dry. Low humidity, low precipitation and low wind conditions slow down the drying process (Filipsson 1999, Persson 2002). Time is also an important factor; the mc in the logs decreases with increased storage time.

There was a difference in mc between the three sampling intervals in this study. The driest logs were found in June and the logs with the highest mc were found in October. These findings correlate well with previous studies such as Björklund (1988) and Tamminen (1964), demonstrated that the mc varies over the year, with the driest logs observed in the summer. However, only one truck load of logs was taken per sampling period in this study. This low number of trucks per sampling period increases the risk that the logs could become misrepresented, making it difficult to establish conclusions about seasonal changes. In April, the ends of logs had lower mc values than the middle of the logs. In June and October, the butt ends of the logs were drier, but the top ends of the logs were not. Björklund (1988) investigated whether there were any differences in mc at the ends of the logs. He found that during the summer, differences in mc could be very high, up to 9 %, in the first 25 cm of the logs, while in the winter (December to Mars) there were no significant differences. To a certain extent, these results are contradictive to the findings in this study; however, the number of sampled logs and samplings was limited in this study.

In April, mc values decreased with increasing diameter, which was likely correlated with the heartwood content that was increasing with increases in diameter. This is consistent with results from Björklund (1988). In contrast, the mc has been found to increase with increasing diameter (Nylinder 1953, cited in Tamminen 1964). In June, mc values showed slightly different patterns, but because some of the diameter classes included very few discs, no conclusions could be drawn.

Mc values decreased with increases in heartwood content in April and October, a finding that was similar to results achieved by Björklund (1988). In June, the results were a little bit contradictory; the mc value decreased at heartwood contents between 10 % and 50 % but increased at heartwood contents between 0-10 % and 50-60 %.

The heartwood content increased with increasing diameter, similar to results of Tamminen (1964).

This study showed that there can be substantial variation in the mc within spruce logs. Because mechanical pulp mills require that the arriving wood is fresh, it is important to determine how the commodity actually looks when it arrives at the mill. This study shows the difficulties of accomplishing such a requirement. In the future, the focus must be on decreasing the time between harvesting and forwarding, as well as between forwarding the logs and transporting the logs to the mill; this is especially important during summer. If the logs need to be stored at the roadside, it is of great importance to place the logs in shadows when possible.

CONCLUSIONS

- There is significant variation in mc values within single logs and even within single discs.
- Bark injuries occurring during harvesting increase the drying rate and make the pulpwood more sensitive. This indicates that bark injuries should be reduced.
- The focus for spruce logs must be to shorten the time between felling and transportation to the mill.

ACKNOWLEDGEMENTS

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SELF-BINDING FIBREBOARD MADE OF STEAM EXPLODED WOOD

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ABSTRACT

Manufacturing of wood-based panels takes sufficient place in wood processing industry around the World. An application and demand for such materials has been growing up. Wood-based panels are competitive with other plate materials. Wood fibreboard represents 25 % of manufacturing of all the wood-based panels in Europe. Usually synthetic adhesives are used for producing the wood fibreboard. These adhesives (usually phenol formaldehyde) are obtained from petroleum and gas products; therefore, they make 50 % of all the manufacturing costs of the boards. The cost of petroleum has a trend to increase; therefore the cost of wood-based panels could not be stable. Besides, synthetic adhesives are not environmentally friendly and there is a problem of utilization.

It is possible to obtain wood fibreboard without synthetic adhesives by means of using steam explosion (SE) pre-treatment. A saturated steam of 250 °C temperature makes certain pressure in hermetic reactor where wood chips are put. After 1-3 minutes the chips are decompressed within a split second and are converted to fibrous mass. During SE process wood chips structure gets broken up to cell wall level. Phenol and other adhesives are generated from wood without any additional chemicals. After the biomass is dried in the open air it can be hot-pressed and there is a possibility to obtain wood fibreboard material which competes with commercially obtained wood fibreboard. The board is called self-binding material because in the manufacturing process synthetic adhesives are not used.

Self-binding board samples hot-pressed from locally grown grey alder (*Alnus incana* (L.) Moench) at temperature 168–192 ˚C and pressure of 5–8 MPa for 10 min have a good form stability and other properties comparing to commercial boards.

Key words: wood-based panels, steam explosion pre-treatment, self-binding board.

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INTRODUCTION

In the recent years there are widely talking about renewable resources and it's more effective usage. Notably takes aim bio fuel or other kind of energy from non-food products. All of this is because of fossil imminent resources as well as of air pollution. Wood industry is considerably dependent of fossil for the synthetic adhesives are produced from it for obtaining of wood composite materials. In quest of alternative solutions, once again is reviewed the SE technology which was invented by William H. Mason in the first quarter of 20th century (1925 - Masonite Founded). The process allows generating the substances from processed wood which then act as self-adhesive during hot-pressing. In nowadays the technology is active used in bio refinery (Gravitis and Della Senta 2001). SE is one of leading pre-treatment methods for second generation bio ethanol and bio gas production from lignocellulosics (Scott Miller 2007). Nowadays the SE technology includes such modifications as ammonia fiber explosion, supercritical CO_2 pre-treatment, deinking, etc., which are different from Mason process (Taherzadeh and Karimi 2008).The SE treatment also is used by Japanese researchers for getting an alternative product from forest industry wastes to commercial fiberboard. (Laemsk and Okuma2000).

The general aim of the study is fast-growing grey alder treat by SE and then hot-pressed self-binding board samples compare to commercially obtained fiberboard. Usually there are used softwood species in the fiberboards, but our preliminary research (Abolins et. al. 2008) gives hope for enough effective application of little value grey alder. In the paper described the processing of the self-binding fiberboard samples, its mechanical (bending strength, modulus of elasticity and internal bond) and form stability properties (swelling in thickness and water absorption). Compared to other soft deciduous tree species, growing of grey alder for production of wood mass is beneficial due to its fast growing (Daugavietis and Daugaviete 2008). Therefore grey alder also could be advantageous tree species for obtaining self-binding fiberboard.

MATERIALS AND METHODS

In the study only one locally fast-growing tree species: Grey alder (*Alnus incana* (L.) Moench) was used to obtain the fibreboard samples. The raw material was crushed by a "Bruks" (Sweden) wood chipping machine, cleaned of bark and air-dried to constant mass (8-9 % of moisture content).

Steam explosion pre-treatment

Steam explosion (SE) is a rather simple process but differentiates in technical details (Gravitis 1987). The biomass is treated with saturated steam, usually at pressures up to 4 MPa. The treatment time varies from some seconds to some minutes. After the treatment, within a split second, the biomass is decompressed (exploded) to the pressure of ambient atmosphere. The diagram of the SE process is shown in Fig. 1. The SE equipment with periodical activity allows change such processing conditions as time, pressure and temperature. All the settings of the process are controlled by integrated computer program. Modified grey alder fibres have been generated under certain SE conditions: 235 °C temperature and 3.2 MPa pressure for 1 minute. After the SE process

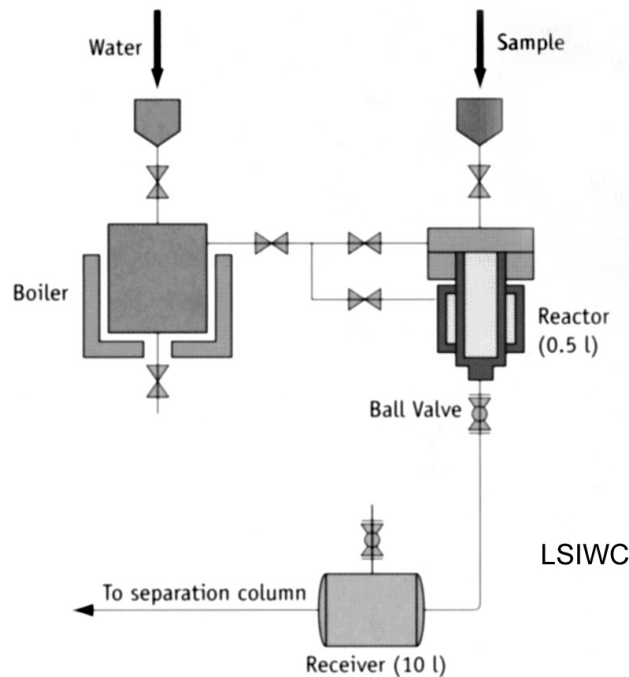the steam-exploded biomass was dried in the open air to constant mass (4–5 % of moisture content) for 2 weeks.

Fig.1. Diagram of the experimental SE unit

Pressing of the board samples

The steam-exploded and air-dried grey alder fibre mass with moisture content of 4–5 % was pressed in a single stage hydraulic hot press. There was used the press form of size 105 x 105 x 105 mm to obtain the board samples from SE fibre mass. The weight of pressing sample was evaluated to 100 g of oven dry fibre mass. The fibre mass was put into the press form without the mass separation into different fractions and pre-pressed by hand. Foil sheets were used on both the bottom and top surfaces of the mat to avoid destruction of pressed board during opening of the press. Then so prepared mat of fibre mass pushed on the heated press platen and pressed for 10 minutes. There was taken one step pressing method with platen temperature of 170 and 190 °C and pressure 5 and 8 MPa (see Table 1). Two replications were made for each pressing regime. The hot-pressed boards were left in the press to cool down for more than one hour while the pressure decreased.

Testing of the board samples

After the pressing the board samples were cut into various test specimens and then conditioned in the open air at temperature of 20 (±2) °C and relative humidity of 60 (±5) % prior to following testing. Mechanical properties (modulus of elasticity, bending strength (EN 310:1993) and internal bond strength (EN 319:1993)) of hot-pressed board samples were tested by a universal machine for testing material resistance ZWICK/Z100. For the bending strength testing (see Fig. 2 a) the specimens size were 30 x 95 mm; the distance between supports 74 mm and the test speed 1 mm min^{-1}. For the internal bond testing (see Fig. 2 b) the board specimens in size 30 x 30 mm were bonded to hardwood plywood testing block by PVAC glue and then after conditioning for at least 72 h tested with test speed of 3 mm min^{-1}.
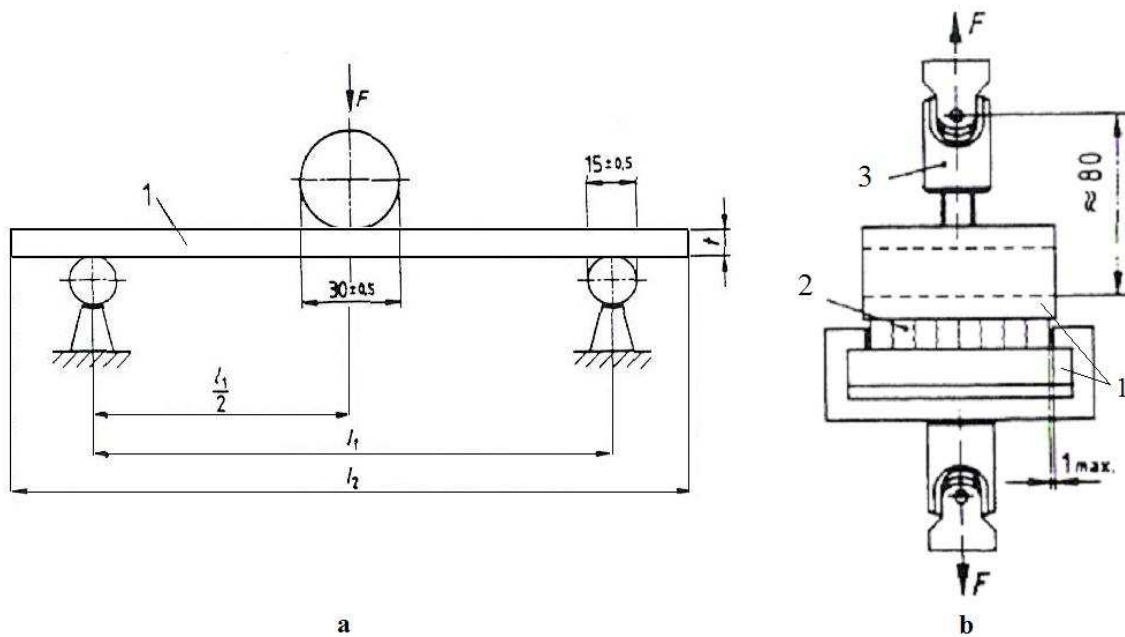
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Fig. 2. Diagrams of the mechanical properties testing. **a** – arrangement of the bending strength testing: 1 – test piece; t – thickness of the test piece; l_1 – distance between supports; l_2 – length of the specimen; F – load. **b** – arrangement of the internal bond testing: 1 – hardwood plywood testing block; 2 – test piece; 3 – self-aligning ball-and-socket joint; F – load.

The board samples density evaluated for specimens in size 30 x 95 mm. One part of each specimen broken at bending strength testing was used to determine form stability at swelling and water absorption. After cutting off the broken edge the specimens in size 30 x 30 mm were immersed in deionised water for 24 hours, then thickness and mass measured. The swelling G_t was calculated from Eq. 1 (EN 317:1993) and the water absorption G_a from Eq. 2.

$$G_t = \frac{t_2 - t_1}{t_1} \cdot 100, \% \tag{1}$$

where t_1 is thickness before soaking, t_2 – thickness after soaking in water for 24 hours.

$$G_a = \frac{m_2 - m_1}{m_1} \cdot 100, \% \tag{2}$$

where m_1 is mass before soaking, m_2 – mass after soaking in water for 24 hours.

RESULTS AND DISCUSSION

After cutting to various specimens, all the board samples were hard and heavy with smooth surfaces and had dark brown colour with light specific smell. Thickness of all the board samples was 7 mm. The hot-pressed board samples, transferred out of the press at higher temperature than 70 °C, had one gap in the cross-section of the board

less than 1 mm thick and approximately two third of the board long. It's the unfriendly technological nuance that should be improved because it takes time for cooling the board in the press at least 2 hours. This fact will be seen below on the variable results of internal bonding too. The board samples, taken out of the hot-press after at least 2 hours (at less temperature than 70 °C), were qualitative and without gaps.

The properties of the obtained self-binding fibreboard samples are summarised in Table 1. The tested mechanical properties of the board samples increase with increasing density. The best properties belong to the board samples pressed at high pressure (8 MPa) and relatively low temperature (168 °C, Table 1). Interesting to mention that density of the board sample, pressed at high temperature and at lower pressure, is higher of density of the sample pressed at the same temperature and at higher pressure (Table 1). This allows conclude that the fibres already destroyed during SE and then pressed at the temperature of 190 °C are destroyed more significant and that the pressing regime should not be useful in this case.

Table 1. Properties of the self-binding fibreboard samples

Pressing conditions		Board samples properties					
T, °C	P, MPa	ρ, g cm^{-3}	G_t, %	G_a, %	f_m, N mm^{-2}	E_m, N mm^{-2}	$f_{t\perp}$, N mm^{-2}
168	8	1.34 ± 0.04	8 ± 1	7 ± 3	32 ± 5	4701 ± 1296	0.6 ± 0.6
172	5	1.27 ± 0.04	9 ± 1	10 ± 3	29 ± 5	4121 ± 1237	0.8 ± 0.6
189	8	1.24 ± 0.18	11 ± 1	17 ± 6	14 ± 5	2573 ± 1273	0.4 ± 0.4
192	5	1.30 ± 0.03	10 ± 1	11 ± 2	16 ± 1	3593 ± 332	0.9 ± 0.2

T – average temperature at pressing; P – pressure at pressing; ρ – density; G_t – swelling in thickness; G_a – water absorption; f_m – bending strength; E_m – modulus of elasticity; $f_{t\perp}$ – internal bond (tensile strength perpendicular to the plane of the board).

As seen from Table 1 very good form stability properties of the board samples were achieved. The board samples obtained at temperature of 170 °C and pressure of 8 MPa show the best properties of swelling in thickness and water absorption. It's due to low porosity of SE fibres that also had low moisture content as mentioned above.

Comparing the properties with European Standard for hardboards (EN 622-2:2004) we see that the board samples obtained at temperature of 190 °C mismatch with no one requirement of the standard because of too low bending strength property. However the board samples obtained at temperature of 170 °C and pressure of 8 MPa comply with the requirements for load-bearing boards for use in dry conditions (type HB.LA). Because of good swelling property the board samples could be assigned to the type HB.E which belongs to boards for use in exterior conditions, but only one property – internal bond after boil test – was not tested to confirm it.

CONCLUSIONS

Based on the results of the study the conclusions could summarize following:

The obtained grey alder self-binding fibreboard samples from steam-exploded fibres are comparable with those of commercially obtained fibreboards.

Due to all the board samples density exceed the value of 1.2 g cm^{-3} it could be defined as hardboard.

The optimal pressing conditions for the grey alder self-binding fibreboard are following: temperature of 170 $^\bullet$C and pressure of 8 MPa.

Due to very good swelling property the board samples could be assigned to boards for use in exterior or humid conditions.

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APPLICATION OF THE NEW CATALYST MANUFACTURED ON THE BASIS OF AMMONIUM NITRATE IN THE PRODUCTION OF PARTICLE BOARDS

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ABSTRACT

Particle board is an engineered wood product manufactured from wood particles, synthetic resin and other components. Catalyst is an important element in the particle board production process. The purpose of using catalyst in the production of particle boards is simple: allow resin to cure in the hot press. Nowadays particle board production uses three different catalyst solution types: ammonium chloride, ammonium sulfate and ammonium nitrate.

Ammonium nitrate based catalyst has been specifically designed as a core and surface layer catalyst for particle board resins to increase production rates. These increases can only be taken as an advantage, if all the other parts of the line can sustain (flake preparation, drying, blending, forming, loading, pressing, unloading, trimming etc). If all other parts of the line can maintain, then production increase of up to 25% can be achieved.

Ammonium nitrate is faster in reactivity than standard ammonium chloride or sulphate solutions and the high solids content allows lower core moisture contents and higher surface moisture contents for better heat transfer inside the board which permits higher press temperatures and faster press times to be achieved without a reduction in board properties. This generally leads to a reduction in overall board costs. Although it has a high reactivity at elevated temperatures, it still has good pot life at room temperature when mixed with the resin. It is suitable for use with urea-formaldehyde and melamine-urea-formaldehyde resins and works well with E0 and E1 resins.

Ammonium nitrate based catalyst has been tested and compared with current catalysts at two European particle board factories. The current article gives an overview of a new type of catalyst, trials, results that have been achieved and makes further recommendations.

Key words: particle board, catalyst, resin.

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INTRODUCTION

Ammonium nitrate based particle board catalysts have been designed to increase production rates in both single- and multi-daylight presses. It is necessary to mention that these production rate increases are not at the expense of board properties.

Ammonium nitrate catalysts are supplied as high concentration liquids. This allows them to be transported and stored economically and eliminates the need for plants to mix their own catalyst solutions, which is a potential source of error and hazard.

If a conventional ammonium salt catalyst (ammonium chloride or ammonium sulfate) at a solution concentration of 10-25% solids is being used at 2-4% (solid catalyst on solid resin), ammonium nitrate catalyst at a higher solids (65-70%) reduces the moisture of the board by up to 1%. For plants with drier capacity problems this is an immediate benefit since the lower board moisture allows fluctuations in the dry flake moisture content to be absorbed by the plant without the need for press time adjustments.

Ammonium nitrate based catalysts have a scavenging effect on free formaldehyde present in the board due to urea that is one of the catalyst constituents. The quantity of catalyst added is so small that the scavenging effect is not great - up to 0.5 mg using the WKI method. The catalyst can be made a true catalyst/scavenger and the level added increased to achieve greater scavenging, if it is desired. The scavenger is also very high in solids (80-90%), so it does not increase the moisture content and negate the benefits of the catalyst and is more effective than simply adding a urea solution to the board which is a common practice. As a result, catalyst can be tailor made to each individual mill's requirements.

The catalysts are chloride free, which ensures that the environmental concerns of using ammonium chloride are avoided. This is particularly relevant when "Total Life Cycle" of the finished product is considered. The cost of the catalysts is competitive with Ammonium Salt solutions on a solids basis and generally an increase in raw material costs of only 0.5-1.0% is experienced. When a capacity increase of up to 25% is achieved, however, other savings can outweigh the small increase in raw material cost.

MATERIAL AND METHODS

The aim of this study is to increase the productivity of particle board factories (see Table 1) via lowering press time in the hot press by using new generation high solids ammonium nitrate based catalyst. In addition, all physical-mechanical properties of the final board should correspond to EN 312 standards [1,2], since these are decreasing with particle board line speed increase. Free formaldehyde emission is tested by EN 120 [3].

Ammonium nitrate based catalyst trials took place in August 2008. Different particle board types were in the production of plants during the trial period: Company A – P2 (16 mm), Company B – P6 (22 mm). According to EN 312:2 (P2) and EN 312:6 (P6)

standards, the following physical-mechanical properties of the particle board are needed to be tested to meet the standard requirements (see Table 2):

P2 - bending strength, modulus of elasticity, internal bond, surface soundness.

P6 - bending strength, modulus of elasticity, internal bond, swelling 24h.

Table 1. Comparison of two particle board plants

Characteristic	Company A	Company B
Foundation year	1975	1971
Annual production rate, m^3	110 000	300 000
Board types	P2, P4, P5, P6	P1, P2, P3, P5, P6
Board thicknesses, mm	From 6 to 30	From 11 to 25
Board formaldehyde class	E1	E1
Board layouts, mm x mm	P2, P4, P5, P6: 600 x 2750	P2, P3: 1830 x 2500; P1, P5, P6: 600/1200 x 2400
Hot press type	Single-daylight x 2 production lines	Multi-daylight
Hot press temperature, ^0C	225	176

Table 2. EN 312-2 and EN 312-6 requirements for board strength grades P2 and P6

Characteristic	Unit	Requirement 16 mm P2	Requirement 22 mm P6
Bending strength (min)	N/mm^2	13	16
Modulus of elasticity (min)	N/mm^2	1 600	2 550
Internal bond (min)	N/mm^2	0,35	0,40
Surface soundness (min)	N/mm^2	0,8	-
Swelling 24h (max)	%	-	14

The catalyst types that have been used at Companies A and B during the trials and the comparison of these products with new high solids ammonium nitrate based catalyst PC2015 is provided in Table 3.

Table 3. Comparison of PC2015 with existing catalysts

Characteristic	PC2015	Company A catalyst	Company B catalyst
Package	1000 kg IBC	25 kg bags – solid 100% $(NH_4)_2SO_4$	25 kg bags – solid 100% NH_4NO_3
Use	Direct	Produce 23,7% aqueous solution	Produce 20% aqueous solution
Chemical composition, %	NH_4NO_3 – 50%, $(NH_2)_2CO$ – 15%, H_2O – 30%, other – 5%	$(NH_4)_2SO_4$ – 23,7%, $(NH_2)_2CO$ – 18,4%, H_2O – 57,9%	NH_4NO_3 – 20%, H_2O – 80%
Density, kg/m^3	1230	1180	1150
pH	6,17	6,6	6,68
Addition rate, %	3 (solid /solid resin)	3 (solid /solid resin)	3 (solid /solid resin)

RESULTS AND DISCUSSION

Particle board strength properties have been tested initially at nominal press times and then it was lowered until the board properties corresponded to the minimum/maximum limit of EN standards (see Table 2). Trial results can be seen in Table 4.

Table 4. Trial results of PC2015 catalyst at Companies A and B

Company	System	Press time, s	Bending strength, N/mm^2	Modulus of elasticity, N/mm^2	Internal bond, N/mm^2	Swelling 24 h, %	FA emission, mg/100g	Surface soundness, N/mm^2 (not tested)
Company A	Old	123	13,51	2181	0,50	-	6,4	-
	PC2015	123	13,46	2137	0,51	-	6,8	-
	Old	115	*12,61*	2009	0,46	-	6,3	-
	PC2015	115	13,02	2068	0,47	-	6,5	-
	Old	110	*12,36*	1922	0,43	-	7,3	-
	PC2015	110	*12,41*	1963	0,41	-	8,0	-
Company B	Old	366	17,5	2748	0,59	12,5	6,3	-
	PC2015	366	17,9	2883	0,62	12,1	6,25	-
	Old	340	16,1	2721	*0,35*	13	6,3	-
	PC2015	340	16,4	2811	0,51	12,6	6,25	-

From the results presented in Table 4, it is clearly seen that ammonium nitrate based catalyst PC2015 performed better than the existing catalysts. As a result press time was lowered at Company A by 7,0% from 123 s to 115 s and at Company B by 7,1 % from 366 s to 340 s.

To take the full advantage of the decrease in press time, it is needed that all the other parts of the line (flake preparation, drying, blending, forming, loading, pressing, unloading, trimming etc.) must run faster by the amount of press time decrease. This aim was fully obtained at Companies A and B, consequently production rate increase of 7% and 7,1% was achieved at factories respectively (see Fig. 1). Moreover, the enhancement in plant productivity increases potential net profit of particle board plants (see Fig. 2).
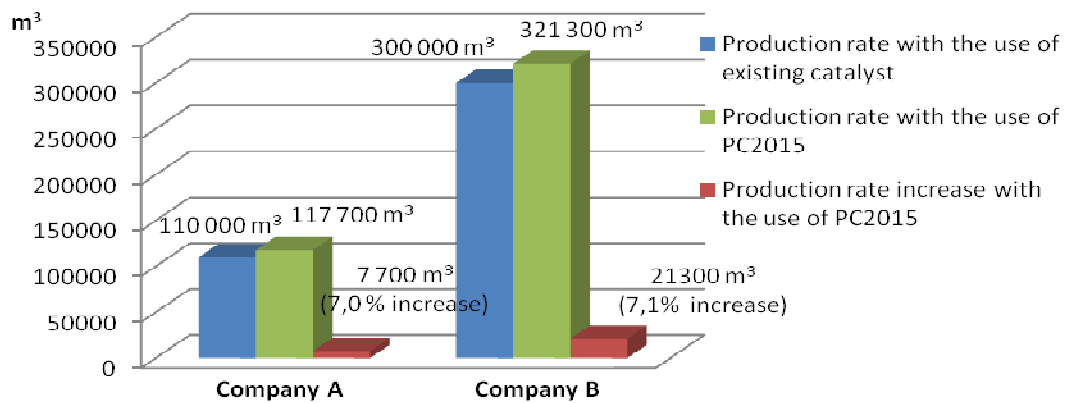

Fig. 1. Expected annual production rate increase of Companies A and B in m^3
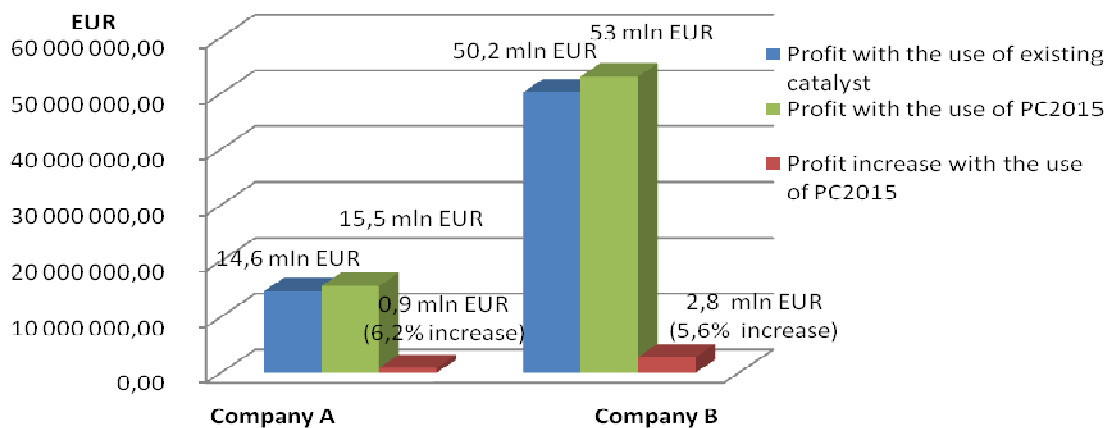

Fig. 2. Expected annual net profit increase of Companies A and B in EUR

The net profit increase of Companies A and B is not growing proportionally with the production rate increase, since the price of new ammonium nitrate based catalyst PC2015 is higher than the price of conventional catalysts. However, it is clearly seen that PC2015 is performing better than other catalysts and small increase in the raw material price can be easily overdriven by provided net profit increase.

CONCLUSIONS

According to the results obtained during the catalyst trials the following conclusions can be made:

- Using the new generation ammonium nitrate based catalyst PC2015 productivity of the particle board plants has been increased by 7,0% (7700 m^3) and 7,1% (21300 m^3) accordingly via lowering press time in the hot press and increasing production line speed.
- Furthermore, due to the production rate enhancement annual net profit of Company A can be increased by 6,2% (0,9 million EUR) and Company B by 5,6% (2,8 million EUR)

ACKNOWLEDGEMENTS

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WATER SORPTION PROPERTIES AND DIMENSIONAL CHANGES OF HIGH WOOD-CONTENT WPC

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ABSTRACT

The increased use of wood plastic composites (WPCs) for outdoor building applications is accompanied by an increased need for research about their durability properties. One particularly important feature is their water sorption behaviour which relates to e.g. their dimensional stability, mechanical properties and decay resistance. In this study, we have investigated the water sorption ability and resulting dimensional changes of WPCs with a comparable high wood content, i.e. ca 70 weight-%, prepared with either a heat treated, acetylated or unmodified wood component. The experiments involve immersion of thin veneers of the composites in water with registration of their weight and dimensional changes until they have reached saturation. The results show that the WPCs containing a modified wood component show the lowest level of water sorption and dimensional changes after saturation compared with the WPCs containing unmodified wood. A notably lower degree of a supposedly algae growth is also observed for the samples with acetylated wood. One question that was generated during this investigation relates to the density of the wood cell-wall and its relation to the applied wood modification route and moisture uptake. The general conclusion regarding this is that further studies are necessary to encompass such a topic, e.g. by more precise measurements of the wood cell-wall density in both dry and wet state.

Key words: WPC, water sorption, dimensional changes, wood modification

INTRODUCTION

Wood plastic composites (WPCs) is a new category of material which recently has been introduced on the building and furniture materials markets in Scandinavia and Europe, see e.g. some advertising web pages in Anonymous (2009a–f). In North America WPCs have gained continuously increasing market shares during the last 15 years for the use in outdoor applications such as decking, sidings and window frames (Eastin et al. 2005).

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It has been estimated that these composites have reached a market share of ca. 23,5% of the total decking market in US, where pressure treated wood has ca. 50 % and other woods (redwood, western red cedar, tropical hardwoods etc.) have ca 20 % of the market (Eastin et al. 2005). WPCs are in general composed of a reinforcing wood component combined with an olefin thermoplastic matrix. The former usually consists of wood residuals from the saw mill and wood working industry, e.g. sawdust and shavings, and the latter of recyclable plastics, e.g. polyethylene (PE), polyvinyl chloride (PVC) and polypropylene (PP). These components are usually "thermo-formed" through extrusion into continues profiles or injection moulded into final three-dimensional shapes, see example in Fig. 1. (Left) of an extruded WPC profile.

It is obvious that an increase of the wood content in the composite, and thus using less amount of thermoplastic matrix, would be beneficial in a raw material cost perspective since the plastics used are several times more expensive than the wood component. In this work we elaborate on using wood contents of up to 70 dry weight-% in the WPC. An important question that arise when applying such high wood-content levels in WPCs is, of course, how this influence their in-service behaviour in out-door use, in particular their water sorption properties and related dimensional stability? The WPC processing temperatures, around 180–200°C, means not only a risk for thermal degradation of the wood component but also that in principal all of its natural moisture will be vented out from the extruder creating a, close to, completely dry composite material. We argue therefore here that one of the most critical in-service issues for the use of WPCs in out-door applications is the high moisture sensitivity of such an absolute dry wood component, even though it is embedded in a hydrophobic thermoplastic. The general observation, however, is that moisture uptake is slow in conventional WPCs compared with solid wood, even when immersed in water, but continues over a long period of time. Wang and Morrell (2004) have shown that moisture will not penetrate deep into the material, but the moisture levels close to the surface may be very high. A moist environment will swell the wood particles close to the surface, and the particles will shrink upon drying. This will cause stresses within the material and create microcracks, especially in the form of interfacial cracks between the wood and plastic components (Segerholm 2007), which may create new pathways for water intrusion deeper into the material. An accelerated moisture uptake may therefore take place after some years.

Regarding the use of very high wood contents, one critical problem is that an interconnecting network of touching particles/fibres may be created above a certain wood content threshold following that the susceptibility to absorb moisture dramatically increases. It has been shown that the rate and extent of moisture uptake increases when the wood part exceeds 50 % of the composite (Rowell 2005). This will lead to poor dimensional stability and also an increased risk for biological decay by micro organisms. To be able to use a high wood content in WPCs there is thus necessary to reduce the moisture sensitivity of the wood component, and one means for this is to use modified wood in the WPCs instead of conventional untreated wood residuals. For cost efficiency reasons, the main concept here is to use residuals from the production of heat treated and acetylated solid wood boards which means that the wood raw material cost can be held to a minimum. And furthermore, if this concept makes possible a 20–25 % higher wood content in the composites than otherwise possible, the increased wood raw material costs will most likely be out ruled by the fact that the thermoplastics used are even more costly than such modified wood residuals.

Similar to solid wood, the macroscopic performance and behaviour of WPCs are strongly related to their microscopic structure. Some important microstructural features, in this case, are related to distribution, dispersion, orientation, form, and damage of the wood component embedded in the plastic matrix (Segerholm 2007, Segerholm et al. 2007), see the example of a WPC´s micromorphology in Fig. 1. (Right).
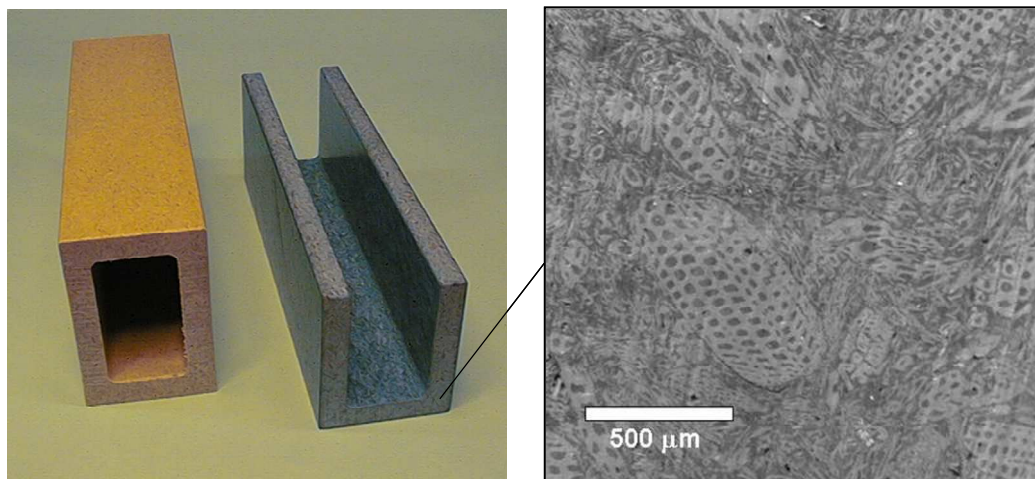

Fig. 1. Left: Examples of extruded WPCs with approximately 70 weight-% wood, 25 weight-% polypropylene and 5 weight-% additives (coupling agent, lubricant and UV inhibitors). Right: Micrograph exposing the micromorphology of the composite (lighter parts represent the wood component and the darker parts the polypropylene matrix

Of course, the properties of the separate components and any porosity within the composite are also essential for the macroscopic properties of WPCs. One thing that we find important to highlight in this work is that it is critical to know the wood component (or wood cell wall) density, in other words, the densities of the separate composite components plays a central role for the final density of the composite and also for finding suitable composite formulations with optimal volume fractions of the different components. Kellogg and Wangaard (1969) reported density values, determined pycnometrically in toluene, of dry softwood cell walls in the range of 1.48–1.50 g/cm^3 (containing ca 2% voids), whereas Hill and Ormondroyd (2004) reported significantly lower corresponding values of 1.42 g/cm^3 and 1.44 g/cm^3 (based on helium pycnometry) for an unmodified and an acetylated softwood species, respectively. Some uncertainties of such measurements seem to exist, however, e.g. regarding effects of cell wall micropores, which are generally inaccessible to some displacement media in non-swollen cell walls. It is also important to point out another important factor that influence the final WPC performance, namely wood-thermoplastic adhesion or compatibility, i.e. the problematic contrast between the inherent hydrophilic wood substance and the hydrophobic nature of olefin thermoplastics. However, this topic is not dealt with in this paper, see other studies by e.g. Bryne (2008).

The objective of this paper is to present some observations about the water sorption ability and resulting dimensional changes of WPCs with a comparable high wood content, i.e. ca 70 weight-%, prepared with either a heat treated, acetylated or unmodified wood component.

MATERIAL AND METHODS

The wood raw material used in this study was prepared from acetylated and unmodified boards of Scots pine (Pinus sylvestris L.) sapwood and from heat treated Norway spruce (Picea abies L.). The acetylation was performed according to Rowell et al. (1986) in a pilot plant with a microwave heated reaction vessel of 0.67 m^3. The degree of acetylation was about 20% expressed as wood acetyl content. The heat treatment was performed by Stora Enso according to the ThermoWood® D procedure which has a peak temperature of 212 °C (Anonymous 2003a). All boards where ground into particles in a two step process. First 190 mm long blocks were fed into a disk flaker (Bezner) and processed into thin veneer strands. In the second step the veneer strands were fed into a dry grinding knife-mill (Condux) and chopped into fine particles. The particles where characterized by standard sieve analysis. The thermoplastic matrix used was polypropylene (PP, Moplen HF 500N). The unmodified and modified wood components were dried to a moisture content (MC) of less than 1% and mixed with the PP and compounded into pellets on a counter rotating twin screw extruder at OFK Plast AB in Karlskoga, Sweden. The wood/thermoplastic ratio was 70/30 based on dry weight and. The pellets were then fed into a conical extruder located at Conenor Oy in Tampere, Finland, and extruded into rectangular-shaped hollow profiles, see Fig. 1. (Left), i.e. three different WPC samples were produced: a) a control with an unmodified wood component; b) an acetylated wood component; and c) a heat treated wood component. The cross-section of the profiles measured 60 x 40 mm^2, with a wall thickness of ca 8 mm. Thin specimens were then cut out using a small band saw from these profiles in three different ways: 1) in the extrusion direction from one of their wider sides (here denoted Axial long); 2) in the extrusion direction from one of its narrower sides (here denoted Axial short); and 3) transversal to the extrusion direction from the opposing wider side (here denoted Cross), see Fig. 2.
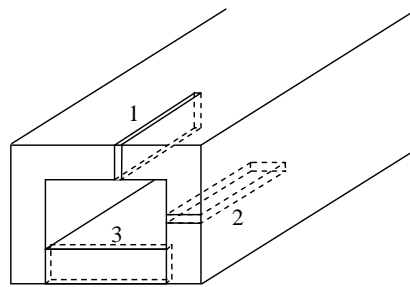

Fig. 2. Schematic drawing of the three types of specimens sawn out of the hollow WPC profiles

The specimens were about 40 mm long, 1.8 mm thick and the width corresponded to the original thickness of the hollow profile (ca 8 mm). One set of matching specimens were then oven-dried and exclusively used to determine the initial moisture content of the composites. The initial dimensions and weight were recorded for the rest of the specimens prior to immersion in de-ionized water kept in closed jars. All immersed specimens were weighed after three weeks and then left immersed again and left for

three years before the test was terminated and the final moisture and dimensional changes were recorded. The specimens were washed and wiped of excess water before the weight and dimensions measurements.

RESULTS AND DISCUSSION

Table 1 presents the starting and final moisture content (MC) of the water immersed WPC samples, both for the total WPC, and by excluding the polypropylene (PP) matrix. Since this matrix material do not absorb any moisture, the latter value is more representing the actual MC in the wood component including also the moisture in any voids. As can be seen, and as expected, the WPC samples containing a modified wood component gained significantly less moisture compared with the samples with unmodified wood. It can also be noticed that the final MC of the WPCs with unmodified wood, excluding the PP matrix, reached a MC content higher than a normal fiber saturation point (FSP) for pine wood, indicating that this material has a porosity of approximately 5–10%, and/or that voids have been formed within the material, perhaps due to swelling stresses. A similar observation can be made for the composites with a modified wood component, if it is assumed that the FSP of the acetylated wood is ca 10% and for the heat treated wood ca 20 %, based on reported water vapour sorption values at high humidity levels for similar materials (Segerholm 2007). I should also be noted that all of the WPCs had reached saturation already after three weeks immersion. At this stage it was also observed some supposedly algae growth on the samples with untreated and heat treated wood. No or very little of such algae growth could be observed on the samples containing an acetylated wood component even after three years of water immersion.

Table 1. Start and final moisture content (MC) of the WPC samples. Based on 5 replicates, standard deviation in parentheses.

WPC sample	MC [%] of the total WPC		MC [%] of the WPC excluding the PP matrix	
	Start	Final [%]	Start	Final
Unmodified Axial long		28.6 (0.3)		40.9 (0.5)
Unmodified Axial short	3.2 (0.2)	29.0 (0.2)	4.6 (0.3)	41.5 (0.3)
Unmodified Cross		28.2 (0.2)		40.2 (0.3)
Acetylated Axial long		10.2 (0.2)		14.6 (0.2)
Acetylated Axial short	1.4 (0.2)	10.8 (0.2)	2.0 (0.3)	15.4 (0.3)
Acetylated Cross		9.9 (0.1)		14.1 (0.2)
Heat treated Axial long		19.9 (0.4)		28.5 (0.6)
Heat treated Axial short	2.5 (0.1)	19.8 (0.2)	3.6 (0.2)	28.4 (0.2)
Heat treated Cross		20.0 (0.1)		28.6 (0.2)

Table 2 presents the corresponding dimensional changes of the water immersed WPC samples. As can be seen the resulting swelling is significantly lower for samples containing modified wood as compared with the controls. There is also a notable higher swelling transverse the extrusion direction (for the samples denoted Axial representing the thickness and width values and for samples denoted Cross representing the length and width values) for all three type of samples, which indicates a high degree of alignment of the wood component along the extrusion direction.

The porosity of WPCs is generally in the range of 2–10%, i.e. very low compared to most wood species. By applying the rule of mixture for the densities of the different WPC components and literature values of the dry wood cell-wall of untreated pine, combined with the over-all densities of the WPCs in their dry and saturated state, as presented in Table 3, indicates a dry wood cell-wall density for the two modified wood samples in the range of 1.4–1.5 g/cm^3. Such an estimation should, however, be verified by more accurate measurements of the modified wood cell walls.

Table 2. Swelling of the WPC materials due to water soaking (note that the directions are the specimen directions, not the original profile directions). Based on five replicates. Standard deviation was 0.1–0.3% for the length and width directions and 0.5–1.3% for the thickness direction.

WPC sample	Swelling [%]		
	Length	Thickness	Width
Unmodified Axial	1.9	11.1	9.6
Unmodified Cross	7.6	4.0	8.5
Acetylated Axial	0.3	3.2	1.7
Acetylated Cross	1.6	2.2	1.8
Heat treated Axial	1.4	5.2	6.3
Heat treated Cross	4.4	2.3	6.3

Table 3. Estimation of the density of the WPC samples with an unmodified, acetylated and heat treated wood component, before (Start) and after soaking (Final). Based on 5 replicates. Standard deviation was 0.01 g/cm^3 for all samples.

	WPC density, std in parentheses [g/cm^3],		
	Unmodified	Acetylated	Heat treated
Start	1.19	1.15	1.19
Final	1.16	1.17	1.19

CONCLUSIONS

The water sensitivity and resulting dimensional changes of wood plastic composites (WPCs) with a comparably high wood content of ca 70 weight-% can be significantly reduced by using a modified wood component instead of a conventional untreated one. It can also be concluded that thin sections (1.8 mm thickness) of such WPCs had reached a saturated state after three weeks water soaking.

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TIMBER ELEMENTS STRENGTH-STIFFNESS EFFECTS ON THE PERFORMANCE OF GLUED LAMINATED BEAMS

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ABSTRACT

In order to determine changes of strength characteristics in glued laminated timber a research was made with flat and edge glued specimens and by changing their length. Pine timber specimens of primary sizes 2000 x 50 x 30 mm and 2000 x 50 x 40 mm were tested. Edge glued specimen beam modulus of elasticity (MOE) increases, while the flat glued specimens MOE and general MOE of all beams decreases comparing with separate elements MOE. Results, gained from beams of flat, edge glued timber and from beam length changes, show the decrease of MOE when density is increasing. Nevertheless general MOE of all tested glued laminated beams increases with increase of density. However, due to limited amount of specimens and the initial testing character, it is not possible to make exact conclusions; therefore, it is necessary to perform research that is more exhaustive.

Key words: glued laminated timber, non-destructive methods, strength, stiffness.

INTRODUCTION

With development of wood industry, the use of timber products has significantly increased. Glued laminated wood products, beams are used in furniture industry, and also as load bearing elements and structures or just like the elements of décor. This kind of products has advantages, like large dimensional interval, different forms (various shape, technological holes in glued laminated wood products etc.), large strength interval, which depends on quality, geometric parameters etc. Despite all those advantages, there is one very important disadvantage: defects in inner layers, which are not seen, but effect the quality and strength of beam. For this reason, many researches are made with ultrasound, vibrant, x-ray or other examining in purpose to determine inner defects not only in manufacture, but also in exploitation period.

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Investigating defects – voids of glued laminated beams with ultrasound, the beam, which dimensions were 222.25 x 419.1 x 1219.2 mm, was used. This beam was made from 11 Douglas fir layers, which each dimensions were 38 x 222.25 x 1219.2 mm [1]. The beam was investigated with ultrasound waves, which were released through length and width of beam. All eleven layers were inspected individually within the width, and all beams were inspected in 92 places along the height. Ultrasonic inspections were made over 50.8 mm in length. This inspection was made with commercial 38.1 mm diameter, 100 kHz broadband sensors. Energy sensors were plugged to the surface of beam using pressure system. The results showed that the speed of ultrasound wave, the parameters of amplitudes allow to determine unseen voids and their approximate dimensions and location in glued laminated beams. However, there are some difficulties investigating small voids because of the inconsistent frequency and amplitude values of waves

In other research, the beam with longitudinal crack was investigated. The dimensions of block were (width x height x length) 120 x 440 x 2100 mm. The crack begins in one end of block and propagates longitudinal direction. It is seen on both side layers the most part of its length. In this research two piezoelectric (ultrasound) transducers - transmitter and receiver - were used positioned in front of each other in the middle of width on the smaller blocks layers parallel to the height. Received ultrasound waves signals were analyzed by three scalar parameters: wave propagation time, two biggest amplitudes and the first amplitude. All these parameters had significant correlations with full or partly seen investigated crack. The results show, that ultrasound is a good non-destructive method for investigation of glued laminated wood products in order to determine defects and general quality [2].

There are also researches made for purpose to determine glued laminated wood products strength in different humidity. It was made using small straight beams (50 x 100 x 1800 mm), which were loaded with constant load $\sigma_{max} = 10$ MPa, when temperature was 19 ± 1 °C and humidity was periodically changed from 65 % to 95 %. The time of cycles was one, two and four weeks, during which the changes of dimensions, longitudinal and transversal stresses, coefficient of shrinkage and moisture content were measured. Part of specimens was made from juvenile wood in order to compare changes of characteristics and their influence to strength. The results showed that changes of moisture content have major influence to juvenile wood loading. The main influence for changes of mature wood specimens had one-week cycle and for juvenile wood specimens – four weeks cycle. These results show that it is necessary to consider the exploitation conditions and period when using glued laminated beams [3].

For the current research the device „Timber Grader MTG" was used in order to determine glued elements stiffness-strength. The measurement principle of the device is based on acoustic-wave propagation in the wood, when the density, natural frequency and modulus of elasticity are measured [5]. With the help of special software, the measured signal is converted to measurement results quickly and with high accuracy. There are many studies with MTG device focused on determination and validation this non-destructive method reliability and accuracy. Both softwood [6] and hardwood [7] were used for investigations. In both cases the good correlations were gained between bending modulus of elasticity and modulus of elasticity, measured with the device „Timber Grader MTG". However, the modulus of elasticity, measured with this device, is dynamic, thus, it was important to evaluate its connection with static modulus of elasticity gained in bending test [4]. As a result, the formula, which lets to determine

static modulus of elasticity using the data received from dynamic modulus of elasticity, was recommended.

The purpose of current investigation was to determine stiffness and strength characteristics of glued engineering wood products (GEWP) using the data of individual sawn wood elements, and to estimate the correlation of characteristics. Using special configurations of GEWP it was examined whether the number of elements and the specifics of gluing affect the final product strength and quality.

MATERIAL AND METHODS

Sawn Scots pine wood specimens, which target dimensions were 2000 x 50 x 40 mm, 2000 x 50 x 30 mm and 2000 x 50 x 25 mm, were examined with the device „Timber Grader MTG" and the strength class and modulus of elasticity (MOE) was established. Then the specimens, belonging to the same strength class, were glued to beams using polyvinyl acetate dispersion adhesives corresponded the requests of D3 class. The schemes of gluing are given in figure 1. The specimens were glued in two ways: flank (Fig. 1, a) and edge (Fig. 1, b). The dimensions of glued specimens are given in table 1. They were in turn also tested with the device „Timber Grader MTG" in order to determine the changes of modulus of elasticity with the changes of beam dimensions (width, height, length) and the number of adhesive bonds.
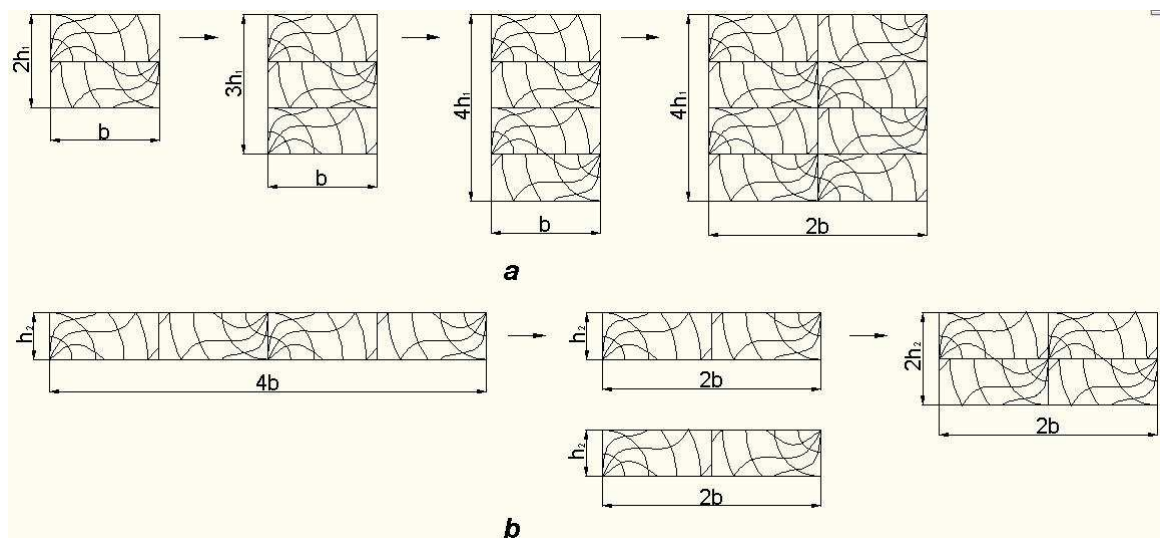

Fig. 1. The scheme of gluing: a) flank gluing; b) edge gluing

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Table 1. Glued specimens dimensions

Specimens code	Length, mm	Width, mm	Height, mm
Flank gluing			
2F	2005	44	50
3F	2010	43	75
4F	2010	43	99
4F	1997	43	99
8F	2005	100	84
8F 1part	900	100	82
8F 2part	900	100	82
Edge gluing			
2E	2000	81	35
2E	2000	83	35
4E	1999	167	35
2E2F	1991	84	66

RESULTS AND DISCUSION

GEWP modulus of elasticity depending on glued beam mode (gluing timber elements by flanks, edges and changing their length), variable element density in various configurations and their interdependencies were determined (2 – 4 figures). As the aim of study was to test hypothesis whether controlled optimization of the general MOE and strength of GEWP is possible appealing on data of separate elements the results are presented primarily in this meaning. Figure 2 illustrates the changes of elements and GEWP modulus of elasticity, when the mode of gluing changes.
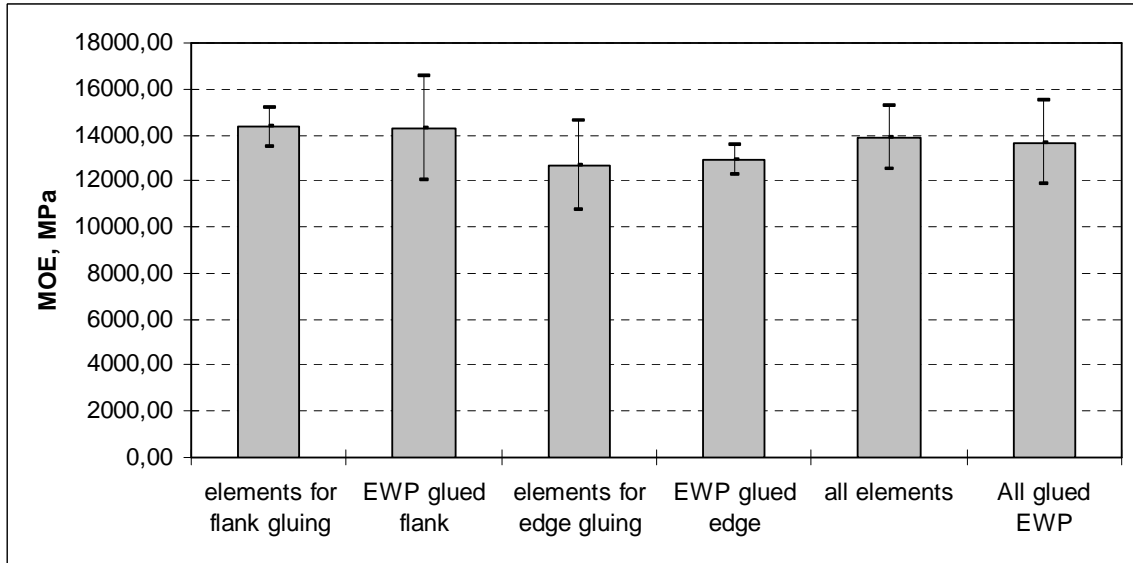
Fig. 2. The changes of separate elements and glued specimens modulus of elasticity (EWP – engineering wood products; MOE – modulus of elasticity)

For flanks glue specimens, their modulus of elasticity decreases 0.5 %, but for glued by edges increases 2 %; general GEWP modulus of elasticity decreases 1.7 %. Thus, the strength class remains unchanged: for elements, it is C30 and for glued specimens – GL28h, except specimens glued by flanks, which strength class is higher – GL32h (accordingly to the values of modulus of elasticity, given in the standard EN 1194 [8]).

Figure 3 illustrates the changes of MOE and density depending on the specimens' parameters changes (flank and edge gluing, and length changes).
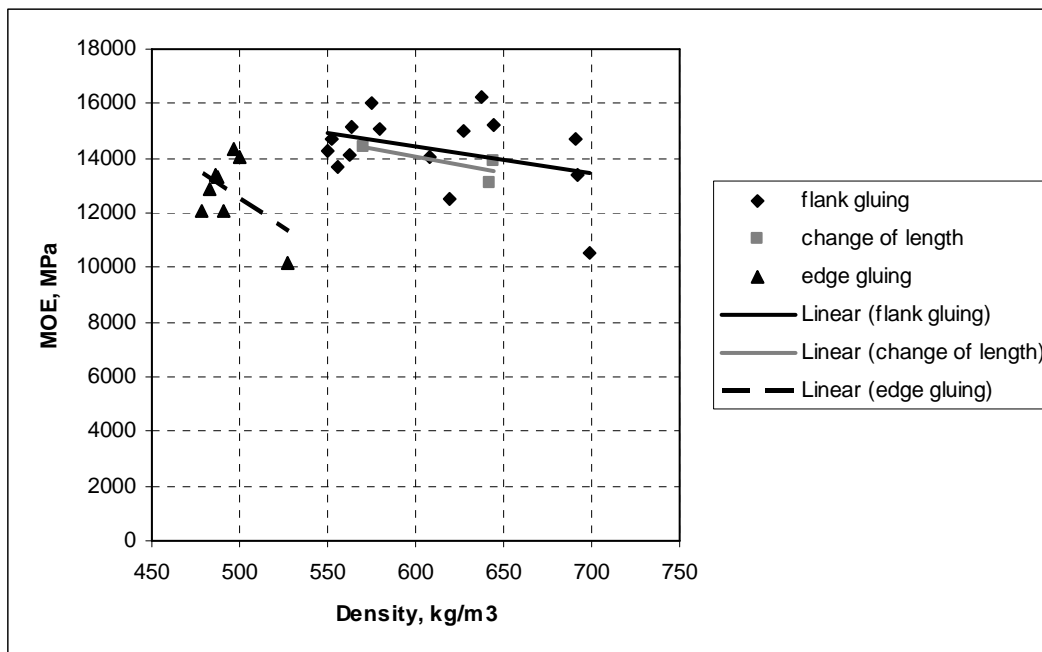

Fig. 3. MOE (modulus of elasticity) and ρ (density) interrelation

When specimens are glued by flanks and by edges and when their length is changed MOE and density interrelation is inverse that is when ρ increases the MOE decreases. However, in theory and known by practices, in sawn wood, ρ correlates with MOE. It

could be explained by changes of GEWP properties when an adhesive bond exists, also by change of grain direction comparing with separate sawn specimens. Yet the received correlation coefficients are very low. Nevertheless, it is not possible to claim that relation between these gauges does not exist, because the amount of specimens was not sufficient to confirm the hypothesis.

Figure 4 illustrates the modulus of elasticity and density correlation of elements and GEWP.
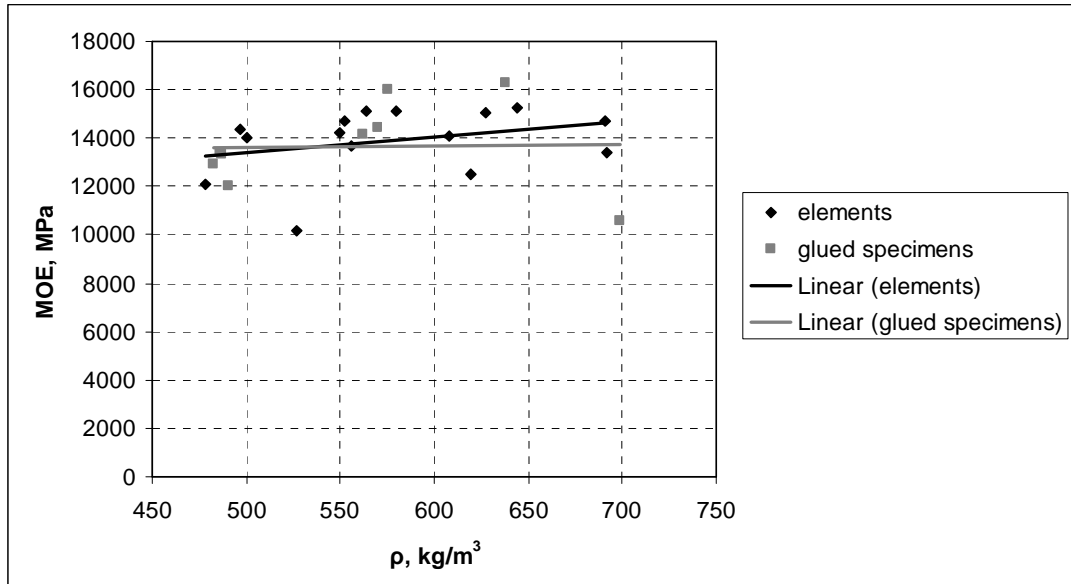

Fig. 4. MOE (modulus of elasticity) and ρ (density) interrelation (all tested elements and glued specimens)

Correlation between elements modulus of elasticity and density is linear, which is coincident with other researches and knowledge. The main all glued specimens interrelation is also positive, but it cannot be claimed as linear, because the coefficient of correlation was very low. In order to determine correlations and confirm received data, it is necessary to perform research that is more comprehensive.

CONCLUSIONS

Gluing timber elements by edge or by flank results in stiffness-strength characteristics of beams (GEWP) that do not necessarily follow the initial strength class or density of the elements.

Glued engineered wood products (GEWP) strength class remains the same as elements, except when gluing by flanks. Main specimens' strength remains similar or changes in very small interval.

Gluing specimens by edges slightly increases mean modulus of elasticity, while gluing by flanks decreases GEWP and main specimens MOE.
In all cases (gluing by edges, flanks and changing length) the increase of density decreases the modulus of elasticity, but the received correlation coefficients are very low due to small amount of specimens, or because the correlation does not exist between these gauges.

Main modulus of elasticity of GEWP increases with increase of density. However, it is not evident if the trend line is linear, because it is necessary to perform research that is more exhaustive.

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BENDING PROPERTIES OF PLYWOOD I-CORE SANDWICH PANELS

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ABSTRACT

Lightweight structures as sandwich panels are one of the innovation products to drive the future of the wood/plywood industry for the near future. Material consumption, thus environmental impact, is the driving factor to replace commonly used plywood panels with the plywood sandwich structures.

The aim of this paper is to elaborate the design methodology for different core type plywood sandwich panels under the flexural loading. The methodology is based on sampling of the numerical experiments by the finite element code ANSYS and approximation of the response values of the four point bending tests. This methodology is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which structural responses are influenced by several variables and the objective is to optimize these responses. The methodology is often referred to as metamodelling as they provide a model of a model, replacing the expensive simulation analyses during the optimisation process.

Moreover, validations of metamodelling procedure for design of I-core sandwich panels with physical tests have been evaluated. The sandwich panels used in physical experiments were made of plywood outer plate and I-core filling strips and the bending properties have been tested according to EN 789.

The structural flexural stiffness capacity and weight efficiency have been elaborated for the I-core sandwich panels by the metamodelling procedure. The design guidelines have been elaborated and validated with the physical experiments.

Key words: veneer, birch, lightweight structures, wood based panels

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INTRODUCTION

Plywood production has a significant role in the economics of Latvia Forest production. Plywood production value was a 180 000 m^3 and its takes 6 % share of all European plywood production in 2008 (FEIC 2009).

Approximately 2.6 - 3 m^3 of raw materials (logs) are necessary for producing 1 m^3 of plywood. There are several technology process stages which cause reduction of production effectiveness. One of the last stages is edge trimming, which is due to the oversize of panels. The panels before the final cutting are oversized because of the aim to minimize the risk of edge delamination and range of veneer dimensions in production site. More than 10% of panel is cut off depending from customer specifications and plywood producing technology. When the dimension specifications of panel are very wide the cut-off part from panels could be more than 300 mm wide. It gives approximately 18000 m^3 of cut-offs yearly in Latvia. These cut-offs can be sold as a small dimension plywood panels or as fire wood (they could be chopped). The value (price) of cut-offs is relative low compared to the plywood in both cases. The fire wood chips cost approximately 6 EUR/m^3, the plywood average price in 2009 was 550 EUR/m^3 (Latvia Ministry of Agriculture 2009), and the lower grade birch veneer log price was 31 EUR/m^3. The price difference (fire wood, raw material, and wood panel) shows economical benefit to reuse cut-offs from edge trimming for new product production. In wood-based panel production in Latvia, More than 1000000 EUR could be saved up by using cut-offs instead a veneer logs.

A plywood production from edge trim plywood strips as a core of panel was described in USA patent 3970497. The trim strips in this patent are laid up side by side with the edges glued to produce a flat and solid core panel. The edge trim core panel is proposed to glue over with veneer sheets to produce a thick plywood panel.

The mechanical properties of sandwich panels manufactured from plywood with plywood cut-offs as core material are investigated in this paper. The sandwich panel core material is composed from plywood strips with several distances between strips with an aim to reduce panel weight. Such kind of solution gives two benefits – reduction of raw material usage and reduction of panel weight.

MATERIAL AND METHODS

The sandwich panels consist of plywood skins and plywood edge trim strips in a core (Fig. 1).
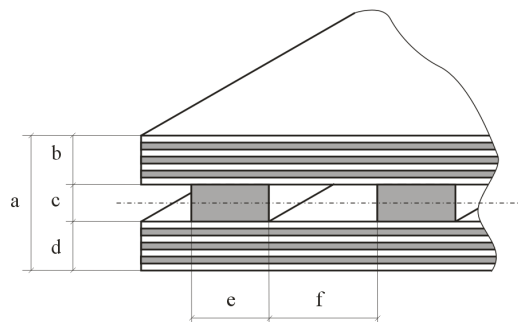

Fig. 1. Plywood sandwich panel

The plywood skins are made from birch (*Betula sp.*) veneers with thickness of 1.4 mm and glued with phenol formaldehyde resin glue. The core strips are made from the same birch plywood edge cut-offs. The grain direction in adjoining veneer layers is perpendicular. The 9 mm plywood was made from 7 and 6.5 mm from 5 birch veneer. The nominal dimensions of sandwich panels are shown in Table 1.

Table 1. Sandwich panel dimensions

Abbreviation	a	b	d	e	f
6.5×9@17	28	6.5	9	15	17
9×9@17	28	9	9	15	17
9×9@22	28	9	9	15	22
9×9@27	28	9	9	15	27

The core consists of 15 mm thick plywood strips which are set in three different distances from each other – 12; 17; 22 mm. The panels were pressed in cold press with pressure 1 MPa and time 6 h. The panel dimensions are 300 mm wide and 1200 mm long. The core strips are oriented lengthwise. Three panels from each type were tested. The bending properties were evaluated according to the EN 789 standard test method.

Metamodelling procedure

In industrial applications, to cut down the computational cost of complex, high fidelity scientific and engineering simulations, metamodels, also referred to as surrogate models, are constructed that mimic the behaviour of the simulation models as closely as possible while being computationally much cheaper to evaluate (Chen et al. 2006, Kalnins et al. 2006, Kalnins et al. 2008, Kalnins et al. 2009a). The process of design optimization involving metamodelling usually comprises three major steps which may be interleaved iteratively: 1) sample selection (known as design of experiments); 2) construction of the metamodel that best describes the behaviour of the problem and estimation of its predictive performance; 3) employment of the metamodel in the optimisation task, i.e., finding the best values for input variables with which the system achieves the optimum response.

In this study, for metamodelling a sparse polynomial model building approach called Adaptive Basis Function Construction, ABFC (Jekabsons 2009a) is used. The approach enables automatic adaptive generation of sparse polynomials of arbitrary complexity and degree specifically for the data at hand. A more complete discussion on the ABFC is given in (Jekabsons 2009a). ABFC together with a number of other metamodelling techniques is implemented in the freely-available VariReg software tool (Jekabsons 2009b).

Pure plywood solid panel versus I-core plywood sandwich have been modelled according to the EN 789 using ANSYS 4-node shell element SHELL 181. It was assumed that each ply has thickness of 1.4 mm both for solid panel and sandwich design. Moreover stacking sequence has been modelled assuming that each layer is perpendicular to the upper and lower one, thus the plywood always consists of an odd number of plies. The stiffness responses from the four point bending test under the

constant load P = 1000 N have been elaborated by extracting the global deflection value. The stiffness ratio ΔK is calculated as division of solid plate stiffness value Kp by corresponding sandwich plate stiffness Ks value extracted from the numerical analyses. The ΔK value indicates the stiffness increase or decrease of the sandwich concept versus pure plywood plate design. Another measurement extracted is weight efficiency ratio ΔW, which indicate the weight savings from the sandwich design concept. Five design variables are chosen for the sandwich panel design: the panel height – H, the number of plies in the upper sandwich plate – $T1$, the number of plies in the lower sandwich plate – $T3$, the number of plies for the I-core stiffener plate – $T2$. The stiffener spacing ratio is independent variable – $K1$, which directly influences the simulation section width – B for both panel and sandwich designs. The numerical values of the design spaces are outlined in (Kalnins et al. 2009b).

RESULTS AND DISCUSSION

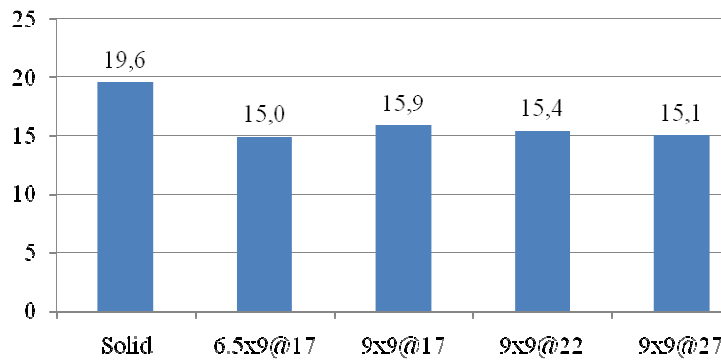The panel surface weight is shown in Fig. 2.

Fig. 2. Birch plywood (solid) and sandwich panel surface weight m^2 kg^{-1}

The weights of 6.5×9@17 and 9×9@27 are very close, but due to functionality reasons, more sandwiches are investigated with skin lay-up 9 mm plywood on a top and bottom. In these cases sandwiches are lighter by 19 – 23 % comparing to the solid birch plywood. Bending properties of the sandwiches are shown in Fig. 3.
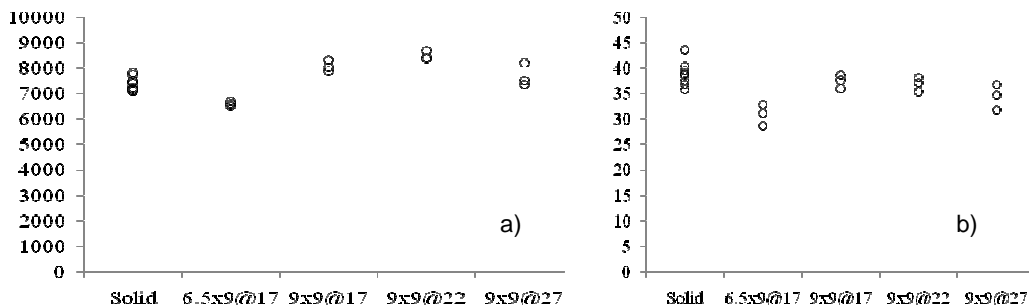

Fig. 3. Birch plywood (solid) and sandwich panel bending properties N mm^{-1}:
a) modulus of elasticity; b) strength

The sandwich panel shows higher specific strength of material. The panel weight could be reduced by 23 % (9×9@27) while reducing the bending strength by 11 %,

Optimization results

A Pareto optimisation problem is formulated where maximisation of the relative stiffness ratio ΔK is coupled with minimisation of the weight efficiency ratio ΔW. It could be assumed that the best performance could be reached when relative stiffness ratio tends towards the value of 1. Nevertheless the cost efficiency is directly linked with weight reduction. Thus dual strategies may exist for optimisation of sandwich performance: first to have sandwich panel stiffness close to the pure panel stiffness, which practically is weight inefficient, or second to have the sandwich height mach the stiffness while drastically reducing the total volume of the plywood.

A Pareto optimal front has been elaborated to evaluate the stiffness and weight effectiveness ratios for each panel height level. Comparison of the Pareto optimal front and physical experiments (Fig. 4) for different profile plywood sandwich designs indicates the overall tendency that there is no only one best solution between the stiffness ratio ΔK and the weight efficiency ratio ΔW thus decision for the trade off design should be left for the designer to decide. Thus the design guidelines elaborated by metamodeling procedure provide efficient tool for tailored plywood sandwich panel design and manufacturing procedure. Furthermore Pareto optimum fronts can be elaborated in any combination of design variables used for metamodeling thus the design could be tailored to meet the specific load carrying capacity and weight efficiency requirements.
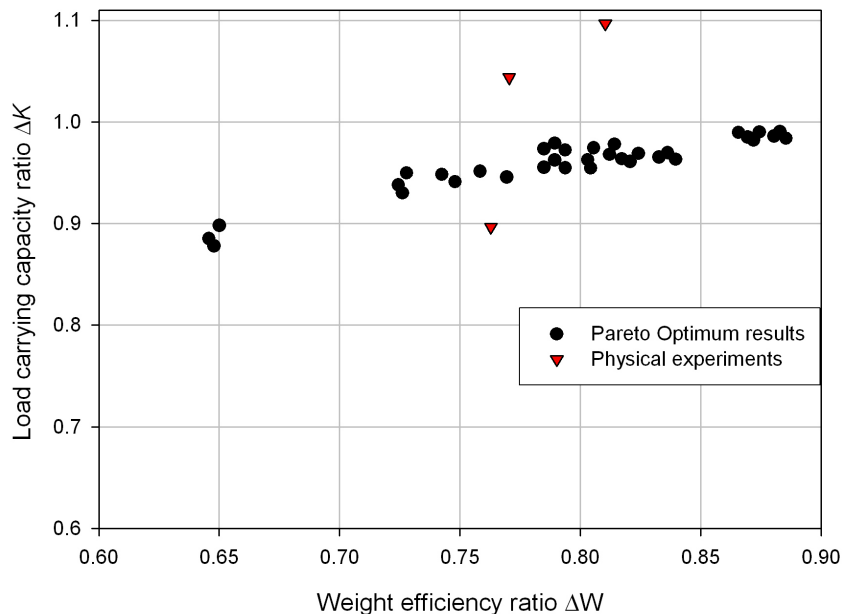

Fig. 4. Pareto optimal front between the load carrying capacity ratio and weight efficiency ratio for different 6.5 x 9 and 9 x 9 plywood sandwich panel designs compared with the solid plate designs.

It should be noted that physical experiments indicate stiffer structural response compared with the solid plate, this could be associated with the assumptions used in the numerical model as ply thickness as numerically no imperfection have been introduced.

However in fact there is a significant scatter in manufactured solid and sandwich panel overall thickness description scenarios. Nevertheless the decisions made upon the numerical solutions have been approved by physical experiments indicating around 20% scatter which is reasonably well predicted as far as numerical models for the wood structures have been considered.

CONCLUSIONS

The tests results shows that the best result was achieved for sandwich panel with be symmetrical lay-up. The difference of panel 6.5×9@17 and 9×9@27 weight is less than 1 %, but symmetrical lay-up (both skins from 9 mm plywood) shows 11 % higher results in bending strength and more than 16 % modulus of elasticity.

The Pareto optimisation problem has been formulated and methodology based on metamodelling has been developed for the plywood sandwich panel stiffness and the weight efficient designs. Five design variables were considered and elaborated in numerical sampling strength analysis procedure by finite element code ANSYS.

The elaborated metamodels applied in the optimum design guidelines provide efficient tool for tailored plywood sandwich panel design procedure.

A further study is needed to elaborate the geometrical imperfections influence on numerical modelling procedure.

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TRADITIONAL WOODEN FLOORINGS IN FINLAND

Silvo, J.[1] & Vahtikari, K.[2]

ABSTRACT

The purpose of this research is to study how wooden floorings were maintained in the past in Finland and compare them with wooden floorings used today. In the past floorings were built to function for over hundred years. Nowadays wood is often considered as a material with poorer durability than what other common flooring materials (laminate and plastic) have. In the past wood was widely used and there seemed not to be similar problems with durability and esthetic matters that today are faced when wood is used as a flooring material. The hypothesis is that there is forgotten knowledge of maintaining wooden floorings that could be used also nowadays.

The conclusion is that maintenance and cleanability of wooden surfaces are issues that have not been studied comprehensively so far, but still they play a significant role in the life cycle of wooden surfaces. To support and develop the use of wooden floorings in Finland, extensive analytical and applied research in the field of maintenance and cleanability needs to be done.

Key words: floorings, wood, maintenance

INTRODUCTION

In the past floorings were built to function for over hundred years. Wood was widely used and there were no similar problems with maintenance, durability and esthetic matters that are faced nowadays when wood is used as flooring material. The use of wooden floorings, especially in public buildings, is not well-established in Finland today, because the properties and behavior of wood in interiors are not well known. There is no correct, research based information available for designers and decision makers.

This study concentrates on the maintenance of wooden floorings. The hypothesis is that there is forgotten knowledge of maintaining wooden floorings in the past in Finland that could be used also nowadays. Traditional knowledge is compared with the modern maintenance practices. This research includes massive wooden floorings and parquets,

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but other wooden or wood imitating floorings are excluded. The study is based on literature, both academic and non-academic sources are used to be able to deepen the discussion.

FACTORS AFFECTING THE USE OF WOODEN FLOORINGS

From architectural point of view flooring is much more than only a surface. Besides the looks of the flooring, also the feeling of the material is important. When you walk on a floor every step gives you a sensation of the floor; hard, soft, noisy, silent. (Laine 2002). Colour, acoustics and warmth of the flooring affect the atmosphere of a room (Aulanko 1993). Broman (1996) has studied people's attitudes towards wood and found out that people prefer a wooden surface with at least one of the following characteristics: fresh look, harmony, interesting to look at, elegant, exciting to look at, restful, eventful appearance, not look like an imitation, imaginative and not gaudy. Sakuragawa (2006) has linked a wooden surface to calmness.

According to Laine (2002), architects consider the following aspects when they are choosing a flooring material: the base, stress conditions, appearance, costs, the whole life cycle, cost of the maintenance, acoustics and insulation. It is claimed that architects, civil engineers, flooring entrepreneurs and suppliers have too little interest in the maintenance costs of floorings. Their concerns are basically in the esthetic, technical and buying cost matters because they don't want to interfere in the maintenance discussion partly because of status reasons. (Forslöw 1989).

Forslöw (1989) has stated that there are four important E's in the decision making process when choosing a flooring material. These are economy (low working expenses), ergonomics (reduced work load), esthetics (retained function and appearance) and ecology (reduced use of cleaning chemicals). Also symbolic, rationale based and cultural things have an effect on the decision making of choosing flooring materials (Aulanko 1993). In another research, technical criteria like usability and durability of the surface were considered as the strongest influential things for the end-user together with the economical aspects (Tarkela 1988).

Importance of environmentally friendly products is supposed to grow in Finland during the next decades and this may strengthen the position of wood in the interior market. In Germany this trend can already been seen. (Pakarinen 1999). In addition to the environmental reasons for using wood, there are also hygienic and antibacterial properties in wood of which wood as a material could benefit more than it does today (Schönwälder 2002).

WOODEN FLOORINGS IN THE PAST AND PRESENT

Massive wooden floorings (boarded floorings)

In the 18th century floorings were usually uncoated splitted round timbers or planks but already a century later floorings were coated because of the style and to ease the cleaning process. An exact point when the coating started is though hard to say because the tradition varied strongly depending on the type of the flooring, if it was a floor in

countryside or in towns and how wealthy the owner of the house was. (Kaila 1989, Niiranen 1981). Massive wooden floorings have been coated in Finland since the 19th century (Keitele 2006, Niiranen 1981) and coating is the traditional way to protect the surface. Suitable varnishes for massive wooden floorings and parquets are carbamide, polyurethane and acrylic (Jokelainen 1988). There have been periods when wooden floorings have been considered as a material that only the poorest were using, but nowadays it is the other way around, to use wood is luxurious in many cases. (Aulanko 1993).

Nowadays the most common material for boarded floorings is pine, but a small amount is also produced from spruce, birch and oak. Usually the boards are sanded and surface finished with coating or varnish before the installation, but the surface can also be left untreated. A coated surface is sensitive for scratches and the floor needs regular maintenance. (Jokelainen 1988, Peltokorpi 1991).

Different kind of parquets

In the 18th century the use of massive wood parquets in Finland was very small, but since then the use has grown and parquets are considered an exclusive flooring material (Kaila 1989, Niiranen 1981). Parquets are divided depending on the way they have been made. Boarded parquet consists of a three layer cross laminated parquet board structure, but they can also be made of massive wood pieces assembled in the same direction or as a mosaic flooring. Special parquets are made usually as ordered works for official premises. Parquets are usually surface finished after the installation with lacquer or hot wax (hard species). (Jokelainen 1988, Peltokorpi 1991).

Maintenance of wooden floorings

Before coating the floorings became common, plank floorings were usually washed with ash lye and they were scoured with sand and water with a help of e.g. spruce branches. (Niiranen 1981, Pietarila 1989) The surface was worn smooth, but because of different hardness of the wood and knots it became uneven (Finnish specifications SIT 42-610016). After the floorings were built more tightly, water was decreased in cleaning and oil coated floorings became popular. The floorings were mopped. (Pietarila 1989). Even today the recommendation for untreated floorings is to scour with soap and water. After the scouring the floor is washed with cold water and mopped dry. (Furusjö, 1995).

Coated flooring should be cleaned so often that sand does not scratch the surface (Jokelainen 1988). Vacuum cleaning and a dry or damped mop or cloth is used for waxed, oiled and lacquered floorings. Occasionally they need a treatment with solvent conditioner or waxes. (Kujala 2003, Peltokorpi 1991). Smears and stronger contaminations should be removed with wet cloth, but the water has to be dried immediately; otherwise stronger cleaning methods than water are needed and they may harm the surface of the flooring. A combined cleaning machine can be used to wide areas. (Ahonen et al. 1997, Peltokorpi 1991).

When cleaning, it is important to avoid rough and abrasive washers because they scratch the surface (Jokelainen 1988). Avoiding water on the floor is the main rule for all wooden floors, especially if the floor is lacquered (Furusjö 1995, Kujala 2003,

Nyquist 1993). The water penetrates to the cracks and even though the cracks disappear for a while, the water damages the floor structure. Too warm cleaning water damages also the lacquered surface. (Furusjö 1995, Kujala 2003). Some experts recommend wet scrubbing machines because the flooring is polished at the same time. With untreated floorings this method shares opinions. (Nyquist 1993).

The flooring material has an impact on how often and how the floor has to be cleaned and also in the life cycle of the floor. If the floor is cleaned with wrong methods, the damage doesn't necessarily show up immediately but in the course of time. (Rissanen 2004b). Surface topography has an influence on how the floorings react to soil as well as on the physical properties like surface structure, porosity, moisture, temperature and chemical composition (Rautiainen & Wäänänen 1982). Washing agent producers claim that one of the common mistakes when cleaning wooden surfaces seems to be using too strong washing agents. Coated and finished wooden floorings must not be washed with strong washing agents because during time the surface will gray.

DISCUSSION

Concerning the maintenance of wooden surfaces, there are several problems that have to be faced. One problem is that the simplest and the most obvious cleaning methods used in the past are very poorly documented. Especially cleaning has been a work task for women and it has been taught for new generations only orally. (Tunander 1998). This has caused that the existing instructions for maintenance of wooden floorings are not collected and knowledge is hard to find.

Another factor is that wooden floorings usually need a surface treatment. With wood coatings the problem is that new products are coming to the market continuously and there is no independent, research based testing done. This kind of monitoring testing of durability and behaviour of the coatings needs to be done. (Rissanen 2004). Also wax and oil, the traditional treatments, are used more and more. In practise it seems that there is an enormous scale of surface treatment methods for floorings, but only a little knowledge of maintaining them.

The designer is an influential person, because he often decides which flooring materials to use especially in public buildings. Unfortunately designers often have only a limited knowledge of the flooring materials. (Aulanko 1993). Maintenance of floorings form 60 % of the total maintenance costs in public buildings in Sweden (Forslöw 1989). Besides the importance of cleaning floorings, also the other maintenance (e.g. sanding) is as important during the life cycle of wooden floorings. This seems to be characteristic for wood compared with other flooring materials.

It's difficult to give common rules for cleaning, because the floorings are so different. Some common rules for cleaning the wooden floorings have though been written;

- It's better to do too little than too much.

- Search for knowledge from experts and different sources.

- Use as mild and well tried methods as possible.

- Always test a new method first on something else than the floor.

- Try to predict what will be the end result of the planned cleaning actions. (Tunander 1998).

CONCLUSIONS

There is plenty of cleaning instructions for wooden floorings but still many of the floorings are maintained with wrong methods. One reason can be that there is too much information and people don't bother to read it. Another possibility is that the more simple methods used in the past for cleaning were better today too.

The conclusion is that maintenance and cleanability of wooden surfaces are issues that have not been studied comprehensively so far, but still they play a significant role in the life cycle of wooden surfaces. To support and develop the use of wooden floorings in Finland, extensive analytical and applied research in the field of maintenance and cleanability needs to be done.

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PRODUCTION COST ANALYSIS OF CARPENTRY AND JOINERY WOOD PRODUCTS IN LATVIA

Tunkele, S.[1]

INTRODUCTION

Today is very important not only the material properties of wood and their research, but also efficient wood production for forest industry development. Latvian forest industry is oriented to quality and high value-added wood products production and delivery to the consumer. Wood and wood products in Latvia is increasing every year. However, the production of high value-added wood products is to low.

Carpentry and joinery sector in Latvia

Carpentry and joinery products are the one product of forest industry, which characterized by large variety of products. Carpentry and joinery wood products are referred the wooden windows, glued beams, doors, stairs, floor boards, parquet and wooden building materials. These wood products make up almost 100 % of the total sector turnover in Latvia. It should be noted that this sector is characterized not only with high value-added production, but also quite large proportion of small and medium enterprises (abbreviated as SMEs), which make up around 70 % of the forest industry enterprises in Latvia.

In 2008 was conducted a study on the Latvian forest industry sector, which has been studied carpentry and joinery sector and the economic role. After study data and revenue the highest proportion in carpentry and joinery sector is the doors and stairs by 40 % of total sector. The second place is the wooden windows and glued beams by 38 %. In the following places are the construction materials by 12 % and the floor boards, parquet by 10 % (Fig. 1).

The important criterion is the raw material consumption in the wood products production of carpentry and joinery. This sector involves with products of different raw material consumption in the production process. The technological process and characteristics of wooden window and glued beam products dominate a large raw material consumption per unit of output. In production process of floor boards, parquet and building materials is a large wood advisability, but production units are small. In door and stairs products production are relatively high raw material consumption, but the output volume is high.

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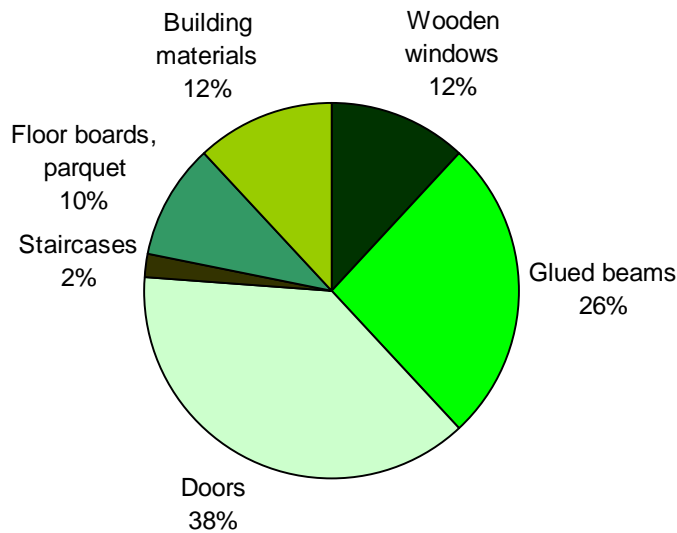
Fig. 1. Joinery and carpentry sector's revenue structure

Cost analysis of carpentry and joinery sector

The cost identification and struturing takes place the following cost postion - purchases of raw material costs, other material costs, energy costs, staff costs, other admnistrative costs, maintenance costs, transport costs and other costs. This classification allows for cost analysis objectively obtained data and information.

The carpentry and joinery product assortment is wide with different cost classification in the each product group, but average the material and staff costs are the largest cost position of total cost and it is 82 % after study data in 2008. The cost structure changes is associated with raw material consumption and buying prices.

RESULTS AND DISCUSSION

After data in the Latvian carpentry and joinery sector a large cost position is material and other material costs by 53 %, but second place is the staff costs by 29 %, including the pay and taxes. The last position is the other costs by 18 %. At the other costs are a transportation costs, servicing costs, storage costs, other administrative costs and other costs.

After data can to see that still now dominante the raw materials such as sawn timber by 59 % of total volume, round timber by 35 % and pallet materials by 6 % (Fig. 2).

After data follows that the sawn timber used for stairs, doors, wooden windows, glued beams and building materials production, but round timber for floor boards and parquet, glued beams and wooden windows production.
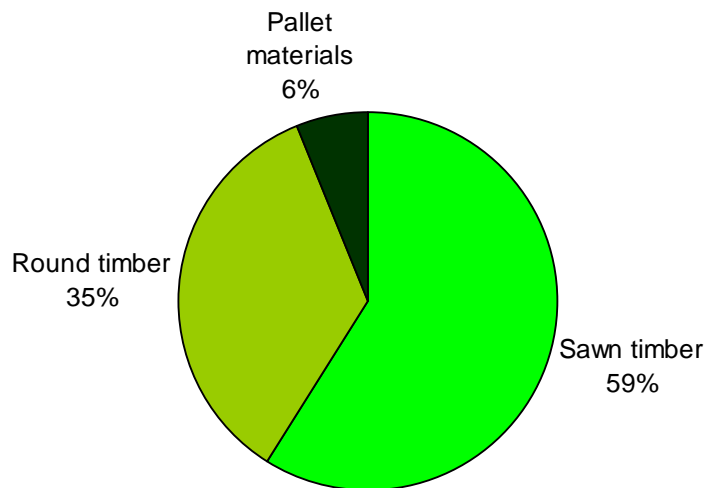
Fig 2. The raw material structure of joinery and carpentry sectors

The second largest cost position is staff coss, where 62 % of salary are below the average wages level in the sector and only 38 % are above average in this sector in Latvia. In this sector, where 85 % of salary are below the average wages level in Latvian rural areas and 15 % in Riga and its region.

SUMMARY

The basic wood products are referred the wooden windows, glued beams, doors, floor boards and wooden building materials in the carpentry and joinery sector in Latvia. In the carpentry and joinery sector material and staff costs are the general cost in the production of wood products and average it is 80 %. Cost-effective optimization is necessary the professional competence what promote the SMEs business in Latvia.

RENEWING WOOD PRODUCT VALUE CHAINS AND TIMBER PROCUREMENT SOLUTIONS

Heräjärvi, H.[1], Verkasalo, E.[2] & Sirén, M.[3]

ABSTRACT

Changes in the make-up of commercial forest resources, priorities for wood and timber quality, forest ownership and customer structure, as well as changes in global and local climate pose challenges to timber harvesting methods, transportation logistics, information systems and entire chains of wood utilisation. The working and business environment has already altered in ways that emphasise the need for skills in economic management and customer interface within harvesting and wood processing companies. In today's environmentally-conscious business environment, the sustainability, renewability and safety of wood as a raw material, its capability to store carbon, and other positive environmental performance elements combine to give a strong competitive advantage to the wood products sector. New value-adding wood products and customer solutions based on integrated product systems and service functions diversify the uses of wood and increase its competitiveness as a construction and furnishing material.

The Finnish Forest Research Institute (Metla) has launched a five-year-long (2009–2013) interdisciplinary research programme "Renewing wood product value chains and timber procurement solutions (PUU)" in the fields of wood science and technology, forest engineering, and business economics. The programme serves timber producers, procurement organisations and wood product industries by improving their strategic development and operative planning. It also supports national and regional forest policy initiatives to promote the uses of wood and the development of wood product industries. The programme consists of three different themes: 1) Raw material potentials of wood and timber trade functions, 2) Timber procurement and competitiveness of harvesting companies, and 3) Wood products and customer solutions. These themes are further divided into research topics and detailed research projects. The versatile concept of value chain analysis can cross from one theme to another to provide an advantage to the individual research projects. Annually, approximately 30–50 researchers from Metla and its partner organisations will work in the projects.

Key words: competitive ability, harvesting, timber procurement, wood-based value chains, wood product industries, wood raw materials.

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INTRODUCTION

The availability of logs representing appropriate quality, value potential, and customer appreciation in the economically relevant market segments, is turning into a hot topic, especially in the wood product industries. Simultaneously, the positive properties of wood, such as renewability, ability to store carbon, as well as some other critical issues of environmental performance, are turning into more and more important factors enhancing wood's competitiveness against substituting raw materials.

Finnish wood product industries have, for some decades already, experienced downhill in the quality grade distributions of sawn timber and plywood veneers. Gradual change of timber supply from forests of natural origin to cultivated forests, younger age classes and peatland forests suggests further challenges. Timber procurement is hindered by the fragmented forest ownership. Areas with insufficient silvicultural management, i.e., tending of seedling stands, improvement of young stands, and postponed commercial thinnings, appear to grow, which eventually leads to decreasing timber quality. The volumes of roundwood imported from Russia have collapsed, and the deficit of 3–4 million cubic metres of saw and plywood logs should be purchased from other sources. In the Finnish perspective, this means younger stands and peatland forests. Currently peatlands provide some 5 million m^3 of timber per annum, whereas the sustainable cut is estimated to 12–14 million m^3. Peatland forests, however, require either solid permafrost or forwarder solutions with lower ground pressure. Within longer perspective, climate change will obviously have impacts on the structure of forests, wood properties and, thus, possibilities to utilise wood. In addition, the requirements set for the wood raw materials are changing as a result of the customer's expectations and competition by other materials. In the future, more and more attention is paid on the applicability of a material to the production processes, the functionalities for the end users and the overall match to the value chains. Logistic chains set requirements for the control and preservation of timber quality.

Deficiency of non-renewable raw materials, increase in energy prices, and tightening environmental requirements alter the competitive relationships between the raw materials, mostly in favour for wood. Also roundwood markets and timber valuation systems should change more flexible and value creative. This necessitates new information on objective pricing methods of marked stands with as low pre-measurement effort as possible. Both timber sellers and buyers need more exact information on the dimensions and qualities of raw materials, and their effects on the economical results of the respective businesses. Timber scaling and grading must also follow the needs of logistics, production processes and verification of wood origin.

The customer solutions of the future are based on understanding the needs and predicting the behaviour of consumers and industrial customers. The traditional way of exploiting incremental innovations, i.e., developing the existing products, technologies or service models, represents low risk of failure, but cannot be the only solution in the longer perspective. Radical innovations, although having higher risks of failure, may open new markets, business opportunities or accelerated growth of revenue. Only a few radical innovations were developed in the Finnish woodworking industries during the past few decades, such as LVL (Kerto[®]) in the 1980's, thermally modified timber in the 1990's, and wood-plastic composites during the 2000's.

Whatever is the course of innovations, it is important to involve the customers in the development of business models. The wood product industries consist mostly of small and medium sized companies with limited resources for systematic research and development. Therefore, there is a big challenge in establishing the companies with the idea of thinking beyond years or even decades. The poor market situation and decline in the production of pulp and paper in Finland can be interpreted not only as a threat but also as an opportunity for the wood product industries. Political decision makers, as well as the R&D financers and industrial investors might be more open to proposals outside the pulp and paper sector. Wood as a material for building products and customer solutions based on integrated product systems awakes interest, and has obvious advantages as the only renewing, industrially utilised construction material. Financial recession strikes hard the construction business, but the need for construction per se, does not disappear. Systematic production of objective information increases the competitiveness of wood products in comparison to the other building materials.

The information related to the environmental performance of construction materials, *i.e.* usage of resources in relation to the obtained benefit, is becoming globally acknowledged. Wood should be able to use this benefit without any specific efforts. However, it appears that a lot of work is required in information production, but especially in lobbying for decision makers. The competitiveness of wood is expected to improve in 2011, when the environmental performance will be included as mandatory information in the CE-label of construction products in Europe. The business concepts among the wood product industries are rather inflexible in comparison to the competing industry sectors. Options of networking and partnerships are not familiar or utilised for some other reasons. Also investments in marketing and promotion are few, although the challenge has been known for years. As a result, wood often looses the fight against competing materials, albeit the obvious opportunities for better performance.

In general, it is obvious that the future competitiveness of Finnish forest industries will depend on high quality timber supply, efficient forest technology and logistics, high quality products, and elaborated business and customer service models. Production of bulk in countries with high labour costs will not thrive in the globalised competition. Changing timber supply, logging conditions and customer requirements call for research and development efforts. In addition to the incremental innovations exploiting existing technologies with low risk, radical ones exploring new technologies with higher uncertainty are needed, as well. It takes time for inventions to turn into innovations.

IDEA AND OBJECTIVES OF THE PUU PROGRAMME

The Finnish Forest Research Institute (Metla) has launched a five-year-long (2009–2013) interdisciplinary research programme "Renewing wood product value chains and timber procurement solutions (PUU). The programme is viewing and analysing timber flows from raw material to end use, and vice versa. The general objectives of the PUU programme are:

- Provide information on raw material sources and raw material availability for the wood product industries, and search new business concepts, logistical solutions and technological innovations in timber procurement and trade.

- Advice the forest owners the profitable options for timber sales, and how to manage their forests in order to grow timber with profitable markets.
- Support the product and production development with the emphasis on utilising the quality potential of raw materials.
- Facilitate the marketing of wood products by providing information on the properties and competitiveness of materials and products, as well as customer interfaces, requirements and decision processes.
- Develop services applicable to timber trade planning and timber pricing systems.
- Utilise the forest inventory data to support timber procurement in strategic and operative levels.
- Upgrade the timber scaling and grading methods.
- Synchronise the work within the three research themes in a way that the project's outcomes provide versatile value chain analyses in addition to the detailed, focussed research results.

The emphasis areas of the programme are derived from the research strategy of the Finnish wood products cluster (Puutuoteklusterin tutkimusstrategia 2008), the road map of the forest technology sector (Asikainen *et al.* 2005) and partly from the results of Metla's previous research programme PKM (Verkasalo & Enroth 2008).

THEMES, PROJECTS AND ORGANISATION

The PUU programme consists of three different themes (Fig. 1). They are further divided into research topics and detailed research projects. The concept of value chain analysis can cross from one theme to another to provide an advantage to the individual research projects.

Theme 1. Raw material potentials of wood and timber trade functions

Co-ordinator Prof. Erkki Verkasalo

This theme concentrates, firstly, on the future properties, value and competitiveness of Scots pine and Norway spruce in selected product segments, emphasising wood from cultivations and thinning forests. The studies aim at industrially applicable results for planning the strategies for companies' raw materials, product segments, and processing technology, as well as for estimating stumpage income for the forest owners. Prospective changes in size and grade distributions of pine and spruce logs are predicted based on the forest inventory data and forecasts of allowable cut. Secondly, the timber trade studies produce information on, and develop methods for timber measurement and scaling, and value prediction and formation of marked stands, for the needs of forest owners, timber buyers, and wood users. Thirdly, durability of timber, its upgrading and utilisation as a criterion for environmental performance are studied. The projects in this programme theme are:

- Raw material potentials, properties, suitability and competitiveness of Scots pine and Norway spruce in wood product industries, 2008–2012 (Prof. Erkki Verkasalo).
- Assessing quantity, quality and value of wood raw-material for timber trade and procurement, 2008–2012 (Dr. Jukka Malinen).
- Environmental performance of weather and decay resistant timber, 2009–2013 (Dr. Martti Venäläinen).

Theme 2. Timber procurement and competitiveness of harvesting companies

Co-ordinator Dr. Matti Sirén

The projects in this theme aim at increasing the utilisation of wood raw material potentials in sustainable, cost efficient and profitable manner. Emphasis is paid on the peatland forests that have vast potential for further utilisation. Taking this potential in the use necessitates new solutions in logging and hauling technology, new machine equipment, and optimising the use of harvesting resources regionally and seasonally. The information systems of forest machines can be applied more efficiently for guiding the machine operator, sense the terrain accessibility, etc. Long distance transport logistics is important field of research as the roundwood flows change and more flexible, energy efficient transport methods are called for. The business economical project focuses on developing new strategies for harvesting and transport companies, as well as searching their critical success factors and tools for decision making. The projects in this programme theme are:

- Possibilities of equipment and accessories in use of forest machinery, 2008–2010 (Dr. Matti Sirén)
- New logistic and technology innovations in wood procurement of forest industry, 2009–2011 (Mr. Kari Väätäinen)
- Profitability development of service businesses of wood procurement enterprises, 2007–2010 (Dr. Markku Penttinen)

Theme 3. Wood products and their customer solutions

Co-ordinator Dr. Henrik Heräjärvi

Developing the customer orientation of the product and service concepts of wood product industries is the key challenge for the business. It can be supported by providing information on the opportunities of company networks, new business concepts and innovation environments. One challenge is to develop systems for defining and measuring the environmental performance of wood products, and to analyse its impacts to their competitiveness. Markets and marketing of products are studied both from the viewpoints of the current user interfaces and the predicted changes in the customer needs in the course of time. The properties of wood raw materials are combined with wood processing and properties of products, with special emphasis on the potential improvements through gluing, drying and physical and chemical modifications. The projects in this programme theme are:

- Business networks, innovation and new product and service concepts in wood products industries of the building construction value chain, 2008–2011 (Mr. Thomas Rimmler)
- Success factors of wooden house and other woodworking firms in a changing competitive environment, 2004–2009 (Prof. Pekka Ollonqvist)
- New wood product solutions and their competitiveness, 2008–2010 (Dr. Henrik Heräjärvi)
- Woodworking industries' customer segments and their product and service needs in the internationalized markets (in preparation), 2010–2012 (N.N.)
- Growth factors of wood product industries (in preparation), 2010–2012 (Dr. Pekka Mäkinen)

The above mentioned projects construct the framework in which the externally funded research projects are running or planned to run. Altogether, there are 30–50 researchers working in these projects annually. The budget for five-year programme period (2009–2013) of approximately 10 million € includes the salaries of permanent personnel. At least 40% of the budged is expected to be raised from external sources. Up to five doctoral dissertations and 10–20 master's theses are expected to be completed during the programme period. The PUU programme needs national and international partners for cooperation to build up consortia that can reply to the information needs of the forest sector, and to successfully compete for the research funding.
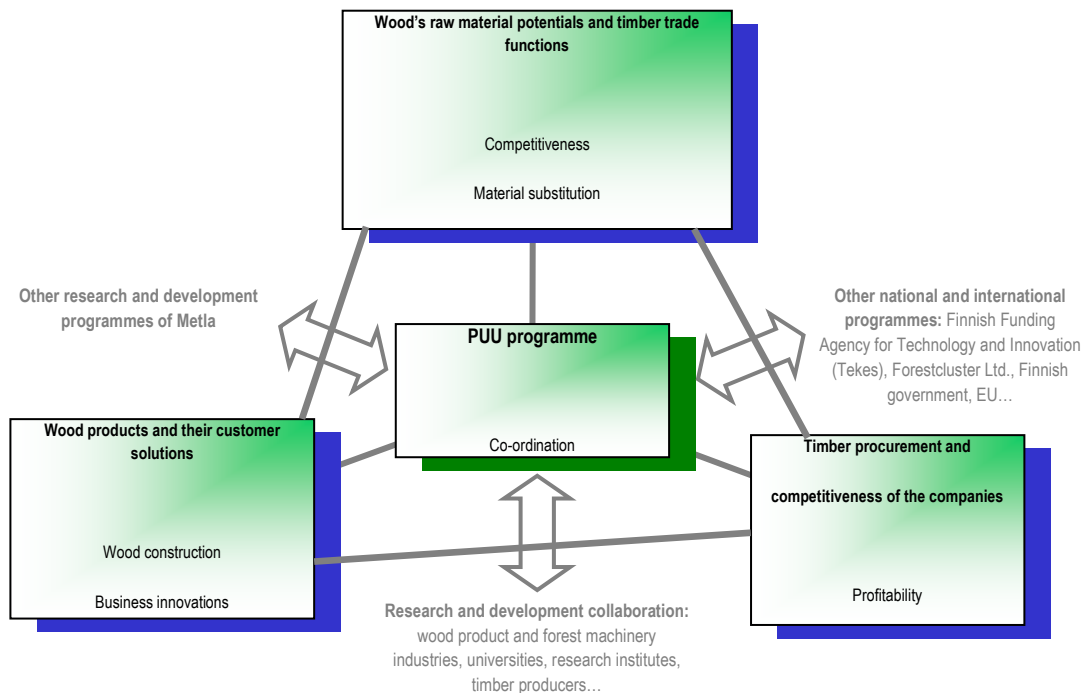

Figure 1. Knowledge needs in wood product value chains and their relations to the PUU programme.

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VARIATION IN SCOTS PINE TREATABILITY
- REVIEW AND FUTURE PROSPECTS

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ABSTRACT

Wood is a traditional building material but in general it underlies restrictions in outdoor applications due to its respective durability against microbiological decay. To face this problem, different impregnation systems are applied to enhance the materials' service life. Scots pine (*Pinus sylvestris*) is the most widely distributed pine in Eurasia and hence easily available. Despite of the previously defined good treatability of Scots pine sapwood, large differences in treatment performance are reported from industry. As process parameters are always adjusted to the material most difficult to treat, permeability variations in wood material are an economical problem. Therefore, it is important to understand the material in order to make a more reasonable material selection possible.

One can divide three levels influencing the impregnation, when questioning why the treatment result is so different. On the one hand, the procedural as drying schedule, process conditions and treatment agent are affecting the result. On the other hand, indirect properties as site-related factors like light exposure, origin and position in the site and tree related factors as the positioning of the material within the stem contribute. Structural properties as anatomical structures and chemical composition are strongly correlated to permeability by building up the fluid pathway.

In the course of the current PhD project, sample material will be collected from the Nordic and Baltic countries in order to obtain differences in material structure and composition to evaluate patterns in treatment performance according to geographical origin. As a consequence the material will undergo different treatment schemes to indicate permeability differences and locate impregnation pathways to be able to portrait a comprehensive picture of structural mechanisms that influence permeability and retention of impregnation fluids. This enables to better predict material's treatment properties. Due to this a more reasonable material selection and process schedules will be possible.

Keywords: impregnation pathways, latitude, northern Europe, Scots pine sapwood, treatability

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