Tallinn University of Technology

# Proceedings of the 6th meeting of the **NORDIC-BALTIC NETWORK IN WOOD MATERIAL SCIENCE AND ENGINEERING (WSE)**

October 21–22, 2010
Tallinn, Estonia

Edited by Pille Meier

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# PREFACE

The Nordic-Baltic Network in Wood Material Science and Engineering (WSE) was established in 2004 by Nordic Forest Research Cooperation Committee (SNS). The field of the network, wood science and engineering, covers wood-water relations, wood durability, wood modification, wood mechanics, wood composites, engineered wood products, eco-efficient wood based products, wood engineering, building, and use of machines and constructions.

The first five meetings were organized by network partners in different countries.

**2005** – Norwegian Forest and Landscape Institute (Norway)

**2006** – Royal Institute of Technology, KTH and Swedish National Testing and Research Institute, SP (Sweden)

**2007** – University of Helsinki, Department of Forest Resource Management (Finland)

**2008** – Latvian State Institute of Wood Chemistry (Latvia)

**2009** – University of Copenhagen, Forest & Landscape Denmark (Denmark)

During the past six years the network has constantly been growing, resulting in attracting 70 researchers from twelve countries in 2010. The present publication contains 21 papers and 11 abstracts.

The Chair of Woodworking and International Relations Office at the Tallinn University of Technology have the honour to host the meeting in 2010. We would like to thank all the speakers for their contribution and the SNS for financial support to make this event possible.

Tallinn, October 2010

Pille Meier

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# TOWARDS STRUCTURAL WOOD PLASTIC COMPOSITES: TECHNICAL INNOVATIONS

Gardner, D. J.[1] & Han, Y.[2]

## ABSTRACT

Wood plastic composites (WPCs) are an important segment of the forest products industry. Applications of WPCs are typically for nonstructural applications and the market has been dominated by rail and decking products in North America while in Europe, emphasis has been on automotive applications. In China and other parts of Asia, the WPC market is experiencing considerable growth and a wider variety of product offerings. There is a great desire to create truly structural WPCs that can be used in infrastructure applications. What constitutes a structural WPC is a subject of debate, but in many instances the objective of research is to increase the mechanical properties of the composite, including stiffness or modulus of elasticity, reducing creep and brittleness. In this presentation, we will discuss research progress in the creation of structural WPCs including: manufacture of structural WPC components, synthetic fiber reinforced hybrid WPCs, cross-linked WPCs, the use of engineering plastics to manufacture WPCs and the creation of structural WPC foams. Demonstration applications of structural WPCs will also be shown and discussed.

**Key words:** wood plastic composites, mechanical properties, structural, reinforced

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## INTRODUCTION

### Traditional Structural Wood Products

For structural applications, wood-based materials should be evaluated according to sorting criteria that are generally guided by stress-grading methods and the philosophy of how properties for engineering designs are derived. For example, lumber in the United States is graded by the derived properties and then used in one of two design formats: (a) the load and resistance factor design (LRFD), which is based on a reference strength at the lower 5th percentile 5-min stress (AF&PA [current edition]), or (b) the allowable stress design (ASD), which is based on a design stress at the lower 5th percentile 10-year stress (Kretschmann 2005). The design of standards is to be associated with basic design properties such as flexural modulus, stress in tension, compression, shear, and extreme fiber stress in flexural mode.

Wood products for structural applications include glue laminated timber (glulam), parallel strand lumber (PSL), laminated strand lumber (LSL), wood I-joists, laminated veneer lumber (LVL), and engineered wood trusses. These wood products have been designed using engineering principles to sustain various external and internal stresses of tensile, compressive, shear or flexural modes. The engineering design of wood products overcomes the heterogeneity of solid wood, which arises from the existence of knots or grain variation in the anatomical structure and defects arising from processing, such as splits, cracks, or warp. Even if the heterogeneity of wood products is addressed for improved properties, other drawbacks can exist: photo-degradation and photo-oxidative degradation, biological decomposition, and thermal degradation. Composites have been suggested as a substitute for wood products but can not replace wood because of the comparative low cost of wood products. Since wood plastic composites (WPCs) were introduced in the 1980's, they have been evaluated for structural applications because WPCs have many benefits for exterior applications because of their superiority to solid wood products in exterior durability.

### Wood Plastic Composites

Since the first WPC products were introduced in the 1980's, the market size has increased up to $1,565 million within 3 decades. That increase represents the potential of WPCs as a construction material. The initial market breakthrough for WPCs began in the US in the decking and railing market in the middle of the past decade. These WPC home construction products were attractive to

consumers because of their low maintenance even though WPC prices were higher than the alternative competitor – pressure treated lumber. In terms of market share, the rate of WPC increase, compared to other deck board products, rose from 2% in 1997 to 8% in 2000, and exceeded over 20% in 2005 (Smith 2002 and Morton 2005). In 2006, the total market size of WPCs in North America reached $1,425 million, which mainly included decking/railing, window, transportation, and other markets (Yangling 2007). The array of WPC products has continuously expanded to roofing, molding or trim, doors, fencing, and landscaping materials. More recently over the past several years due to the global recession, the WPC market has remained relatively stagnant.

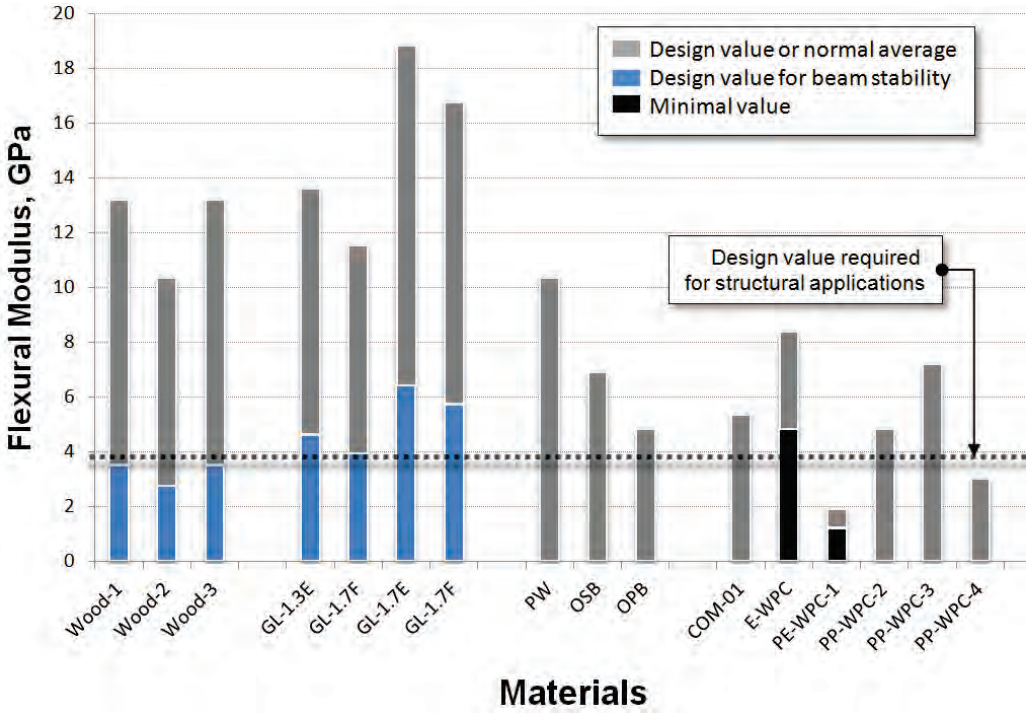
In Europe, indoor applications including relatively inexpensive furniture moldings and trim products have been developed for consumers attracted to the flexibility and the variety of shapes and configurations possible with WPCs. The total market size of WPCs in Europe in 2005 was estimated to be $100 million, which is estimated to increase up to $380 million by 2010 (Green 2003 and Nash 2005). Even though the decking market in Europe is relatively small, the annual growth rate (AGR) has ranged around 12 to 14% during the five years prior to the global recession. In 2007, it was estimated that the growth rate would be over 10% for the next 5 years (Eder 2007). The high growth rate of decking indicates potential for an expanded market for WPCs which had a market share in Europe of only 6.1% in 2007.

In Asia, the major WPC markets have been in Japan, South Korea, and China since the 1990's. The Japanese WPC market which began in the 1990's increased to $300 million by 2005 (Green 2003). Today, about 30 manufacturers produce WPCs for various applications from garden furniture, small garden structures, and balcony floors to indoor floors and outdoor decks. The Korean market which began in 2006 is increasing rapidly since the supply of tropical woods is not stable and customers' concern for the environment is growing. China's WPC industry is making strides, growing 15 to 30% per year and, by some estimates in 2007, Chinese production soon could overtake European production. It was estimated by the Chinese WPC Council that the Chinese WPC market ranged from 75,000 to 150,000 metric tons (Toloken 2007). An early WPC product in China was pallets ,which now comprises 70% of the total WPC market (Song, 2005). It is expected that the WPC market in China will sharply increase because of environmental issues, dramatic increases in the construction materials market, and the decreasing availability of natural resources in China.

It should be noted that the major WPC quality desired by Asian customers is not durability of WPCs but the wood-like appearance even if it contains almost 50% synthetic petroleum polymers. So, the manufacturers of WPCs in Japan and South Korea have focused on the surface treatment combinations of embossing and mechanical processing for producing a realistic wood appearance. WPC products are expanding in market size and dispersion as new applications of WPCs are being developed and adopted according to local market situations and local customers' cultural backgrounds.

Mechanical Properties for Structural Applications

Structural wood products have been categorized for their uses according to stress grades that can be used for engineering design. One example is the American Softwood Lumber Standard PS 20 published by the U.S. Department of Commerce. The standard designates reference design values for timbers categorized by product type: sawn lumber, non-North American sawn lumber, structural glued laminated timber, and applications: decking or structures. The reference design values are compared to other wood composites in Figure 1, showing the differences in mechanical properties. It should, however, be noted that the flexural modulus of elasticity or stiffness is not the only mechanical property value to be considered in designing structures. The flexural modulus of elasticity comparison simply shows significant gaps in the properties, which should be reduced by novel processing methods and formulation in wood plastic composites.




- Wood-1: Alaska Cedar / Wood-2: Aspen / Wood-3: Douglas Fir-South (AF&PA 2005)
- GL: Glued laminated timber / 1.3 or 1.7: Stress grade / E: edgewise / F: flat-wise (AF&PA 2005)
- PW: Plywood / OSB: Oriented Strand Board / OPB: Particleboard (Falk, etc. 1999)
- COM-01: Polyester thermosetting composite with hemp fiber (15% vol.) (Dhakal, etc. 2006)
- E-WPC: Engineering wood plastic composite made of SMA, developed by Univ. of Maine (Han, 2009)
- PE-WPC-1: PE-based wood plastic composite, a commercial decking board by Trex, Inc
- PP-WPC-2: PP-based wood plastic composite, a commercial decking board by Correct Deck, Inc.
- PP-WPC-3: PP-based wood plastic composite, a commercial decking board by Timbertech, Inc.
- PP-WPC-4: PP-based wood plastic composite, a pilot product of sheet pile by UMaine (Han 2009)

Figure 1. Comparison of flexural modulus of various wooden materials for structural applications

## MANUFACTURE OF STRUCTURAL WPC COMPONENTS

Z-Section Sheet Pile

A seawall, also known as a bulkhead or retaining wall, is a structure built to reduce the effects of strong waves and to defend costal land from erosion. Traditionally, seawalls are made of steel, timber or concrete construction. Composite materials, however, have been recently introduced for their ease of installation/maintenance in dry processing, low cost, and environmentally-friendly materials. A WPC seawall system has been developed and patented for its unique hollow structure that can give greater stiffness and stability under various external stresses (Figure 2). The moment of inertia, one of the most important properties for structural applications, of the novel WPC system shows up to 22,900 $cm^4$ which is higher than 19,900 $cm^4$ of a commercial polyvinyl chloride system or 16,200 $cm^4$ of a steel system categorized for light duty applications. The mean flexural stiffness *EI* of the WPC seawall is 8.07 X 104 kip-in2/ft (Alvarez-Valencia 2009), where it can be categorized between very light duty and light duty defined by the US Army Corps of Engineers (Dutta and Vaidya 2003).

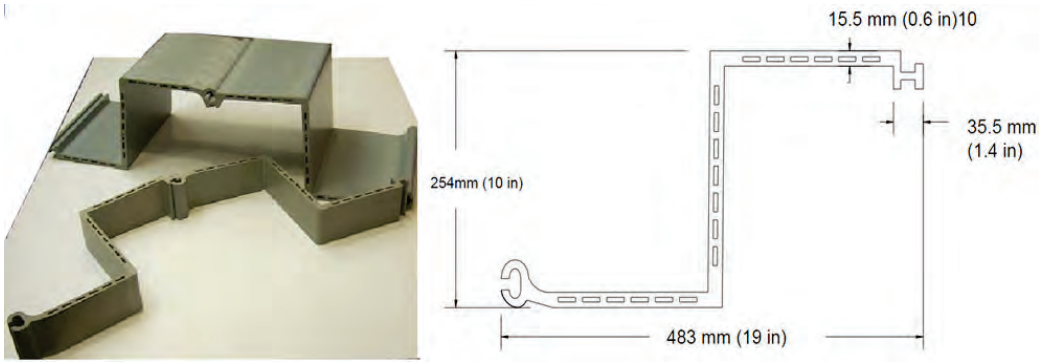



Figure 2. WPC sheet pile system for seawall applications

WPC Glulam and Box Beam

It is a reasonable approach for the production of structural members from WPCs to laminate WPC decking boards with customized adhesives to design larger dimensioned products since the dimensional limits on the extrusion process should be considered. The AEWC Advanced Structures and Composites Center, University of Maine, Orono, Maine, USA has produced

glu-laminated WPCs and a box beam for structural applications (Figures 3 and 7). The flexural moduli were 3.0 GPa and 12.6 GPa for the box beam and glued laminated WPC, respectively. For successful lamination, surface treatments were required to improve the inert and non-polar interfaces between polyolefin matrices. Several treatments were studied and it was found that corona treatment, using an oxidation mechanism created by cold-air plasma was superior to other treatment methods (Oporto 2009). The shear strength was significantly increased after the surface treatment (Figure 4).

Figure 3. WPC box beam and glued laminated WPC for structural applications

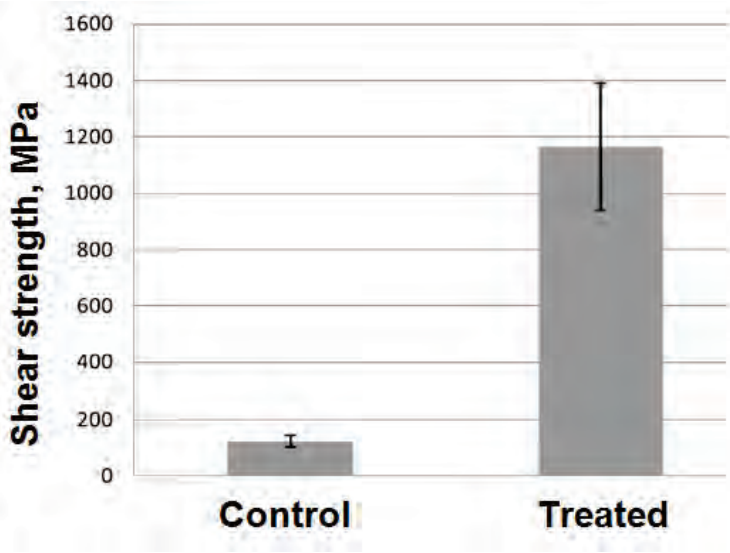



Figure 4. Shear strength of surface treated WPC reinforced with continuous glass fibers (The treatment was cold plasma with air)

Synthetic Fiber Reinforced Hybrid WPCs

Using an extrusion process for composites limits the applications since the dimensions of the extrudate, especially width, can be limited for sheet or panel products. In the T-shape extrusion die for sheets or panels, it's difficult for polymer melts with comparatively high viscosities to evenly flow through all the wide channels during the extrusion process. In some cases, multiple extruders are required to produce wide panel products. A slow output rate of panel products is another negative consideration in extrusion. The University of Maine has developed a prototype of panel products made of WPC using a double belt press processing that can reinforce WPC panels with an addition of reinforcing layers, such as fiberglass embedded polypropylene sheets in a sandwich formation. The width of panels was about 1.3 m which was the maximum of the pilot-machine system, which can be scaled-up to larger sizes (Figure 5). The mechanical properties of the reinforced WPC panels are listed in Table 1, which shows promising potential of the WPC products for structural applications.

Table 1. Mechanical properties of WPC panels developed by the University of Maine

| *Properties* | | *WPC panel* | *Reinforced WPC panel** |
|---|---|---|---|
| *Flexural* | Modulus, GPa | 2.33 | 8.10 |
| | Strength, MPa | 40.07 | 169.78 |
| *Tensile* | Modulus, GPa | 3.52 | 5.56 |
| | Strength, MPa | 20.31 | 77.42 |
| *CTE** in machine direction* | | $4.13 \times 10^{-7}$ | $3.30 \times 10^{-7}$ |

* WPC panel reinforced with two outer layers

** Coefficient of thermal expansion

Figure 5. WPC panel products developed by the University of Maine

Cross-Linked WPCs

To increase the stiffness of WPC-based polyolefin polymers, a cross-linking process has been examined using silane cross-linking. The silane cross-linked high density polyethylene wood composites were stored at high humidity and high temperature to increase the degree of cross-linking (Bengtsson 2006). The toughness was significantly increased but the stiffness did not change. In another study of cross-linked WPCs, a silane compound was used as a coupling agent to improve the interfacial properties between wood fillers and HDPE and another silane compound was applied as the cross-linking agent of the polymer matrix (Han 2007). The combined silane compounds did not have any incompatibility issues since they are similar chemical structures. It was found that both mechanical properties of stiffness and strength were significantly improved. Wood flour acts as a solid structure networked with the cross-linked polymer matrix. Mechanical stresses can be internally transferred into the wood particle, a relatively stiff component of the composite, from the cross-linked polymer matrix. It is believed that a loading of wood filler treated with a coupling agent could interact with the polymer matrix in the cross-linking mechanism, resulting in an enhancement of the close contact and physical linkages between two different materials. The flexural modulus of cross-linked

HDPE wood composite was around 470,000 psi which is two times higher than those of HDPE WPC's in the current market (Han, 2009).

WPCs from Engineering Plastics

To upgrade the stiffness of WPCs, the selection of the polymer matrix is one of the major concerns. Polyethylene terephthalate (PET), polyamide (PA, nylon), and acrylonitrile butadiene styrene (ABS) are typical engineering plastics with superior mechanical and thermal properties. The melting or plasticizing temperatures, however, range from 230°C to 270°C which is enough to cause serious thermal degradation of the wood. Several strategies have been used to overcome this thermal degradation. Two extruders were combined to minimize the retention time for wood exposure to high processing temperatures. One extruder feeds melted polymer into a twin screw extruder designed for efficient and rapid mixing to compound the polymer melt and cold wood flour. The retention time of wood to be exposed to very hot polymer melt was controlled at less than 4 minutes residence time. In this process, the severe thermal degradation could be avoided and nylon-wood composites could be produced. Another method of using engineering plastics in WPCs is viscosity modification of the pure engineering plastics. Several viscosity modifiers, which have low viscosity or special functional groups, were tested to examine the effect of decreased viscosity. Moreover, various polymer blends were tested as well to observe the changes in rheological properties. This study is now in progress and the results will be published in the near future.

Creation of Structural WPC Foams

Foaming WPCs can be achieved by using physical or chemical blowing agents that create cavities inside the polymer matrix. Unlike the general foaming process in unfilled thermoplastics, WPCs are typically highly-filled thermoplastic composites, placing restrictions on foaming properties since wood fillers can negatively impact the foaming mechanism. Considerations and cautions concerning this issue have been well addressed, where appropriate amounts of blowing agent, minimization of gas diffusion to atmosphere, suppression of cell coalescence and cell collapse are controlled (Park 2004). High filler content causes foaming instability since the cells created exist in an open system, resulting in cell coalescence and collapse. Moreover, the cell sizes are various because of the variety of particle sizes. High filler content can lead to cell coalescence in the worst case and relatively weaker strength in several mechanical properties. Even though it is well known that there is a decrease in strength for foamed plastics, the strength decrease in WPCs is greater than with

other thermoplastics. Researchers have focused on development of physical blowing agents using a phase of super critical fluids that can be dissolved into polymer melts under high temperature and pressure (Rizvi 2003 and Matuana 1995). The solubility of physical blowing agents helps distribute the cells evenly and limits the cell size so that significant mechanical deterioration can be avoided.

Foamed styrene-wood plastic composites (FSWPC) have been produced at the AEWC Advanced Structures and Composites Center using reactive extrusion (Han 2008), which is shown in Figure 6. The blowing agents are created by the chemical reactions during the extrusion process and efficiently dissolved into the polymer melt where the dissolution occurs in the mixing zone of the barrel next to the venting zone so that there is a minimum loss of blowing agents through venting. The blowing agent exists in the form of super critical fluid (SCF) under high pressure and high temperature, which enables foaming cells locally initiated and grown into certain size levels. For SCF creation and maintenance, the extrusion system should be developed for appropriate pressure levels with a foaming die. According to a pilot-scale study, the FSWPC shows excellent mechanical properties and low specific gravity (Figure 7). If it is converted to relative modulus that is derived from the value of modulus divided by the sample's specific gravity, the stiffness of FSWPC can be comparative to a minimum design value of general structural timbers (about 6.7 GPa or $9.6X10^5$ psi).

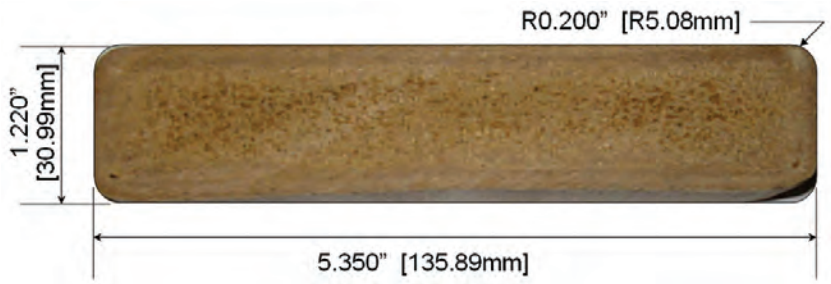



Figure 6. The product dimensions of foamed styrene-wood composites developed by the University of Maine AEWC Center

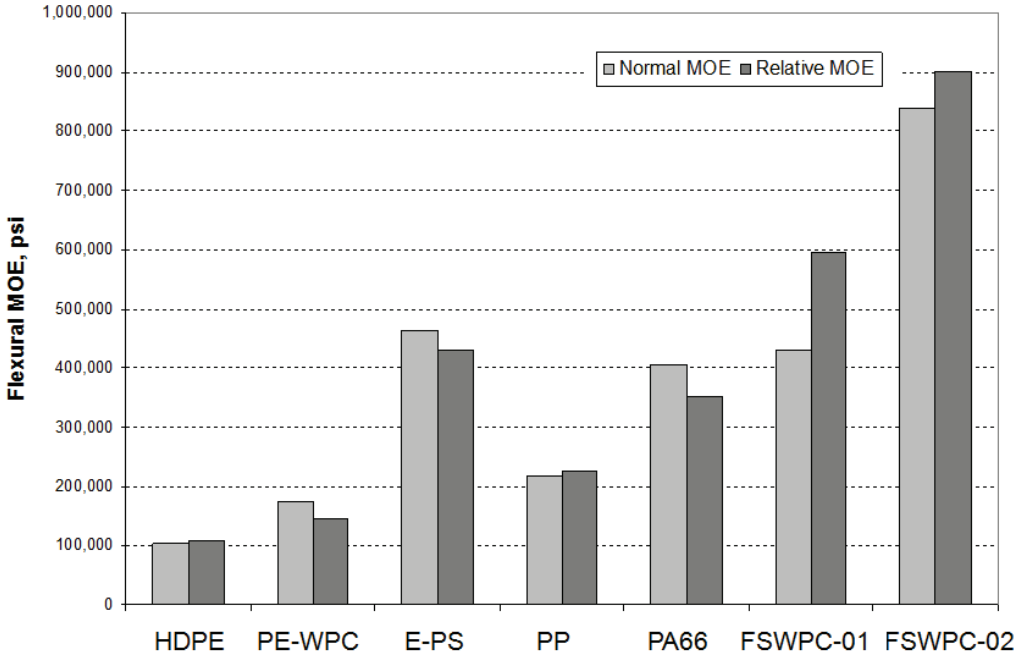



Figure 7. Flexural modulus of foamed styrene-WPC compared to other polymers.
HDPE: high density polyethylene
PE-WPC: polyethylene-based wood plastic composites
E-PS: engineering polystyrene
PP: polypropylene
PA66: polyamide 66
FSWPC-01: foamed styrene-WPC with the specific gravity of 0.8
FSWPC-02: foamed styrene-WPC with the specific gravity of 1.0

## Demonstration Projects

As new WPC technologies are developed by academic, government and industrial laboratories, it is important to showcase these new products to the public in attractive and useful applications. Washington State University has demonstrated some of the WPC technologies developed for the Office of Naval Research at several naval facilities across the U.S. The University of Maine has demonstrated slip resistant decking developed for the US Coast Guard in facilities in New Haven, CT and Owls Head, ME (Figure 8). A WPC and hybrid composite demonstration pier was built for the U.S. Coast Guard in Jonesport, ME. The demonstration pier featured WPC-FRP hybrid laminated and box beams, WPC railings and decking, conventional wood glulam beams,

and FRP glass reinforced concrete composite pilings. These demonstration projects are important steps toward diffusing novel WPC technologies into the commercial marketplace.

Figure 8. WPC hybrid composites demonstrated by the U.S. Coast Guard in Jonesport, Maine, USA

## CONCLUSIONS

The manufacture of structural wood plastic composites is possible using a variety of manufacturing options. Material-level formulation opportunities exist through a variety of means including: thermoplastic matrix cross-linking to increase WPC stiffness properties, reaction extrusion to create novel foamed WPCs, and WPC formulations based on engineering thermoplastic matrices. Adhesive bonding can be used to create larger WPC sections as well as bonding synthetic fiber composites to the WPCs to enhance strength and stiffness properties. Extrusion of structural shapes such as a hollow z-section sheet piling offers opportunities for novel structural WPC products. Demonstration projects utilizing structural WPC materials are important for creating excitement among

potential commercial producers and applicators of such technologies in the marketplace.

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# HEAT TREATMENTS OF WOOD TO IMPROVE DECAY RESISTANCE

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## ABSTRACT

Heating wood to improve performance dates back many thousands of years. This method results in increased decay resistance and improved dimensional stability to different degrees depending on the process used. Reductions in hygroscopicity, increased dimensional stability and decay resistance of heat treated wood depend on decomposition of a large portion of the hemicelluloses in the wood cell wall. In theory, these hemicelluloses are converted to small organic molecules, water and volatile furan-type intermediates. There is a strong connection between reducing the wood moisture content and decay resistance. As dimensional stability increases and hygroscopicity decreases, resistance to decay increases. A reduction in swelling over 40% results in no weight loss in a brown-rot decay test. However, strength properties are reduced in heat treated wood as a result of the degradation of the cell wall matrix due to the degradation of the hemicellulose polymer.
*Keywords:* heat treated wood, brown-rot fungus, equilibrium moisture content, weight loss, strength loss.

## INTRODUCDTION

With an increased awareness of the fragility of our environment and the need for durability in wood products, new technologies have been developed to increase the service life of wood materials without the use of toxic chemicals. Issues of sustainability, carbon sequestration and performance converge in this search for environmentally friendly methods of wood preservation.

Heat treatments of wood has been studied for many years and are now commercial (Rowell 2005). This method results in increased decay resistance and improved dimensional stability to different degrees depending on the process used. Strength properties of the wood is also affected.

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# PROCESSES

Heating wood to improve performance dates back many thousands of years (Stamm 1964). The Kalvträsk wooden ski was bent using heat by the Saami and used in northern Sweden over 5200 years ago (Åström 1993, Insulander 1999). From hieroglyphic pictures of furniture in Egypt between 2500 and 3000 BC, there are chairs made using heat bent wood members (Rivers and Umney 2005). The Egyptians also bent wood for bows using hot water around 1900 BC as shown on tomb paintings (Ostergard 1987). In the 11th century, the Viking shipbuilders also bent wood using heat for parts of the ship (Olsen and Crumlin-Pedersen 1967).

In the Norwegian stave churches, large beams were bent using heat and joined (Bugge 1953, Holan 1990). Finally, the wooden cask makers knew how to heat-bend wood 2000 years ago (Twede 2005). A picture of a wooden cask is shown on the wall of a 2690 BC Egyptian tomb (Kirby 1971). Wooden casks were also made by the Romans to store wine (Twede 2005).

In the early part of the 20th century it was found that drying wood at high temperature increased dimensional stability and a reduction in hygroscopicity (Tiemann 1915, Stamm and Hansen 1937). Later, it was found that heating wood in molten metal at temperatures between 140 and 320 °C reduced swelling in Sitka spruce by 60% and also increased resistance to microbiological attack (Stamm *et al.* 1946). They also found that the increase in stability and durability also increases brittleness and loss in some strength properties including impact toughness, modulus of rupture and work to failure. The treatments usually cause a darkening of the wood and the wood has a tendency to crack and split.

Burmester studied the effect of temperature, pressure and moisture on wood properties (1973). He found that the optimum conditions for pine were 160 °C, 20-30% moisture and 0.7 MPa pressure. He reported high dimensional stability and resistance to brown-rot fungi attack and minimal loss of strength. He named his process as FWD (Feuchte-Wärme-Druck).

More recently, Norimoto *et al.* (1993) and Ito *et al.* (1998) heated wet wood to improve dimensional stability. Inoue *et al.* (1993) heated wet wood to fix compression set in wood.

Several names have been given to the various heat treated products and treatments for wood. Including Staypak and Stabwood in the United States (using dry wood); Lignostone and Lignofol from Germany (using dry wood),

Jicwood and Jablo from the UK, Thermowood in Finland (using water vapour), Plato in The Netherlands (using water), Perdure from Canada (using steam), Oil Heat Treated (OHT) from Germany (using oil) and New Option Wood/Retification in France (using nitrogen) (Hill 2006).

## CHEMISTRY

There are a variety of thermal modification processes that have been developed. The results of the process depend on several variables including time and temperature, treatment atmosphere, wood species, moisture content, wood dimensions and the use of a catalyst (Stamm 1956, Millett and Gerhards 1972). Temperature and time of treatment are the most critical elements and treatments done in air result in oxidation reactions not leading to the desired properties of the treated wood. Wood degrades faster when heated in either steam or water as compared to dry conditions (MacLean 1951, 1953, Millett and Gerhards 1972, Hillis 1975). Stamm (1956) showed that wood heated in the presence of oxygen degraded more rapidly that wood heated in an oxygen-free atmosphere. As the treatment time increases, embrittlement of the wood increases (Yao and Taylor 1979, Edlund 2004). Generally, weight loss occurs to a higher extent in hardwoods as compared to softwoods which may be due to the higher content of acetyl groups in hardwoods releasing more acetic acid during heat treatment contributing to the acid hydrolysis (MacLean 1951, 1953, Millett and Gerhards 1972, Hillis 1975).

As the wood is heated, the first weight loss is due to the loss of water, followed by a variety of chemistries that produce degradation products and volatile gasses (Shafizadeh and Chin 1977). As the temperature increases, wood cell wall polymers start to degrade. Pyrolysis of the hemicelluloses takes place about 270°C followed closely by cellulose. Lignin is much more stable to high temperature (Stamm 1956). In the early stages of degradation, 83% of the weight loss is water (Mitchell *et al.* 1953). The hemicellulose polymers are the first to degrade followed by cellulose resulting in the formation of furans such as furfural and hydoxymethyl furfural (Figure 1). The hemicelluloses and cellulose are also degraded to internal ethers and other rearrangement products. The optimum amount of water that can be lost is three molecules of water from two anhydroglucose units or 16.7 percent of the carbohydrate polymers or 12 percent of the wood (Stamm and Baechler 1960).

Table 1 shows the weight loss resulting from heating wood at different temperatures in the presence of moisture. As the temperature increases, so does the weight loss.

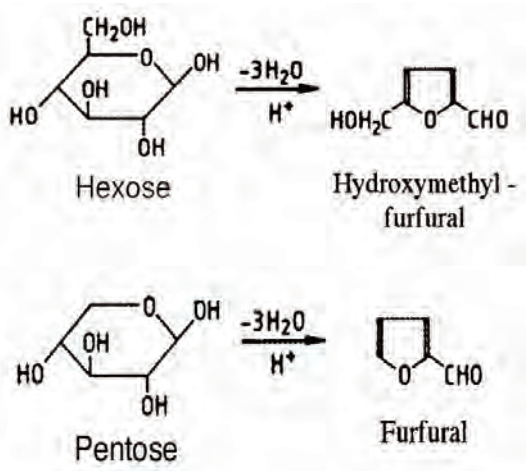


***Figure 1: Formation of hydroxymethyl furfural from hexoses and furfural from pentoses as a result of heat treatments of wood.***

***Table 1: Weight loss due to heating wood ****

| Heating Temperature (°C) | Time (hrs) | Weight Loss (%) |
|---|---|---|
| 120 | 2 | 2-3 |
| 120 | 10 | 5 |
| 180 | 10 | 10-12 |
| 190 | 2 | 4-7 |
| 190 | 12 | 5-10 |
| 200 | 10 | 10-17 |
| 220 | 1 | 6-7 |
| 235 | 4 | 25 |
| 240 | 0.5 | 7 |

** Data taken from several sources*

Table 2 shows the sugar analysis before and after treating aspen with high pressure steam (220°C) for 8 minutes. The data shows that in the very early stages of weight loss, the hemicellulose polymers are breaking down and cellulose remains unchanged. Over half of the arabinan and rhamnans are lost during this initial heating.

***Table 2: Sugar analysis of aspen before and after heating at 220 °C for 8 minutes.***

| Wt Loss % | Total Carbohydrate % | Arabian % | Galactan % | Rhamnan % | Glucan % | Xylan % | Mannan % |
|---|---|---|---|---|---|---|---|
| 0 | 61.8 | 0.56 | 0.68 | 0.30 | 42.4 | 16.3 | 1.6 |
| 2.2 | 59.2 | 0.20 | 0.58 | 0.14 | 42.2 | 14.6 | 1.5 |

## MOISTURE AND DIMENSIONAL STABILITY

Because of the loss of hygroscopic hemicellulose polymers during heat treatment, the equilibrium moisture content (EMC) is reduced. Dimensional stability of heat treated wood was first thought to be due to a cross-linking of cellulose chains (Stamm and Hansen 1937). The furan intermediates that form (Figure 1) from the decomposition of the hemicelluloses have poor hygroscopicity and have little effect on the EMC.

***Table 3: Reduction in EMC as a result of heating wood.***

| Wood species | Conditions | Reduction in EMC (%) | Reference |
|---|---|---|---|
| *Pinus pinaster* | 190 °C<br>8-24 hrs | 50 | Esteves *et al.* 2006 |
| *Pinus sylvestris* | 220 °C<br>1-3 hrs | 50 | Thermowood handbook 2003 |
| *Eucalyptus globulus* | 190 °C<br>2-24 hrs | 50 | Esteves *et al.* 2006 |
| *Pinus sylvestris* | Plato process | 50-60 | Tjeerdsma 2006 |

Table 3 shows a summary of recent results on EMC resulting from heat treatments from various authors. In most cases, a 50% reduction in EMC is observed. In most examples given, the process was done in a vapor atmosphere between 190 and 220°C with a relative humidity of 35 to 65%.

Table 4 shows the reduction in swelling of wood that has been heat treated.

***Table 4: Dimensional stability of various woods as a result of heat treatment.***

| Wood species | Conditions | ASE (%) | Reference |
|---|---|---|---|
| *Pinus pinaster* | 170 °C WL[1] 2% | 50 | Esteves *et al.* 2006 |
| *Eucalyptus globulus* | 190 °C WL 2% | 77 | Esteves *et al.* 2006 |
| *Eucalyptus globulus* | 200 °C WL 10% | 60 | Esteves *et al.* 2006 |
| *Pinus sylvestris* | 220 °C | 40 | Rapp and Sailer 2001 |

[1]*WL = Weight loss, ASE = antishrink efficiency*

# DECAY RESISTANCE

As dimensional stability increases and hygroscopicity decreases in heat treated wood, resistance to decay also increases (Stamm *et al.* 1946, Stamm and Bacchler 1960, Hillis 1984). Table 5 shows the data of Stamm *et al.* 1946). A reduction in swelling over 40% results in no weight loss in the decay test. Similar results were obtained when the test fungus was *Lenzites trabea* 517 (Stamm and Bacchler 1960).

***Table 5: Relationship between reduced swelling and decay resistance of white pine using* Trametes serialis *fungus. (Stamm et al. 1946)***

| Reduction in swelling (%) | Weight loss due to decay (%) |
|---|---|
| 30-33 | 12 |
| 33-38 | 4.5 |
| 40 or more | 0 |

Table 6 shows fungal resistance of two types of heat treated wood (Rapp and Sailer 2001). Pine (*Pinus sylvestris*) and spruce (*Picea abies*) were heated in oil or air at three different temperatures and the treated blocks were tested for decay for 19 weeks in the EN 113 (1996) decay test using *Coniophora puteana* fungus. The data shows that heating in oil is more effective in reducing attack by fungi than heating in air. This may be due to the presence of the oil in the samples.

***Table6: Fungal resistance of pine and spruce heated in oil or ai*r.***

| | Oil Heated | | Air Heated | |
|---|---|---|---|---|
| | **Pine** | **Spruce** | **Pine** | **Spruce** |
| **Temperature (°C)** | **Wt loss (%)** | **Wt loss (%)** | **Wt loss (%)** | **Wt loss (%)** |
| Control | 40 | 48 | | |
| 180 | 13 | 15 | 25.0 | 31.2 |
| 200 | 1.9 | 13.1 | 15.8 | 26.7 |
| 220 | 2.0 | 0.0 | 11.0 | 5.5 |

**Data taken from several sources*

Welzbacher and Rapp compared different types of industrially heat treated products using several different fungi in laboratory tests and in different field and compost conditions. Table 7 shows the weight loss during an EN 113 test using three different fungi. The heat treatment in oil was the most effective but it is not known the effect of the oil in the decay test (Welzbacher and Rapp 2007).

***Table 7: Weight loss (%) of different woods and different heat-treating processes[1] due to attack by* Poria placenta, Coriolus versicolor *and* Coniophora puteana.**

| **Material** | ***P. placenta*** | ***C. versicolor*** | ***C. puteana*** |
|---|---|---|---|
| Pine (control) | 31.0 | 5.1 | 47.5 |
| Douglas fir (control) | 14.0 | 2.6 | 27.4 |
| Oak (ontrol) | 0.8 | 14.3 | 3.9 |
| Plato (Heat Treated) | 10.0 | 6.8 | 3.7 |
| Premium (Heat Treated) | 16.0 | 9.0 | 1.9 |
| NOW (Heat Treated) | 13.3 | 7.8 | 12.2 |
| OHT (Heat Treated) | 7.4 | 5.6 | 3.4 |

[1] *Plato = Heat treated (The Netherlands), Premium = Heat treated (Finland), NOW = New Option Wood, OHT = Oil-heated wood.*

Resistance to decay in heat-treated wood is probably due to the loss of hemicellulose polymers in the cell wall and the reduction in cell wall moisture content as a result (Ibach and Rowell 2000). As was shown

earlier, the most weight loss in the heating process, the more durable the heat-treated wood.

## STRENGTH

Stamm *et al.* (1946) were the first to report a lost of mechanical properties as a result of heat treatments of wood. They heated wood at 320°C for one minute or 150°C for a week and found a 17 percent reduction in modulus of rupture (MOR) when heated in molten metal and 50 percent when heated in air. Under the same conditions, there was less loss in modulus of elasticity (MOE).

Mitchell (1988) found that losses in strength properties were much less when wood was heated dry as opposed to wet, with a greater loss in MOR than in MOE. Rusche (1973) found that strength losses were related to rate and extent of mass loss when heating beech and pine in the presence and absence of air at temperatures ranging from 100 to 200°C. Losses in maximum strength and work to maximum load were greater for compression than for tension loads. Loss in MOE was only significant when the mass loss was greater than 8 to 10% and was the same for both species.

Rapp and Sailer (2001) heated pine and spruce at 180 to 220°C for various times in air and in oil and determined MOR and MOE in a three point bending test. The highest MOE was 11,000 $N/mm^2$ in oil heating and little loss in MOE in both air and oil heating. MOR, however, decreased 30% in oil heating and impact bending strength decreased and the wood became brittle. Oil-heated wood lost about 50% and air-heating lost over 70% of the impact strength compared to controls.

Table 8 gives a summary of other data on strength changes in heat-treated wood. In all cases, there was only a small decrease in MOE but major changes in MOR depending on temperature, time and atmosphere.

***Table 8: Change in MOR as a result of heat treatment of various woods.***

| Species | Treatment | MOR (%) | Reference |
|---|---|---|---|
| *Betula pendula* | Vapor, 200°C | -43 | Johansson and Moren 2005 |
| *Beech* | Vapor 200°C | -50 | Yidiz *et al.* 2006 |
| *Pinus sylvestris* | OHT 220°C | -30 | Rapp and Sailer 2001 |
| *Pinus pinaster* | $O_2$ 180-200°C | -6 - 25 | Esteves *et al.* 2006 |

## CONCLUSIONS

Heating wood under different conditions is a method to increase decay resistance. Reductions in hygroscopicity, increased dimensional stability and decay resistance depend on decomposition of a large portion of the hemicelluloses in the wood cell wall. Strength properties are reduced in heat treated wood as a result of the degradation of the cell wall matrix associated with the hemicellulose polymer degradation. The critical sugar in the hemicelluloses that may be the trigger for fungal attack is arabinose as it is the only sugar in a less stable five-member ring as compared to sugars in a stable six-membered ring.

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# NORWEGIAN FOREST PRODUCTS INDUSTRY – IMPACT ON CLIMATE AND VALUE ADDED

Flæte, P.O.[1]

## ABSTRACT

Forests play an important role as carbon sinks. Productive forest area covers 24% of the total land area in Norway and the forests have a growing stock of 784 million m³. Annual increment is approximately 25 million m³, and annual commercial roundwood removal is approximately 8 million m³. In 2005 the net sequestration was calculated at 28.6 million tonnes of $CO^2$, which would offset 50% of the total greenhouse gas (GHG) emissions in Norway that year.

The forest products industry can play a significant role in combating climate change by optimising the use of raw material, increasing efficiency, producing bioenergy, substitution of materials with high content of fossil raw materials or energy, and by expanding into bio-refinery products while developing the competitiveness of the sector. Utilising this potential necessitates that the entire forest based value chain has to be analysed. Products have to be assessed both on the basis of their GHG balance and value added to arrive at correct decisions for climate friendly and profitable utilisation of the wood resources.

This paper presents results from an ongoing research project analysing material flows, GHG-balance and value added in the Norwegian forest products industry. The paper reports value added, GHG emissions and emission intensities for the Norwegian forest products industry at macro level. The project is the first phase of a larger research program covering the entire Norwegian forest based value chains.

**Key words:** Greenhouse gas emissions, value added, emission intensity, life cycle assessment, forest products.

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# INTRODUCTION

Greenhouse gas (GHG) emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Carbon dioxide ($CO_2$) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. Global atmospheric concentrations of $CO_2$, methane ($CH_4$) and nitrous oxide ($N_2O$) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (IPCC 2007).

Forests play an important role as carbon sinks. In Norway productive forest area covers 24% of the total land area, and the forests have a growing stock of 765 million m³. Annual increment is approximately 25 million m³, and annual commercial roundwood removal is approximately 8 million m³ (SSB 2009). In 2008 the net sequestration was calculated at 28.6 million $CO_2$-equivalents, which would offset approximately 50 % of the total GHG emissions in Norway that year. The sequestration increased by about 153 per cent from 1990 to 2008.The average annual net sequestration from the Land-Use, Land-Use Change and Forestry (LULUCF) sector was about 19.9 million tonnes $CO_2$-equivalents for the period 1990-2008. The explanation for this growth is a continued increase in standing volume and gross increment in Norwegian forests, while the amount of $CO_2$ emissions due to harvesting and natural losses has been quite stable. The increase in living biomass is due to an active forest management policy, and to some extent to natural factors (Climate and Pollution Agency 2010).

The global forest products industry can play a significant role in combating climate change by optimizing the use of raw material, increasing efficiency, producing bio-energy, substitution of materials with high content of fossil raw materials or energy, and by expanding into bio-refinery products while developing the competitiveness of the sector (FAO 2006). Utilising this potential necessitates that products from the forest based value chain (forestry, wood working industry, pulp and paper industry) has to be analysed on the basis of their GHG balance and value added to arrive at correct decisions for climate friendly and profitable utilisation of the wood resources.

The objective of the work presented in this paper was to study value added, GHG emissions and emission intensities for the Norwegian forest products industry at macro level.

# MATERIAL AND METHODS

This report is based on data from Statistics Norway. Data are mainly collected from Statistics Norway´s main subjects: 01 Natural resources and the environment, 09 National accounts and external trade, and 10 Industrial activities (http://www.ssb.no/english/subjects/).

The results are grouped on forestry and logging, wood and wood products, and pulp, paper and paper products.

## Value added

Gross domestic product (GDP) is an indicator for total value added in a country, and also an expression for gross income generated from domestic production. GDP is measured in market prices, and is defined and compiled from three different main approaches: the production approach (I), the expenditure approach (II) and the income approach (III).

(I)
= Output (basic price) - Intermediate consumption (purchaser price) + Taxes on products - Subsidies on products
= Output (producer price) - Intermediate consumption (purchaser price) + Taxes on imports + VAT + Customs duties
= Total value added (basic price) + Taxes on products - Subsidies on products
= Total value added (producer price) + Taxes on imports + VAT + Customs duties

(II)
= Final consumption expenditure + Gross fixed capital formation + Changes in inventories + Exports - Imports
= Final uses - Imports
= Final domestic uses + Exports - Imports

(III)
= Compensation of employees + Operating surplus + Consumption of fixed capital + Taxes on production - Subsidies on production

Value added and gross income generated from domestic production in an industry or sector (or in total for all industries/sectors), is derived and defined as output less intermediate consumption. Value added is published in basic prices. Basic price is amount receivable by the producer from the purchaser for a unit of a good or service produced as output minus any tax payable to government, and plus any subsidy receivable from government, on that unit as a consequence of its production or sale.

## GHG emissions

Figures for GHG emissions are based on the Norwegian emission inventory. The Norwegian emission inventory is a joint undertaking between the Climate and Pollution Agency and Statistics Norway. Statistics Norway is responsible for the collection and development of activity data, and emission figures are derived from models operated by Statistics Norway. The Climate and Pollution Agency is responsible for the emission factors, for providing data from specific industries and sources and for considering the quality, and assuring necessary updating, of emissions models like e.g. the road traffic model and calculation of methane emissions from landfills. Emission data are used for a range of national applications and for international reporting. The Climate and Pollution Agency is responsible for the Norwegian reporting to United Nations Framework Convention on Climate Change (UNFCCC) and to United Nations Economic Commission for Europe (UNECE).

Greenhouse gas (GHG) emissions are measured in $CO_2$-equivalents. In the environmental accounts, the following GHG emission components are included:
Carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), PFCs (perfluorocarbons), HFCs (hydrofluorocarbons) and $SF_6$ (sulphur hexafluoride). The total emission of greenhouse gases is estimated by adding the emissions of all greenhouse gas components converted to $CO_2$ equivalents. The emission of greenhouse gases is weighted in relation to their heating potential with a global warming potential (GWP) value. The GWP value of a gas is defined as the accumulated influence on greenhouse effect from one tonne of emission of the gas compared to one tonne of emission of $CO_2$ over a given time period. The emission of greenhouse gases is weighted together to $CO_2$ equivalents by the GWP values. The GWP for the different gases used in the Norwegian emission model are: $CO_2 = 1$, $CH_4 = 21$, $N_2O = 310$, etc.

The Norwegian emission model uses approximately 130 industries (economic sectors).

## Emission intensity

Emissions per unit of GDP are often used as a sustainable development indicator.

In this paper emission intensities were calculated as the ratio of the GHG emissions from an economic activity over the value added created by that same

activity. To analyse the development over time value added was expressed in constant 2000 prices.

The unit used for the GHG emission intensity here is tonnes of GHG emissions per million NOK (in 2000 prices).

# RESULTS

In 2008 the turnover in the forest products industry (forestry, woodworking industry, pulp and paper industry) in Norway was 47.9 billion NOK (5.5 % of the total turnover in Norwegian industry).

4 100 persons were employed in forestry, 16 047 in the wood working industry, and 5 234 in the pulp and paper industry in 2008. In 1952 32 400 were employed in forestry, 31 700 in the wood working industry, and 21 500 in the pulp and paper industry

## Value added

Value added for the forest products industry increased from 2.718 billion NOK in 1970 to 17.695 billion NOK in 2007. Estimated value added (real value) for the Norwegian forest products industry for the years 1970-2007 is shown in Fig 1.

Although the value added has increased significantly, the forest products industry´s share of the Norwegian gross domestic product (GDP) has been reduced during this period (Fig 2.).

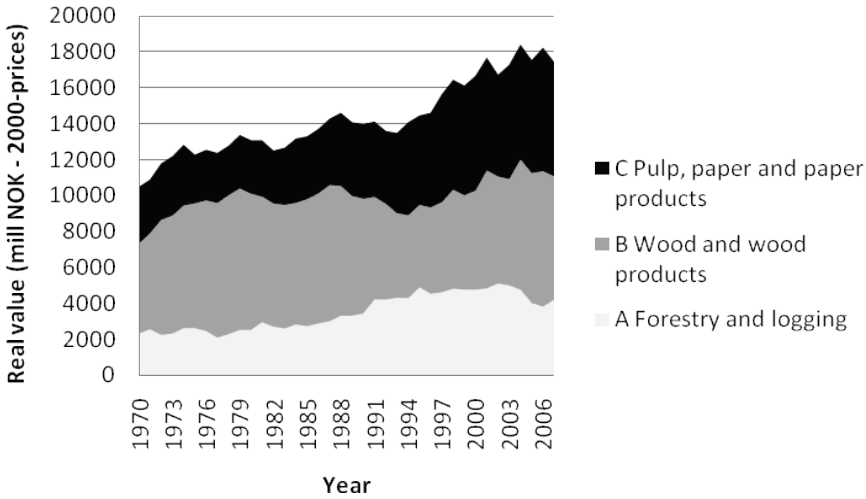


Fig. 1. Real value added (base year: 2000) in the Norwegian forest products industry (1970-2007).

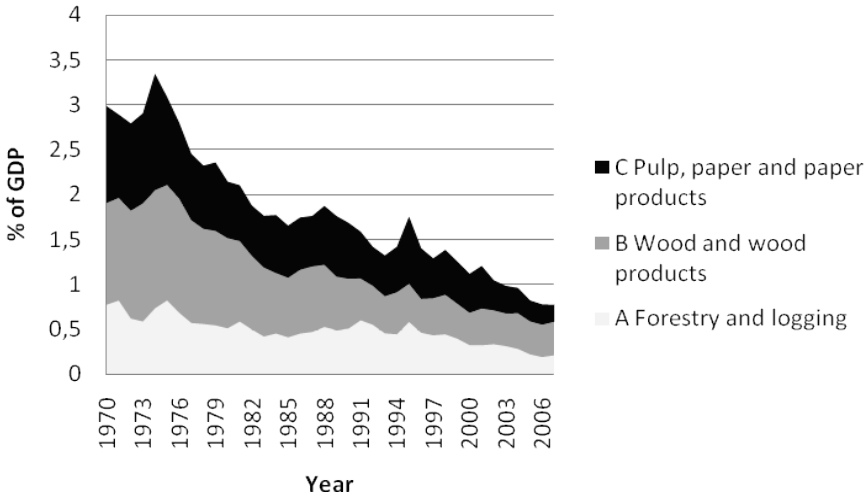


Fig. 2. Value added in the Norwegian forest products industry in percent of GDP (1970-2007).

## GHG emissions

The total GHG emissions for Norway except international air transport and ocean transport were 49,7 mill tonnes $CO_2$-equivalents in 1990 and 53,7 mill tonnes $CO_2$-equivalents in 2008. GHG emissions from the Norwegian forest

products industry for the years 1990-2008 are shown in Fig 3. Fig 4 shows the forest products industry´s share of the total Norwegian GHG emissions from 1990 to 2008.

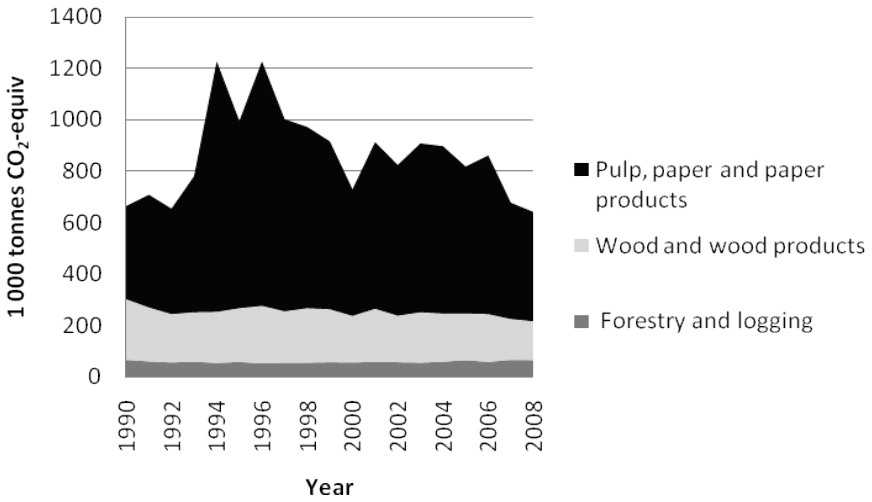


Fig 3. GHG emissions from the Norwegian forest products industry (1990-2008).

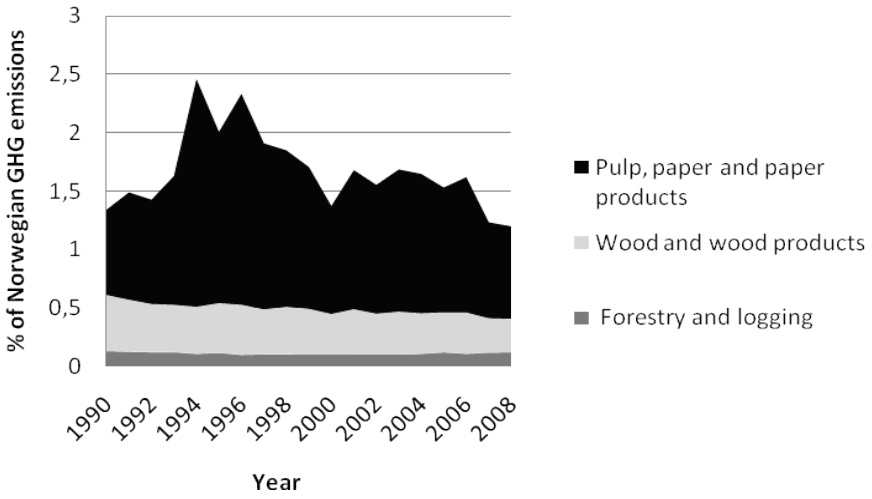


Fig 4. GHG emissions from the Norwegian forest products industry in percent of total Norwegian GHG emissions (1990-2008).

**Emission intensity**

Fig 5 shows GHG emission intensities for the Norwegian forest products industry for the years 1990-2008. Forestry had the lowest emission intensity and pulp and paper industry the largest. However, Fig 5 shows that the emission intensity in the pulp and paper industry has been considerably reduced in recent years.

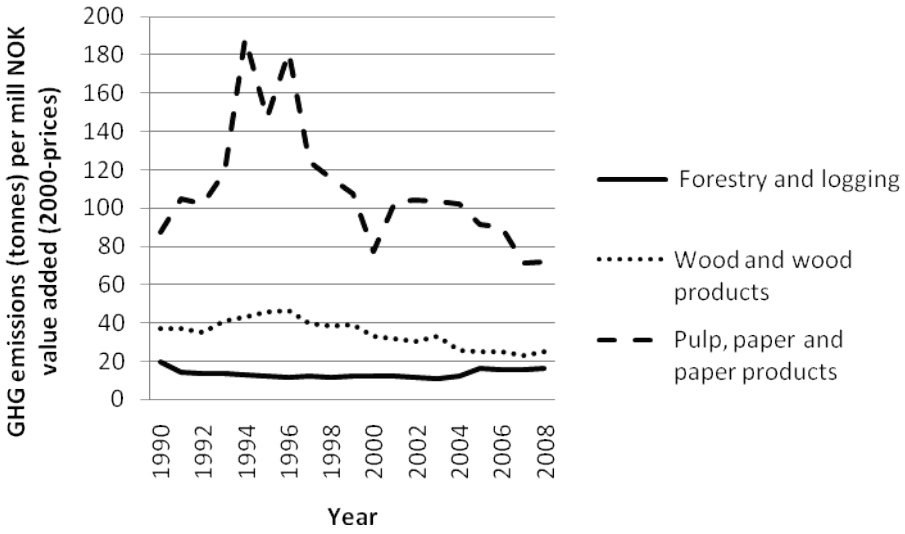


Fig. 5. Emission intensity in the Norwegian forest products industry calculated as tonnes $CO_2$-equivalents per mill NOK value added (1990-2008).

# DISCUSSION

The calculated GHG emissions are partly based on energy statistics and activity data, and on reported figures from single plants, implying that several sources of error can occur. However, the results show very clearly that GHG emission intensity in the Norwegian forest products industry has been significantly reduced during the last 10 years. Another important characteristic is that the largest reductions have been achieved in the pulp and paper industry.

Regarding the forest products industry´s impact on climate it should be emphasised that this paper only focus on GHG emissions from industry. To give a more complete picture the carbon stock change in forest biomass and

harvested wood products should be included, and the effect of using wood for energy and products instead of alternative products should be accounted. Combustion of fossil fuels is the main reason for the increased levels of $CO_2$ in the atmosphere and wood can substitute several energy and GHG intensive products. However, such an approach requires detailed and disaggregated studies to enable comparisons of different products. The top-down approach based on aggregated economic and environmental data lacks the level of details needed to distinguish the GHG balance and value added by specific processes within an industrial sector.

Life Cycle Assessment (LCA) is an objective method to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material uses and releases to the environment, and to evaluate and implement opportunities to influence environmental improvements. The method assesses the entire life cycle (cradle to grave) of the product, process or activities, encompassing extracting and processing material; manufacturing, transporting and distribution; use, reuse and maintenance; recycling and final disposal.

Life Cycle Inventories (LCI) is part of sustainable practices to aid choice of product, product improvements, and carbon sequestration policies. LCI data can be merged into scientific databases to enable a complete LCA of a system (product). LCI essentially measures all inputs and outputs for every stage through a cradle-to-grave assessment. LCA aggregates the data into key environmental risk indices like global warming potential. By comparing different products and manufacturing processes, LCA makes clear the trade-offs between one product and another. The 14000 series of the ISO Standards (ISO 2006) provides an internationally accepted framework for LCA.

Important issues, like system boundaries, definition of realistic life cycles, allocation of multiple inputs and outputs etc, have to be sorted out in the initial phase of the project.

In order to be able to calculate value added at product level, a more detailed method than used in traditional analyses on firm or sector level has to be adapted.

Sathre & Gustavsson (2009) developed a process-based methodology and performed bottom-up analysis based on the material and energy balances of specific industrial processes. By this approach it is possible to focus on the value added by particular industrial transformations, and to compare the value

added by individual processes. Moreover, using this approach one can analyse innovative industrial processes for which technological process data are available, but are not yet established on a commercial scale and thus lack market data needed for macroeconomic analysis.

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# LATVIA FOREST SECTOR FOR THE ACCUMULATED INFORMATION AND THE AVAILABLE DATA ASSESSMENT

Sigita Tunkele[1], Jānis Mārciņš[2]

## ABSTRACT

European forest industry contributes a complex value added chain, including forestry, processing sector of timber industry and further development sector of timber. Each sector is being collected, processed and stored the specific data, which is necessary to collect in the single data system for all forest industry. This data system would allow to understand and to analyze the economic contribution of each sector.

European Union (EU) member states is should seek to harmonize the forest industry data system, it is, to establish a single economic value of forests and consistently linked the forest balance with wooden land, timber, forestry economic activities in the cash flow accounts and wood supply / use in the natural and monetary values. In EU is the data system of forest industry, but each European country is necessary assess its suitability and to adapted to situation which is in the country.

Is necessary to introduce and develop harmonized the forest industry data system in Latvia then is necessary make the current situation evaluation, including a stored information analysis of forest industry, identify all institutions and organizations which deal with forest industry data collection, processing and analysis. Additional is necessary to analyze a regulatory environment which to assess this data suitability and compliance in the forest industry as well the key problems and failures.

**Key words**: data analysis, forest sector, Latvia

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# INTRODUCTION

According with European framework for integrated environmental and forest economic accounting for forests (abbreviation – IEEAF) – European Commission, Eurostat, European union member states should strive on harmonize forest resource accounting system, through a single forests economic value determination on the national account system. IEEAF objective is to consistently to link a forest balance with wooden land, wood resources, forestry economic activities of cash flow accounts and wood supply/use of economy the physical and monetary values in the framework (The European Framework…, 2010).

At the moment various Latvian institutions and organizations engaged in the collection of data on the forest sector, where the one of the most important is the Ministry of Agriculture (abbreviation - MA) and the Central Statistical Bureau (abbreviation - CSB). At the same time is the other institutions dealing with various data collection, what can attributable to the forest sector in accordance with institutions responsible of delegation, as also after their initiative, mostly non-governmental in case. In parallel, many institutions deal with the publicly available of Ministry of Agriculture or Central Statistical Bureau data interpretation, as also deal with in addition calculation to conducting.

**Forest industry description**

The forest industry composed of forestry, timber industry and wood thermal and chemical processing industry. The forest sector combines forest resources and based on the very diverse productions, trades and consumption in the single system whose elements are interrelated.

The forest products includes the key raw materials (a round wood, pulpwood, wood chips and wood technology) and the primary processing of wood products (a sawn wood, wood based panels and energy products (a pellets and briquettes), as also the further development of timber products (a carpentry and joinery products and furniture) (1.pielikums…, 2010).

Forestry supplied in the forest obtained goods and services directly to the consumption market or raw materials for further processing. The forest products may be of material (wood as raw material, mushrooms, berries, etc.), non-material (forest biodiversity, recreation facilities and other services) and the cumulative value (carbon attraction) (1.pielikums..., 2010).

The wood resource extraction has been divided in roughly two equal parts between the state and private forest owners. After forest statistical inventory data (April 1, 2009) 47% of the total forest areas is the state forest and 53% - the others forests including the private forests (Meža…, 2009). The last 70

years, the forest area in Latvia has more or less doubled, while the volume of wood has increased to 630 million $m^3$ after forest inventory statistical data (Meža…, 2009).

The wood resource volumes in Latvian forests each year remains quite stable position – between 10 and 11 million $m^3$ of wood each year. In 2009, according to State Forest Service data, the felling output was 10.73 million $m^3$. 7.73 million $m^3$ of wood was obtained from state forests, and 3.00 million $m^3$ – from other forests, including from private forests (Projekts…, 2009, Fig. 1).

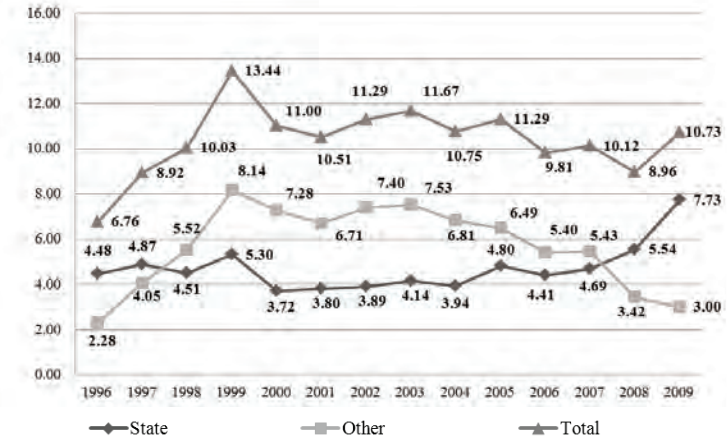


**Fig. 1.** Wood resource extraction dynamics, million $m^3$

**Forest industry information flow**

The forest industry is complexity, what incorporating not only a wide range of production activities and a range of services, institutions and administrative bodies, but also in other sector activities aspects and an influence to forest industry. The forest industry linkage with other industries is referred to as forest industry cluster (Forest…, 2010, Fig.2.).

**Fig.2.** Forest industry cluster in Latvia

Since the forest sector has a different processes and activities complex, which complicates the information tracking in the single system. World practice shows that where there are several sectors or actors then are often set up in the large variety data processing and storage methods and systems that make harder traced the common material flow. In the forest industry material flow, starting from the forestry and logging to finished product trades, is the risk not enumerated the all information in one system - for example, the industry with high added value, because less information about it (G.Niblaeus, 2009,Fig.3.)

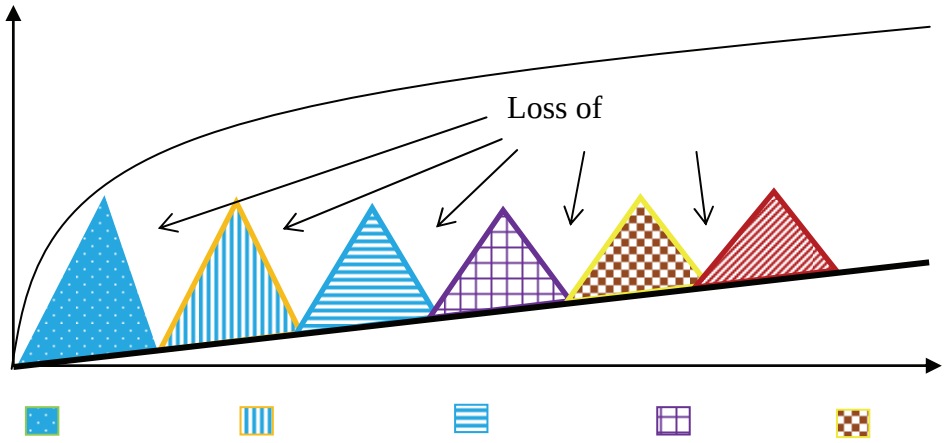


**Fig. 3.** Information accumulated with traceability

## MATERIAL AND METHODS

One of the research methods is the survey. It is a survey of people using special forms, where are given questions. The study target group is the Latvia`s forest institutions, organizations. In the study were included in all institutions dealing with information collection, storage, processing and analysis about the forest industry. The planned sample size was 40 respondents, where include 20 respondents what to batch the information regularly and 20 respondents what to batch the information irregular about forest industry in Latvia. Achieved sample size was 40 respondents.

To identify each of the identified institution within the accumulated data, was developed a common template, under which each institution was conducted the accumulated data analysis. A template consists of three sections:

1. General Information - includes information on institutions, data storage functions and regulatory framework for forest sector data storage.

2. Accumulated data characterization - the sector where the accumulated data, used for data classification;
3. Data groups description:
   3.1. Background information - data group name, physical or monetary value, data sources, data collection frequency, a data group publication date and data group description.
   3.2. Data collection methods - information acquisition method, format, number of involved human resources, IT systems and other information;
   3.3. Data processing methods - methods, deadlines, format, data analysis / modeling techniques, the number of human resources, IT systems and other information;
   3.4. Data storage techniques - techniques of data collected in the further use, the data received at other institutions, number of human resources, IT systems used and other information;
   3.5. Weaknesses / essential problems of the data collection, processing and analysis;
   3.6. Assessment about of the data reliability level.

Obtained compilation of results was used the SWOT analysis method. In business practice competitiveness assessment and development of appropriate strategies are used the SWOT analysis method based on the following elements: internal strengths, internal weaknesses, external opportunities and external threats (4). From SWOT matric is apparent 4 possible strategies (Table 1).

**Table 1.** SWOT analysis

| | ***Strengths*** | ***Weaknesses*** |
|---|---|---|
| ***Opportunities*** | ***SO –*** full use a force to benefit from opportunities. | ***WO –*** reduce the weakness to take advantage from opportunities. |
| ***Threats*** | ***ST –*** use and increase the strength to cope with threat. | ***WT –*** the business to tighten, liquidation or merger. |

## RESULTS AND DISCUSSION

First, the SWOT analysis is to choose the factors that reflect the forest industry within the strengths and weaknesses and identify opportunities and threats affecting it from outside (Table 2).

**Table 2.** Forest sector information chain SWOT analysis in Latvia

| ***Strengths*** | ***Weaknesses*** |
|---|---|
| ▪ Between public authorities the flow of information regulates the interdepartmental agreement, clearly identifying the data group, the time and responsibility.<br>▪ CSB data collection, processing and accumulation uses methods and strong data algorithms what is the proven in long-term.<br>▪ Certain important issues have been settled with local legislation.<br>▪ Ministry of Agriculture, Forest Department employees the long-term experience of forest industry in the data processing and storage.<br>▪ International and EU institutions of regular involve in the forest sector data collection and processing methods for improvement. | ▪ There are no single regulatory frameworks, which clearly tell the responsibilities over the forest sector data collection, processing and accumulation.<br>▪ Available statistical data are stored in the forest sector about various time periods.<br>▪ CSB statistical data available to other institutions are with relatively large time lag, especially the data for the previous year.<br>▪ Not always being tested respondents reported data validity.<br>▪ Data on the various sectors are presented in various formats with different units then in the single accounts can`t be effectively combined.<br>▪ In some cases the data are not stocked in the required format and volume.<br>▪ Joint information system lack in the forest-based data processing.<br>▪ The accumulated data fragmentation. |
| ***Opportunities*** | ***Threats*** |
| ▪ Determined forest policy linking with Latvian forest sector accounts model after IEEAF guidelines and use it in policy planning.<br>▪ Legislative framework to clearly define responsibilities for data collection, processing and storage in the forest sector.<br>▪ Latvian forest sector accounts system model to take into account both the EU and Latvian internal needs.<br>▪ Possible to use CSP methodology data collection, processing and storage.<br>▪ Use of foreign experience, creating a Latvian forest sector account system. | ▪ National policy changes in the forestry or static data collection, processing and storage.<br>▪ Insufficient financial resources for all relevant forest sector data collection, processing and storage.<br>▪ Lack of human resources in the forest sector data collection, processing and storage.<br>▪ Obtaining information from private forest owners can`t be adjusted with local legislation.<br>▪ Common definitions and of international wording absence and other threats. |

# CONCLUSIONS AND RECOMMENDATIONS

The main conclusions from current situation assessment are:

1. At the moment various Latvian institutions and organizations engaged in the collection of data on the forest sector, where the one of the most important is the Ministry of Agriculture (abbreviation - MA) and the Central Statistical Bureau (abbreviation - CSB), but there are other institution that deal with it in accordance with institutions responsible of delegation. In parallel, many institutions deal with the publicly available of MA or CSB data interpretation, as also deal with in addition calculation to conducting.
2. Since the forest sector has a different processes and activities complex, which complicates the information tracking in the single system. In the forest industry information flow, starting from the forestry and logging to finished product trades, is the risk not enumerated the all information in one system - for example, the industry with high added value, because less information about it.
3. Latvian is no single legislative act which establishing a single forest data storage arrangements and the responsible institutions. The current moment each institution out the forest sector data collection, based directly on the relevant institutions determinative regulatory framework - in separately cases based to the law, the government issued rules, or to the specific institution rules.
4. In some cases, traders and non-governmental organizations dealing with primary data collection, but it is usually based on a voluntary basis, and surveys do not cover the entire population, including information, based on non-governmental organization member’s data.
5. Data on the various sectors are presented in different formats, using different units, so that could arise are problems effectively combine in a single forest sector account system model.
6. In some cases, the institutions collect the data in other format or insufficient volume.
7. The during the data collection and by each respondent's obtained data logical and mathematical control, it should be noted that institutions rely on the integrity of respondent, by failing the obtained data the validity control.

**Recommendations**

1. It would be useful to develop a single information system for forest sector data gathering, thereby promoting uniform the principles and methodologies application of data collection, processing or storage.
2. It is necessary legislative framework to clearly define responsibilities for data collection, processing and storage in the forest sector.

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# NUMERICAL MODELLING OF THE TIME-DEPENDENT MECHANICAL BEHAVIOUR OF SOFTWOOD

Engelund, E. T. [1]

When using wood as a structural material it is important to consider its time-dependent mechanical behaviour and to predict this behaviour for decades ahead. For this purpose, several rheological mathematical models, spanning from fairly simple to very complex ones, have been developed over the years. Often these models assume contributions from elastic, viscoelastic and viscous processes acting within the material. However, the physical interpretation of the input parameters is often difficult. This is because these models are mathematical tools which typically are not related to the physical mechanisms causing the observed mechanical behaviour.

In this study, the mechanical behaviour of softwood tracheids is described using numerical modelling. The basic composition and orientation of the tracheid constituents is incorporated by establishing a local coordinate system aligned with the microfibrils of the dominant S2 layer. Composite theory for laminar structures is used to generate the elastic properties in the local coordinate system based on literature values for the properties of the chemical constituents. Time-dependent behaviour is thought to be a result of sliding between the microfibrils. This assumption is incorporated in the numerical model by only allowing non-elastic behaviour in shear deformation modes in the local coordinate system. The rate of shearing is described by deformation kinetics.

The results indicate that time-dependent behaviour such as creep and relaxation originates from simple physical processes. However, the interaction between the sliding of the microfibrils on the microscale (local coordinate system) and the orientation of the microfibrils in the tracheid becomes complex on the macroscale. An example of the simplicity of the current numerical model is that no viscoelastic property is assigned on the microscale; only elastic and viscous properties. Nonetheless, the mechanical behaviour on the macroscale is

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viscoelastic, i.e. the time-dependent macroscopic behaviour is to some extent reversible.

**Key words:** Creep, relaxation, numerical modelling, deformation kinetics.

## INTRODUCTION

The use of wood as a structural material requires knowledge about its rheological behaviour. Due to the desired longevity of our buildings, engineers should be able to predict the behaviour for decades ahead. Several rheological mathematical models have therefore been developed over the years (Morlier and Palka 1994). Many of these models assume contributions from elastic, viscoelastic and viscous processes acting within the material. However, these methods often fail in linking the mathematical description with the physical processes behind the observed mechanical behaviour (Hunt 1997). Therefore, the physical interpretation of the input parameters is difficult (Gril et al. 2004; Hunt 1997). In this study the time-dependent mechanical behaviour of softwood tracheids is described by numerical modelling. The aim is to construct a model based on realistic physical mechanisms and generally accepted physical theories.

## Tracheid structure and time-dependent mechanical behaviour

The key component in terms of load bearing in a softwood tracheid is the cellulose microfibril. This is a highly ordered aggregate of aligned cellulose chains embedded in a matrix of the amorphous wood polymers; hemicelluloses and lignin. The majority of microfibrils are found in the S2 layer of the tracheid wall which constitutes about 80 % of the entire tracheid wall (Brändström 2001). The microfibrils have a helical orientation in the tracheid with a specific inclination relative to the longitudinal axis of the tracheid. This inclination is termed the microfibril angle (MFA) and typically has a value around 3-15° (Barnett and Bonham 2004) for normal softwood tissue. The MFA is closely related to the mechanical behaviour of tracheids, and it affects both the elastic (Persson 2000) and time-dependent mechanical response (Gril et al. 2004; Kojima and Yamamoto 2004) of softwood. The latter is commonly seen as increasing deformation of wood under constant load and is termed creep. Another example is relaxation where the required applied load to maintain a constant deformation is decreasing with time. The causal mechanism for this time-dependent mechanical behaviour has been attributed to sliding between the

microfibrils (Balashov et al. 1957; Lotfy et al. 1972; Olsson and Salmen 2001). Only secondary chemical bonds such as hydrogen bonds exist between the microfibrils, and the rate of sliding is therefore controlled by the rate of breaking, moving and re-forming of these bonds (Bonfield et al. 1996).

## Mathematical description of the mechanical behaviour

The elastic behaviour of softwood can be described by calculating the properties of the tracheid wall using composite theory for laminar structures based on properties of the chemical constituents (Berg and Gradin 1999; Marklund and Varna 2009). In such calculations the orientation of the microfibrils, i.e. the MFA, has to be taken into consideration. This can be done by constructing a local coordinate system that follows the orientation of the microfibrils as seen in Fig. 1 whereas the global coordinate system is oriented along the longitudinal axis of the tracheid. The inclination of the local system in relation to the global system is simply the MFA of the tracheid.

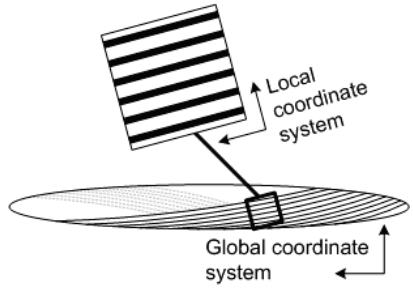


**Figure 1: Global and local coordinate system for a single tracheid. The local coordinate system is oriented along the microfibrils in the S2 layer.**

The sliding of the microfibrils on the molecular level results in shearing on the microscopic level. The basic assumption in this study is therefore that only shearing along the microfibrils exhibits time-dependent behaviour. Since the sliding is controlled by the breaking, moving, and re-bonding of hydrogen bonds, the general equation of deformation kinetics can be used to describe the process.

Deformation kinetics are based on the theory of kinetics of chemical reactions derived by Eyring (Krausz and Eyring 1975). The basic principle is that molecules or segments of molecules can only move from their current position if they attain a certain energy level. The process of movement is in deformation kinetics theory termed flow and is a purely viscous process. Fig. 2 illustrates a

symmetrical potential energy barrier, where the required energy for flow is termed the activation energy.

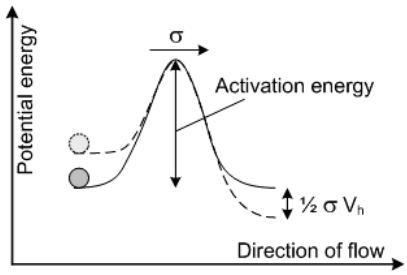


**Figure 2: Symmetrical energy barrier for a flow process. The height of the energy barrier is the activation energy. When a load is applied, the barrier gets asymmetrical and flow in the direction of the load is favoured.**

In a stress free state, a certain percentage of the molecules or segments has the required energy and are free to move due to the thermally induced molecular motions. However, if the energy barrier is symmetrical, there is an equal probability of bonds moving forwards as well as backwards. Only if a force is applied, the barrier becomes asymmetrical and flow in the direction of the force is favoured. The asymmetry of the energy barrier upon load application is related to the magnitude of the load, and thus higher load level will favour faster flow rate.

In this study, time-dependent behaviour is only allowed in shearing modes in the local system seen in Fig. 1, whereas all other deformation modes are given elastic properties described by Hooke's law. Thus, on a microscopic level of the tracheid, shearing deformation gives rise to elastic and viscous behaviour. On the other hand, deformation in the normal directions in the local coordinate system will only result in elastic behaviour. The incorporating of time-dependent behaviour in shearing modes can be described by a summation of the elastic and viscous contributions as seen in (1).

$$\frac{d\varepsilon}{dt} = \frac{1}{G}\frac{d\sigma}{dt} + \frac{V_h}{V_m}\frac{kT}{h}\exp\left(-\frac{\Delta G^{\ddagger}}{kT}\right)2\sinh\left(\frac{V_h\sigma}{2kT}\right) \quad (1)$$

where ε is the shear strain, t is time, G is the shear modulus, and σ is the shear stress. The parameters $V_h$ and $V_m$ are volumes swept by the sliding motion and the volume of the moving segment itself, respectively, k is Boltzmann's constant, h is Plancks's constant, and T is the absolute temperature. The

activation energy is incorporated in the free energy of activation, $\Delta G^{\ddagger}$. The first term on the right-hand side in (1) is the elastic contribution described by Hooke's law whereas the second term is the viscous contribution described by deformation kinetics. Under isothermal conditions, (1) can be simplified to the following form

$$\frac{d\varepsilon}{dt} = \frac{1}{G}\frac{d\sigma}{dt} + A \cdot 2\sinh(B\sigma) \tag{2}$$

## MATERIALS AND METHODS

The numerical modelling in this study is performed using commercially available numerical software. The theory and methods described here can be applied to any such software capable of handling user-defined partial differential equations.

In order to simulate the time-dependent behaviour of tracheids without having too many degrees of freedom, only a length section of 250 µm of a single tracheid is modelled. This is given a nearly quadratic cross section with rounded corners. The wall thickness is set to 2 µm. This is in accordance with typical values of S2 layer thicknesses in the earlywood of Norway spruce tracheids (Fengel and Stoll 1973). The width is set to 40 µm (Fengel and Stoll 1973). The cell wall properties of the tracheid are assigned in the local coordinate system. This is done by using composite theory for laminar structures based on the elastic properties of cellulose, hemicelluloses and lignin. Such structure resembles the stiff and oriented microfibrils embedded in a softer matrix of hemicelluloses and lignin. The input parameters for the viscous behaviour in shearing are taken from the literature (Krausz and Eyring 1975; Bonfield et al. 1996). However, the kinetic parameter A in (2) is varied in order to investigate the effect of moisture on the time-dependent behaviour. Only A is varied since it is assumed that the activation free energy in (1) will be the parameter most affected by the moisture in the cell wall.

## RESULTS

In Fig. 3 the experimental results by Lotfy et al. (1972) are shown along with results from the numerical model. Both the MFA and the kinetic parameter A are varied, where $A_0$ is the value of A calculated based on literature sources

(Krausz and Eyring 1975; Bonfield et al. 1996). In order to simulate the experimental results, the applied load has been tuned to yield equal initial (elastic) strains independent of MFA.

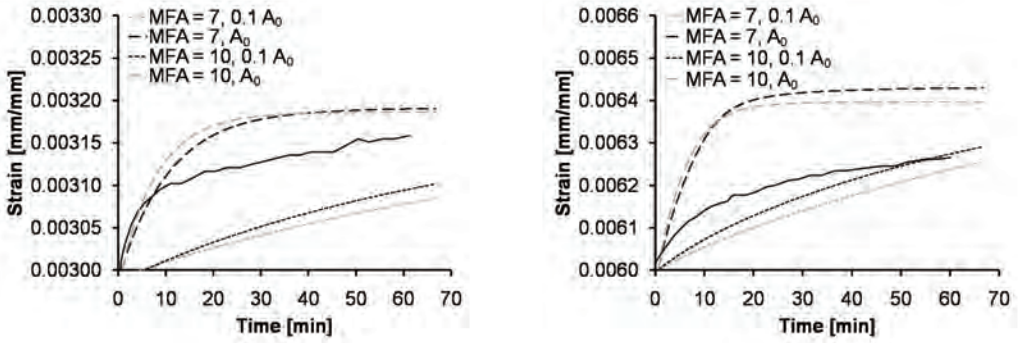


**Figure 3: Creep of Sitka spruce at 23 °C and 50 %RH in tension at two different load levels. Experimental data are taken from Lotfy et al. (1972).**

Experimental results for the relaxation of Norway spruce tissue is shown in Fig. 4 (left) along with results from the numerical model. Again, the MFA and the kinetic parameter A have been varied. However, due to the higher moisture content in the Norway spruce of Fig. 4 compared to the Sitka spruce of Fig. 3, the value of A is also higher.

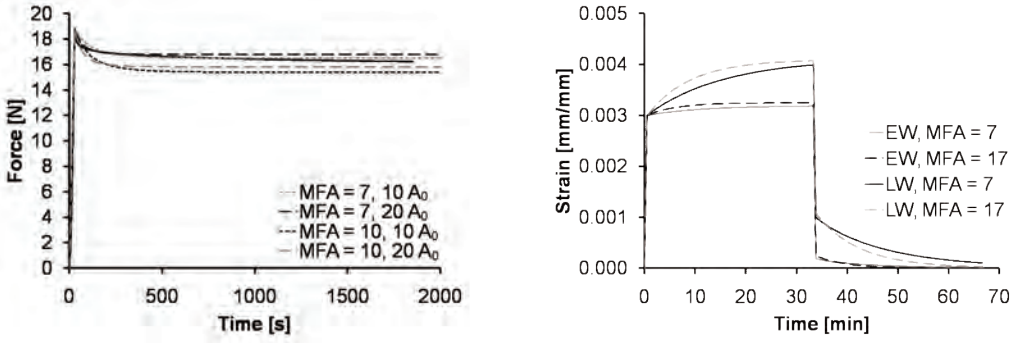


**Figure 4: Relaxation of saturated Norway spruce tissue at room temperature (left) and macroscopic viscoelasticity of numerical model (right). Experimental data for relaxation are taken from Eder et al. (2006).**

In Fig. 4 (right) the macroscopic apparent viscoelasticity of the numerically modelled tracheid is illustrated for two different tracheid types; one with similar

geometry as previously described (resembling an earlywood, EW, fibre) and one with a twice as large wall thickness but half as large diameter (resembling a latewood, LW, fibre). Furthermore, two different MFAs have been selected and the applied load tuned to yield equal elastic strains.

## DISCUSSION

The results from the numerical modelling indicate that it is possible to describe the experimental results based on simple, yet realistic assumptions regarding the causal mechanism behind time-dependent mechanical behaviour. The fitting of the model to both creep and relaxation histories in Fig. 3 and Fig. 4 (left) shows this trend. However, more accurate experimental results of creep and relaxation of fibres and tissues with known MFA are needed in order to evaluate the input parameters of the model.

A somewhat surprising result of the present numerical model is that it is capable of simulating apparent viscoelastic behaviour on the macroscale, even though only elastic and viscous behaviour are permitted on a microscale. This can be seen in Fig. 4 (right) which illustrates the time-dependent behaviour for a load history with constant load for 33 minutes followed by an equal amount of time without load. The fact that only elastic and viscous contributions are needed to describe macroscale apparent viscoelasticity supports the hypothesis regarding the deformation mechanisms of wood. The hypothesis is that the elastic contribution is a result of straining of the covalent and hydrogen bonds, whereas the sliding of microfibrils, controlled by the breaking and re-forming of intermolecular hydrogen bonds, gives rise to the time-dependent behaviour. No additional viscoelastic contribution, which would be difficult to give a physical interpretation, is needed to explain and describe macroscale mechanical behaviour. Hence, the strength of the present numerical model is that, while based on assumptions regarding the deformation mechanisms of wood which are physically realistic, it is capable of imitating the time-dependent mechanical behaviour of softwood.

## CONCLUSION

The basic assumption in this study is that time-dependent mechanical behaviour originates from the sliding of microfibrils past each other. By describing this sliding by deformation kinetics and considering the orientation of microfibrils in the tracheid, it was possible to describe experimental results of both creep

and relaxation histories. Despite the numerical model only incorporated elastic and viscous behaviour on the microscale, the model exhibited macroscale apparent viscoelastic behaviour. The results indicate that time-dependent behaviour originates from simple physical processes that can be described using general physical theories. However, further experimental results are needed to evaluate the input parameters of the current model.

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# EXPERIMENTAL AND NUMERICAL INVESTIGATION OF PLYWOOD SANDWICH PANELS WITH CORRUGATE CORE

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## ABSTRACT

Considering that plywood is a layered cross-ply unidirectional fiber reinforced composite the development of innovative structural solutions require complex experimental and numerical investigation. Currently numerical simulations based on finite element method (FEM) are set as industry standard for composite industry like aerospace. Meanwhile the wood structures traditionally has been analyzed with simple analytical assumptions and approved with extensive experimental testing. Such an assumption restricts the variety of structural applications and imposes restrains on structural weight savings. On contrary comprehensive analysis by FEM can deliver tailored plywood structural solutions non dependant on neither geometrical nor loading configuration. To elaborate reliable FEM analyses, precise determining of mechanical properties of separate veneer ply is required both in longitudinal and circumferential directions. A significant scatter of wood mechanical properties obtained from cross ply specimen tests has been reported in the literature. Evidently for a single layer mechanical properties are more affected by micro cracks appearing after peeling process thus testing assessment is crucial. Roughly three hundred unidirectional specimens have been tested in longitudinal and transverse directions to elaborate the confidence bounds of mechanical properties. These properties served as input variables for simulation of corrugate core sandwich panel by FEM commercial code ANSYS. Bending test configuration according to EN789 has been elaborated for plywood sandwich panel with corrugate core and manufactured by AS "Latvijas

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Finieris". Robustness verification of numerical results versus bending tests according to EN789 for plywood panels confirmed numerical sensitivity towards introduced mechanical properties. The conclusion has been drawn to narrow down the confidence bounds for mechanical properties to be used to design plywood sandwich panels.

**Key words:** Plywood, wood based panels, corrugate core sandwich structures

## INTRODUCTION

Rational exploration of wood resources and environment protection becomes the topic of the day, thus highlighting the need to develop and to establish fabrication of new type wood products, which allows utilizing the wood more economically reducing the waste products. As example, plywood sandwich panels with mechanically transformed plywood sheet - corrugated core - may become that type of solution. Main benefits of such innovation are high specific bending stiffness and considerable wood saving, comparing with traditional plywood. There has been longstanding research associated with the production hardware and methods for manufacturing 3-dimension corrugated plywood as described in US patents Nr. 4816103 (1989) and 5948198 (1999). However those methods are not flexible to establish mass production of these sandwich panels, moreover further research of plywood behavior under different loading conditions using numerical and experimental methods, are needed to satisfy the user requirements. To simulate behavior and to optimize the complicated multilayer material structure the finite element method commercial code ANSYS has been utilized. FEM analysis with commercial codes has been considered as reliable tool by aerospace industry to replace physical experiments in development process. Elaboration of parametrical model in development process allows us to save time in design optimization and for elaboration of design guidelines to tailor the costumer requirements. Considering that plywood are modeled as multilayer material consisting of veneers composed in several layers with different orientation of fibers, material properties also are set separately for every layer not for all structure in general. However mechanical properties given for separate veneer in literature sources often are not consequent or vary in different sources, for example Wood Handbook (1999) or Eurocode 5 (1995). The aim of this research is to determine veneer mechanical properties for small size specimens and use these

values as input data for numerical optimization of sandwich panel with corrugate core.

## MATERIALS AND METHODS

### Veneer single layer specimens

To determine veneer mechanical properties, series of tension tests were performed for small size veneer specimens. As there is no industrial need for single layer veneer specimen tests the testing specimens has been produced according multilayer composite materials testing standard ASTM D3039. Assuming the geometrical characteristics as the specimen length $L$=300 mm, the width $B$=20 mm, 25 mm and 30 mm. The thickness of specimens *T1* for 1, 2 or 3 plies, vary from 1.46 to 4.03 mm. According to ASTM D3039, both ends of the specimen have been glued into cover plates with length *L1* from specimen ends. Cover plates produced from one veneer ply and glued athwart to specimen fibers direction. Tension tests were performed on universal testing machine INSTRON 8802 and INSTRON 8872 (for specimens with perpendicular fibers direction). The distance between the grips *L2* has been assumed constantly 100 mm and tested with loading speed of 1mm/min until failure. In total 220 specimens where tested with longitudinal wood fiber orientation where 120 specimens had width of 20 mm, 60 specimens had width 25 mm and 40 specimens had width 30 mm. Besides 50 specimens with perpendicular orientation of the fibers and width 20 mm has been tested.

### Plywood sandwich panels.

Plywood sandwich panel with corrugated core has been manufactured from 5-ply plywood sheet surfaces and 4-ply corrugated plywood core (Fig. 1). Corrugated core provide outstanding mechanical properties of the structure (modulus of elasticity, bending stiffness), in panel’s longitudinal direction.

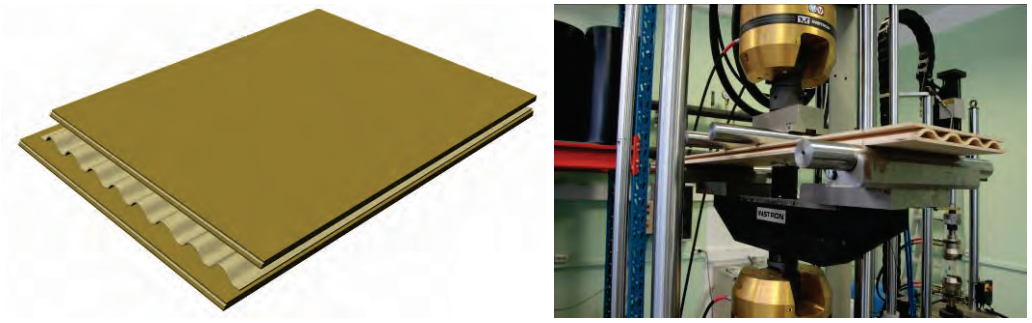

**Fig. 1.** Sandwich plywood panel with corrugated core; to the left: sandwich panel in 4-point bending test set-up on INSTRON 8802.

Panels have been loaded in 4-point bending set up according to EN 798 (2004) standard. Deflections of the panels were measured with three deflectometers. Relative deformations of the structure were measured using strain-gauges (produced by HBM) glued on both outer surfaces of the panel and also on corrugated core surface. Geometrical properties of tested sandwich panels are provided in Table 1.

**Table 1**. Geometrical properties of plywood sandwich panels with corrugate core

| Panel nomenclature | Panel width, [mm] | Panel thickness, [mm] | Panel length, [mm] | Wave width, [mm] | Wave thickness, [mm] | Wave ply count | Panel surface thickness and ply layout | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Upper surface, [mm] | Lower surface, [mm] | Upper surface | Lower surface |
| Panel 1 | 330 | 32.3 | 1200 | 82 | 5.6 | 4 | 6.5 | 6.5 | /-/-/ | /-/-/ |
| Panel 2 | 330 | 31.7 | 1200 | 82 | 5.6 | 4 | 6.5 | 6.5 | /-/-/ | /-/-/ |
| Panel 3 | 325 | 31.5 | 120 | 82 | 5.6 | 4 | 6.5 | 6.5 | /-/-/ | /-/-/ |

/ fibers direction parallel to panel's longitudinal direction

- fibers direction perpendicular to panel's longitudinal direction

### Finite element modeling

For computer simulation of bending tests was used FEM commercial code ANSYS v.11. Parametrical model of panel was created with variable cross section parameters and bending mode options. V-core plywood sandwich has been modeled according the EN 789 set up by using ANSYS 4-node shell element SHELL 181. It was assumed that each ply has thickness of 1.35 mm. Moreover stacking sequence has been modeled assuming that each layer is perpendicular to the upper and lower one, thus the plywood always consists of an odd number of plies. (Kalnins et al.2009). Corrugated core of sandwich panel in numerical model were simplified to straight lines, connected to the outer surface under specific angle. Core roundups are required by manufacturing process, however including roundups in numerical model are not reasonable (Fig.2).

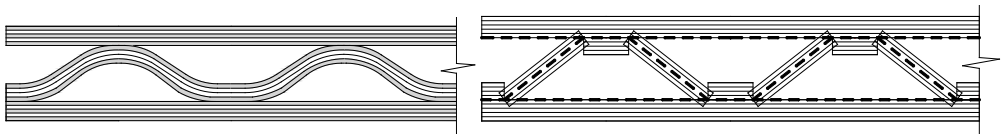

**Fig. 2**. Natural cross-section of sandwich panel (left); Cross-section modeled in ANSYS code (right); dashed line – offset plane for element thickness.

## RESULTS AND DISCUSSIONS

### Material properties

By performing specimens tension tests modulus of elasticity and breaking tensile stress and also maximal and minimal values of these properties has been estimated. For specimens with wood fiber orientation parallel to specimen longitudinal direction, values of elasticity's modulus are shown in Table 2. Average value of modulus of elasticity is 14.81 GPa. For specimens with fiber orientation perpendicular longitudinal direction, average modulus of elasticity is 0.5GPa. It has been achieved that the greatest modulus of elasticity are for 1-ply specimen impregnated with glue and produced under the pressure. By increasing thickness of the specimen, the modulus of elasticity decreases until average value of 13.26 GPa. It could be explained by wood defects appearing in thicker specimen's cross-section. Similar tendency to decrease modulus of

elasticity gives the increasing width of specimens from 20 mm to 30mm. Most robust results from all specimens have specimens made from 2 unidirectional veneers – difference between modulus of elasticity for specimens with 20 mm and 30 mm width vary only 3.5 %. For other specimens results difference between specimens with various width from 5-15 %.

**Table 2**. Modulus of elasticity for specimens with parallel orientation of fibers [GPa]

| Type of specimen | Specimen width, mm | | |
|---|---|---|---|
| | 20 | 25 | 30 |
| Laminated | Avg. | | **16.96** |
| | Max - Min | | max.17.51 min.16.49 |
| 1 ply (compressed) | **15.97** | **15.66** | **14.54** |
| | max. 17.06 min. 14.58 | max.17.53 min.14.77 | max.14.86 min.14.32 |
| 1 ply | **15.19** | **14.61** | **13.99** |
| | max.16.32 min.13.68 | max.15.10 min.14.04 | max.14.96 min.12.21 |
| 2 ply | **14.36** | **14.22** | **13.95** |
| | max.15.60 min.13.17 | max.14.63 min.13.86 | max.14.37 min.13.73 |
| 3 ply | **13.26** | **13.39** | **11.99** |
| | max.13.21 min.12.45 | max.13.55 min.13.18 | max.12.22 min.11.65 |

Average breaking tensile stress for specimens with fibers orientation parallel to specimen longitudinal direction is 125 MPa (maximal value 149 MPa, minimum 104 MPa). Breaking stress has tendency to increase with specimen width, difference between specimens with 20 mm and 30 mm thickness about 10 %.

## Sandwich panels tests

Plywood sandwich tests (according EN 789 (2004)) has been performed recording determined deflection of the panels and outer fibers relative deformation (Fig. 3). Using obtained results panel's modulus of elasticity and bending stiffness has been calculated (Tab. 3). Conventional plywood panels with similar constructive thickness – Panel 4 and Panel 5 has been compared with the sandwich one.

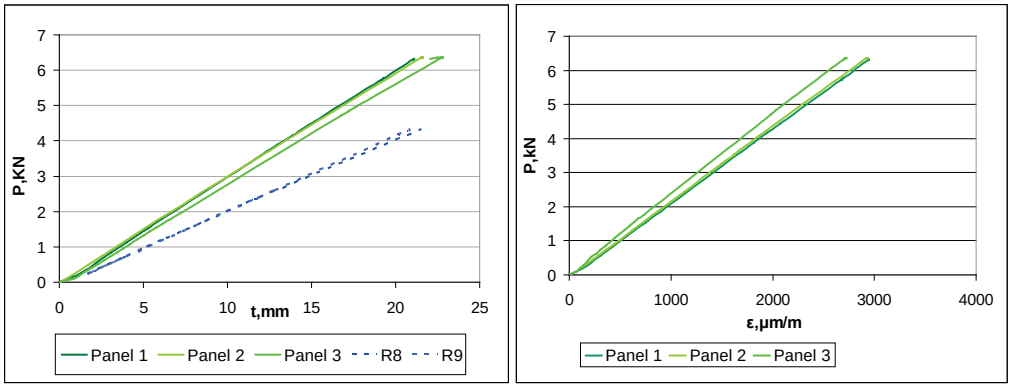


**Fig. 3.** Load and deflection/relative fiber deformation curves for panels bending tests

**Table 3.** Mechanical properties of plywood sandwich panels with corrugate core

| Panel nomenclature | Panel width, [mm] | Panel thickness, [mm] | Cross section area, *(A)*, [cm^2] | Moment of inertia,*(I)* [cm^4 | Modulus of elasticity, *(E)*, [GPa] | Bending stiffness,*(E*I)*, [KNm^2] | *(E*I)/A*, [KNm^2] | *(E*I)/A*, relatively to Panel 4, % |
|---|---|---|---|---|---|---|---|---|
| Panel 1 | 330 | 32.3 | 61.9 | 73.6 | 10.1 | 7.49 | 0.12 | 133.1 |
| Panel 2 | 330 | 31.7 | 61.9 | 73.6 | 10.0 | 7.37 | 0.12 | 132.9 |
| Panel 3 | 325 | 31.5 | 61.9 | 73.6 | 9.7 | 7.16 | 0.12 | 132.6 |
| Panel 4 | 300 | 27.9 | 83.7 | 54.8 | 11.5 | 6.58 | 0.08 | 100 |

The Panel 4 has been added to the Table 3. to illustrate the advantage of wood economy by applying sandwich panels. Panel 4 is a plywood panel with traditional ply layout, which is taken as reference point (100 %) to compare bending stiffness and consumed material volume relation between standard plywood and sandwich panels. Higher relation means higher bending stiffness value over the consumed wood volume.

From acquired data we can conclude that plywood sandwich panels (Panel 1, 2, 3) have better results than traditional plywood average by 33 %. It can be explained by relatively small area of cross-section comparing to the panel with full cross-section. Slightly higher thickness of sandwich panels (production factor) affected results also.

## FEM analysis

Using FEM commercial code ANSYS v.11. were performed virtual bending tests for sandwich panels with corrugate core. Panel's deflection and outer fibers relative deformations were acquired. Results comparisons with experimental data are demonstrated in Figure 5. For numerical calculations were used average value of elastic modulus acquired by testing of small size veneer specimens – 16 GPa in fibers longitudinal directional and 0.5 GPa in perpendicular direction. As one can see in Figure 4. results acquired using FEM analysis are very close to experimental values of panels deflections. Values of relative deformation of outer fibers are 10% lower than experimental, its mean some bearing reserve of material remains.

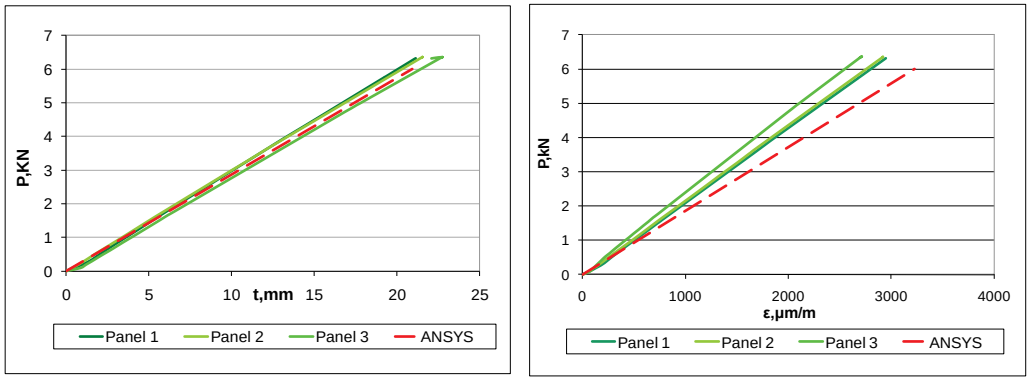


**Fig. 4.** Load and deflection/relative fiber deformation curves for panels bending tests and ANSYS virtual bending tests results.

## CONCLUSIONS

Performing tension tests for small size veneer specimens were determined material mechanical properties, which are suitable as input data for plywood sandwich panel's numerical calculations. Calculation model created with ANSYS v.11. computer program are suitable for performing 4-point bending tests for plywood sandwich panels with corrugated core, precision of the such calculations can be expected from 5-15%, comparing with experimental results. More detailed robustness analysis should be performed in order to increase numerical and physical discreapancy.

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# STRUCTURAL ROUND TIMBER OF SCOTS PINE FROM SOUTHERN NORWAY

Vestøl, G. I.[1] & Høibø, O.[2]

## ABSTRACT

Finding new applications of Scots pine that does not fulfil the requirements of sawlogs is an important issue in some parts of Norway where Scots pine comprises a substantial part of the timber production. One proposal is to increase the use of round Scots pine timber in structural frameworks, and a project has been carried out to provide data on mechanical properties, and to establish a basis for strength grading.

Density, modulus of elasticity (MOE) and bending strength were tested on 533 logs with diameter from 75 mm to 250 mm. The logs were sampled from 150 trees from 10 sites in southern Norway. The results showed high values of bending strength even for logs with poor visual quality. According to EN338, the whole sample was classified to strength class C35, but there were large differences between sites. Overall, MOE was the limiting property.

Visual characteristics explained some of the variation in both MOE and bending strength, but significant parts of the residual variance were due to site. This means that visual strength grading would have to be conservative in order to be valid across sites. Models of bending strength with MOE as independent were more accurate, and not different between sites. It showed a better potential for machine grading based on measuring MOE alone or in combination with visual grading.

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Some of the variation in MOE and bending strength could be explained by stand- and tree variables, showing a potential for a coarse sorting in the forest by using simple stand- and tree-variables. Combined with measuring MOE, this can be a good basis for strength grading of structural round timber.

Key words: Bending strength, density, modulus of elasticity, round timber, Scots pine.

## INTRODUCTION

Scots pine (*Pinus sylvestris* (L.) is the second most important species in Norway, and it comprises a significant part of the timber production in many areas. Finding new applications for low qualities has been emphasized since these obtain low prizes in the timber market, particularly in areas that are far from industries that utilize Scots pine pulpwood as raw material. One proposal that has been raised is to use round Scots pine timber in structural frameworks. It is known from old buildings that slender round timber of quite poor visual quality has been used as load-carrying members.

Round timber can be expected to be stronger and stiffer than sawn timber because of the surface continuity of wood fibres. In sawn timber the fibres around knots are cut and discontinuous, leading to stress concentrations and fracture initiation (Wolfe 2000). This effect may be particularly important in timber with low quality where the fibre deviations due to knots are severe. Wolfe and Moseley (2000) stated that round timber bending strength is not highly correlated with visual characteristics such as knots or spiral grain, but is well correlated with bending stiffness. Another reason why round timber is stronger and stiffer than sawn timber is the radial variation in wood properties. Both density and fibre length increase with number of growth rings from pith (Atmer and Thörnqvist 1982). This transition takes place in the first growth ring from the pith forming ‘juvenile wood’ as opposed to ‘mature wood’ farther from the pith. Mature wood is denser, stiffer and stronger than juvenile wood. Retaining this sheath of mature wood around the juvenile-wood core provides a bending element with strength and stiffness having higher mean value and lower variability than sawn timber (Wolfe & Murphy 2005).

In order to enable use of round Scots pine timber in structural framework, it is necessary to have documentation of strength and stiffness properties. Such documentation is available from a European study that analyzed round timber

from first thinnings of different species (Ranta-Maunus 1999, Boren and Barnard 2000), including Scots pine from Finland and Great Britain. Since it is based on timber from first thinning, the values cannot be applied to older Scots pine in Norway without further investigations. It was decided to perform a study of the bending properties of round Scots pine timber from southern Norway. The aim of the study was 1) to provide documentation of density, stiffness, and bending properties, and 2) to evaluate different methods of strength grading of round timber. This paper presents a summary of the main results that have been published in two previous papers (Høibø and Vestøl 2010, Vestøl & Høibø 2010). Some new models are developed to compare the main result from the two papers, particularly the random effect of site.

## MATERIAL AND METHODS

The material consisted of 533 logs from 150 Scots pine trees sampled from 10 locations in southern Norway. The locations were chosen from three counties where Scots pine constitutes a substantial part of the timber production. The sites were chosen to represent the variation in growth conditions within each county and included poor sites close to the timberline and both poor and fertile sites located at lower altitudes. The site indices, defined as dominant height at 40 years age ($H_{40}$), ranged from 6 m to 14 m.

Distribution of diameter at breast height was recorded at each site, and trees with breast height diameter between 15 cm and 30 cm were assigned to one of five diameter-classes, 15–18 cm, 18–21 cm, 21–24 cm, 24–27 cm or 27–30 cm. Three trees were sampled randomly within each diameter-class, and measurements of diameter at breast height, crown height, crown length, and tree height was performed before the trees were crosscut into logs with length depending on the small end diameter. Minimum small end diameter was 75 mm. The logs were debarked and air-dried during summer before being conditioned in a laboratory with temperature 20˚C and 65% relative humidity.

The physical properties measured on the logs before testing were tapering, maximum knot diameter, maximum knot sum and grain angle. Knot properties and grain angle were measured at the central part of the logs. Annual ring width and proportion of compression wood were measured at the small end of the logs. In accordance with criteria for visual strength grading proposed by Boren and Barnard (2000) 288 of the 533 logs were accepted for strength class C24, and of these only 93 were accepted for strength class C30. Taper was the most

frequent cause of rejection. Ignoring taper, 364 logs were accepted for strength class C24, and of these 275 logs were accepted for strength class C30.

Bending strength and modulus of elasticity (MOE) were measured in four-point-bending as described by the voluntary product standard VPS-SRT-1 (Ranta-Maunus 1999). The testing corresponds to testing of bending strength and local MOE in EN 14251 (2004a) that describes test methods for structural round timber. The calculations were performed to adjust the measured values to EN 14251 (Vestøl and Høibø 2010). Moisture content and density were measured from samples taken close to the failure point. In accordance with EN 384 (2004b) density was decreased by 0.5% for every percentage point for which the moisture content was higher than 12%. MOE and bending strength were increased by 2% for every percentage point for which the moisture content was higher than 12%, and bending strength was also adjusted to 150 mm dimension by using the correction factor given in EN 384 (2004b).

MOE and bending strength were described as linear mixed models treating each site as a random effect.

$$Y = \mu + f(A,B,C...) + S_i + \varepsilon_{ij}$$

$f(A,B,C...)$ = covariate function
$S_i$ = random effect of site (i = 1–10)
$\varepsilon_{ij}$ = residual (j = 1 – 533)

The models were first estimated with covariate function based on wood properties that can be used in visual grading, i.e. maximum knot diameter, relative knot diameter, knot sum, relative knot sum, taper, grain angle, compression wood and annual ring width. Then the bending strength model was estimated using MOE as the only covariate, and then by using both MOE and visible wood properties as covariates. These models estimated the potential for machine grading based on measuring MOE alone and in combination with visual grading. Finally the models were estimated using tree- and stand variables alone or, in case of bending strength, combined with MOE. These models estimated the potential for pre sorting in the forest.

# RESULTS

Corrected mean values and fifth percentiles of density and bending properties are presented in Table 1. Following EN 384 (2004b), characteristic values were calculated based on fifth percentiles of density and uncorrected bending strength and mean MOE for logs with nominal dimension between 75 mm and 200 mm. Characteristic density was 420 kg/m$^3$, characteristic bending strength was 40.0 N/mm$^2$ and characteristic MOE was 13915 N/mm$^2$. Corresponding strength class according to EN 338 (2003) was C35 due to MOE, while density and bending strength were sufficient for C40.

Table 1. Moisture content, density, and bending properties of round Scots pine timber. Density and MOE are corrected to 12% moisture content, and bending strength is corrected to 12% moisture content and 150 mm dimension

| Nominal dimension | N | Moisture content (%) | Density $\rho_{12}$ [kg/m$^3$] | | Bending strength $f_m$ [N/mm$^2$] | | MOE $E_m$ [N/mm$^2$] | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | $\rho_{05}$ | Mean | $f_{05}$ | Mean | $E_{05}$ |
| 75 mm | 73 | 15.7 | 474 | 416 | 56.6 | 40.3 | 13945 | 8919 |
| 100 mm | 85 | 16.1 | 480 | 419 | 58.9 | 41.6 | 11082 | 6952 |
| 125 mm | 92 | 16.1 | 484 | 418 | 62.1 | 40.3 | 12898 | 8788 |
| 150 mm | 90 | 16.7 | 506 | 441 | 70.5 | 48.5 | 15537 | 9814 |
| 175 mm | 83 | 17.2 | 502 | 421 | 67.7 | 44.1 | 14275 | 8256 |
| 200 mm | 54 | 17.3 | 513 | 445 | 71.1 | 46.5 | 15033 | 9890 |
| 225 mm | 33 | 17.6 | 509 | 422 | 73.1 | 35.8 | 15367 | 8059 |
| 250 mm | 23 | 18.2 | 511 | 425 | 71.3 | 47.0 | 15372 | 10465 |
| All | 533 | 16.6 | 494 | 424 | 65.1 | 42.9 | 13888 | 8313 |

Note: Abridgement from Vestøl and Høibø 2010.

Models describing bending strength are presented in Table 2. Model 1.1 describes bending strength based on a covariate function of visual timber characteristics. It explains 52.9% of the variation, and a significant part of the unexplained variance is due to site. Model 1.2, which describes bending strength as a function of MOE, explains 69.5% of the variation, and only a minor proportion of the unexplained variance is related to site. By combining MOE with visual characteristics (Model 1.3), 78.0% of the variance is explained, and only a minor part of the unexplained variance is due to site.

Table 2. Models describing bending strength variations.

| Model | Covariates |
|---|---|
| 1.1 | Tapering, maximum knot diameter, relative knot sum, grain angle, annual ring width |
| 1.2 | MOE |
| 1.3 | Maximum knot diameter, relative knot sum, grain angle, MOE |
| 1.4 | Breast height diameter, tree height, relative log height |
| 1.5 | Breast height diameter, tree height, relative log height, MOE |

Decomposition of bending strength variation according to models

| | Variance [$(N/mm^2)^2$] | | | | |
|---|---|---|---|---|---|
| Source of variation | Model 1.1 | Model 1.2 | Model 1.3 | Model 1.4 | Model 1.5 |
| Covariate function | 109.0 | 143.1 | 160.6 | 140.4 | 163.5 |
| Random effect of site | 28.2 | 2.6 | 3.6 | 1.2 | 1.5 |
| Residual variation | 68.7 | 60.2 | 41.7 | 64.3 | 40.9 |
| Total | 205.9 | 205.9 | 205.9 | 205.9 | 205.9 |

The covariate function in model 1.4 describes bending strength based on forest and tree measurements. It explains 68.2% of the variance, and only a minor proportion of the unexplained variance is due to site. By combining forest and tree measurements with MOE (Model 1.5), the explained variance increases to 79.4%, and only a minor part of the unexplained variance is due to site.

Models describing MOE are presented in Table 3. Model 2.1 describes MOE based on a covariate function of visual timber characteristics. It explains 35.0% of the variance, and a significant part of the unexplained variance is due to site. Model 2.2, which describes MOE with a covariate function based on forest and tree measurements, explains 50.2% of the variance, and the random effect is of minor importance compared to model 2.1. The residual variances of the two models are similar (Table 3.)

Table 3. Models describing MOE variations.

| Model | Covariates |
|---|---|
| 2.1 | Tapering, maximum knot diameter, relative knot sum, grain angle, annual ring width |
| 2.2 | Breast height diameter, site index ($H_{40}$), relative log height |

Decomposition of bending strength variation according to models

| | Model 2.1 | | Model 2.2 | |
|---|---|---|---|---|
| Source of variation | Variance [$(N/mm^2)^2$] | % | Variance [$(N/mm^2)^2$] | % |
| Covariate function | 4174423 | 35.0 | 5996095 | 50.2 |
| Random effect of site | 2196722 | 18.4 | 320155 | 2.7 |
| Residual variation | 5559645 | 46.6 | 5614540 | 47.1 |
| Total | 11930790 | 100 | 11930790 | 100 |

# DISCUSSION

The results show high values of bending strength even for logs with poor visual quality. However, since Model 1.1, describing bending strength from visual timber characteristics, had significant effect of site, rules for visual grading have to be conservative in order to be valid across sites. This corresponds to the results obtained by Green et al (2004), who concluded that it is questionable whether visual grading adequately assesses the potential of round timber for structural uses. It is contrary to the results of Boren and Barnard (2000), who found that the same grading rules could be used in Finland and Great Britain.

Models 1.2 and 1.3 show that bending strength can be more accurately predicted by MOE than by visual characteristics. By including MOE, there is also a much smaller effect of site, meaning that the models can be used across sites. Another argument for using MOE is that this property is limiting the strength class, and therefore should be given priority in strength grading.

Using forest and tree variables can add valuable information about bending strength and MOE. These variables explain both bending strength and MOE more accurately than visual log characteristics do. The models (Models 1. 4 and 2.2) also have much smaller random effects of sites compared to the models for visual grading (Models 1.1 and 2.1). This means that parts of the site effects are explained by stand and tree variables, and the covariate models better describe the potential for round timber across sites. The most accurate prediction of bending strength was obtained by combining forest and tree measurements with MOE (Model 1.5). Forest and tree measurements also gave the best prediction of MOE (Model 2.2). A good basis for strength grading of round timber could be a coarse sorting in the forest combined with measuring MOE.

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# VARIATION OF SCOTS PINE PERMEABILITY IN NORTHERN EUROPE

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## ABSTRACT

Scots pine (*Pinus sylvestris*) sapwood is per definition (EN-350-2) easy to treat. Combined with its good availability on the European markets, it is a construction and building material in demand. However, partially large differences in penetration are reported from industry and research. To keep a reliable product quality, impregnation processes are aligned to the material most difficult to treat. Hence, it is crucial to know about the factors inhibiting the fluid flow into the material.

Scots pine samples from a wide geographic distribution, 25 different sites in 6 different countries in northern Europe, have been collected and impregnated with an aqueous monomer furfuryl alcohol solution.

From each of the respective sites logs of 1.3 meter in length were collected from nine trees belonging to three different breast height diameter classes. Three trees from each dominance class were chosen randomly. The log was drawn from the felled stem in a height of 1.2 meters with exact marked north/south exposition. Sapwood slabs, orientated in the cardinal directions, underwent a drying procedure at 40°C for 48 h and small clear samples of 20 x 20 x 50 mm were prepared from this material.

A large variation of the ratio of filling was found for the material tested. Diameter as well as sample origin seem to influence the materials permeability.

Key words: Geographic origin, permeability, RoF, Scots pine sapwood

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# INTRODUCTION

Scots pine (*Pinus sylvestris*) is a coniferous tree easily available in the northern European area due to its large natural distribution and cultivation (Grosser, 1977). Additionally its heartwood combines desirable mechanical properties with a sufficient natural durability which makes it a common material for constructing purposes as well in- and outdoors. Its sapwood consists of a wooden matrix with nearly the same mechanical properties even though the durability is poor (classified 5) according to the EU standard EN 350-2. EN 350-2 though categorizes it to be easy to impregnate for extended durability. Industry and lately research however found themselves confronted with large variations in liquid uptake and the materials permeability when exposing the wood to impregnation processes (Lebow et al. 2006, Larnøy et al. 2008, Lande et al. 2010). Recent studies found differences of more than 80% in permeability after impregnating small wooden samples in the same batch in a mild treatment schedule. A variation was found from only slightly impregnated material to samples close to a full impregnation (Lande et al. 2010).

There is still lack of a full explanation for this variation. Studies conducted at the Norwegian Forest and Landscape Institute found sample origin, macro anatomical and chemical properties to be contributors to impregnation results (Larnøy et al. 2008, Lande et al. 2010, Zimmer et al. 2009). These tests though, were performed on a rather small geographical range.

For quality assurances of the material impregnated, process adjustments have to be aligned to the material least permeable as the preservative treatment standard of the Nordic Wood Preservative council requires a full sapwood penetration (NWPC Document no. 3 1998).

Hence, gaining the knowledge about differences within the wooden material inhibiting fluid flow during impregnation is not only of scientific interest but also of economic significance.

To be able to better predict the permeability of the Scots pine material given, trees from a large geographical range with a wide variation in properties were collected in this study.

# MATERIAL AND METHODS

## Wood material collection

In total 225 Scots pine trees were collected from 6 different countries in northern Europe (table 1).

**Table 1:** Summary of data for different trees in the study

| | | ***Norway*** | ***Sweden*** | ***Finland*** | ***Estonia*** | ***Lithuania*** | ***Scotland*** | *overall* |
|---|---|---|---|---|---|---|---|---|
| Number of sites | | 9 | 6 | 5 | 2 | 1 | 2 | 25 |
| Number of trees | | 81 | 54 | 45 | 18 | 9 | 18 | 225 |
| latitude | min | 57°37N | 57°37N | 60°01N | 58°36N | 55°44N | 57°32N | 57°32N |
| | max | 66°52N | 66°15N | 65°05N | 58°36N | | 57°38N | 66°52N |
| longitude | min | 5°19E | 12°50E | 23°02E | 26°45E | 21°07E | 3°41W | 3°41W |
| | max | 15°17E | 21°02E | 28°57E | 26°47E | | 4°17W | 28°57E |
| altitude | min | 50 | 20 | 50 | 50 | 20 | 20 | 20 |
| | max | 560 | 275 | 100 | 60 | 20 | 60 | 560 |
| site index (H40) | min | 1.4 | 6.7 | 7.8 | 7.2 | 8.2 | 11.6 | 1.4 |
| | max | 15.6 | 16.7 | 20.1 | 13.9 | 15.4 | 17.1 | 17.1 |
| | mean | 8.7 | 12.01 | 13.16 | 14.31 | 13.78 | 14.44 | 11.99 |
| tree age | min | 72 | 77 | 75 | 85 | 98 | 88 | 72 |
| | max | 182 | 141 | 209 | 124 | 118 | 98 | 209 |
| | mean | 138.56 | 108.67 | 111.47 | 107.12 | 110.78 | 90.11 | 113.26 |
| diameter | min | 13.5 | 16 | 19.5 | 14.5 | 17 | 18.4 | 13.5 |
| | max | 41 | 33 | 30 | 29 | 39 | 42.1 | 42.1 |
| | mean | 25.83 | 23.48 | 25.03 | 23.06 | 25.22 | 30.53 | 26.48 |
| height | min | 8.1 | 13.3 | 15.5 | 13.6 | 13.8 | 17 | 8.1 |
| | max | 24 | 23.8 | 26.3 | 28.5 | 24.6 | 24.5 | 28.5 |
| | mean | 16.02 | 18.71 | 19.87 | 22.03 | 19.92 | 20.19 | 18.93 |

25 stands were chosen where nine trees were harvested. Per site a circular area with an area of 500-1000 m² depending on stand density with at least 30 Scots pine trees was selected and the diameter of each tree over 10 cm in thickness was measured. Those trees were separated into three diameter classes: small, intermediate and dominant, with diameters including dependent on site properties. From each of the diameter classes 3 trees were chosen randomly to harvest giving a total of 9 trees per stand. Height of the selected trees was measured and the northern exposition marked. A 1.3 m log was sampled from 1.2 m tree height upwards.

A 10 cm disk was cut off from the bottom part of the log and stored in the freezer at -20 °C. The sapwood was cut off from the logs in slaps according to cardinal directions always including a little heartwood area to assure full sapwood utilization.

## Drying

All sapwood slabs underwent a drying procedure where they were in the oven for 48 hours at 40°C. Exact temperatures and times were recorded.

## Sample preparation

On each of the northern slabs the area with annual rings perpendicular to the cutting edge was marked and a 2.5 cm wide stick with bark was produced. Depending on the radial sapwood width, as many sticks (20 x 20 mm) as possible were cut from the raw stick including bark. Three clear wood samples per layer were selected in a size of 20 x 20 x 50 mm and conditioned in a climatic room to a moisture content of 13.9%. Before impregnation weight and dimensions of the samples at 13.9% MC were recorded. The cross sections were sealed twice with a two component sealer (Dreisol–2K–Aussen–Schutzlack) to assure penetration only from the lateral surfaces.

## Impregnation

All samples were exposed to the same impregnation schedule, where they were placed in an aqueous Furfuryl alcohol (FA) solution in an autoclave. The experimental impregnation mix was received from the Kebony ASA furfurylation plant and consisted of approximately 69% water, 28% FA and 3% additives. The samples were exposed to a vacuum of 0.004 MPa for 5 min followed by an air pressure of 0.8 MPa for 10 min. Finally, the samples were cured for about 19 hours at 105°C. These process times are too short to achieve a full treatment. Thus, a large variation in penetration was intentionally expected.

## Data analysis

To analyse the penetration, the weight percent gain (WPG) of the sample was calculated as well as the ratio of filling (RoF) (Eq. 1, 2). The WPG is a value comparing the weight after the impregnation with the one before. Hence, this value is density dependent. When using the ratio of filling, the actually filled volume of the sample gets related to the void volume, which theoretically could be filled (Lande et al. 2010). This leads to a value independent from density but describing the permeability of the individual sample.

| | |
|---|---|
| $V_{void} = V_{12\%} - V_{cellwall} - V_{water} + V_{swell}$ | *Equation 1* |
| $RoF = V_{uptake} / V_{void} \times 100$ [%] | Equation 2 |

$V_{void}$: Void volume in wood
$V_{12\,\%}$: Volume of the sample at 12 % MC
$V_{cellwall}$: Volume of the cell wall material
$V_{water}$: Volume of water at 12 % MC
$V_{swell}$: Potential increase in volume due to swelling
$V_{uptake}$: Volume of the treating liquid

For the statistical data analysis the JMP version 8.0 software (2009) from SAS Institute Inc. (Cary, North Carolina) was used.

## RESULTS AND DISCUSSION

Studying the permeability of Scots pine sapwood a large variation as well in tree properties (table 1) as in sample properties is apparent (table 2). One can find a large variation in within the trees within the countries and sample properties and the mean values within the countries differ a lot.
Sample densities (at 13.9% MC) were found in a total range from 0.39 g/cm³ to 0.72 g/cm³. According to the prior large variation in properties, the measured permeability measured in the RoF value diversifies from 5.67 % to 85.43 % in single samples. Comparing the mean values of the countries, the difference is still 23.9 % when studying the minimum mean RoF found in Norway and the maximum mean RoF calculated for Scottish samples (table 2).

**Table 2:** Summary of data for the samples in the study

| | | ***Norway*** | ***Sweden*** | ***Finland*** | ***Estonia*** | ***Lithuania*** | ***Scotland*** | *overall* |
|---|---|---|---|---|---|---|---|---|
| Number of samples | | 321 | 209 | 185 | 69 | 44 | 122 | 950.00 |
| density 13.90% [ g/cm³] | min | 0.39 | 0.45 | 0.48 | 0.53 | 0.56 | 0.51 | 0.39 |
| | max | 0.68 | 0.71 | 0.71 | 0.72 | 0.71 | 0.72 | 0.72 |
| | mean | 0.54 | 0.59 | 0.6 | 0.61 | 0.63 | 0.62 | 0.58 |
| uptake [%] | min | 11.32 | 19.98 | 11.26 | 20.41 | 35.17 | 30.67 | 11.32 |
| | max | 138.28 | 84.52 | 99.41 | 106.53 | 94.27 | 116.55 | 138.28 |
| | mean | 54.07 | 47.03 | 52.98 | 48.43 | 56.37 | 72.14 | 55.22 |
| WPG [%] | min | 4.52 | 5.53 | 7.19 | 8.01 | 9.6 | 4.75 | 4.52 |
| | max | 27.75 | 14.86 | 22.89 | 20.08 | 18.49 | 24.35 | 27.75 |
| | mean | 11.36 | 10.31 | 12.19 | 12.28 | 12.53 | 15.17 | 12.17 |
| RoF [%] | min | 5.67 | 12.47 | 9.4 | 16.51 | 30.39 | 27.32 | 5.67 |
| | max | 82.55 | 59.26 | 85.1 | 80.19 | 68.9 | 85.43 | 85.43 |
| | mean | 35.8 | 36.22 | 40.19 | 39.56 | 48.45 | 59.7 | 41.64 |

Figure 1 displays the variation of the RoF over latitude. In this figure, the diamond's cross line shows the group mean and the vertical span of each diamond represents the 95% confidence interval for the respective group.

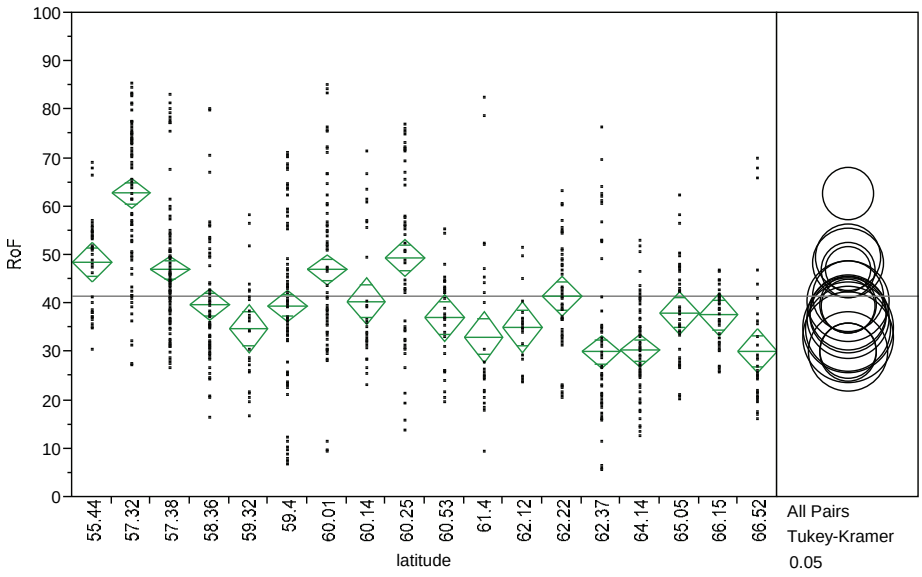


**Figure 1:** Range of the ratio of filling along the latitude

Considering the mean values, a slight slope can be seen with increasing latitude in a way that the mean permeability of the samples decreases with its origin northwards. However, latitudinal origin cannot be taken into account to be the only and main contributing factor to permeability and impregnation performance when dealing with a large variation of properties itself. Former studies showed on a smaller geographical range the origin in north south axis to be a large contributor on permeability by changing inner tree properties going north or southwards (Lande et al. 2010, Larnøy et al. 2008, Zimmer et al. 2009).

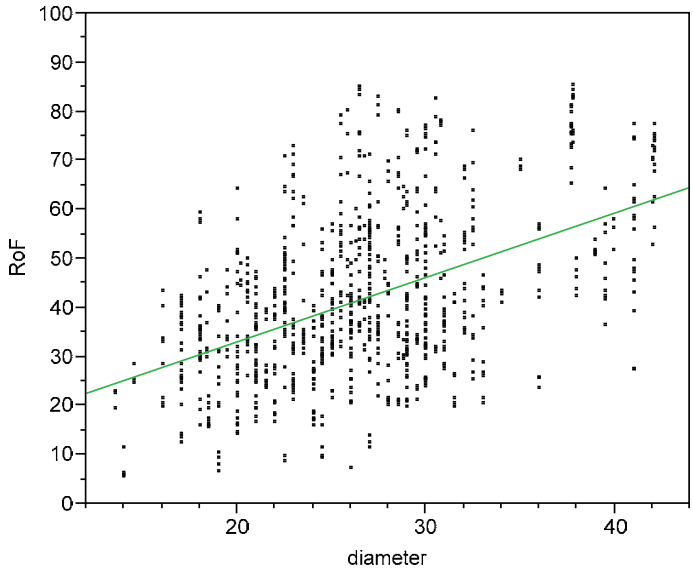


**Figure 2:** Ratio of filling correlated to the diameter

For a correlation of RoF with diameter (figure 2) a coherency seems to be apparent where the permeability of samples from larger diameter trees tends to be increased to those cut from small diameter trees. Hence through the changes caused by an increased diameter, the material structure seems to change in a way to make the tissue more permeable, without influencing density properties of the samples itself. Other anatomical properties as for example the latewood proportion (Koljo, 1953, Buro and Buro 1959), presence, aspiration state and amount of pits connecting the cells (Buro and Buro, 1959, Liese and Bauch, 1966, Stamm, 1946) and the increased age of the cambium initials could be influencing the permeability and were assumed to be contributing factors to permeability before. Those have to be investigated in the future.

## CONCLUSIONS

The RoF is a good value explaining the permeability as it displays a wider range as the WPG without containing the influencing factor of density in its calculation. A wide range of the RoF was found for the samples investigated from 5.67 % to 85.43 % in single samples.

Origin as well as structural properties seem to influence the permeability of the wood material.
To be able to give a reliable prediction of the samples permeability, further analysis of the current data as well as a more specific analysis of macroanatomical, microscopical and chemical properties of the material used in this study is necessary.

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# TREATABILITY VARIATION OF SCOTS PINE HEARTWOOD FROM NORTHERN EUROPE

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## ABSTRACT

Scots pine (*Pinus sylvestris*) and especially its heartwood is one of the most common construction materials for general outer use e.g. windows or facades in northern Europe. It is considered being durability class 3 and is according to EN 350-2 'not treatable'. Reports from industry and researchers indicate that the heartwood treatability is not uniform. It is still unclear what causes these differences. To increase its durability by means of impregnation would be a contribution to extend the use of both a natural and native material. The understanding of a potential pattern analog to latitudinal/longitudinal origin or other forest or wood properties could help to improve the impregnation by better material selection.

Scots pine samples from 25 different sites in 6 countries in northern Europe have been collected throughout autumn and winter 2009/2010.

A circle of varying size containing approximately 30 trees was set up in a representative site of each stand. All diameters were measured and arranged in three classes. Three trees of each class were chosen randomly. Only the middle and upper diameter classes were used for studying heartwood permeability. The small diameter class had insufficient heartwood width to be processed. Samples of 20 x 20 x 50 mm were cut and conditioned in a climate chamber. The samples were impregnated with a water-soluble monomer furfuryl alcohol solution in a standard pressure/vacuum process.

Results showed a generally low permeability but a few samples had an unexpected high ration of filling. Further on, the samples with the highest and

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lowest treatability will undergo anatomical and chemical tests to explain these properties.

**Key words:** furfuryl alcohol, heartwood, impregnation, permeability, Scots pine

# INTRODUCTION

Scots Pine (*Pinus sylvestris*) heartwood is one of the most traditional and common construction materials for general inner and outer use in northern Europe. It has a wide geographical distribution, a good availability and it is cheap compared to other materials. It is considered being durability class 3 and is 'not treatable' according to EN 350-2. Reports from industry and researchers indicate that the heartwood treatability is not uniform. It is still unclear what causes these differences. To increase its durability by means of impregnation would be a contribution to extend the use of both a natural and native material. The understanding of a potential pattern analog to latitudinal/longitudinal origin or other forest or wood properties could help to improve the impregnation by better material selection.
There is an ecological and economical need to improve the use of the resource wood and especially domestic species such as Scots pine by broadening its use without increasing the impact on nature. Initial aim of the sample collection throughout northern Europe was to study the variation of Scots pine sapwood permeability. It is highly interesting to see if the heartwood would react in similar patterns or if it would behave differently. The idea was brought up by Holger Militz in a discussion with the authors.

# MATERIAL AND METHODS

## Material collection

To achieve a wide geographical distribution Scots pine samples from 25 different sites were collected in the following six countries in northern Europe: Norway, Sweden, Finland, Estonia, Lithuania and Scotland during autumn and winter 2009/2010. In total 225 logs were collected by Katrin Zimmer and the author. Examinations are done by the PhD student Katrin Zimmer regarding sapwood permeability and concerning heartwood properties by the authors.

**Table 1:** site properties by country

| | | *latitude* | *longitude* | *altitude* [ m] | *diameter* [cm] | *tree height* [ m] | *age* | *site index* (H40) |
|---|---|---|---|---|---|---|---|---|
| **Norway** | min | 59°32' | 5°19' E | 50 | 18.5 | 11.8 | 85 | 4.1 |
| | max | 66°52' | 15°17' E | 560 | 41.0 | 22.2 | 180 | 13.0 |
| | mean | | | | 28.8 | 16.7 | 143 | 8.6 |
| **Sweden** | min | 57°38' | 12°50' E | 20 | 19.5 | 13.5 | 81 | 7.3 |
| | max | 66°15' | 21°02' E | 275 | 33.0 | 23.8 | 141 | 16.7 |
| | mean | | | | 26.1 | 19.5 | 111 | 12.1 |
| **Finland** | min | 60°01' | 23°03' E | 50 | 23.0 | 15.5 | 75 | 8.0 |
| | max | 65°05' | 28°57' E | 100 | 31.0 | 26.3 | 209 | 20.1 |
| | mean | | | | 27.0 | 20.5 | 115 | 13.2 |
| **Estonia** | min | 58°36' | 26.45' E | 50 | 21.5 | 15.6 | 85 | 9.4 |
| | max | 58°36' | 26°47' E | 60 | 29.0 | 28.5 | 124 | 19.4 |
| | mean | | | | 25.4 | 21.8 | 105 | 14.2 |
| **Lithuania** | min | 55°44' | 21°07' E | 20 | 27.0 | 19.7 | 98 | 12.3 |
| | max | 55°44' | 21°07' E | 20 | 39.0 | 24.6 | 118 | 15.4 |
| | mean | | | | 34.0 | 22.2 | 114 | 13.8 |
| **Scotland** | min | 57°32' | 3°41' W | 20 | 25.5 | 17.4 | 88 | 11.8 |
| | max | 57°38' | 4°17' W | 60 | 42.1 | 24.5 | 98 | 17.1 |
| | mean | | | | 33.9 | 20.8 | 92 | 14.4 |

The sample trees were chosen in a circle of varying size containing at least 30 Scots pine trees in a representative site of each stand. All diameters were measured and arranged in three classes. Three trees of each class were chosen randomly. Their heights were measured and north direction and breast height marked.
Site indices were considered being low to middle but had a wide spread from 4-20 [H40= height of tree at age 40].
Only the middle and upper diameter classes were used. The small diameter class had insufficient heartwood width to be processed.

## Sample Preparation

The stem parts from 1.2 m - 2.5 m height were taken to the Norwegian Forest and Landscape Institute in Ås, Norway. A disc at the lower end (primary breast height: 1.3 m) was cut off for annualring analysis (tree age, heartwood and sapwood age and distribution). On a stationary saw the sap and heartwood were separated. One 2.5 cm wide radial stick per heartwood beam was cut, reaching

from pith to the heartwood-sapwood border. To avoid juvenile wood, the first sample-stick has a 2 cm distance to the pith. Depending on the heartwood diameter, one, two or three sticks (2.5 x 2.5 cm) were cut. After planning, the sticks with straight annual rings measured 20 x 20 mm and were 1m long.
Five Samples of 50 mm length were cut from each stick and conditioned in a climate chamber to 13.8 % moisture content. Three samples were used for the impregnation, two will be used for further chemical an anatomical analysis. They were weighed at equilibrium moisture content and measured in all three directions to specify their volume. The three impregnation samples were sealed twice with a two component (Dreisol-2K-Aussen-Schutzlack) paint at both axial ends to eliminate longitudinal penetration.

## Impregnation

The used treatment agent is an experimental impregnation mix consisting of approximately 69% water, 28% furfuryl alcohol and 3% additives provided by the Kebony ASA furfurylation plant. A pressure/vacuum process using 0.004 MPa for 20 minutes and 0.8 MPa for one hour was applied. The specimens were weighed directly after the surface was wiped clean of excess liquid. The time delay of weighing was recorded from the first to the last sample and uptake figures were corrected with a linear regression (Zimmer & Treu, 2010, unpublished). The curing at 120 °C took 19 hours. The oven was switched off and the samples were slowly cooled for 15 hours. They were weighed again to determine their post treatment mass.

## Data analysis

Data collection and preparation was done by the use of Microsoft's Excel 2003. For the statistical data analysis the JMP version 8.0 software (2009) from SAS Institute Inc. (Cary, North Carolina) was used.
The following equations were used to calculate the ratio of filling (RoF):

| | |
|---|---|
| $V_{void} = V_{12\%} - V_{cellwall} - V_{water} + V_{swell}$ | *Equation 1* |
| $RoF = V_{uptake} / V_{void} \times 100$ [%] | Equation 2 |

$V_{void}$: Void volume in wood
$V_{12\,\%}$: Volume of the sample at 12 % MC

$V_{cellwall}$: Volume of the cell wall material
$V_{water}$: Volume of water at 12 % MC
$V_{swell}$: Potential increase in volume due to swelling
$V_{uptake}$: Volume of the treating liquid

## RESULTS AND CONCLUSION

A large variation in heartwood permeability was found; The heartwood permeability varies highly; the RoF varies from mere 5 % to almost 70 %. But 50 % of the samples' RoF lies between only 8.7 % and 12.7 % and 80 % lie between 7.7 % and 16.6 %. The mean value is 12.1 % and the median is 10.4 % (figure 1).

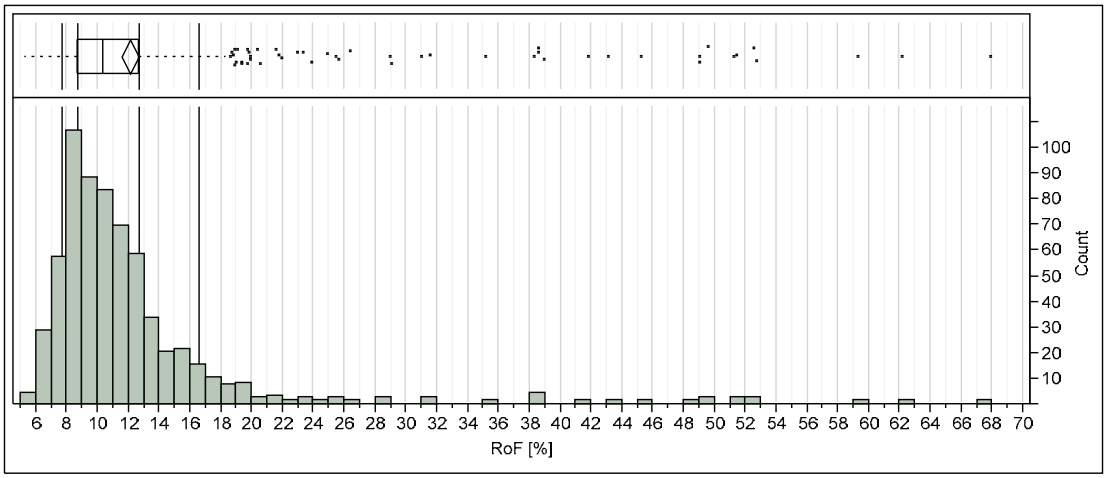


**Figure 1:** total RoF distribution showing mean confid diamond, median and 50 % and 80 % interval borders

The heartwood treatability does not seem to be influenced significantly by site properties or tree characteristics. The RoF of some single specimens was above average, but appears in very different diameter classes and latitudes (figure 2 and 3). The only exceptions to this are the upper diameter classes which tend to have a higher RoF than the smaller diameters (figure 3).

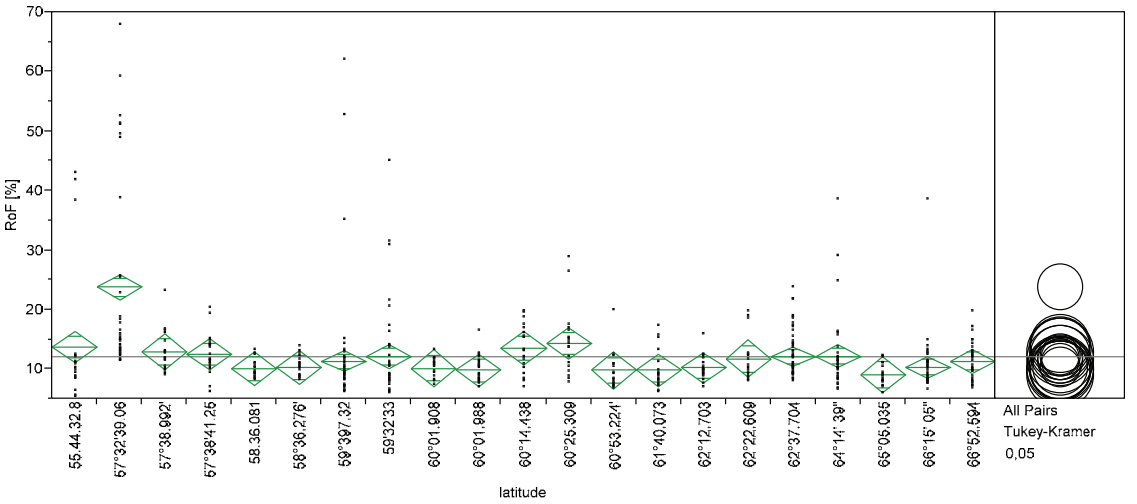


**Figure 2:** RoF by latitude showing means/Anova and comparison of all pairs using Tukey-Kramer HSD

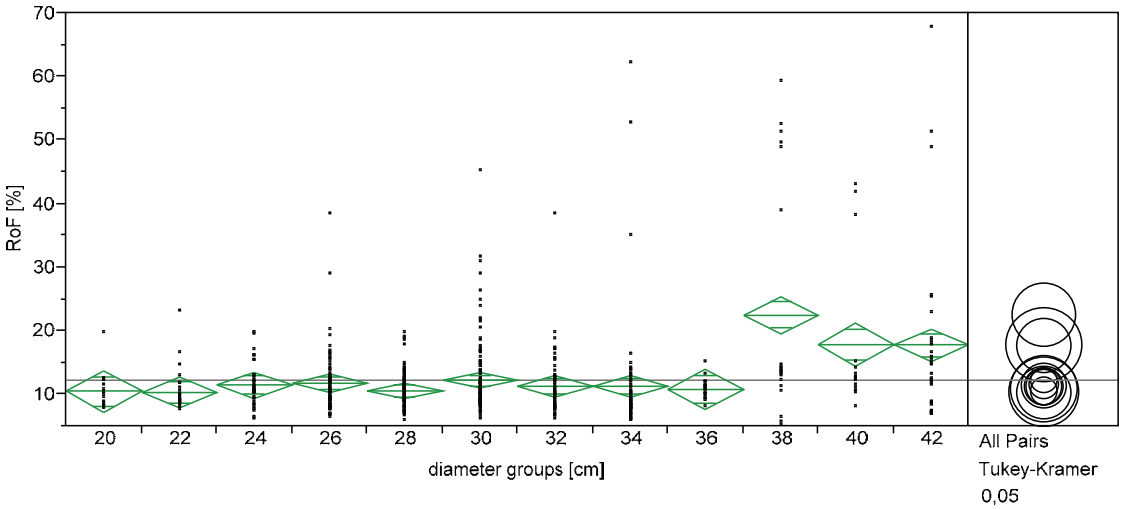


**Figure 3:** RoF by grouped diameters showing means/Anova and comparison of all pairs using Tukey-Kramer HSD. Each group represents a two centimetre wide class: group 20 stretches from 18.1 to 20.0cm; group 22 from 20.1 to 22.0.

In average the RoF values are very similar, except for the Scottish samples, which tend to have a much higher RoF. Scotland's average is 20.9 % whereas all other countries' average is between 10.3 and 12.5 % (Table 2).

**Table 2:** sample properties by country

| | *Norway* | | *Sweden* | | *Finland* | | *Estonia* | | *Lithuania* | | *Scotland* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| density | min | 0.40 | min | 0.45 | min | 0.43 | min | 0.52 | min | 0.59 | min | 0.44 |
| (13.8%) | max | 0.65 | max | 0.68 | max | 0.62 | max | 0.67 | max | 0.67 | max | 0.60 |
| [g/cm³] | mean | 0.52 | mean | 0.54 | mean | 0.52 | mean | 0.57 | mean | 0.61 | mean | 0.53 |
| RoF | min | 6.6 | min | 7.2 | min | 6.7 | min | 8.6 | min | 5.8 | min | 9.7 |
| [%] | max | 27.9 | max | 25.7 | max | 17.1 | max | 13.0 | max | 26.5 | max | 50.1 |
| | mean | 12.5 | mean | 12.0 | mean | 10.3 | mean | 10.5 | mean | 12.0 | mean | 20.9 |

The overall average RoF of all samples is 13 %, maximum RoF is 50.1 % and minimum RoF is 5.8 %. The average density (13.8 %) is 0.55 g/cm$^3$, maximum density (13.8 %) is 0.68 g/cm$^3$ and minimum density (13.8 %) is 0.40 g/cm$^3$.

The present impregnation trail was the first test in a series to examine the heartwood permeability. It showed the distribution of all the sample's RoF (figure 1). Up to now the statistical analysis does not answer the question why the RoF distribution is like that. Further research is needed to fully understand the materials performance. Extractives and resin content have not yet been studied, but are known to have a major influence on the heartwood treatability performance.

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# INVESTIGATION OF ELASTICITY AND STRENGTH PROPERTIES OF SCOTS PINE WOOD USING ULTRASOUND AND ACOUSTIC METHODS

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## ABSTRACT

In order to determine dynamic modulus of elasticity and strength classification of Lithuanian grown Scots pine, comparative a research was made using two non- destructive devices: "Timber Grader MTG" and ultrasonic elasticity and strength meter, developed at Kaunas University of Technology. Pine timber specimens of primary sizes 1011 × 95 × 45 mm, 1011 × 145 × 45 mm and 1011 × 170 × 45 mm were tested. Modulus of elasticity (MOE), natural frequency (NF), time of flight and strength classes was determined. Modulus of elasticity, gained with the ultrasound tester, showed better correlations with density then the ones, measured with the device "Timber Grader MTG". Moreover, MOE from "Timber Grader MTG" were higher on about 10 % for specimens with width of 95 mm, 8 % for width of 145 mm and 12 % for width of 170 mm then the ones from ultrasound tester for the same specimens' width. Nevertheless, the correlations between MOE, measured with these two non-destructive methods, are sufficient and fluctuating from 0.46 to 0.69.

Key words: wood, non-destructive methods, time of flight, modulus of elasticity, strength.

## INTRODUCTION

Wood is a shifting natural resource and because of it is used very widely. In purpose to use appropriately all kinds of wood it is necessary to evaluate its elastic and strength qualities, assess strength class, humidity, number of defects

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and etc. Those qualities strongly influence possibilities of wood applications and use.

In industry wood can be assorted into strength classes by examining it visually. However, in this case, quality and output depends on the experience of a worker [1].The other important weakness of this method is evaluation of visible external defects and not evaluating influence of internal invisible defects. Because of those reasons non-destructive research methods, when wood is explored by using specific devices, are being used more widely. These methods are new enough and there are a lot of research done in order to identify reliability and possibilities of such devices.

One of the most widely used non-destructive wood research method is determination of elastic wood qualities by using devices which operation principle is sustained by acoustic wave spread in wood. “Timber Grader MTG” works using such principle. It is patented as a manual wood strength measurement system [2]. Researches were done in order to evaluate the potential of this device. During those researches non-destructive methods’ (Timber Grader MTG, Metriguard and Long Span) errors, compared to wood strength which was made after performing 4 points flexure test, were determined [3]. Received results showed that the best correlation between dynamic modulus of elasticity and static strength while flexing were received using the device “Timber Grader MTG”. There are more research done in pursue to determine accuracy and reliability of non-destructive wood research methods. Both, conifer and leafy wood was used for those researches. In all cases, good correlations were determined between static strength modulus and dynamic modulus of elasticity, which was received by using the device “Timber Grader MTG”.

The other widely used non-destructive wood research method is sustained by the spread of ultrasound in wood. Using this method the research is done not only with wood elements [6], but also with glued timber [7] and “standing” wood [8] that means that the quality of the wood is examined while the tree is not cut yet. Reliable results were received in all cases while determining wood’s mechanic qualities in the case of dried and non-dried wood.

Researches done using the device “Timber Grader MTG” and ultrasound elasticity and strength meter, developed in Kaunas University of Technology, are presented in this article. The purpose of this research was to compare two different non-destructive methods’ stiffness-strength modulus and their inter-relations.

## MATERIAL AND METHODS

For this research Lithuania - grown pine wood (e.g., *Pinus Sylvestris*) specimens cut from the model logs delivered from seven Forest Directorates

(Mažeikiai, Kretinga, Jurbarkas, Dubrava, Druskininkai, Anykščiai, Švenčionėliai) were used. The diameter of the timbers ranged from 158 mm to 355 mm. Central boards from three diameter-related sawing patterns were later cut into specimens with the sizes: 1011 × 95 ×45 mm, 1011 ×145 ×45 mm and 1011 × 170 × 45 mm. Average specimen density was – 521 kg/m$^3$, moisture content – 11 %.

Dynamic modulus of elasticity an strength class was determined for all specimens using the device „Timber Grader MTG" (Fig.1, a). MOE evaluation principle is based on acoustic wave spread in wood, assessing specimens density and moisture content [2]. „Timber Grader MTG" grades wood assortment into strength classes according to the EN 338 standard "Structural wood. Strength classes". [9].

**a** **b**

**Fig. 1.** Devices used in the research: a – „Timber Grader MTG"; b - ultrasound elasticity and strength meter.

After that the, specimens were tested using ultrasound elasticity and strength meter (Fig. 1, b). The work principle of this device is based on the ultrasound wave spread in wood while measuring Lamb wave spread time between transceiver and receiver fixed at 380 mm distance. Each specimen was measured on four planes- scanning 10 times each plane lengthwise at every 60 mm. Dynamic modulus of elasticity for sequent positions was calculated using the following formula [10]:

$$MOE_{dl} = \rho \cdot \upsilon^2, \qquad \text{Eq. 1}$$

here: $MOE_{dl}$ – topical dynamic modulus of elasticity, N/mm$^2$;

$\rho$ – density of the wood, kg/m$^3$;

$\upsilon$ – ultrasound speed, m/s, calculated $\upsilon = 2 \times l_u \times f$ or $\upsilon = 2 \times l_u / T$;

$f$ – frequency of acoustic wave, Hz;

$l_u$ – distance between transceiver and receiver, m;

$T$ – time of flight, s.

Specimen apparent dynamic modulus of elasticity is calculated:

$$MOE_d = \sum MOE_{dl} / n, \qquad \text{Eq. 2}$$

here: $n$ –number of measurements on single specimen.
According to calculated modulus of elasticity, strength classes were determined with reference to standard EN 338 "Structural wood. Strength classes" [11].

## RESULTS AND DISCUSSION

Graphic dependences comparing used two testing methods are given on Fig. 2-4. Also, there is graphically performed the devices „Timber Grader MTG" ultrasound elasticity and strength meter elasticity variation when vary frequency rate and density of the specimens (Fig. 5, 6). All results' statistical evaluation was done and correlation rates were determined.
Different width specimens' module of elasticity and density dependence when for measurement using „Timber Grader MTG" and ultrasound elasticity and strength meter is performed in the figure 2.

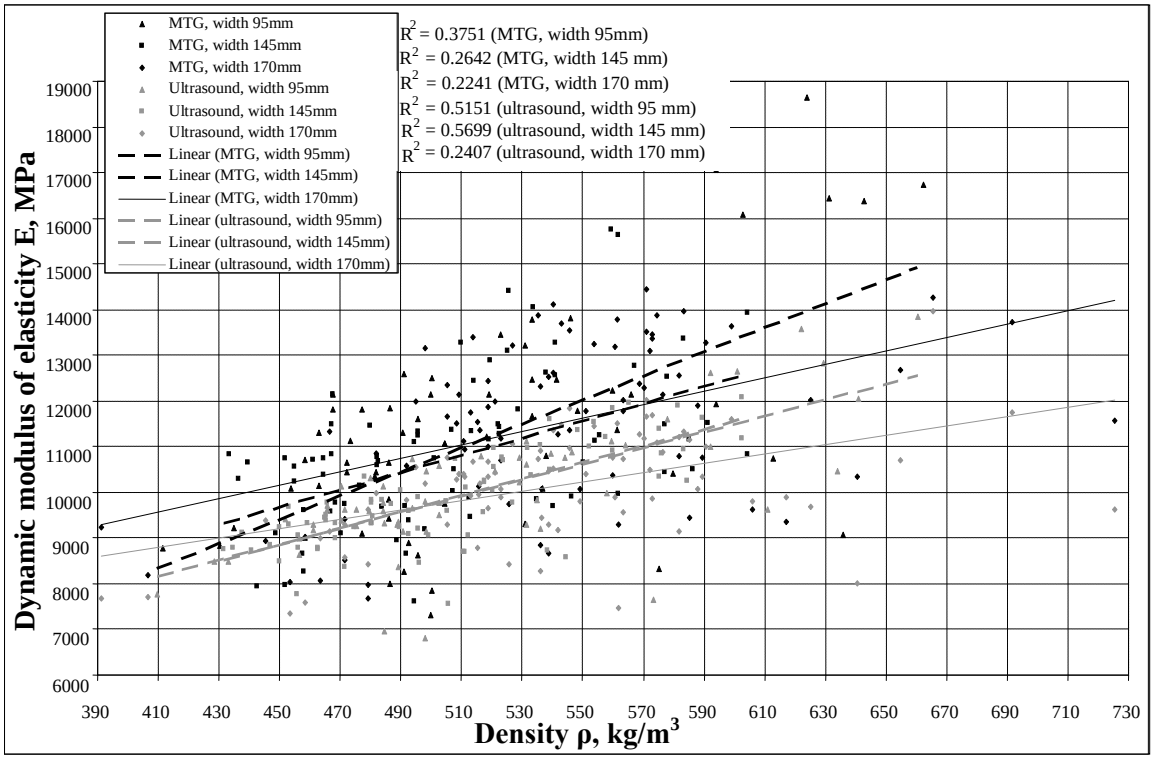


**Fig. 2** Dynamic modulus of elasticity dependence on wood density (ultrasound and acoustic waves).

As it is seen from the picture, dynamic modulus of elasticity, as well as static, is directly proportional for density because received correlation rates are positive. However, when measuring specimens with ultrasound elasticity and strength meter, correlation between those measurements is better than when measuring with the device „Timber Grader MTG". In the first case the best correlation is among 145 mm width specimens and the worst is among 170 mm specimens. However, when using the device „Timber Grader MTG" correlation is poor and connection between module of elasticity and density is weak. After performing statistic evaluation of results it is received that 75mm width specimens' modulus of elasticity evaluated by using „Timber Grader MTG" is moderately 10 % higher than the one measured with ultrasound elasticity and strength meter when the density is the same. When the width of the specimen is 145 mm the module of elasticity is 8 %, and when the width is 170 – 12 %.
Dynamic modules' of elasticity connection is given in Fig. 3.

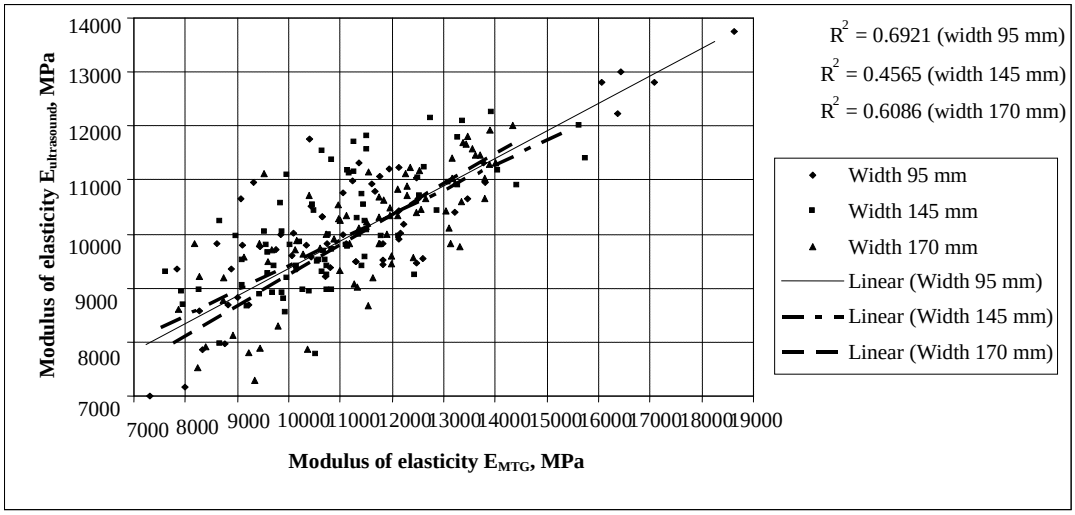


**Fig. 3** Dynamic modulus of elasticity correlation (three-width specimen).

It is seen from the picture 3 that there is a good internecine relation between dynamic modulus of elasticity which were measured using two different methods. Modulus of elasticity correlate best when the width of the specimens is 95mm, the worst correlation is at 145 mm. Despite this, after statistic analysis was done it was noticed that the lowest difference of modulus of elasticity was received for 145 mm width specimens. It is almost 8 %. Meanwhile, this difference for 95 mm width specimens is almost 10 % and for 170 mm specimens – almost 12 %. In all cases higher modulus of elasticity is received by using the device „Timber Grader MTG".

Distribution of rates, measured in two different non-destructive methods is given in Fig. 4.

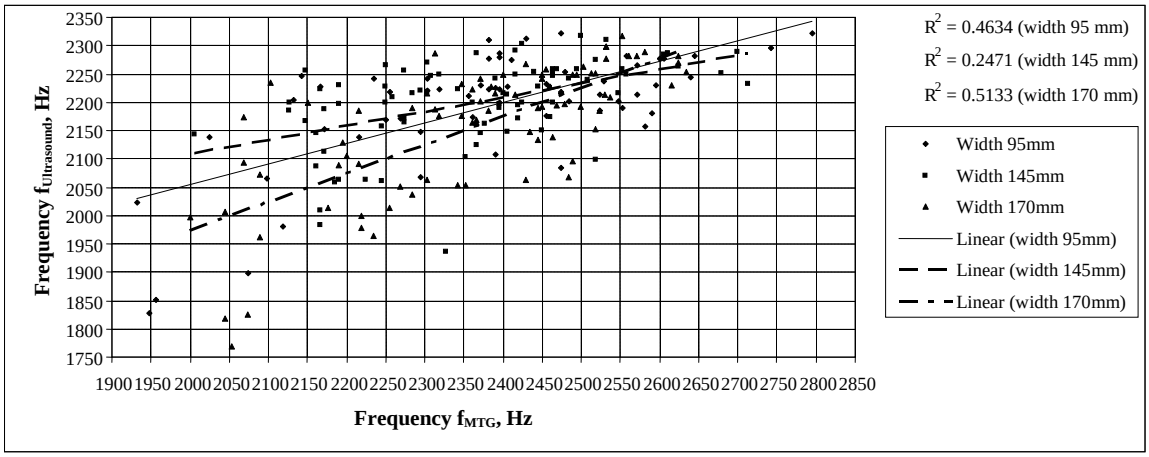


**Fig. 4** Internecine relation of frequency rates (specimens of three widths)

It is seen from the figure 4 that there is average strength correlation between determined wood own range rates. The rates correlate best when the width of the specimens is 170 mm and the worst correlation is at 145 mm. After statistic analysis was done it was noticed that the rates measured with „Timber Grader MTG" are higher at 8 % when the width of the specimens is 95 mm and at 7 % when the width is 170 mm compared to the rates measured with ultrasound meter.

Modulus' of elasticity variation tendencies when the wood density and own range rates vary while measuring with „Timber Grader MTG" were calculated. It was found that 95 mm width specimens' modulus of elasticity measured with "Timber Grader MTG" increases when the density of the wood and frequency rate increases. Modulus of elasticity in this case can be calculated using the following function:

$$MOE_{MTG} = -23497.8 + 22.6\rho + 9.7f, \qquad \text{Eq. 3}$$

here: $MOE_{MTG}$ – „Timber Grader MTG" is used to measure dynamic modulus of elasticity, N/mm$^2$;

$\rho$ – density of the wood, kg/m$^3$;

$f$ – frequency, Hz.

Correlation of those values is strong because good correlation coefficient is received. (R = 0.993). Strong correlation (R = 0.986) between modulus of elasticity, density of wood and frequency rate is received when examining the

specimens of 145 mm width. Function describing those values is: $MOE_{MTG} = -21279.3 + 21.2\rho + 9.1f$. When the width of the specimens is 170 mm strong correlation is also received (R = 0.991). Modulus of elasticity can be described by the following function: $MOE_{MTG} = -21826.8 + 20.0\rho + 9.6f$.

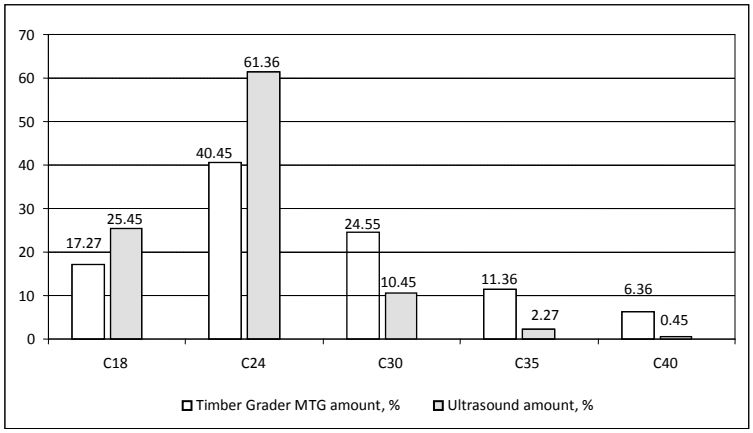


**Fig. 5** Pine wood specimens' distribution into strength classes („Timber Grader MTG" and ultrasound elasticity and strength meter)

As it is seen from the picture using both non-destructive methods the biggest number of specimens got to C24 strength class. Higher percentage of the specimens measured with ultrasound got to the group C18, and the ones measured with acoustic method got to the group C30. Because of this, Lithuanian pine wood correspond European Union raised requirements for structural wood and can compete with the same type wood of other countries.

## CONCLUSIONS

1. Higher dynamic modulus of elasticity (MOE) is received when exploring wood using acoustic method rather than when exploring with ultrasound. MOE spread depends form measurement elements (in this case the width), density of the wood and resonant rate.
2. Correlation between MOE, examined with „Timber Grader MTG" and MOE, examined with ultrasound elasticity and strength meter is good, so we can make a conclusion that those means can quickly and reliably measure elastic wood qualities and relate them with strength by bringing them into strength classes.

3. Dynamic modulus of elasticity functions expressed through the wood frequency rate and density are of a similar character when the wood is examined by both non-destructive methods. Those three values have very strong correlations.
4. The biggest percentage of the pine specimens got to the C24 strength class. Wood of such strength qualities is widely used in construction industry and can be used for bearing structures.

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# HIGH CAPACITY TIMBER SAWING BASED ON ACCURATE LOG SCALING

Gjerdrum, P.[1] & Hamar, B.[2]

## ABSTRACT

Commercial timber sawing is always done in trade-off between yield and capacity, between cost of raw material and of production. Accurate knowledge of the dimensions for every single log is needed for successful breakdown. Traditionally, mills sawing to customers' order, i.e. timber lots of given dimension and quality, start the breakdown process by scaling and sorting unbarked logs. However, accuracy can be greatly improved if scaled after barking. Scaling barked logs to adapt sawing pattern to each log inevitably slows down production speed, and also produces a variety of sawn boards besides the ordered one. The goal of the project described in this paper was to optimise the yield while maintaining high capacity and sawing to order. A modern, medium-sized sawmill producing ca. 60 000 $m^3$ spruce timber annually was about to renew the sawlog intake. A two-stage log scaling/sorting and sawing twin mini-series was concluded. The first stage is the traditional sorting of unbarked logs. In the new intake, when the order is to be produced, logs are debarked before a second scaling with a 3D scanner based on laser beams reflected from the smooth and bright log surface. Logs are directed to either of two log decks, or buffers, each of ca. 25 logs, and sawn in twin mini-series alternating between the two. Sorting criteria might be purely diameter, log length, quality prediction generated from log geometry, or a combination. The sawn timber yield was increased by up to 3 000 $m^3$ annually, corresponding to the contribution margin improved by 3 mill. NOK or more. Production speed is increased by ca. 4%, but producing two orders simultaneously increases planning complexity, requiring additional training for involved personnel. It can be concluded that the chosen set-up: Two-stage log sorting with accurate

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scaling in the final sorting and sawing twin orders in alternating twin mini-series, has proved successful with respect to sawn timber recovery and production capacity.

Key words: log scaling, dual mini-series, production capacity, twin orders.

## INTRODUCTION

In mature industries like sawmilling, profit margins are generally rather small, but, fortunately, also quite consistent. Any sawmill will have to improve the efficiency year by year, and only the most competent companies will survive.

Cost of raw material and of operating and depreciating the sawmill is crucial for the overall profit. Increasing the yield of sawn timber from available sawlogs and fine-tuning production routines to improve the production speed will always be part of a sawmill's struggle to advance profitability.

Scandinavian sawmills operate in two different modes: Either sawing unsorted logs, producing all falling dimensions and qualities. Customers' orders will subsequently be sorted out of the available stock of sawn timber. The other group does even the primary breakdown according to the customer's order, termed "sawing to order". These mills need a substantial stock of sawlogs, sorted into lots possibly homogeneous in dimension and quality. As most sawmills prefer to keep the logs unbarked in the stock, sorting accuracy is negatively influenced by variation in bark thickness and bark damages; this inaccuracy causes yield losses during breakdown. Consequently, such lots are termed "rough-sorted". Assuming independent factors, the resulting accuracy in scaling sawlog diameter can be estimated from Eq. 1 (Gjerdrum & Høibø 2000):

$$s^2_{SortingDiametreUnderBark} = s^2_{BarkThickness} + s^2_{BarkDamage} + s^2_{Ovality} + s^2_{ScannerAccuracy} \quad \text{Eq. 1}$$

In modern scanners, the 95 % confidence interval for sorting diameter under bark was estimated to approximately ±8 mm for unbarked spruce and ± 4 mm for barked logs.

A typical set-up for "sawing to order" mills is to do keep a stock of unbarked logs. When the breakdown process is to be started, logs pass through the "log in-take": Logs are singulated, turned to small-end first, debarked and scaled, usually in a 3D log scanner, to control the immediate in-feed to the saw. This second and more accurate scaling might be used to increase the yield by adjusting the saw to an individual breakdown pattern for each log. However, the

adjustment takes a certain amount of time, leading to reduced production capacity and increased cost.

The idea of the work presented here was to analyse the profitability of dividing the rough-sorted lot into two, thicker and thinner, by accurate sorting after barking; these logs to be accumulated in two independent log decks (buffers) and subsequently sawn in alternating dual mini-series.

## MATERIAL AND METHODS

A major Norwegian sawmill was about to rebuild the "log in-take". Several options were available, and following initial analyses, the mill decided on an additional 3D log scanner based on laser beams reflected from the smooth and bright log surface immediately after debarking, and two independent log decks (Fig. 1). Each deck is fed based on observations made by this scanner on the barked logs (Fig. 2), either pure dimension or predicted timber quality or a combination. Dual orders are produced, alternating between the decks, each in a preset sawing pattern. The mini-series is some 20-30 logs. In this way, production losses caused by changing the sawing pattern are kept low. Rebuilding the log in-take took place during the summer 2009. A number of observations have been done to evaluate the investment; in this report we have focused on yield and capacity.

**Fig. 1. Barked logs sorted to the twin log decks.**

Statistical reports for 226 production orders have been recorded and analysed, representing 40 800 $m^3$ sawlogs before and 41 100 $m^3$ logs after the investment, for a total of 81 900 $m^3$ or nearly 404 000 logs. Only lots sorted according to diameter were included. Log and yield characteristics, order information and production description were recorded and analysed statistically. The information is collected from various sources along the primary breakdown chain, mostly automatically generated. It should be considered that no such observation is perfectly correct and that cut-off between orders might be inaccurate; however, all figures have been screened and assessed, and only sensible datasets were kept.

Average yield depend most notably on the small end diameter; consequently, average yield per diameter class for all different sawing patterns were calculated. Next, analytic-empirical regression models for main and total yield, respectively, were established for the before and after investment observations. Details for model estimation are given in Gjerdrum (2007). Available log supply has averaged to 120 000 $m^3$ annually (equivalent to ca. 60 000 $m^3$ sawn timber annually), exclusively Norway spruce. To have a possibly plain and straightforward differential calculation before-after, most input values were kept unchanged, e.g. diameter classes and sawn timber prices. However, the mix of sawing pattern has certainly changed due to the ever-changing dynamics in customers' preferences. Sawn timber prices were set to 1 400 and 1 000 NOK (ca. 175 and 125 EUR, with exchange rate 1:8) for main yield and sideboards, respectively; all prices net FOB per $m^3$.

**Fig. 2. Even if not perfect, scaling accuracy is greatly improved after barking – whether scaled by calliper or in a 3D scanner**

# RESULTS AND DISCUSSION

## Sawn timber yield

The yield increase has been verified in two different ways. First, the average outcome from each of the 20 applied diameter classes were compared (Fig. 3). A substantial improvement is readily seen, both for main yield and sideboards. The additional gain in sawn timber, weighted by log volume in each class, adds up to 1 681 $m^3$ main yield and 1 386 $m^3$ sideboards, total 3 067 $m^3$.

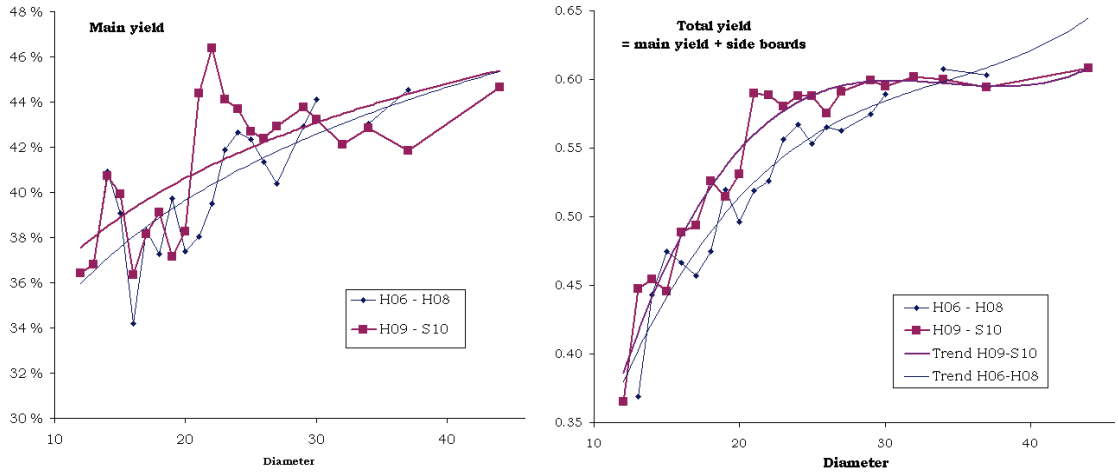


**Fig. 3. Main yield and total yield both increased considerably from before (H06-H08) to after (H09-S10) the investment**

The "peaks and downs" in the main yield graph (left part of Fig. 3) can be explained in this way: Most volume is asked for 100 and 150 mm wide centre boards. The highest yield is achieved when sawing a quadratic pattern, and then these two widths correspond to ca. 15 and 22 cm diameter – exactly where the highest yield can be found. For other diameters, either non-quadratic main yield or over-sized logs are frequently used, and consequently lower recovery. However, as can be seen from the smother curve in the right part of Fig. 3, most of the loss is regained as sideboards. The gain corresponds to 3.0 mill. NOK annually.

Second, recovered yield were calculated applying the analytical-empirical regression model (Gjerdrum 2007), with separate models estimated for before and after investment periods, respectively. The yield was calculated for a number of typical sawing patterns (Table 1.) and scaled to annual volume.

Additional yield estimated this way is 2 348 $m^3$ total sawn timber (1 020 $m^3$ and 1 328 $m^3$ for centre and side boards, respectively), corresponding to increased revenue 2.1 mill. NOK. As the increased volume is produced from an unchanged sawlog input, the added value equals the added revenue.

**Table 1. Summary of results from before-and-after results calculated by the regression models for typical orders and scaled to annual volume**

| Diam, cm | no. of logs | Typical saw pattern | Log volume m3 | Additional yield m3 | Gross revenue NOK | Added revenue NOK |
|---|---|---|---|---|---|---|
| 13 | 1000 | 2 * 38 * 100 | 95.6 | 1.5 | 66 189 | 1 240 |
| 14 | 1000 | 2 * 50 * 100 | 108.8 | 0.2 | 79 027 | 500 |
| 17 | 1000 | 2 * 50 * 125 | 148.4 | 4.3 | 113 020 | 3 923 |
| 20 | 1000 | 2 * 50 * 150 | 196.6 | 6.8 | 149 575 | 5 779 |
| 21 | 1000 | 2 * 63 * 150 | 216.9 | 9.2 | 177 150 | 8 024 |
| 24 | 1000 | 2 * (38+44) * 150 | 283.1 | 5.7 | 228 786 | 5 631 |
| 26 | 500 | 2 * (38+44) * 175 | 162.9 | 4.4 | 134 805 | 4 180 |
| 29 | 500 | 4 * 44 * 200 | 186.0 | 3.8 | 156 659 | 3 715 |
| 32 | 500 | 4 * 50 * 200 | 225.5 | -0.5 | 181 005 | -310 |
| 37 | 500 | 4 * 50 * 225 | 270.2 | 1.7 | 210 072 | 1 025 |
| Sum | | | 1894.1 | 37.1 | 1 496 290 | 33 706 |
| Additional raw material and production cost | | | | 0.0 | | 0 |
| Additional contribution margin | | | | | | |
| | - for chosen lots | | | 37.1 | 1496289.5 | 33 706 |
| | - scaled to annual volume | | 120 000 | 2 348 | | 2 135 497 |
| | | | | | | 2.3 % |

## Other effects of the investment

The breakdown capacity has undoubtedly increased, as has been experience in a number of – mostly minor – challenges that need consideration and adjustment to obtain a smooth production flow. It is well known, that when capacity is increased in one part of a production line, new bottlenecks will emerge in other locations, so this was no big surprise. At the time of reporting, the overall weekly capacity has increased ca. 4%, the joint effect of straight sawing with fixed pattern for the mini-series and reduced down-time for the new section of the sawmill.

The most serious bottleneck now is kiln capacity, due to changed situation for production assumption. At the time of deciding the new log in-take, the assumption was to produce an unchanged volume of sawn timber, consequently reducing sawlog input and production time. After experiencing higher demand

for sawn timber and the successful operation of the new equipment, however, this was changed to producing at full capacity the same weekly hours as before, considerably increasing the weekly sawn volume – and running into a kiln bottleneck. At the time of writing, the solution for this has not been decided.

Also, labour cost and maintenance have been reduced. However, some additional cost to fine-tune all new equipment must be accepted.

Reduced cost for higher capacity has been estimated to 0.4 mill. NOK and reduced labour cost to 0.35 mill. NOK annually. Thus, sum calculated additional contribution margin adds up to 2.9 to 3.7 mill NOK per year.

## CONCLUSIONS

The idea of the work presented here was to analyse the profitability of dividing the rough-sorted lot into two, thicker and thinner, by accurate sorting after barking; these logs to be accumulated in two independent log decks (buffers, Fig. 1) and subsequently sawn in alternating dual mini-series. It can be concluded that the chosen set-up has proved successful with respect to

- sawn timber recovery, and
- production capacity.

Corresponding to these improvements and reduced need for labour and maintenance, the contribution margin increased 3 mill NOK or more annually.

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# PREDICTION MODELS FOR DENSITY IN STEMS OF *PICEA ABIES* (L.) KARST. AND *PINUS SYLVESTRIS* L. IN SOUTHERN NORWAY

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## ABSTRACT

Random coefficient mixed models were developed to predict vertical and horizontal density variations in stems of Scots pine and Norway spruce. Modeling and validation were based on investigations of 132 spruce and 60 pine trees in southern Norway. Density was measured on discs and small clearwood samples that were taken from 4 different tree heights (stump, 25%, 50%, and 75%). In pine, the common vertical trend in disc density increased with approx. 100 kg m-3 from the stump to the top; the level of this trend, however, varied strongly among trees. The horizontal density trend was less clear than the vertical one and considerably differed between pine trees. Within trees, it was strongly dependent on the tree height position. The most accurate model for density in pine included the following explanatory variables: the ratio of tree height to diameter at breast height, diameter of stem disc with bark, bark volume on disc, and ring width. Validation on independent material gave R2 of 0.45 for density of clearwood samples.

In spruce, the vertical difference of density was low as compared to pine. The average disc density was approx. 15 kg m-3 higher at 75% tree height than at the stump. In vertical direction, density varied considerably between spruce trees. Silviscan measurements revealed that density rapidly decreased by approx. 100 kg m-3 within the first 5 annual rings. Differences between the average densities of clearwood samples were not statistically significant at any tree height level. The most accurate model gave an R2 of 31% in the validation procedure. The model included sample position, site index, diameter at breast height, and bark volume as input variables.

Key words: density, random coefficient mixed models, wood quality prediction

# INTRODUCTION

Wood density has a great importance for manufacturing processes and quality of forest-based products, which has aroused a growing scientific interest to create models for predicting density in recent years (Duchesne et al. 1997; Kellomäki et al. 1999; Lindström 2000; Wilhelmsson et al. 2002; Repola 2006; Mäkinen et al. 2007; Ikonen et al. 2008; Steffenrem et al. 2009).

In the sawmilling industry, only few factories have density measurement systems for green boards although technology is available in form of weighing methods or X-ray technology. Such equipment, however, needs some kind of moisture content approximations either through inline measurements or quality control of drying batches. This implies that the use of this equipment at an early stage in the process gives poor density estimates due to the strongly varying moisture content in logs and green boards (Brännström 2005). A prediction of density will consequently improve the saw milling process in terms of both grade yield and production efficiency. The simplest systems for a saw mill could be to predict density from the dimension of the boards and the position in the cross section. (Steiner and Øvrum 2010). More advanced prediction models could include forest data like stand variables, tree variables, and what log in the tree the logs come from (Duchesne et al. 1997; Bergstedt and Olesen 2000; Lindström 2000; Wilhelmsson et al. 2002; Mäkinen et al. 2007).

The present study has the objective to extend the knowledge on density variation in Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L). In this context, linear mixed models were developed based on investigations of 132 spruce and 60 pine trees in southern Norway to predict horizontal and vertical density variations in stems. The investigations are part of the project "Wood quality predicting systems as a tool for differentiation and sorting of wood raw material" (Norwegian Research Council, project no. 178330) that aims to create better utilisation of Norwegian forest resources.

# MATERIAL AND METHODS

## Material

The sampling procedure included stratification with regard to stands, tree status, and sample extraction within the stem. The spruce material came from 22 stands (12 natural regenerated and 10 planted) and the Scots pine material from 10 stands (all natural regenerated) in southern Norway. For each stand, twenty-four trees were randomly chosen in an area of approx. 500 $m^2$. The tree

diameter was measured at breast height (DBH, ~1.3 m above ground). The trees were grouped into tree diameter classes based on the diameter. One tree per diameter class was randomly sampled, resulting in 2 suppressed, 2 co-dominant, and 2 dominant tree per stand.
Eleven site variables, 26 exterior tree variables, and 28 variables describing wood properties were recorded. Site indexes (SIT) were calculated for each tree, based on tree height and age and the H40 functions for Scots pine and Norway spruce (Tveite and Braastad 1981). The site index of each stand (SI) was derived from the SIT of the dominant trees. Discs with a thickness of 30-50 mm were taken at 4 different heights of each tree ($H_1$ = stump, $H_2$ = 25%, $H_3$ = 50%, $H_4$ = 75%).
Small clearwood samples with a dimension of 20 x 20 mm (radial x tangential) were taken along an axis from pith ($R_1$) to bark ($R_n$) from the west face of the discs ($H_1$-$H_4$). The basic density of the clearwood samples was determined according to Skanorm 4 (Kučera 1992) in order to map the density variation in radial and vertical direction along the stems.
In addition to the clearwood samples, a pith-to-bark bar was sawn from the west face of discs of 30 pine and 30 spruce trees. Samples were free of knots and obvious compression wood. The mean density and width of each annual ring was measured with the SilviScan-system (Evans 1997) at Innventia (formerly STFI-Packforsk) in Sweden and The Commonwealth Scientific and Industrial Research Organisation in Australia.

**Models for density in spruce and pine stems**

The variation in density was modeled, by linear mixed models, using the individual tree as a random effect. The random and fixed effects were assessed by using the Restricted Maximum Likelihood (REML) estimation of the software JMP (Version 7.0.0. SAS Institute Inc.) in compliance with Littell et al. (2006). The random elements were assumed to follow a normal distribution.
The models were stepwise developed on the dataset of 13 spruce stands and 6 pine stands. Initially, the horizontal and vertical profile of density in the stem was described with the radial position (R) and vertical position (H) of the clearwood samples.
The variable ln (H+1) was used instead of ln (H) to avoid a zero value when H=1. Random effects for the intercept and the R-elements were tested by log-likelihood ratio tests ($\chi^2$; $p \geq 0.05$).
After modeling the vertical and radial density variation in stems, fixed effects were gradually added according to their type and the effort, which is necessary

to measure them: Step I=site variables, Step II=Step I and exterior tree variables, and Step III=Steps I and II and interior tree variables.
The variables were rejected at the 5% level. The Coefficient of Determination ($R^2$) and the Root Mean Square Error (RMSE) were computed based on both random and fixed effects. This is equivalent to a situation in which each tree is individually fit. Subsequently, $R^2$ and RMSE values also were calculated from residuals of the random coefficient mixed model outputs, where only the fixed effects were included.
The models were validated based on independent datasets from 9 spruce stands and 4 pine stands. The intercept and the slope of the linear regression between predicted and measured values were constrained to 0 and 1, respectively, to include the model bias and to enable valid comparisons to be made between the model step and the validation. $R^2$ and RMSE were calculated from the residuals from these regressions.

## RESULTS

In pine, the common vertical trend in disc density increased with approx. 100 kg $m^{-3}$ from the stump to the top (Fig. 1a); the level of this trend, however, varied strongly among trees. The vertical stem position solely explained 95% (random and fixed effects) in modeling and 69% (only fixed effects) in validation, respectively, of the density variation on disc level. The horizontal density trend was less clear than the vertical one and differed considerably between trees. Within trees, density profiles strongly depend on the height position in the tree. At stump and 25% tree height, density increased by approx. 30 kg $m^{-3}$ within the first radial 75 mm from pith; afterwards, it decreased slightly towards the bark. In comparison, density showed very little radial variation in upper parts of the pine stems. The radial position became insignificant in models that included both the radial and the vertical stem position as independent variables. The most accurate model for density in pine (Table 1, model IIIa P) included as explanatory variables the ratio of tree height (TH) to diameter at breast height (DBH), diameter of stem disc with bark (DDB), bark volume on disc (BVB), and ring width (RW). A similar model including an estimation of RW with diameter of disc without bark (DD) and ring number (RN) gave lower $R^2$ (Table 1, model IIIb P). Validation on independent material gave $R^2$ of 0.45 (Table 2, model IIIa P) and 0.36 (Table 2, model IIIb P) for density of clearwood samples, respectively.
For spruce, the vertical variation in density was low compared to what was found for pine. The average disc density was approx. 15 kg $m^{-3}$ higher at 75% tree height than at the stump. The vertical profiles varied considerably between

the trees, and several trees showed no increase or even a negative trend in density towards the top of the stem. Silviscan measurements revealed that density rapidly decreased by approx. 100 kg $m^{-3}$ within the first 5 annual rings. In the following, density slightly decreased by further 20 kg $m^{-3}$. A radial trend was however scarcely seen in the comparison of densities of clearwood samples. Differences between the average densities of clearwood samples (R-positions) were not statistically significant at any tree height level (Tukey HSD test, $p$ = 0.05). The most accurate model gave an $R^2$ of 31% in the validation procedure. The model included sample position, site index, diameter at breast height, and bark volume as input variables (Table 2, model II S). The use of inner tree variables, such as ring width (RWD) or ring number (RN), did not result in more accurate predictions (Table 2, model III S).

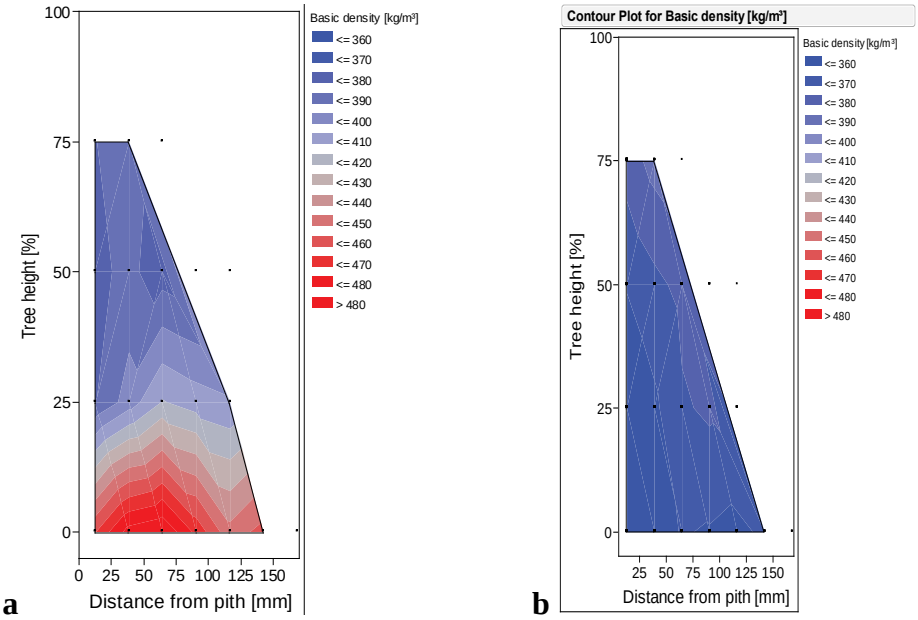


**Fig. 1:** Mean density variation in stems of Scots pine (a) and Norway spruce (b) derived from basic density measurements on clearwood samples. Each stem position is represented with n ≥ 10.

**Table 1:** Models for density with variance components and summary statistics for the comparison of modelled and measured values of density. Only models with significant variance-component estimates and significant parameter estimates of fixed effects are presented.

**Variance components and summary statistics**

| Variance components | Step (model no.) | | | | | | |
|---|---|---|---|---|---|---|---|
| Source | I P | II P | IIIa P | IIIb P | I S | II S | III S |
| Tree | 825.89 | 746.48 | 666.83 | 745.12 | 453.05 | 344.62 | 444.72 |
| H * tree | | | | | 164.84 | 145.46 | 101.87 |
| R * tree | | | | | 144.98 | 146.69 | 148.05 |
| ln (H+1) * tree | 38.96 | | | | | | |
| Residual | 904.25 | 1046.13 | 914.83 | 1033.61 | 1243.58 | 469.23 | 471.07 |
| **Summary statistics. including fixed and random effects** | | | | | | | |
| $R^2_{adj}$ | 0.79 | 0.75 | 0.78 | 0.75 | 0.71 | 0.72 | 0.72 |
| RMSE [°] | 30.07 | 32.34 | 30.25 | 32.15 | 21.90 | 21.66 | 21.70 |
| **Summary statistics. including fixed effects** | | | | | | | |
| $R^2_{adj}$ | 0.38 | 0.53 | 0.57 | 0.52 | 0.09 | 0.18 | 0.15 |
| RMSE [°] | 46.93 | 42.28 | 40.37 | 42.77 | 34.48 | 32.76 | 33.27 |

**Models without random effects**

| | |
|---|---|
| I P | 548.22 – 24.92 * ln (H+1) + 5.23* H40 |
| II P | 302.27 - 5.83 * H40 + 113.81 * TH/DBH + 0.26 * DDB + 4.1 BVD |
| III Pa | 273 + 89.29 * TH/DBH + 0.26 * DDB + 3.87 BVD – 18.85 * RW |
| IV Pb | 350 + 0.22 * DDB + 4.54 BVD – 28.75 * (0.5 * DD/RN) |
| I S | 392.27 + 7.24 * H + 5.09 * R - 2.83 * H40 |
| II S | 390.72 + 4.07 * H +5.95 * R – 2.49 * H40 – 0.12 * DBH + 3.42 * BVD |
| III S | 409.07 + 9.31 * H + 5.93 * R – 0.11 * DBH – 22.30 * RWD |

**Table 2:** Validation statistics on models for pine (P) and spruce (S).

| Model | Fixed-effects | $R^2$ | RMSE [°] |
|---|---|---|---|
| I P | ln (H +1), H40 | 0.36 | 47.70 |
| II P | H40, TH/DBH, DDB, BVD | 0.40 | 46.83 |
| IIIa P | TH/DBH, DDB, BVD, RW | 0.45 | 45.59 |
| IIIb P | TH/DBH, DDB, BVD, DD, RN | 0.36 | 50.80 |
| I S | H, R, H40 | 0.23 | 34.84 |
| II S | H, R, H40, DBH, BVD | 0.31 | 32.93 |
| III S | H, R, H40, DBH, RWD | 0.23 | 34.20 |

# DISCUSSION

The results reveal that the density of a wood piece from a pine log can be quite accurately predicted just by using the information on the vertical origin of the piece (Table 1 and 2, model I P). The addition of information about site index of the stand, tree height, diameter of breast height, and bark volume at specific height increased the $R^2$ values with 4 % (Table 2, model II P). Such variables are available though the forest inventories and can also be derived from the information a harvester measures during processing the tree. When using information about ring widths, $R^2$ increased to 45% (Table 2, model IIIa P). It has been frequently reported that density is closely related to ring width and cambial age (Johansson 1993; Pape 1999; Molteberg and Høibø 2007; Jyske et al. 2008). Such variables are difficult to obtain in industrial processes. The challenge therefore is to create models with easily recordable variables (Wilhelmsson et al. 2002). This implies that variables, which are difficult to measure, must be explained by subjacent models, as it is seen at the models developed in the Indisputable Key project (Sixth Framework Programme, project no. 34732). The application of an expression for ring width with stem diameter and ring number (Wilhelmsson et al. 2002) reduced $R^2$ by 9% (IIIb P). Ring number must however be estimated by another sub-model. An alternative to sub-models is to use automated measurement for inner log properties, such as the BoardMaster-EndSpy of the company FinScan. Although the measurement algorithms of such scanning systems are still debated, the current development suggests that these systems will become state-of-the-art in industrial processes (Brüchert et al. 2008).

The vertical and horizontal trends for density in spruce comply with findings reported in most earlier studies (Nylinder and Hägglund 1954; Foslie and Moen 1968; Frimpong-Mensah 1987; Høibø 1991; Kučera 1994; Lindström 1996; Vestøl et al. 2001; Raiskila et al. 2006). The models for density in spruce trees gave poor estimations for density (models I-III S). This can probably be ascribed to the low in-tree and between-tree variation of density in the dataset, which is based on forest stands in southern Norway. Wilhelmson (2002), for example, developed a model explaining approx. 50% of the density variation in spruce, which was based on 252 trees coming from stands throughout Sweden.

Steiner and Øvrum (2010) carried out a case-study in a sawmill on the effect of pre-sorting of spruce boards with a dimension of 50 x 200 mm on density. The average density of inner boards, i.e., boards closer to the pith, was 18 kg $m^3$ greater than that of outer boards, which results in a theoretical reduction of drying time by approx. 10%. However, the low variation in vertical and especially in radial direction of spruce trees suggests that pre-sorting of spruce

boards is of limited value. Further research is going on to investigate the applicability of pre-sorting and prediction models in industrial processes.

## SUMMARY AND CONCLUSIONS

- the vertical position accounts for most of the density variation in stems of pine
- the density variation in vertical direction of spruce stems is much lower than in pine stems
- the radial position is of little importance for density prediction for both pine and spruce
- the most accurate prediction model for density in pine stems explained 45%
- the most accurate prediction model for density in spruce stems explained 31%
- all necessary input information for the models are obtainable from forest inventories, harvester measurements, and scanner technologies for industrial application

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# THE FUTURE OF MOISTURE DETERMINATION

Fernández Cano, V. [1] & Hultnäs, M.[2]

## ABSTRACT

The gravimetric method that is used today to determine the moisture content in wood is very tedious. The results are received after 24 hours, and it can be quite hard to use the achieved information in industrial processes. We have tested a new method based on X-ray to determine the moisture content in wood. It is a fast method ≈ 1 min/measurement, and in difference to many other techniques. Results achieved with this method on wood chips (Scots pine, Norway spruce and birch) have shown good agreement with the gravimetric method that has been used as a reference method. Standard deviation has been low, around 0.4-0.9 percentage points for repeatable measurements on the same sample.

**Key words:** Moisture content, Norway spruce, determination of moisture content, dry matter content.

## INTRODUCTION

To know the moisture content (mc) in wood is needed in many different situations. The knowledge of mc helps for example to control chip impregnation and refiner control in the pulp industry. Besides, mc determination can also be of interest for energy plants and board-mills; because by monitoring the mc in the flow of wood chips to the process, some parameters can be adjusted to optimize the process. Furthermore, in parts of the world (for example, Sweden and Germany) the compensation between sellers and buyers of wood chips are based on the dry weight of the fibers.

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The gravimetric method used nowadays is considered to be accurate, but it requires time (24 hours per sample) and is rather laborious. Over the years many studies have been conducted to try to find other techniques that could replace the gravimetric method (1,2,3,4,5,6,7,8,9,10,11,). The results of the struggle have been poor. However, during recent years, dual energy X-ray absorptiometry (DXA) has shown good results when it comes to determine the mc in wood chips. A few studies have been made with this technique and have shown very good results (12,13). Other benefits with the technique are that it is fast, about one minute per measurement, and non-destructive.

This paper gives a summary of results achieved so far with the DXA technique for studies done on pine and spruce. It also presents new findings, with measurements done on birch.

This article is the result of the collaboration between the department of Forest Products at the Swedish University of Agricultural Sciences, who has performed the studies and the evaluation, and Mantex AB, who has developed the technique.

## MATERIAL AND METHODS

The wood chips used in these studies came from sawmills and pulp-mills in Sweden and are typically used for pulp production. The species used have been Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and birch (*Betula* spp.).

The device used in these studies was developed by Mantex AB and uses the DXA technique to determine the mc. The device uses X-ray radiation of two different wavelengths; the sample is placed in the device and scanned twice, one scan for each energy level. The sample is then attenuating some of the energies that are sent through. The quotient between the energies provides information about the composition of the material. Since every substance has a specific attenuation of X-ray energies, the device could be calibrated against samples of wood chips with known mc; the attenuation of each measurement is compared to earlier measurements of samples with known mc, and the mc in the measured sample could be determined (12,13).

The chips were measured both raw, and dried to different mc levels in order to achieve a broad range of mc. The different materials have been measured, first

by the Mantex method (non-destructive), and afterwards the reference mc was determined by the gravimetric method. This procedure was performed according to the Swedish Standard SS 187170 (14). Table 1 shows the number of samples used, number of measurements per sample and the mc range achieved for each of the studies.

Table 1. Overview of the studies performed, mc range is achieved with the gravimetric method (12, 13)

| Parameter | Scots pine | Norway spruce | Birch |
|---|---|---|---|
| **No. of Samples** | 70 | 35 | 10 |
| **No. Measurements per Sample** | 10 | 10 | 4 |
| **MC Range (%)** | 8 - 57 | 18 - 61 | 12 – 39 |

In order to calculate the average standard deviation for repeatable measurements on the same sample, Eq. 1 was used (15);

$$SD = \sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n_j}\frac{(x_{ij}-\bar{x}_j)^2}{df}} \quad \% \qquad (1)$$

Where:
$m$ is the number of samples
$n$ is the number of measurements of sample j
$x_i$ is the i:th measured moisture value of sample j
$\bar{x}$ is the mean of all the measurements of sample j.

The denominator, Eq. 2, is the total number of degrees of freedom (df) for the estimate of standard deviation formed by combining all the data. It is the sum of the degrees of freedom $df_j$ of the measurements of the samples (15):

$$df = \sum_{j=1}^{m} df_j = \sum_{j=1}^{m} (n_j - 1) \qquad (2)$$

# RESULTS

## Summary part

In order to evaluate the correlation between the Mantex method and the gravimetric method, a regression analysis of each material was performed. These are shown in figures 1-3 (12,13).

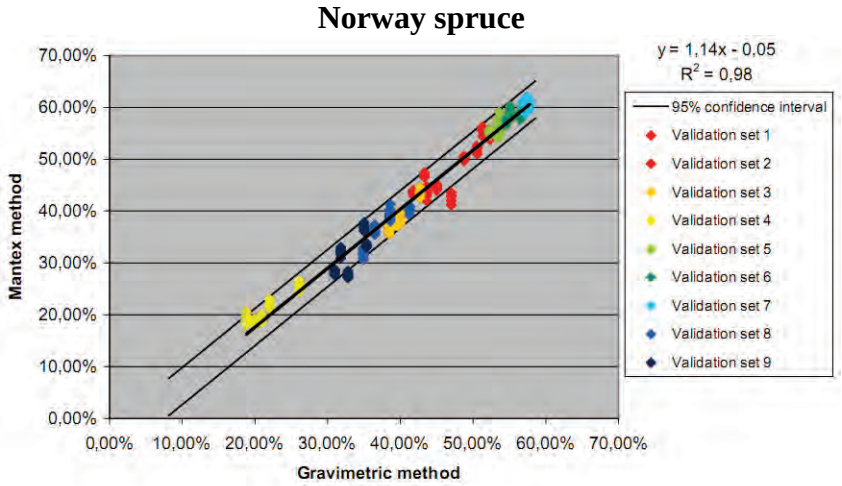


Figure 1. Correlation between the Mantex method and the gravimetric method for Norway spruce. (12).

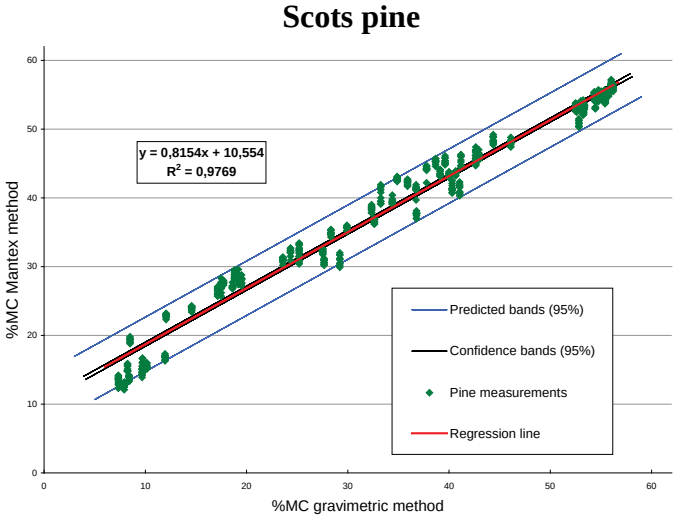


Figure 2. Correlation between the Mantex method and the gravimetric method for Scots pine. (13).

**New findings**

**Birch**

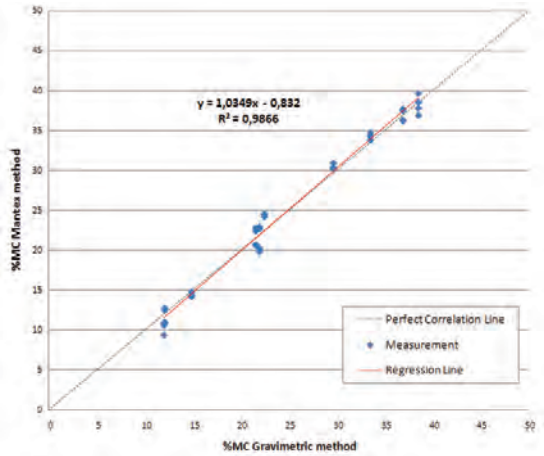


Figure 3. Correlation between the Mantex method and the gravimetric method for birch.

In table 2, the parameters of the regression analysis are shown for the different tree species. It also displays the standard deviation (SD) for repeatable measurements on the same sample and the standard error of estimate (SEE). The $R^2$ shows how well the data fits to the model.

Table 2. Summary of the results achieved for the different materials

| Parameter | Scots pine | Norway spruce | Birch |
|---|---|---|---|
| **Slope** | 0.82 | 1.14 | 1.04 |
| **Intercept** | 10.55 | -0.05 | -0.83 |
| **$R^2$** | 0.98 | 0.98 | 0.99 |
| **SEE (%)** | 2.01 | 1.83 | 1.17 |
| **SD (%)** | 0.45 | 0.53 | 0.88 |

## DISCUSSION

The DXA technique has shown excellent consensus with the gravimetric method for spruce chips, with [a] low number for the SEE (1.83%). Also the SD showed satisfactory low numbers (0.53%), which indicates that the same

result, would be achieved for several measurements on the same sample. These results have earlier been discussed by Hultnäs *et al.* (12).

The pine study that is presented shows an even lower SD (0.45%) but a little bit higher SEE (2.01%). The aim of that study was to see if the calibration model that was used for spruce, could also be used for pine. The difference on slope and intercept indicates that a separate calibration model for pine is needed. First tests have been done with a calibration model that is developed for pine, and the first preliminary results indicate that slope and intercept become much better and maintaining the SEE at the same level as it is in the spruce study. The lower SD achieved in this study could be related to the fact that wood chips from sawmills were used in this study, while in the previous mentioned study chips from round wood were used. Sawmill chips consist mainly of sapwood this due to the processing in the saw mills, meanwhile chips of round wood consist of both sapwood and heartwood and are therefore more heterogeneous, in it chemical composition. Since the absorption of the X-ray energies takes place in the atoms, the result of measurements will be dependent on how big chemical variation can be found in the measured sample, a more heterogeneous material will lead to a higher SD (13).

The study of birch is not as robust as the ones performed for spruce and pine, due to the limited amount of samples that has been measured for birch (10 samples, while it has been 35 samples measured for spruce and 70 samples for pine) and the smaller mc range achieved in the study. Still, the DXA technique has shown excellent consensus with the gravimetric method for birch chips. The results are at very low levels with a SEE of 1.17% and a SD that is 0.88%. The SD is a little bit higher than the ones obtained in the studies of pine and spruce but, is still well below 1%, which must be seen as fully acceptable results. The most likely explanation for this higher SD is the low amount of measurements per sample performed in comparison to the spruce and pine studies.

# CONCLUSIONS

The studies show that for the three species it is possible to accurately and precisely determine the mc to a certain extent. It seems that the difference in chemical composition between the tree species creates a need to develop different calibration models for the Mantex method.

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# VARIATION IN STRENGTH PROPERTIES OF SCOTS PINE WOOD AFTER TWO DIFFERENT HEAT TREATMENTS

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

## ABSTRACT

Investigations to improve the durability and dimensional stability of wood using heat treatment have been carried out since the early 20th century. Despite quite a long history of research work, industrial scale manufacturing of heat treated wood is still in its beginnings in Finland. To better control the properties of heat treated wood, two classes – Thermo-S and Thermo-D – were introduced in 2003. Thermo-S (190 ºC, classified as moderately durable according to EN 113) is recommended for indoor objects, e.g., fixtures and furniture, whereas Thermo-D (212 ºC, classified as durable according to EN 113) is suitable for outdoor purposes, e.g., claddings, environmental structures and garden furniture.

The aim of the study was to find out how uniform industrially produced heat treated wood is considering wood strength. Scots pine planks after Thermo-S and Thermo-D treatments were provided by a significant Finnish manufacturer. The planks were first machined to sample pieces for two loading tests: static bending (ISO 3133) and compression (ISO 3132). Before testing the strength with Lloyd Instruments EZ50 device, wood density and average ring width were determined. About 100 samples per treatment were measured. Untreated pine wood was used as a reference material. The data was analysed with statistical methods.

Bending strength was about 15% higher in Thermo-S than in Thermo-D treatment, whereas the average compression strength was slightly higher for

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Thermo-D samples. Strength properties increased linearly with increasing wood density. Variation in the strength properties was large due to large variation in growth rate and wood density.
Key words: Scots pine, heat treatment, strength properties

# INTRODUCTION

Investigations to improve the durability and dimensional stability of wood using heat treatment have been carried out since the early 20$^{th}$ century. Despite quite a long history of research work, industrial scale manufacturing of heat treated wood is still in its beginnings in Finland. To better control the properties of heat treated wood, two classes – Thermo-S and Thermo-D – were introduced in 2003. Thermo-S (190 ºC, classified as moderately durable according to EN 113) is recommended for indoor objects, e.g., fixtures and furniture, whereas Thermo-D (212 ºC, classified as durable according to EN 113) is suitable for outdoor purposes, e.g., claddings, environmental structures and garden furniture. Heat treated wood is not recommended for uses with permanent ground contact (ThermoWood® Handbook 2003).

Heat treatment increases wood durability, especially against rot. The disadvantage is the deteriorated mechanical properties, although mild treatments may even improve certain mechanical properties (Esteves and Pereira 2009). For example, experiments with Norway spruce show that the modulus of rupture (MOR) can be half smaller in the treated samples compared to untreated (Borrega and Kärenlampi 2008). The deterioration of properties heavily depends on mass loss of wood in the treatment.

Mechanical properties of wood depend on density and properties of cell wall (Gibson and Ashby 1997), whereas the properties of cell wall depend, among other things, on the moisture content. Under fibre saturation point, the strength and stiffness of wood usually increase as the moisture content decreases. On the other hand, the heat treatment changes the ability of cell wall to absorb moisture: in a given air moisture content, heat treated wood absorbs markedly less water than untreated wood (Esteves and Pereira 2009). This also affects the mechanical properties of wood. It has been shown that the MOR of heat treated wood can be larger than MOR of untreated wood, when compared in the same ambient moisture content (Borrega and Kärenlampi 2008).

Wood density varies considerably within tree species, and therefore also the mechanical properties have a large variation. Variation in properties is problematic from the end-use point of view, and preferably the raw material should be as homogenous as possible. Two interesting questions are raised in

this study: how large is the variation in strength properties in commercial heat treated wood, and does the heat treatment increase variation in mechanical properties? The first question interests end-users, when they choose material to their applications, whereas the second question interests manufacturers, who also would like to have means to reduce variation in their products.

## MATERIAL AND METHODS

The study material was provided by a big Finnish manufacturer pruducing heat treated wood. The planks (32 x 100 mm in size) represented the classes Thermo-S and Thermo-D, and were originally produced for terrace deckings. The planks were first sawn and planed into test pieces for static bending 20 x 20 x 300 mm in size (ISO 3133). The distance between the centres of the supports was 240 mm. After performing the bending tests, pieces of 20 x 20 x 30 mm were sawn from sound parts of the specimens for compression tests (ISO 3132). Set-ups of the tests are illustrated in Fig. 1. Furthermore, the following characteristics were determined.

*Average ring width (growth rate), mm* – Distance between the furthermost visible (whole) rings devided by the number of rings. Average ring width was measured from one cross-cutting in every piece.

*Wood density, kg/m*$^3$ – Mass of sample devided by volume of sample. Wood density was determined from every piece.

*Moisture content (MC), %* – Mass of water in sample devided by oven-dry mass of sample. MC was determined from every 10$^{th}$ piece.

In order to have some reference, Thermo-S and Thermo-D treated wood was compared to untreated pine wood. Characteristics of these three groups are presented in Table 1.

**Fig. 1.** Set-up for static bending (left) and compression (right) tests. (Photos: Juha Rikala)

**Table 1.** Characteristics of the study material. Mean values of the properties with standard deviation in parentheses are given.

| Study material | No. of samples | Ring width, mm | Wood density, kg/m$^3$ | MC, % |
|---|---|---|---|---|
| **Thermo-S** | 96 | 3.2 (1.7) | 407.0 (24.7) | 4.7 (0.2) |
| **Thermo-D** | 113 | 3.0 (1.1) | 419.6 (38.8) | 4.4 (0.4) |
| **Control** | 100 | 1.3 (0.5) | 514.3 (24.2) | 8.4 (0.2) |

The differences in strength between Thermo-S and Thermo-D treatments were analysed with statistical methods.

## RESULTS AND DISCUSSION

Average compression and bending strengths were lower in the heat treated wood than in the control samples as could be expected (Table 2). The differences in bending strength between Thermo-S and Thermo-D were moderate: Thermo-D samples were 15% weaker than those of Thermo-S. These results are in line with literature, which indicates that high temperature treatment results in lower strength (e.g., ThermoWood® Handbook 2003).
The compression test results differed drastically from bending test results. High temperature treatment resulted in stronger wood than low temperature treatment (see Table 2). The difference is small, but two-tailed paired t-test reveals that it is statistically significant ($p = 0.047$). Increase in compression strength after heat treatment has been observed also in previous studies with Scots pine (Boonstra et al. 2007). It is assumed that the cross-linking of lignin increases in heat treatment, which in turn causes stiffening of the molecular matrix and increase in compression strength.

**Table 2.** Results from the bending and compression tests. Mean values of the properties with standard deviation in the parentheses are given.

| Treatment | Bending strength, MPa | Compression strength, MPa | Wood density, kg/m$^3$ |
|---|---|---|---|
| **Thermo-S** | 77.4 (13.8) | 48.2 (6.0) | 407.0 (24.7) |
| **Thermo-D** | 65.9 (15.3) | 50.0 (6.8) | 419.6 (38.8) |
| **Control** | 109.4 (9.7) | 57.8 (4.8) | 514.3 (24.2) |

Figure 2 shows the breaking strength in bending as a function of density, fitted with linear regression equations. The strength linearly depends on density in both treatments and in the control samples. The treatments have not changed the dependency into non-linear form. The situation is similar for compression strength (Fig. 3).

The variation in strength properties was larger in heat treated than in untreated samples, and larger in samples treated in higher temperature than in those of lower temperature. However, the density variations cause problems in the comparisons, since the standard deviation of density was 1.6 times higher for Thermo-D treated samples than for Thermo-S treated samples (see Table 2). The variation in wood density may explain most of the observed variation in the strength properties.

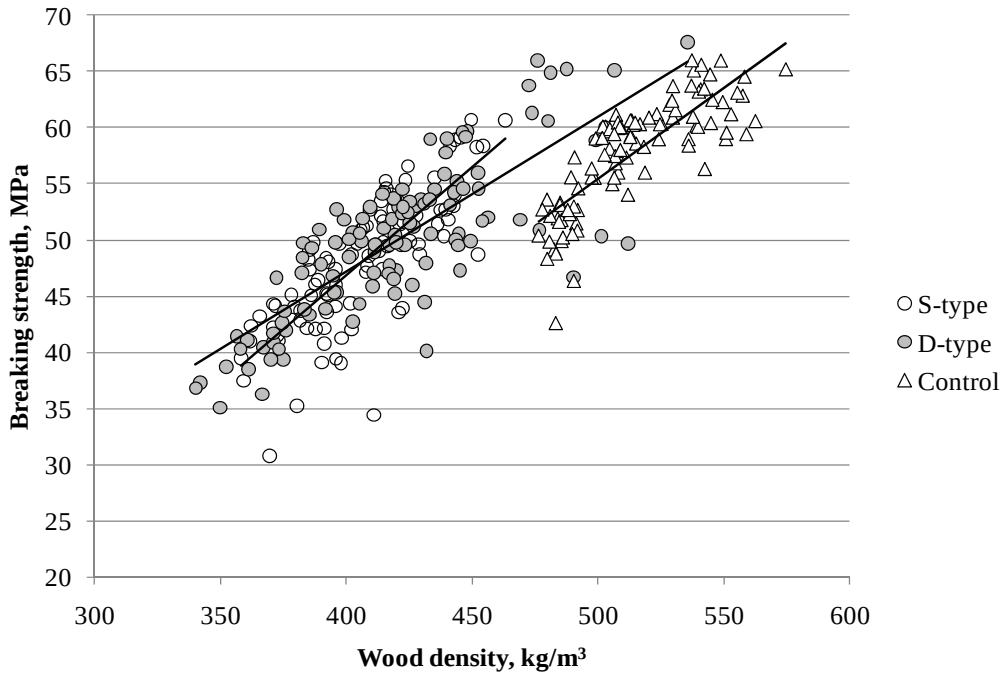


**Fig. 2.** Breaking strength of samples in bending. Fitted trendlines are presented.

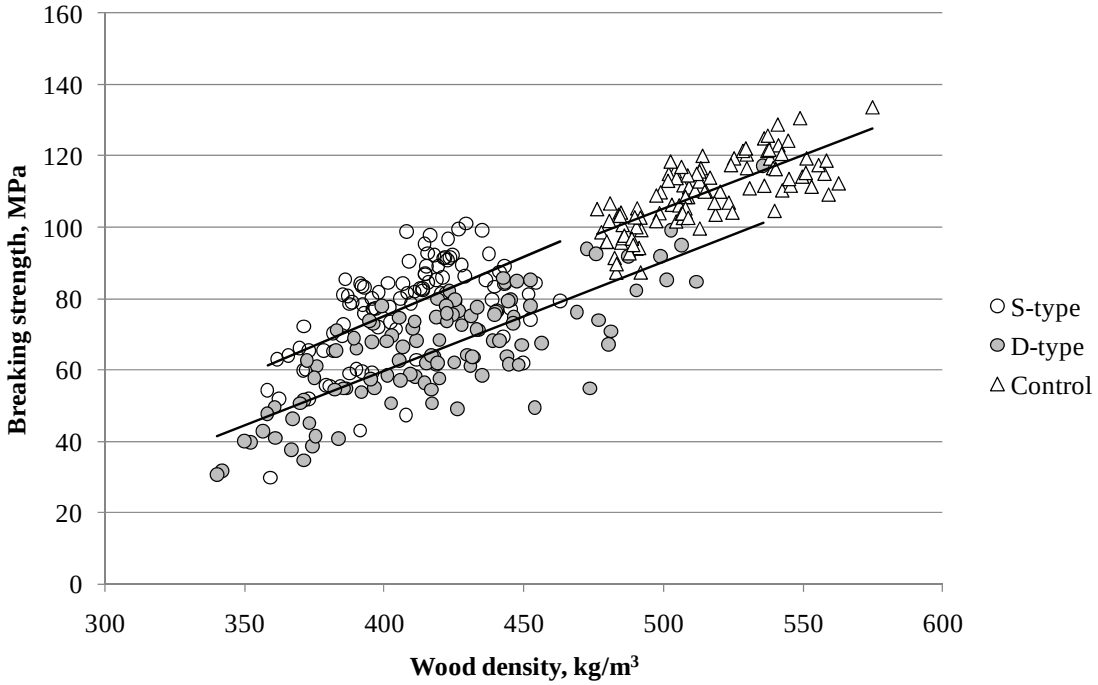


**Fig. 3.** Breaking strength of samples in compression. Fitted trendlines are presented.

Higher average wood density of Thermo-D was against expectations and earlier findings, particularly when the raw material for the heat treated wood can be assumed to be similar: the average ring width (growth rate) of Thermo-D was close to that of Thermo-S samples. On the contrary, the reference material used in this study (control) was more or less first-class wood with more homogenous properties. The next step will be testing of better comparable wood material, i.e., wood to be heat treated at the mill. Altogether, the heat treated wood material showed a large variation in properties. For example, the average ring width in the samples varied from 1 to 7 mm.

## CONCLUSIONS

The results showed that variation in the strength properties of Thermo-D was somewhat higher than in Thermo-S. However, higher variation of wood density in Thermo-D hindered reliable comparisons, and it could not be concluded that higher temperature would directly increase variation in the strength properties.

This study indicates that wood material used for heat treatment is quite heterogenous in properties. Even though it fulfils certain quality requirements regarding, for example, knottiness, it still contains a large variation in growth rate and wood density. This study raises further questions to be considered: Does the heterogeneity of raw material cause problems in end-use applications? If yes, should we then apply more strict quality requirements (e.g., including growth rate) for certain uses?

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# THE SYNERGISTIC EFFECTS BETWEEN CHITOSAN AND DIFFERENT WOOD PROTECTION AGENTS

Witt, B.[1] & Treu, A.[2]

## ABSTRACT

Legislation restricted the continued use of chromate copper arsenate (CCA) preservatives and creosote. Hence, wood protection agents using different fixation systems were brought forward or were developed as well as new environmental friendly solutions were investigated. Earlier investigations attributed an antimicrobial effect to chitosan. Chitosan is a derivative of the natural amino polysaccharide chitin and it is produced from the exoskeleton of crustacean. For a reliable wood protection a concentration of 5% chitosan is needed, which raises the cost of the end product. Previous studies display synergistic effects between chitosan and different wood protection agents. The current work investigates the amount of chitosan and wood protection agent needed in order to gain synergistic effects. Furthermore, the influence of the quality of chitosan on the synergistic effect is evaluated.

Wooden samples treated with the various chitosan-wood-preservative-combinations were leached according to EN 84. After leaching, the samples were exposed to *Coniophora puteana* in a modified EN 113 test for eight weeks. An anti-fungal effect could be seen for the leached chitosan products. However, none of the chitosan treated wood samples reached a mass loss below 3%. Mixing chitosan with the wood protection agent boron, copper or the wood presevatie Scanimp leads to different results between the combinations. Low amounts of chitosan and Scanimp showed an improved protection compared to Scanimp alone. Synergistic effects between boron-chitosan- and copper-chitosan combinations could not be detected.

**Keywords:** chitosan, boron, copper, Scanimp, leaching test, fungal decay test

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# INTRODUCTION

Wood is one of the major construction materials for buildings and furniture. One of its biggest advantages is its high strength combined with low density and certain elasticity. As a biodegradable material it can be degraded by bacteria, fungi, insects and marine borers in addition to the degradation by weathering and UV light. The major decay of wood in buildings is caused by fungi due to high wood moisture content, the basis of fungi infestation.

There are many possibilities to protect non durable wood species or those of insufficient durability. They reach from constructive wood protection, chemical treatments to wood modification. In many cases constructive wood protection is neither sufficient, nor feasible. Chemical wood modification (e.g. acetylation and furfurylation) and heat treatment of wood have not replaced wood preservative treatments. At present they are only used for special applications due to their high costs and partly missing documentation of long term durability. Therefore chemical wood protection is still necessary.

During the last twenty five years regulations have been introduced regarding the use of chromium, arsenate, pentachlorophenol and creosote for wood protection in several countries. The drawback of the new copper organic preservatives is a ten times higher leaching rate than chromated copper arsenate (CCA). Copper can not be degraded in nature like organic compounds and is toxic to water living organisms (about 0.1mg/l). Therefore, the disposal of wood with copper-based preservative will still be difficult and expensive (Eikenes 2005). Hence, the development of wood protection agents focuses on more environmental friendly applications. A promising environmental friendly fungicide agent could be chitosan. Chitosan is a fully or partly N-acetylated derivate of chitin, a 1→4 linked heterogeneous polymer consisting of glucosamine (2-amino-2-deoxy-D-β-Glucan) and *N*-acetyl glucosamine units (2-acetamido-2-deoxy-D-β-Glucan) (Stössel and Leuba 1984; Roberts 1992; Kumar 2000).

When it comes to fixation , chitosan is leaching out to that extent that sufficient protection against fungal decay is not guaranteed (Alfredsen et al., 2004; Raiser et al., 2008). To keep a reliable performance and the enhancement of wood properties chitosan has been combined with wood preservation agents like boron, copper and the commercial wood preservative “Scanimp”. Several synergistic effects occurred. Boron combined with chitosan increased the fixation of chitosan, whereas chitosan and Copper give a good protection against the white-rot fungus *Trametes versicolor*. Low concentrations of Scanimp and chitosan provide sufficient protection against wood destroying fungi (Raiser et al., 2008).

# MATERIAL AND METHODS

## Chitosan solutions

Four commercial chitosan products varying in molar mass, degree of deacetylation and purity, were dissolved in deionised water to a concentration of 5% (w/v) (table 1). With acetic acid to a pH range between 5 to 5.5. To reduce high viscosity after dissolving a 4% (w/v) aqueous solution of potassium nitrite solution was added.

The ph value of each solution was determined with Mettler Toledo FG2/EL2 ph Meter using two-point calibration.

## Combined solutions

The chitosan solutions were combined with the different protection agent in aqueous solution with two various concentrations apart in a decadic step as it could be seen in table 2.

**Table 1:** Characterisation and composition of the different chitosan products and used wood preservation/-agents

| **Chitosan products** | **Composition/characterization** | **wood preservation and wood preservation agent** | **Composition/characterization** |
|---|---|---|---|
| Kitoflokk | Chitosan produced from crabs, free flowing powder<br>- average degree of deacetylation: 0.80 (L), 0.91(M)<br>- ash content [%]: < 3 (L), 3.04 (M)<br>- molar mass [Dalton]: 16 K<br>- company: Norwegian Chitosan Ltd. | Scanimp | liquid, based on:<br>-20-50%dipropylenglycoltyl-eter<br>-2,5-10% propiconazol,<br>-2,5-10% 1-metoksy-2-propanol<br>-2,5-10% 3-iodo-2-propynyl-butylcarbanate<br>-pH-value: 3,96 |
| Kitonor | Chitosan made of crabs, free flowing powder<br>- average degree of deacetylation: 0.90 (L),1.00 (M)<br>- ash content [%]: < 2(L), 0.81(M)<br>- molar mass [Dalton]: 41 K<br>- company: Norwegian Chitosan Ltd. | copper (II) chloride dihydrate | solid, $CuCl_2$ 2 $H_2O$<br>CAS-number 10125-13-0 |
| Multimar | Chitosan made of lobster, free flowing powder<br>- average degree of deacetylation: 0.83(M)<br>- ash content [%]: 0.42(M)<br>- molar mass [Dalton]:14 K<br>- company: Mutlimar As | boric acid | solid, $H_3BO_3$<br>CAS-number 10043-35-3 |

**Table 2.** Chitosan solutions mixed with Scanimp and two wood preservation agents in two different concentrations

| Different wood protection agents and their substantials | chitosan soltion | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Kitoflokk [c] 5.08% | | Kitonor [c] 5.10% | | Multimar [c] 4.90% | |
| | | pH-value | [c] of the substances in the solution | pH-value | [c] of the substances in the solution | pH-value | [c] of the substances in the solution |
| | Scanimp | 4.97 | Kitoflokk 2.54% Scanimp 1:2 | 5.04 | Kitonor 2.55% Scanimp 1:2 | 5.20 | Multimar 2.45% Scanimp 1:2 |
| | Scanimp (1:10) | 4.94 | Kitoflokk 2.54% Scanimp 1:20 | 5.18 | Kitonor 2.55% Scanimp 1:20 | 4.94 | Multimar 2.45% Scanimp 1:20 |
| | boric acid [c] 1% (w/v) | 4.98 | Kitoflokk 2.54% boric acid 0.5% | 5.16 | Kitonor 2.55% boric acid 0.5% | 5.37 | Multimar 2.45% boric acid 0.5% |
| | boric acid [c] 0.1% (w/v) | 5.00 | Kitoflokk 2.54% boric acid 0.05% | 5.16 | Kitonor 2.55% boric acid 0.05% | 5.38 | Multimar 2.45% boric acid 0.05% |
| | $CuCl_2$ [c] 0.52% (w/v) | 4.78 | Kitoflokk 2.54% $CuCl_2$ 0.26% | 4.91 | Kitonor 2.55% $CuCl_2$ 0.26% | 4.91 | Multimar 2.45% $CuCl_2$ 0.26% |
| | $CuCl_2$ [c] 0.052% (w/v) | 5.01 | Kitoflokk 2.54% $CuCl_2$ 0.026% | 5.06 | Kitonor 2.55% $CuCl_2$ 0.026% | 5.27 | Multimar 2.45% $CuCl_2$ 0.026% |

**Impregnation and retention of the solution in wood samples**

Scots pine (*Pinus sylvestris* L.) sapwood was used with dimension of 10 x 5 x 30 $mm^3$. For each treatment eight wood samples were selected randomly and dried at 103°C for 24h to record the initial dry weight. Afterwards the samples were conditioned chamber at 21°C and 65% relative humidity. The conditioned weight was taken before impregnation.

Placing the samples in the solutions, 4 kPa vacuum for 20 min was applied, followed by a 0.9 MPa pressure of 60 min. For drying the samples were stored in the conditioning chamber as it is mentioned above. The calculation of the retention was based on the recorded weights and was calculated as follows:

$$retention = \frac{(W_{imp} - W_{cond}) * C}{V} \quad [kg/m^3] \qquad \text{(Equation 1)}$$

$W_{imp}$ = weight after impregnation
$W_{cond}$ = conditioned weight
V = Volumen of the sample
C [%] = concentration of the substances

**Leaching of impregnated wood samples**

Before leaching the samples according to EN 84 (1997) the constant conditioned weight of all samples was taken. The test vessels were place in a vacuum desiccator and vacuum of 4 kPa was established for 20 min. The test specimens maintained for 2 hours, before the water was changed the first time. During the remaining 13 days the water was changed 9 times.

**Decay test**

The fungi test was carried out according to Bravory (1996), a shortened version of EN113.

For recording the dry weights the samples were dried at 60°C vacuum (40mbar) for 48 hours.

The samples were sterilized by gamma irradiation of 25 kGy at the Norwegian Institute for Energy Technology. Each of the eight wood samples for the respective treatment were placed in a petri dishes (diameter 9 cm, height 2 cm) containing 20 ml 4% (w/v) malt agar together with one untreated control sample. To separate the samples from direct contact with the media a plastic mesh was used. Five replicates were inoculated with *Coniophora puteana* (Schumach.), a brown rot fungus. Other three were treated without fungus as correction values for calculation of mass loss. Calculations of decay (mass loss) and water content after decay were performed as described in EN113. The incubation time was eight weeks at 22°C and 65% relative humidity.

## RESULTS AND DISCUSSION

**Decay test**

The decay varies in the leached wood samples impregnated with the three different chitosan solutions: Kitoflokk, Kitonor and Multimar. Only the treatment with Multimar shows significantly lower mass loss compared to other chitosan treatments and virulence. The mass loss (ML) of Kitoflokk and

Kitonor impregnated samples was over 20%. However, Multimar had a mean mass loss of 14%. Mean retention of the chitosan solutions was similar.
The finding of Raiser et. al. (2008) shows that Multimar impregnated samples have even higher mass loss (21.7%) by using the same condition. Exposed to the fungus *Trametes versicolor* the same mass loss obtained. Comparison to unleached samples shows that chitosan has got a insufficient fixation (Alfredsen et al., 2004; Raiser, et al., 2008).
The mean mass loss for samples impregnated with different chitosans combined with the wood preservative Scanimp in different proportions ranges between 0% and 1.52%. Further dilution of Scanimp mixed with Kitoflokk increases the mass loss from 0% (Kitoflokk mixed with Scanimp 1:2) to 17.83% (figure 2). Varying the Scanimp concentration in decadic steps in the mixtures mixed with Multimar and Kitonor no significant difference is observable in the mean mass loss. Also the use of different chitosans causes no significant effect. Comparing samples impregnated with chitosan solutions mixed with Scanimp 1:2 with them impregnated with undiluted Scanimp (ML= 1.60%) a significant decrease in mass loss appeared between the mixtures with Multimar (ML= 0%) and Kitoflokk (ML= 0%), but not between Kitonor (ML= 0.26%). This may lead to the assumption that the average molar mass of chitosans (table 1) has an influence on the synergistic effect. Raiser et. al. (2008) is showing the same results for higher concentrated Kitoflokk and less amount of Scanimp (1:4). Comparing Scanimp 1:20 impregnated samples to those treatments with chitosan solutions mixed with the same Scanimp amount (1:2) no significant effect is observable.
Leached samples impregnated with the various chitosan- boron- combinations are showing no significant difference in decay amongst each other and to their controls. A comparison between unleached Kitonor- boron- combinations to boron impregnated samples with the same boron concentration are showing no difference in decay.
The theory that the negatively charged $[B(OH)]^{4-}$ ion interacting with cationic compounds of chitosan is not fulfilled. The same observation as for leached and unleached samples impregnated with chitosan solutions mixed with Boron can be seen by the mixtures with copper (II) chloride dehydrates. No synergistic effect appears between them.

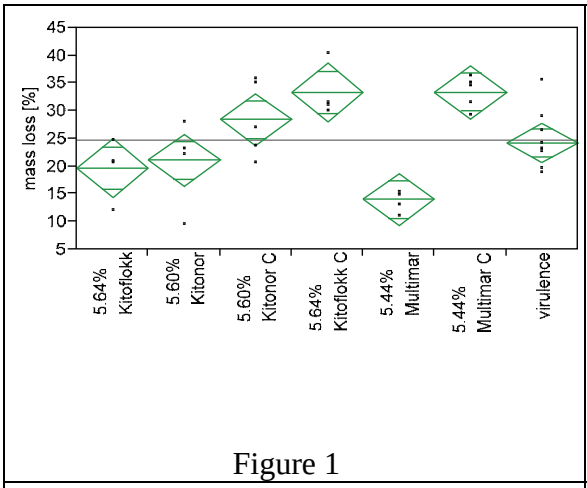


Figure 1

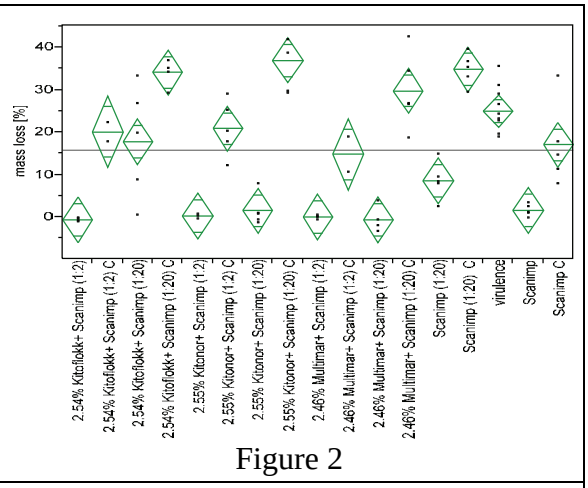


Figure 2

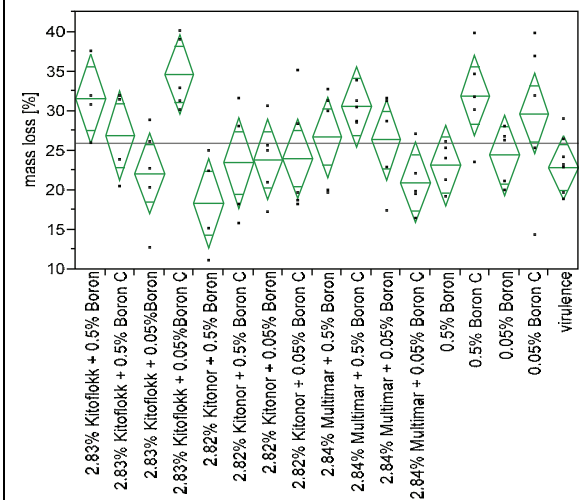


Figure 3

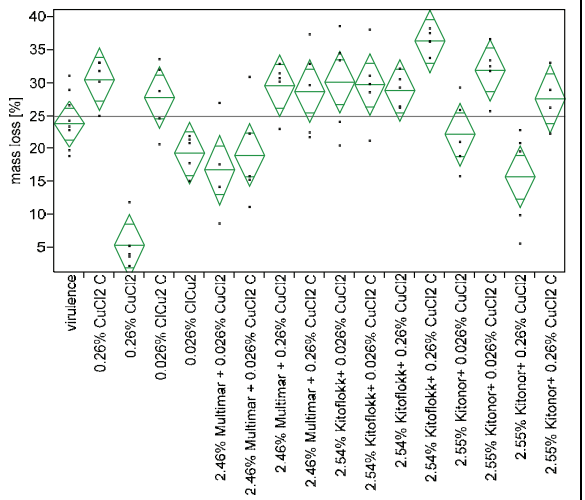


Figure 4

**Figure 1-4.** Mean mass loss of wooden samples impregnated with Chitosan and their combinations to a wood preservative and wood preservative agents. **Fig.1.** Mean mass loss of samples impregnated with different chitosan products. **Fig.2.** Mean mass loss of samples impregnated with various chitosan products combined with "Scanimp" in two different concentrations. **Fig.3.** Mean mass loss of samples impregnated with various chitosan products combined with Boron in two different concentrations. **Fig.4.** Mean mass loss of samples impregnated with various chitosan products combined with $CuCl_2$ in two different concentrations.

## CONCLUSION

Mixing chitosan with different wood protection agents shows various synergistic effects:

- Efficiency of the commercial wood protection agent “Scanimp” increases with addition of chitosan. Good results were obtained using low molecular weight chitosan together with Scanimp. The mean mass loss decreased compared to samples impregnated with Scanimp alone. Mixing Scanimp with higher molecular weight chitosan shows no difference.
- A synergistic effect between $CuCl_2$-chitosan- and borates-chitosan-combinations does not occur.


## ACKNOWLEDGEMENTS

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# ADHESION STUDIES OF SCOTS PINE-POLYPROPYLENE BOND USING ABES

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## ABSTRACT

Injection moulded wood plastic composites (WPCs) are generally built up by wood in the shape of fibres or flour, mixed together with a thermoplastic matrix and a coupling agent. The most common coupling agent is different types of maleic anhydrides (MA). It is still not known to what extent the MA works as a chemical coupling agent or as a dispersing agent in the WPC, of which both functions would help to improve the mechanical properties of the WPC. The objective of this study was to solely evaluate adhesion between a wood surface and a matrix material with and without MA, by using an automatic bond evaluating system (ABES). The ABES allows a wood-plastic compression at desired temperature and cooling, as well as mechanical testing the formed bond in a closed loop. Sapwood and heartwood veneer specimens of Scots Pine (*Pinus sylvestris* L.) were melt bonded together with a sheet of either pure polypropylene or polypropylene with a high content of MA placed between the veneers. In addition to the ABES bond-strength tests, after the tests the fracture surfaces were evaluated. Results indicate large differences in bond strength between specimens with and without MA.

**Key words:** Wood, polypropylene, maleic anhydride, MAPP, Adhesion.

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# INTRODUCTION

The common way of evaluating the efficacy of a coupling agent incorporated in a wood plastic composite (WPC) is to measure changes in mechanical properties and examination of the fracture surface of the tested WPC specimen. An alternative to such procedures, and perhaps also more efficient means to evaluate wood-thermoplastic bonding mechanisms, would be to make a screening of promising coupling agent candidates prior to the making of the WPC.

Recently, a new type of experimental equipment has been developed for evaluation of the strength development of wood-adhesives bonds while curing (Humphrey 1993, Humphrey 2005, Wescott et al. 2007). The equipment is named automated bond evaluating system (ABES) and has the potential to shortening the times in tailoring new and improving existing thermoset wood adhesives (Humphrey 1993, Humphrey 2005, Wescott et al. 2007).

The objective of this study was to use the ABES equipment for evaluating the efficiency of using maleic anhydride as a coupling agent in the forming of a wood-polypropylene bond.

# MATERIALS AND METHODS

The materials were cross cut veneers of Scots pine with a thickness of 0.7 mm. Heart- and sap-wood areas were punched out into 120 x 20 $mm^2$ specimens in the longitudinal direction of the wood. The thermoplastic used was thin films of a commercial polypropylene (PP) and a commercial maleic anhydride polypropylene (MAPP).

The automated bond evaluating system (ABES) used consists of heated press plates, forced air cooling plates as well as a system for mechanically testing the joint, see **Fig 1**. The plates, grips and the tensile test stage is controlled by 7 bar air pressure and it is possible to program the whole gluing cycle.

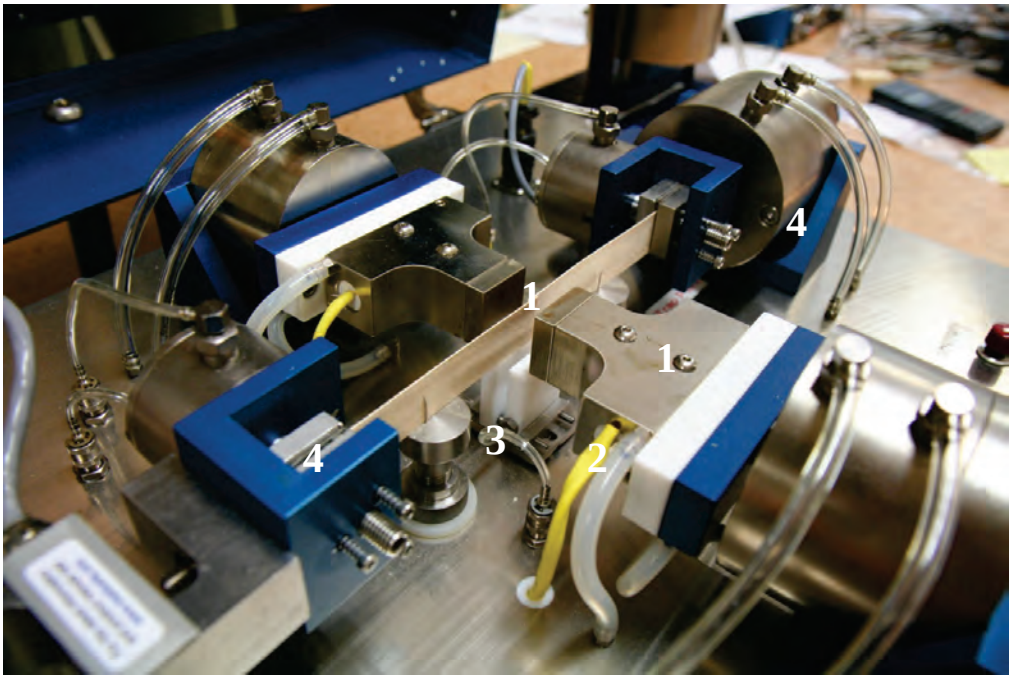


**Figure 1**: Overview of the ABES, 1) Press plates, 2) Forced air cooling plates, 3) Guidance pins, 4) Grips for mechanical testing.

Single-lap shear specimens were produced placing the punched out wood veneers in the ABES, with an overlap of ca 4.5 mm and the thermoplastic film was placed between the veneers.

The melting time was set to 20s for both types of bonds. The melting temperature was 195 °C for the specimens with PP and 165 °C for the specimens with MAPP. After pressing the specimens were cooled for 2 minutes in forced air and removed from the ABES and stored in a climate of approximately 65 % relative humidity (RH) and 25 °C. All specimens were then mechanically tested in the tensile test stage of the ABES and the shear strength of the bonds was calculated.

## RESULTS AND DISCUSSION

The results show large differences between the two thermoplastic systems, see a summary of shear strength values presented in Table 1. The joints between

wood and MAPP showed 50% higher shear strength values compared with the wood-PP joints. There was, however, no significant difference between the heartwood-plastic and the sapwood-plastic joints, i.e. irrespectively if MAPP or PP was used. The fracture surface of the wood-MAPP samples showed a high proportion of wood fracture, especially in the case of sapwood, whereas the wood-PP samples showed a high proportion of thermoplastic matrix fracture, see examples of overview photos of fracture surfaces in **Fig 2**. The pronounced wood fracture failure type for the wood-MAPP samples indicates that the wood-plastic interface (or the interphase) is stronger than the shear strength of the wood component. It is nevertheless important to also take the edge effects into account, which will influence the mechanical performance of the components.

Table 1. Shear strength of the tested combinations.

| | PP | MAPP |
|---|---|---|
| Sapwood | 3.4 (0.2) | 5.1 (1.1) |
| Heartwood | 3.7 (0.5) | 5.4 (0.6) |

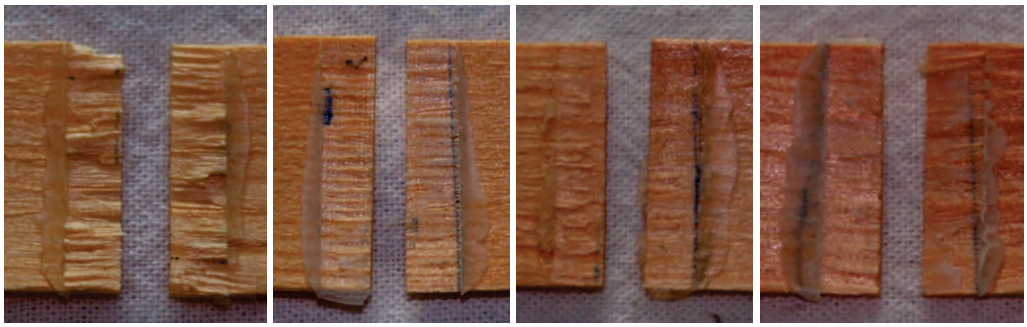

**Figure 2**: Fracture surfaces from some of the tested specimens, from left to right, MAPP-sapwood, PP-sapwood, MAPP-heartwood and PP-heartwood respectively.

There were large differences in melt viscosity between the PP and the MAPP. The MAPP had much lower viscosity which would improve the mechanical entanglement in the wood, which makes it difficult to draw conclusions whether the higher mechanical data is a source of better chemical coupling or if it is because of deeper penetration and more mechanical entanglement, but we believe there is probably a combination of both effects.

In order to develop the ABES to a more reliable evaluation approach of the wood-thermoplastic adhesion efficiency, it is suggested to use thermoplastic materials with more similar melt properties. Influences of earlywood or latewood, method of surface preparation, extractives would also be interesting fields to explore with this method.

## ACKNOWLEDGEMENT

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# THE BEHAVIOUR OF HEAT TREATED WOODEN CLADDING EXPOSED TO EXTREME CLIMATE CHANGES

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## ABSTRACT

The heat treated (HT) ThermoD and oil heat treated (OHT) samples were prepared for the test. ThermoD samples were prepared by treating wood with superheated steam and saturated steam. Oil heat treated samples were heat treated in oil under 180ºC and cooled directly in clean oil at the room temperature. During cooling the samples absorbed some oil. Untreated samples of pine, spruce and aspen were prepared as the reference samples.
The material was tested for 5 cycles. Each cycle contained: soaking in water for 24 hours, direct freezing for 6 days and direct warming for 30 minutes. The tested species were pine, spruce and aspen. Water absorption depended on type of species and treatment. Pine had higher water absorption but after oil heat treatment had the lowest water absorption due to high oil contain. Spruce and aspen had approximately the same water absorption. Heat treatment reduced water absorption as it was expected. Samples degraded in colour more or less and some started to crack. Almost all untreated and ThermoD treated pine samples cracked. Spruce had the highest visible change of the colour after the test. Aspen showed the best results because the colour did not change significantly and the material did not crack. Oil heat treated samples of pine lost some oil after the test

**Key words:** heat treatment, oil treatment, heat treated wood

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# INTRODUCTION

The Swedish climate is characterized by changes in temperature during the year: from freezing in winter to warm weather in summer. The climate is rich in precipitation especially in spring and autumn periods. The winters are becoming milder due to the global warming. Thus rainy weather can occur after freezing during winter and autumn. [6]

The temperature drops have a negative impact on the lifetime of the materials exposed outside, for instance wooden cladding. Many efforts are done in order to improve the life span of the wooden cladding. It is important to choose better specie and technology to produce durable material. It is evident that the cladding should preserve better appearance and structure for many years. To investigate the long-term properties of the cladding, the 5 weeks experiment was performed. During the experimental the extreme climate changing conditions were created. The aim of the study was to investigate the climate change resistance of heat treated wood.

# MATERIAL AND METHODS

The steam heat treated ThermoD (HT), oil heat treated (OHT) and untreated reference (R) samples of pine, spruce and aspen were prepared for testing.

Steam heat treated samples (HT) were prepared according to the ThermoD technology of ThermoWood: the samples were treated under superheated and saturated steam under 212°C.

Oil heat treatment (OHT) was performed during one hour in the hot oil with temperature 180°C with the direct cooling in the bath with clean new oil for one hour. During cooling samples absorbed some oil.

16 samples, dimensions 10x120x300 mm, of each species and treatment method were tested for the extreme climate changes.

The material was tested for 5 cycles. Each cycle contained: soaking in water for 24 hours, direct freezing for 6 days and direct warming for 30 minutes.

Soaking in water was performed in a big vessel for 24 hours at the room temperature. The samples were submerged under water and pressed by the

weight. In the first cycle the water absorption (W) of samples was calculated in percentage (Eq. 1)

$$W = (Mw - Md)/Md \times 100\% \quad (1)$$

Md – mass before soaking,
Mw – mass after soaking.

Freezing was performed for 6 days at -28ºC.

Warming was performed with the help of the patio infrared lamp. The samples were warmed until their surface reached +40°C; it took 30 minutes for every sample.

## RESULTS AND DISCUSSION

### Soaking and water absorption

Results of the water absorption during soaking in the first cycle are displayed in the table 1. Water absorption of untreated samples had higher values than water absorption of treated samples, because heat treatment reduced absorption of water. [2]

**Table 1: Water absorption of samples (W – water absorption, St D – standard deviation)**

| Treatment | Specie | W, % | St D, % |
|---|---|---|---|
| HT* | Spruce | 16,3 | 3,1 |
| | Pine | 28,2 | 7,7 |
| | Aspen | 18,1 | 2,8 |
| R** | Spruce | 30,8 | 3,1 |
| | Pine | 36,8 | 1,7 |
| | Aspen | 27,7 | 4,1 |
| OHT*** | Pine | 12,0 | 2,4 |
| | Spruce | 28,7 | 5,9 |
| | Aspen | 19,7 | 3,2 |

*HT – steam heat treated at 212ºC (ThermoD), **R – untreated (reference), ***OHT – oil heat treated at 180ºC

Among R wood samples aspen had lower water absorption. Aspen is diffuse-porous hardwood with small vessels which can prevent high water absorption; density of aspen is higher than density of spruce and pine. [4,7] Because of high standard deviations, it is possible to conclude that HT spruce had approximately the same water absorption as HT aspen. HT pine had the highest water absorption among other HT samples, also R pine samples show higher water absorption compare to other R samples. Even though pine and spruce belong to softwoods, they have essential distinctions on anatomical level. There is difference in connections between longitudinal tracheids and horizontal parenchyma cells in rays of pine and spruce. Looking at the radial view it can be seen that pine has a large pit (fenestriform pit) and thin membrane between adjacent cells. Spruce has a number of small piceoid or cupressoid pits in the membrane (Fig. 1). [8]

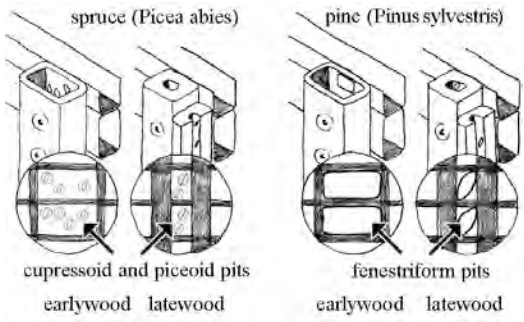


**Figure 1: Interconnecting pits between ray parenchyma and vertical tracheids in pine and spruce, earlywood and latewood [8]**

Water absorption of OHT spruce was higher than absorption of ThermoD spruce, because oil heat treatment was performed at 180°C (not like ThermoD which has treatment temperature 212°C for softwoods) and higher treatment temperature reduced water absorption [2]. OHT aspen absorbed less water than other OHT species, but also absorbed more compare to HT aspen. Interesting values were achieved for OHT pine. Water absorption of OHT pine was much lower than absorption of spruce and aspen; water absorption of OHT pine was also lower than water absorption of HT pine. It can be explained by the fact that pine absorbs much oil (75% and higher) in the process of oil heat treatment with cooling in the oil bath [9]. Thus there is not much space remaining for the water inside the sample.

**Results after 5 cycles of testing**

HT pine practically did not change colour after cycling. Cracks appeared on pine samples (Fig. 2). This can be explained by high water absorption during soaking. HT spruce became darker and greyish, but there was no cracking on the samples. HT aspen became a bit greyish but the colour change was not significant. No cracks were observed on HT aspen samples.

**Figure 2: Cracks on ThermoD pine after cycling**

OHT pine became a bit darker, but there were no cracks like in HT pine. It can be explained by the fact that OHT pine had low water absorption, since pine absorbed much oil during heat treatment process. At the same time oil started to come out on the surface of OHT pine during warming of the samples (Fig. 3). OHT spruce degraded in colour, but there was no oil on the surface of samples during warming. OHT aspen also became a bit darker, but visible colour change for aspen was less than for pine and spruce. Aspen degraded less of all three species and spruce had the highest degradation of colour.

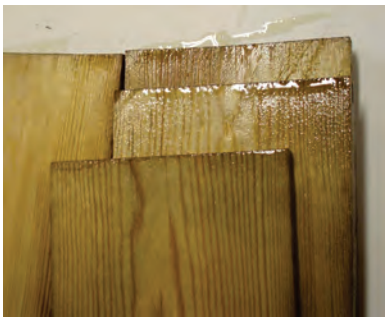

**Figure 3: Oil on the surface of OHT pine after warming**

Untreated (R) pine, spruce and aspen degraded in colour. The colour degradation was more visible on untreated samples than on HT or OHT samples. Pine and spruce got big bluish spots on the surface. Pine also got cracks. Aspen became darker, but no spots were visible.

Interesting visual changes occurred on R spruce after experimental. The material not only degraded in colour, but also the stripes perpendicular to the board length appeared (Fig. 4). It is possible to suggest that they were the stains from the stickers that are used in the drying process. The function of the stickers is to separate the levels of the timber and to enable the moist air and heat circulate into stacks of wooden boards for proper drying. The sticker marks can be remaining even after the planing process. They can be not visible after drying but can appear after heat treatment process. [3] So the process of cycling designed as in this paper could probably cause the visual appearance of the sticker stains on the surface of the samples.

**Figure 4: R spruce (up – before cycling; down – after cycling)**

## CONCLUSIONS

Water absorption of untreated wood had the highest values as it was expected. Pine had higher water absorption than spruce and aspen in the case of untreated wood and wood treated according to ThermoD. Oil heat treated pine had lowest water absorption compare to oil heat treated spruce and aspen and even ThermoD wood because pine absorbed much of oil during treatment process.

Oil heat treated pine had oil on the surface after warming process.

Low water absorption is an advantage for oil heat treated pine, but unfortunately the oil which was leaving pine during cycling would cause the increase of water absorption. Thus it is important to develop coating or impregnation which will prevent the loss of oil from the timber.

All the samples degraded in colour. Aspen had the lowest colour degradation. Spruce had highest colour degradation. Thus it is important to protect colour not only from UV radiation but also from changing climate conditions.

Untreated and ThermoD pine had cracks after cycling. The absence of cracks on the oil heat treated pine can be explained by low water absorption. Cracking of the material showed that it is very weak to resist the changeable climate conditions.
The weak colour resistance is the drawback for heat treated wood. Necessary coatings or impregnations should be used for the HT timber.

The cycling process described in this paper probably can cause the visual appearance of the sticker stains. More investigation has to be done on this topic.

Comparing all three species, aspen showed the best results, because it did not cracked and its colour degradation was the lowest.

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# WHY CONSUMERS AVOID USING WOOD AS FLOORING MATERIAL

Vahtikari, K.[1], Silvo, J.[2], & Mauno, A.[3]

## ABSTRACT

Even though wooden floorings have been used in Finland for centuries both in residences and in civic buildings, material characteristics of wood are nowadays often unrecognized when interior materials are selected. In many building and designing cases people avoid wood without specifying their reasons. The important question that needs to be answered is why wooden floorings are not chosen.

To better understand the reasons behind the diverse positive and negative attitudes towards wooden floorings, consumers in Finland were interviewed. In the interviews the consumers were asked to tell what kind of floorings they appreciate and would choose to their homes.

**Key words:** wood, floorings, consumers

## INTRODUCTION

Even though wooden floorings have been used in Finland for centuries both in residences and in civic buildings, material characteristics of wood are nowadays

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often unrecognized when interior materials are selected. In many building and designing cases people avoid wood without specifying their reasons.

Few materials can compete with wood in versatility; just in Finland there are naturally more than 20 wood species (Vepsä 2000). As building material wood has a good moisture buffering efficiency compared with bricks, cellular concrete and gypsum plaster (Padfield 1998). Wood has also shown antibacterial properties that could be used in product development (Ak et al. 1994, Schönwälder et al. 2002 & Milling et al. 2005).

Both professionals and consumers, consider materials from their own, varying perspectives. This perspective consists of the knowledge and the experiences the person has of different materials. To better understand the reasons behind the diverse positive and negative attitudes towards wooden floorings, consumers in Finland were interviewed. The key findings from the interviews are discussed in relation to the studies where the material selection process of professionals like architects and designers have been described (Paloheimo 2009, Nisonen 2010). The purpose of this study is to answer to the question why people avoid using wooden floorings.

In this study wooden floorings include both solid wood floors and different kind of parquets.

## CONSUMERS' ATTITUDES TO FLOORINGS

70 consumers in Finland were interviewed briefly in order to find out what kind of flooring they appreciate and would choose to their homes. They were also asked to give reasons for their choices. The interviews were done as a part of the M.Sc. level course Marketing Wood Products in 2009 and the results have been published only partly earlier.

36 men and 34 women from southern Finland were interviewed. Their age varied between 17 and 69 years. The age group of 17-34 years was the biggest, including 32 interviewees. The age group of 35-49 had 15 interviewees and the age group of 50-69 23 interviewees. Men and women were evenly represented in the different age groups. Approximately half of the interviewees (37 persons) lived in apartments, 20% lived in row houses and the rest in one-family-houses. The clear majority of the youngest age group (80%) lived in apartments. 60% of the oldest age group lived in one-family-houses. Only 14 of the 70 interviewees

said that they had some previous experience concerning flooring materials through education, work etc. This means that the results show quite well the thoughts of an average consumer.

The interviewees were asked to choose flooring material for their own kitchen, bedroom and living room. They were also asked to give reasons for their opinions. The results are shown in **Fig. 1** where it can be seen that almost all chose wood to their living room and bedroom but almost none chose wood to their kitchen. At least 75 % of the 17-34 years old and of the 50-69 years old chose wood to their living room and bedroom. The 35-49 years old preferred laminate more often than the other age groups, only 60 % of them chose wood.

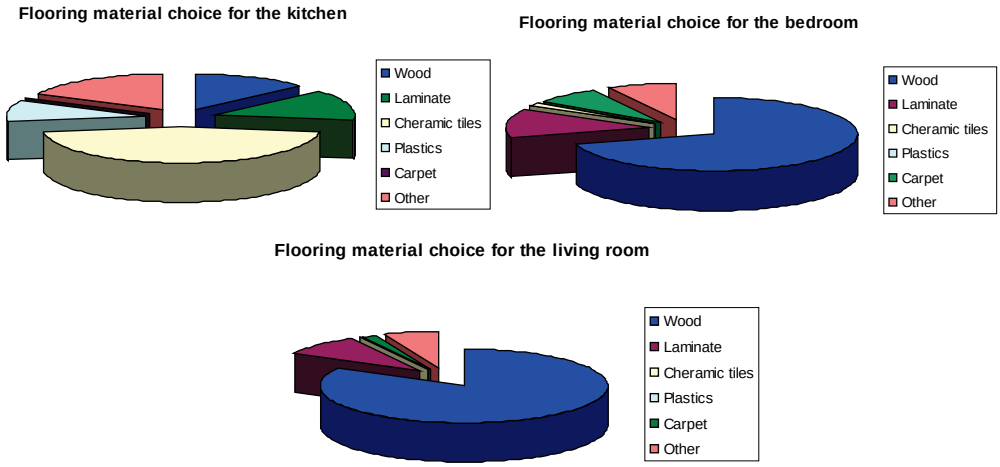


*Figure 1. Preferred flooring material for the kitchen, the bedroom and the living room (70 people were interviewed in Finland).*

When the interviewees described wooden floorings, words like stylish, looks good, expensive, needs maintenance, warm, natural and pleasant came up. When they were asked specifically about the cleaning, it came up that wooden floorings are considered hard to maintain and hard to clean. Interviewees were asked to rank the given flooring materials according to the easiness of cleaning. Half of the interviewees thought that wooden flooring was the hardest one to clean. Plastics and ceramic tiles were considered the easiest ones to clean, both materials collected one third of the answers. These results are presented in **Fig. 2**.

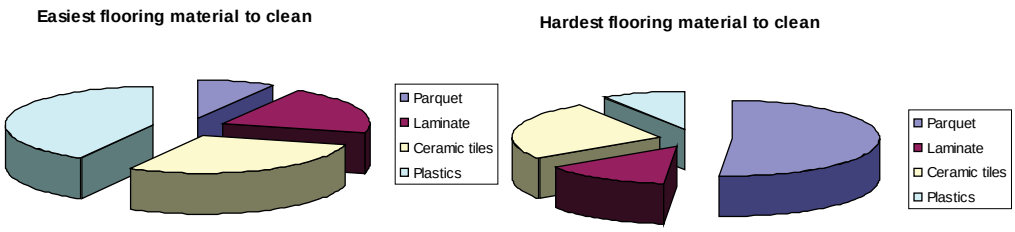


*Figure 2. The flooring materials divided according to the easiness and hardness to be cleaned (70 people were interviewed in Finland).*

The interviewees were also asked to rank the same given flooring materials according to the price-quality ratio. Both parquet and laminate collected one third of the answers when the best price-quality ratio was asked. Plastic again was considered as the material with the poorest price-quality ratio. Over half of the answers shared this opinion. The results are shown in **Fig. 3**.

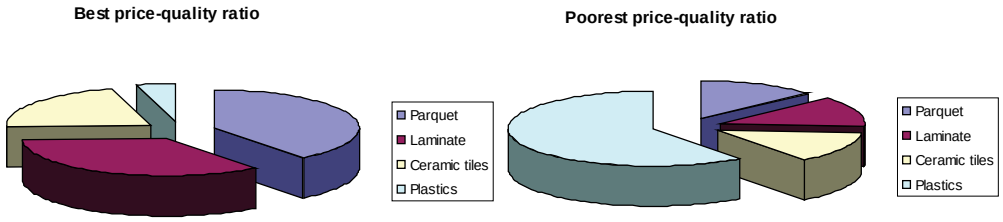


*Figure 3. The flooring materials divided into the best and into the poorest according to the price-quality ratio (70 people were interviewed in Finland).*

To find out how environmentally friendly wood is considered, the interviewees were asked how they would rate the flooring materials considering the friendliness to the environment. Wood was chosen in 75 % of the cases as the first choice as can be seen in **Fig. 4**.

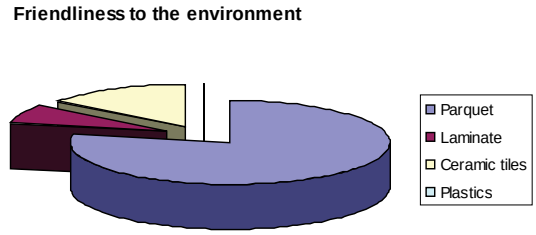


*Figure 4. The most environmentally friendly flooring materials (70 people were interviewed in Finland).*

# DISCUSSION AND CONCLUSIONS

The interviews show that wood is a wanted material to bedrooms and living rooms, but not to kitchens. When asked why other material than wood was chosen to kitchens, the answer was usually “they are easy to clean”. This proves that in people’s mind the cleanability of wooden floorings is considered as a problem.

The customers used a very wide scale of words to describe wood as flooring material. The terms were mostly positive such as warm and natural, but also negative words such as expensive and hard to maintain were mentioned. When these answers are compared to what the professionals answered when architects and designers were interviewed (Vahtikari & al. 2009), it can be noted that similar issues came up. When architects were interviewed they told that along with the existing building regulations the most important criteria to choose wood are aesthetics and the natural feeling of wood. According to the designers, price reliability and maintenance intervals are emphasized among builders.

How to change the image of wood as problematic material is a difficult question. In any case it should be answered, if any progress in the use of wood in interiors is wanted. Several flooring materials, excluding wood, have been studied from the cleanability point of view (Kuisma 2004, Määttä 2007). Cleanability and maintenance are important factors, when materials are selected and research in this area is needed also concerning wooden floorings.

In the real life the price may influence the decision making more than what came up in this interview. Especially parquet is considered as an expensive material. On the other hand the price-quality ratio of wooden floorings was considered good.

Some of the things that people consider as wood material’s weaknesses, for example the patina it gets, could on the other hand be turned to strengths for wood. Wood is natural material and consumers love the feeling of wood, how it looks like and how it positively influences the atmosphere. Marks of living can be seen on it after a certain while, but it can also be re-treated and thus modernized or reconstructed when needed.

A positive thing is that wooden floorings were considered friendlier to the environment than other flooring materials. People are more and more conscious of the environmenttal aspects of their choices. In the future material properties

like re-usability and durability may become significant factors when people choose flooring materials, which will be advantageous for wood.

This paper shows that people avoid using wooden floorings because they assume that wood is difficult to maintain and to clean. There is a need for further research in this area. The results of the research should be brought near to the consumers, not only discussed among the researches and scientists.

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# MODIFIED WOOD – EXCELLENT RAW MATERIAL FOR PRODUCTION OF GRANULAR ACTIVATED CARBON

Rizhikovs, J.[1] & Zandersons, J.[2]

## ABSTRACT

Activated carbon can be prepared from a variety of raw materials. The most frequently used precursors for activated carbons are wood and its residues, nut shells, fruit stones and agriculture residues. A raw material with a high bulk density and a low content of volatiles such as nut shells and fruit stones is appropriate to produce mechanically strong granular activated carbon with a high adsorption capacity. In North Europe, however, these raw materials are either non-available or available in insufficient amounts. Therefore, it is proposed in this study to obtain mechanically strong granular activated carbon by physical activation with superheated steam under a self-generated atmosphere from hydrothermally treated and pelletized grey alder (*Alnus incana* (L.) Moench) wood.

The influence of the moisture content before pelletization in the range 4-12 wt% on the mechanical properties and the developed porous structure of the obtained carbons was studied. The mechanical and surface properties of activated carbons depend on the combined effect of the conditions employed. If microporous high density sorbents are necessary, the pelletization with the moisture content 6-10 wt% is preferable.

Key words: Lignocellulosic sources, hydrothermal treatment, pelletization, carbonization, activated carbon.

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# INTRODUCTION

Biomass is currently a promising renewable and potentially neutral raw material in relation to global warming. Activated carbon has a big volume fraction of very small pores, which results in a large specific surface area. Typical activated carbons have surface areas from 600 to 1200 $m^2/g$ prepared from a variety of raw materials. The most frequently used precursors for activated carbons are wood and its residues (Amaya et al., 2007), nut shells, fruit stones and agriculture residues (Gergova et al., 1994). Raw materials with a high bulk density and a low content of volatiles are more appreciative for production of granular activated carbon. Therefore nut shells and fruit stones could be ideal precursors to produce mechanically strong granular activated carbon with a high adsorption capacity. In North Europe these raw materials are either non-available or available in insufficient amounts.

Our recent work showed that treatment of grey alder (*Alnus Incana* (L.) Moench) wood with saturated steam at 180 $^oC$ resulted in significant yield of water soluble substances, which improve the pelletizing ability of the obtained MW (Rizhikovs et al., 2008). Due to the high content of hemicelluloses, grey alder wood is a promising raw material for hydrothermal modification under pressure for further pelletization. The hydrothermal treatment process is also called autohydrolysis, because the reaction is catalyzed by the hydronium ions from the autionization of the water and acetic acid released from hemicelluloses by the cleavage of acetyl side chains, and the weak acidic environment created thereby is sufficient to promote the hydrolysis of the rest of hemicelluloses. As a result, free sugars are reactive and can be decomposed under heat into furfural and other decomposition products, which can be further transformed into a polymeric substance to provide a bounding and bulking effect on the obtained lignocellulosic material by the application of heat and pressure in a pelleting operation, resulting in composite products with a good mechanical strength and an excellent dimensional stability (Cheng, 1989).

Water acts as both a binding agent and a lubricant, it helps in developing Van der Waals' forces by increasing the area of contact between the particles. Several studies have shown that the strength and durability of densified materials increases with increasing moisture content until an optimum is reached, and good quality wood pellets can be produced with initial moisture contents of 6-12 wt% (Li and Liu, 2000). For modified wood, however, the optimal moisture must be determined to obtain dense and mechanically strong pellets. It is very important to retain the mechanical properties of the pellets also after carbonization and activation. Therefore, the effect of the moisture

content before pelletization on the adsorption and mechanical properties of steam activated carbon was investigated.

## MATERIAL AND METHODS

The technology for the production of granular activated carbon from modified wood consists of the following steps:

- Drying of wood chips;
- Hydrothermal pretreatment of chipped grey alder wood;
- Milling of dry modified wood chips;
- Pelletizing of modified wood;
- Carbonization and activation of pelletized modified wood.

### Sample preparation

Freshly cut grey alder wood chips (3 to 6 cm), after drying at room temperature to the moisture content 10-15% on the wet mass basis, were used for modification.

Five variants of the initial moisture content before pelletization (4, 6, 8, 10 and 12 % w.b.) were prepared to study the impact of water on the mechanical properties of modified wood pellets, carbonized pellets and granular activated carbon. The initial moisture content necessary for the experiments was achieved, mixing the modified wood with the fractional composition below 2 mm with the calculated water amount and holding in an air-tight vessel at room temperature for 48-72 h.

### Modification (hydrothermal treatment)

GA wood chips were hydrothermally treated in a 370 l laboratory plant (WTT A/S) slowly raising the temperature up to 180$^{o}$C in a saturated steam atmosphere and holding for 2 hours under these conditions. Dry MW chips were milled in a cutting mill SM 100 (Retsch GmbH & Co) to pass the sieve of 2.00 mm.

### Pelletization

Flat die type pelletizator (Amandus Kahl GmbH) was employed for pelletization of dry and milled modified wood with the fractional composition ≤

2 mm. Material was pressed through a flat die with holes of diameter 6 mm by pan grinder rollers, formed into endless strands, and then cut to the desired particle length by means of knives. The temperature on the die was about 100-110$^{o}$C.

## Mechanical properties of pellets

The mechanical properties of carbonized and non-carbonized pellets were determined using a pellet Hardness tester (Amandus Kahl GmbH) with the measuring range up to 1000 N, where the hardness is the maximum crushing load at least 10 mm long pellet can withstand before cracking or breaking.

## Carbonization and activation

Carbonization was carried out in an electrically heated 1 l laboratory scale retort. 250 g of MW 2 pellets or coconut shells (control) were heated up to desired carbonization temperature (600 $^{o}$C) at a heating rate of 2 $^{o}$C/min, controlled by electronic temperature regulator.
About 35 g of crushed and sieved granules (1-3 mm) of the carbonized pellets or coconut shells (control) were inserted in a stationary retort equipped with a steam-superheating coil. The retort was placed in the furnace and heated up to the temperature 850 $^{o}$C at a rate of 20 $^{o}$C/min. The superheated steam (1.17 g/min, heated-up to 850 $^{o}$C), was introduced into the retort for 90 min to ensure the chosen oxidizing agent/charcoal ratio (3:1).

## Characterization of the activated carbons

Abrasion number of the obtained GAC was determined using a wet attrition test as described by (Toles et al., 2000).
Parameters of porous structure of the samples were determined using a Sorptometer KELVIN-1040/1042 (Costech Microanalytical). Gas volume (N2), adsorbed on the surface of AC at the temperature of liquid nitrogen (77 K), was measured. Prior to gas adsorption measurements, the GAC samples were degassed at 250 oC in a vacuum for at least 300 min to remove adsorbed water vapor. pore size distribution, micropore volume, Brunauer-Emmett-Teller (BET) apparent surface area and total pore volume were determined from the adsorption/desorption isotherms of the adsorbed gas volume by the Barret, Joyner and Halenda method (Gregg and Sing, 1982).

# RESULTS AND DISCUSSION

## Pelletization of modified grey alder wood

To obtain high density granular activated carbon it is very important to have precursors with high enough physicomechanical properties, which will retain also after carbonization and activation. High-quality pellets from modified grey alder wood can be made with initial moisture contents of 6-10% w.b., and water contents above or below this range would lead to lower quality pellets (Table 1).

**Table 1:** Impact of the moisture content of raw modified wood before pelletization on the properties of pellets

| Moisture content [%] | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|
| Yield [%] | 88.1 | 92.9 | 92.3 | 92.2 | 88.4 |
| Bulk density [g/cm$^3$] | 0.75 | 0.76 | 0.74 | 0.74 | 0.73 |
| Apparent density [g/cm$^3$] | 1.33 | 1.36 | 1.35 | 1.36 | 1.37 |
| Hardness [kgf] | 52±8 | 58±8 | 57±4 | 54±8 | 46±6 |

The positive influence of the optimum moisture content remains also after carbonization and activation, because the target product is that comply with aim to obtain mechanically strong GAC.

## Carbonization and activation of modified grey alder wood pellets

The obtained modified wood pellets were carbonized for further activation. Dense and mechanically strong carbonized pellets with bulk density 0.6 g/cm$^3$ can be obtained, if the initial moisture content is 6-10 wt% before pelletization. (Table 2).

**Table 2:** Impact of the moisture content of raw modified wood before pelletization on the properties of carbonized pellets and GAC

| Moisture content [%] | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|
| Carbonization (600$^{o}$C, 2$^{o}$C/min) | | | | | |
| Ash content [%] | 3.02 | 2.15 | 2.65 | 2.35 | 2.2 |
| Bulk density [g/cm$^{3}$] | 0.57 | 0.61 | 0.60 | 0.60 | 0.60 |
| Apparent density [g/cm$^{3}$] | 1.16 | 1.16 | 1.16 | 1.14 | 1.11 |
| Hardness [kgf] | 18± 4 | 22± 4 | 23± 3 | 20± 3 | 16± 4 |
| Activation (850$^{o}$C, 90 min, steam and charcoal ratio 3:1) | | | | | |
| Ash content [%] | 6.29 | 4.43 | 5.31 | 4.45 | 4.35 |
| Bulk density [g/cm$^{3}$] | 0.40 | 0.44 | 0.44 | 0.46 | 0.44 |
| Yield [% o. d. MW] | 18.1 | 20.3 | 20.2 | 20.9 | 20.8 |
| Attrition [%] | 6.8 | 5.3 | 6.0 | 4.3 | 4.9 |

The carbonized granulated material retains its physical and mechanical properties after superheated steam activation. The yield of derived activated carbon is 20-21% (d.b. modified wood), the ash content is comparatively low 4.3-5.3%, which meets the requirements of most standards for the gas cleaning granular activated carbon.
Comparative activation results of the carbonized modified wood pellets and coconut shell charcoal, activated at 850$^{o}$C for 90 min and the steam-charcoal ratio 3:1, can be seen in Table 3.

**Table 3:** Properties of granular activated carbon obtained from modified wood pellets and coconut shells

| Quality indicators | Modified wood pellets | Coconut shells |
|---|---|---|
| BET surface [m$^{2}$/g] | 1338 | 1390 |
| Total pore volume [mm$^{3}$/g] | 880 | 686 |
| Micropore volume [mm$^{3}$/g] | 398 | 500 |
| Attrition [%] | 4.3 | 4.8 |
| Bulk density [g/cm$^{3}$] | 0.46 | 0.48 |

Dense and mechanically strong microporous granular activated carbon was prepared by superheated steam treatment. The porous structure characteristics were close to those of the coconut shell activated carbon: BET surface 1338 and

1390 $m^2$/g, total pore volume 880 and 686 $mm^3$/g, and micropore volume 398 and 500 mg/g, respectively. Also bulk density and attrition number, namely, 0.46 g/$cm^3$ and 4.3% is close to that of the granular activated carbon obtained from coconut shells, namely, 0.48 g/$cm^3$ and 4.8% (Table 3). So, these carbon materials would be promising products from renewable biomass.

## CONCLUSIONS

The best results obtained, if the relative moisture content is 6–10 % w.b..
The porous structure characteristics were close to those of the coconut shell activated carbon.
By environmentally friendly modification of soft structure deciduous wood that is out of high grade demand, it is possible to produce an effective sorbent for industry - for purification of gaseous emissions.

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# THE USE OF FORMIC ACID FOR EXTRACTION OF ARSENIC AND CHROMIUM FROM IMPREGNATED WOOD

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## ABSTRACT

In the second part of the last century, a very popular method for the protection of wood was impregnation with preservatives, which contained arsenic (as insecticide and fungicide) and chromium (as an arsenic fixating compound, which also provides UV light resistance). After 20-50 years of use, wood becomes old and needs to be replaced; therefore, an essential problem is how to recycle or utilize this impregnated waste wood.

The present research provides information about the extraction of arsenic and chromium from the chips of impregnated waste wood, performed by using formic acid solutions with different concentrations (0.5, 1.0, 1.5, 2.0 and 2.5 M). The content of arsenic and chromium in the impregnated wood, extraction and washing solutions and in the wood after extraction was determined. The content of arsenic was determined by UV-visible spectrophotometry using silver diethyldithiocarbamate, and the content of chromium was determined by UV-visible spectrophotometry using diphenylcarbazide and flame atomic absorption spectrophotometry. The impregnated waste wood before extraction contained 912 ± 22 mg/kg of chromium and 520 ± 14 mg/kg of arsenic. Applying the extraction method, the best result was for arsenic, because after the extraction with 2.5 M formic acid, waste wood contained only 1 % of arsenic from the initial one. The waste wood after extraction with 2.5 M formic acid still contained 16 % of chromium from the initial one, which means that the residual content of chromium is well bonded with wood components.

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Key words: Impregnated waste wood, formic acid, extraction, arsenic, chromium.

# INTRODUCTION

Wood is one of the most important materials in construction and buildings; therefore, it is vital to protect it from insects, fungi and weather effects such as humidity and radiation. For that reason, wood is treated with preservatives that may be oil-soluble (for example, creosotes (tar-oils of a special boiling range), pentachlorophenol) or waterborne salts (for example, chromated copper arsenate (CCA), ammoniacal copper quats (ACQ), chromated zinc chloride (CZC), chromated copper borate (CCB)).

In Latvia, the wood impregnated with preservatives containing arsenic and chromium had been used mainly for electricity and telephone communication poles. Those remained useful for 20 to 50 years and then needed to be replaced. Therefore, the main problem is to develop a method that removes the toxic and carcinogenic compounds from waste wood.

There are some methods how to remove biocides from impregnated waste wood, such as chemical extraction using acid solutions (acetic acid, sulphuric acid and hydrogen peroxide, oxalic acid, citric acid, hydrochloric acid), biodegradation with microorganisms, thermal destruction. However, in this research, extraction with formic acid solutions was used. When chemical components are separated from the impregnated waste wood, it is possible to use it for chemical or thermochemical recycling.

# MATERIAL AND METHODS

## Extraction of impregnated waste wood

For research, waste wood chips (length 1-3 mm), impregnated with preservatives containing arsenic and chromium, were used. The chemicals from the wood chips were extracted with 0.5, 1.0, 1.5, 2.0 and 2.5 M formic acid solutions. Approximately 30 g of wood chips and 400 mL of formic acid were used for extraction (3 h, temperature 80 $^{o}$C). After extraction, wood chips were washed with 300 mL of deionized water (1 h, temperature 80 $^{o}$C). With each concentration of formic acid, the wood chips were extracted and washed twice.

The content of arsenic and chromium in the impregnated waste wood chips was determined before and after extraction, and in the extraction and washing solutions.

### Determination of arsenic content

The content of arsenic was determined by UV-visible spectrophotometry. 0.5-2.5 mL of the prepared sample solutions was weighted and transferred to a generator bottle. 10 mL of $H_2O$, 5.0 mL of diluted HCl, 5 mL of KI solution, and 4 drops of $SnCl_2$ solution were added to the prepared sample solutions, which were allowed to stand for ≥ 45 min.

A cotton wool wad saturated with lead nitrate was placed in a sulphide absorption tube. 3 mm diameter solid glass beads were placed in the trap over a small glass wool pad until ¼ full, and 3.0 mL of silver diethyldithiocarbamate solution was added in a chloroform-morpholine mixture (v/v 100:1). 4.0 g of Zn was added to the generator bottle, attached immediately, and allowed to react for 30 min. The generator bottle was disconnected from the aspirator assembly. The trap with three 2 mL portions of the chloroform-morpholine mixture (v/v 100:1) was washed and aspirated into the 25 mL volumetric flask. Absorbance was measured at 520 nm. For determination, an UV/VIS spectrophotometer Lambda 25 „Perkin Elmer" was used, bandwidth - 1 nm, path length of the cuvette - 1 cm [1, 3].

### Determination of chromium content

In the extraction and washing solutions, the content of chromium was determined by UV-visible spectrophotometry using diphenylcarbazide solution. 0.5-2.5 mL of the prepared sample solutions was weighted and transferred to a volumetric flask. 0.5 mL of 0.2 M sodium periodate and 5.0 mL of deionized water were added and heated at 45 $^{o}$C for 1 h. 5.0 mL of a 5 % glucose solution was added and allowed to stand for 20 min. 0.25 mL of concentrated phosphoric acid and 1.0 mL of the diphenylcarbazide solution were added. Absorbance was measured at 540 nm. For determination, an UV/VIS spectrophotometer Lambda 25 „Perkin Elmer", bandwidth 1 nm, path length of the cuvette 1 cm was used [2, 4, 6].

In the impregnated waste wood chips, before and after extraction, chromium was determined by a flame atomic absorption spectrophotometer „Shimadzu

AA 6300". A chromium hollow cathode lamp was used as a radiation source at 357.9 nm. Before determining the chromium content, 0.5 g of wood chips was mineralized with 10 mL of concentrated nitric acid in a microwave "MarsXpress" for 15 min, temperature 200 $^{o}$C [5].

## RESULTS AND DISCUSSION

Before extraction, impregnated waste wood chips contained 520 ± 14 mg/kg of arsenic and 912 ± 22 mg/kg of chromium.

### Extracted content of arsenic

The greatest amount of arsenic was removed at the first extraction, 24 % with 0.5 M formic acid and 64 % extracting with 2.5 M formic acid (Fig. 1). Comparing the content of arsenic in the first and second extractions, together with the washing solutions, the major part was in the first extraction and washing solutions, namely, from 38 % with 0.5 M formic acid to 90 % with 2.5 M formic acid, but in the second extraction with washing solutions, only approximately 10 % was extracted, comparing with the case of the impregnated waste wood before extraction.

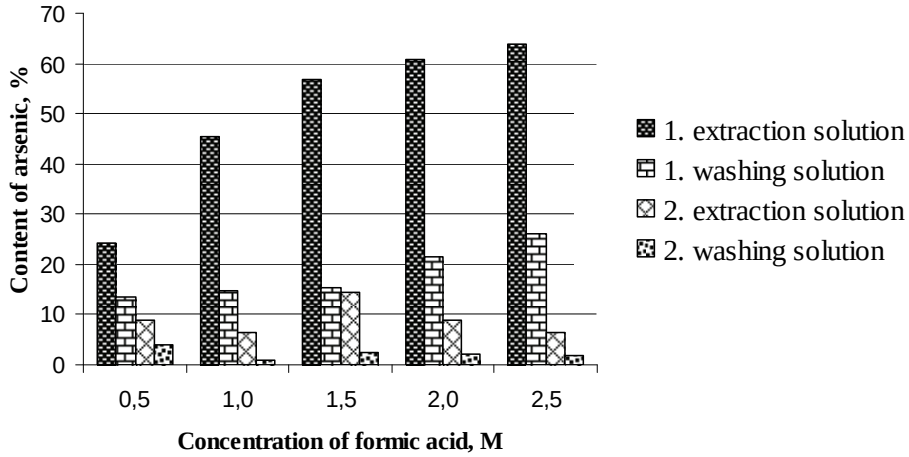


**Figure 1.** Content of arsenic extracted from impregnated waste wood.

Increasing the concentration of formic acid from 0.5 M to 2.5 M, the total content of the removed arsenic changed from 51 % to 99 % from the initial one.

**Extracted content of chromium**

The greatest amount of chromium was removed at the first extraction – extracting 17 % with 0.5 M formic acid and extracting 56 % with 2.5 M formic acid (Fig. 2). Comparing the content of chromium in the first and second extractions together with the washing solutions, the major part was in the first extraction and washing solutions, namely, from 27 % with 0.5 M formic acid to 73 % with 2.5 M formic acid, but was only approximately 10 % in the second extraction with washing solutions, comparing with the case of the impregnated waste wood before extraction.

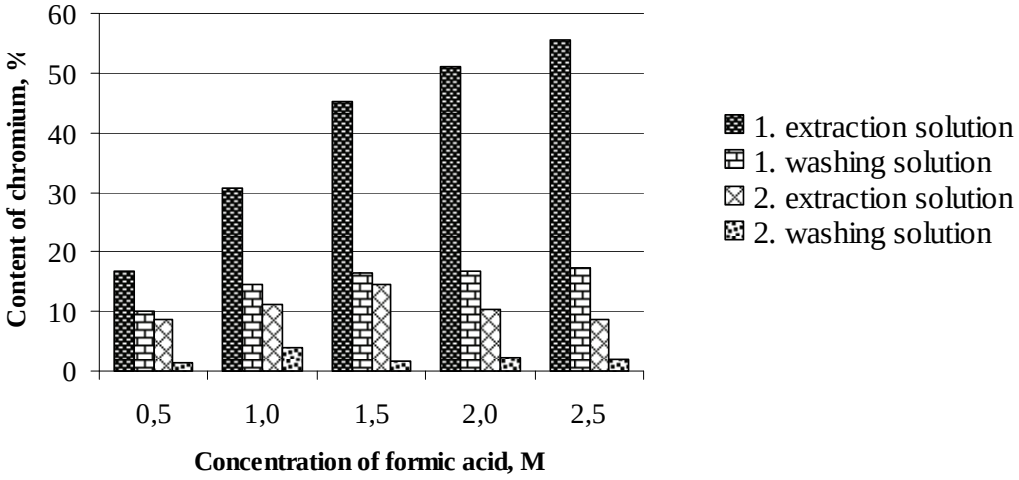


**Figure 2.** Content of chromium extracted from impregnated waste wood.

Increasing the concentration of formic acid from 0.5 M to 2.5 M, the total content of the removed chromium changed from 37 % to 84 % from the initial one.

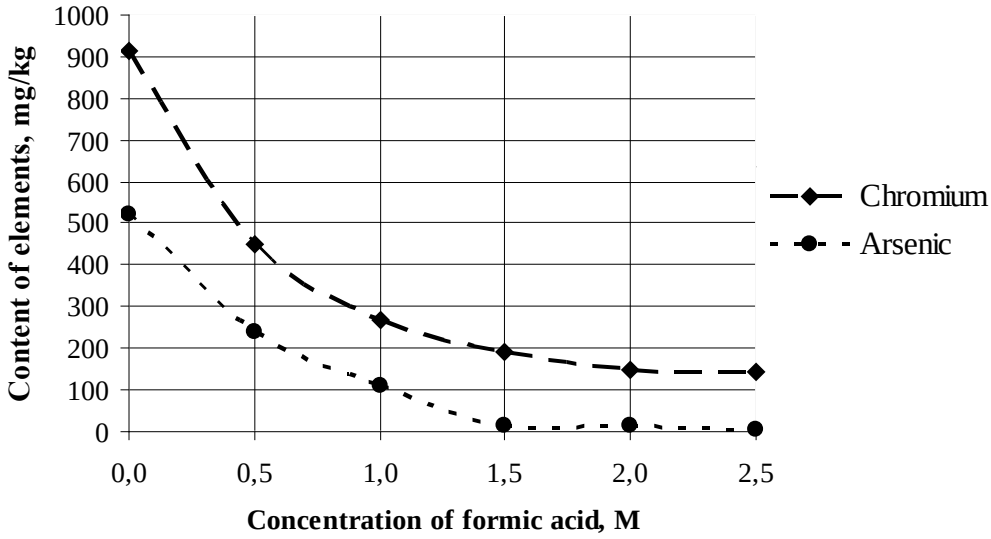


**Figure 3.** Content of arsenic and chromium in the impregnated waste wood after extraction with formic acid.

The most effective removal was for arsenic after the extraction with 2.5 M formic acid, 4.88 ± 0.09 mg/kg of arsenic remained in the waste wood (the value that classifies the impregnated wood as a hazardous waste is 2.00 mg/kg) (Fig. 3). However, a great amount of chromium was also removed; after extraction with 2.5 M formic acid, 144 ± 2 mg/kg of chromium remained in the waste wood (the value that classifies the impregnated wood as a hazardous waste is 30 mg/kg).

## CONCLUSIONS

- The best results were for the extraction of arsenic: 2.5 M formic acid extracted 99% of the total arsenic content from the impregnated waste wood.

- Chromium was well bonded to the components of wood, and after extraction with 2.5 M formic acid, 16 % of the total chromium content remained in the wood.

- Increasing the concentration of formic acid from 0.5 M to 1.5 M, the content of the extracted chromium and arsenic increased very fast, but continuing to increase the concentration of formic acid to 2.5 M, the content of the extracted elements increased quite slowly.

- After the extraction with 2.5 M formic acid, the content of arsenic in the waste impregnated wood exceeded the value, which classifies waste wood as hazardous by 2.4 times and 4.8 times for chromium.

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# QUANTIFICATION OF 4 DARK COLORED MOULD FUNGI BY REAL TIME PCR

Larnøy, E.[1], Hietala, A.M.[1] & Gobakken, L. R.[1]

## ABSTRACT

Coated wooden claddings in building facades are widely used in the Scandinavian countries, and are often preferred to other materials. Wood experience an increasing competition from other materials that are less labor intensive at the construction site and materials with less demand for maintenance thru service life, and makes further development of wooden claddings essential. Growth of discoloring moulds on exposed coated wooden claddings is mainly of aesthetic concern, and is especially disfiguring for light-colored surfaces. Growth of surface fungi often initiates repeated cleaning and shorter maintenance intervals, which in turn increase the total cost of ownership for wooden claddings. Cost and effort of ownership is often an important factor considered when choosing a product, and the traditionally good market situation for wooden claddings is therefore threatened.

The development of real-time PCR (polymerase chain reaction) and taxon-specific primers has provided new possibilities for specific detection and quantification of fungi in their natural substrates. In qPCR (quantitative real-time PCR), the accumulation of the PCR product is detected for each amplification cycle. An efficient and reproducible sampling and extraction of DNA is required for a high-throughput qPCR based quantification of discoloring fungi. The authors have now adjusted DNA isolation protocols and optimized real-time PCR assays for species specific detection of fungi frequently found on painted surfaces (*Aureobasidium pullulans, Alternaria alternata, Cladosporium cladosporides, Ulocladium atrum).*

Key words: Dark colored mould fungi, real time PCR

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# INTRODUCTION

Coated wooden claddings are traditionally widely used in Norway, and are still often preferred to other cladding materials. The increasing competition from other materials that has less input of labour at the construction site and less demands for maintenance is increasing, making further development of wooden claddings essential. On wood and wood-based products in outdoor exposed constructions, disfigurement by mould fungi is one of the main challenges and the most evident treat to the aesthetical service life of the application (Gobakken 2009). Discolouration by fungi is mainly of aesthetic concern, and is especially disfiguring for light-coloured surfaces. Growth of surface fungi often initiates repeated cleaning and shorter maintenance intervals, which in turn increases the total cost of ownership for wooden claddings. Cost and effort of ownership is often an important factor considered when choosing a product, and the traditionally good market situation for wooden claddings is threatened.
If the conditions are optimal for fungal growth, fungal colonization is inevitable. The four most important factors for fungal growth are: moisture, temperature, oxygen and nutrients (Ayerst 1969, Adan 1994, Bravery 1985, Carlile et al. 2002, Deacon 2006, Hudson 1986) (Figure 1). The requirements are often different for spore germination and fungal growth (colonization) (Deacon 2006, Hudson 1986).

The degree of mould growth on the surface of coated wood is a measure of the substrates susceptibility to mould infestation and is a way of rating the substrates according to quality, treatment, time, climatic factors, workmanship, design etc. Assessing mould growth coverage aesthetically implies that there is a need for quantification to allow objective numeric validation without considerable subjective appraisal. Visual assessment is the traditional and most common way to measure mould growth coverage on the surface of coated wood. Several standards used for this purpose describes a rating scale often from 0-3 or 0-5 where 0 is no growth and 3 or 5 are heavily infested or fully covered. The objectivity of using visual assessment is often questioned (Bardage 2004, Sexton et al. 1993, Van den Bulcke et al. 2006, Van den Bulcke et al. 2005) and there is an interest for finding additional or alternative methods for more objective assessment. Digital image processing has been used by several scientists for assessing mould growth on coated wood with good results (Van den Bulcke et al. 2005, Van den Bulcke et al. 2006, Bardage 1996, Graystone 2002, Terziev 1997, Bardage 1998). DNA-based and spectroscopic techniques are used in several fields of research for qualitative and quantitative identification, and have also been introduced in the field of wood protection and wood durability (Siebert 1995, Alfredsen et al. 2007, Alfredsen et al. 2008, Holme and Jelle 2006, Diem et al. 1999).

The development of DNA-based real-time PCR (polymerase chain reaction) and taxon-specific primers has provided new possibilities for specific detection and quantification of fungi in their natural substrates (Hietala et al. 2003). In qPCR (quantitative real-time PCR), the accumulation of the PCR product is detected for each amplification cycle. These highly sensitive techniques have already been applied to quantify plant pathogens in a number of cases (Mumford et al. 2000; Weller et al. 2000; Hietala et al. 2003) and in wood materials (Eikenes et al. 2005). For sensitive and target specific monitoring of phytopathogenic microbes in and on their natural substrates, polymerase chain reaction (PCR) based techniques can be used. Real-time PCR is a promising PCR method for quantifying DNA. The measurements are performed during the exponential phase of the reaction, when PCR efficiency is not influenced by limiting reagents, small differences in reaction components, or cycling conditions. The incorporation of probes increases the specificity relative to traditional PCR and allows the monitoring of several DNA targets in the same reaction tube (multiplex real-time PCR). As a result, real-time PCR has been increasingly used for the quantification of infectious agents. The development of DNA-based real-time PCR and taxon-specific primers has provided new possibilities for specific detection and quantification of fungi in their natural substrates (Hietala et al. 2003). These highly sensitive techniques have already been applied to quantify plant pathogens in a number of cases (Mumford et al. 2000, Weller et al. 2000, Hietala et al. 2003) and in wood materials (Alfredsen et al. 2008, Eikenes et al. 2005). More knowledge of discolouring fungi on surface treated wood is of commercial interest, both with regard to objective evaluation methods and with regard to early prediction of coating performance and increased aesthetic service life.

In this study the development of Q-PCR as an objective tool for qualitative and quantitative identification and evaluation of early colonization by discolouring fungi on painted surfaces, in the paint matrix and in the wood was investigated. A sampling technique is under construction and the extraction steps are presently being optimised for *Aureobasidium pullulans Cladosporium cladosporiodes*, *Ulocladium atrum* and *Alternaria alternata*.

## MATERIAL AND METHODS

**DNA isolation**

To obtain DNA from the four included test fungi, strains representing each were grown aseptically on cellophane-coated malt extract agar plates for 5-7 days. The peeled mycelium was manually ground with a pestle in a liquid nitrogen

chilled mortar. The ground powder was stored at -20°C until further processing. For DNA isolation, a 20-mg-aliquot of pulverized mycelium was processed by using the standard protocol #8 (Isolation of DNA from mouse tail) of Easy-DNA™ Kit (Invitrogen, Carlsbad, CA, USA). Total DNA was then quantified using micro-volume spectrophotometer NanoDrop 2000 (Thermo Scientific, Wilmington, DE, USA) and a dilution series containing 100, 10, 1, 0.1, 0.01 and 0.001 ng DNA in a volume of 3 µl was prepared as a standard curve for real-time PCR.

**qPCR**

The prepared DNA standard curve samples of *Aureobasidium pullulans*, *Cladosporium cladosporioides*, *Ulocladium atrum* and *Alternaria alternata* were quantified by using primer/probe sets available in public domain (http://www.epa.gov/microbes/moldtech.htm) and targeting the ITS rDNA gene cluster. All primer and probe concentrations were optimized as recommended by Applied Biosystems (Anonymous 2002). For *A. pullulans* the ApullF1/R1 forward and reverse primers and ApullP1 probe was employed with 300 nM primer and 100 nM probe concentration. For *C. cladosporioides* the Cclad1F1/R1 forward and reverse primers and CcladP1 probe was used with 300 nM primer and 150 nM probe concentration. For profiling *U. atrum*, the forward and reverse primers UatrmF2/R2 and probe UloP1 with 300 nM forward primer concentration, 900 nM reverse primer concentration and 150 nM probe concentration were employed. *A. alternata* was profiled with 300 nM of forward (AaltrF1) and reverse (AaltrR1) primer and 250 nM probe (AaltrP1) assay. All the probes were TaqMan probes labelled with the reporter dye VIC at 5' end and with the quencher dye, 6-carboxy-tetramethylrhodamine (TAMRA) at the 3' end. The primers and probes were ordered from ABI PRISM Primers and TaqMan Probes Synthesis Service.

Each 25-µl-PCR reaction for standard curve samples was performed in TaqMan Universal mix by using a 3-µl-volume of the DNA solution as template. Standard PCR cycling parameters, according to ABI Prism 7700 (Applied Biosystems) instrument, were used.

## Standard curves

Standard curves for the profiled four fungi were constructed based on the relationship of Ct values and known fungal DNA concentrations: the Ct values were plotted against DNA amounts, and regression equations were calculated for the quantification of DNA pools by interpolation in unknown samples.

# RESULTS

For all the monitored fungi, the real-time PCR assays detected the target DNA in a linear fashion in the range 10 - 0.001ng whereas 100 ng exceeded the linear detection range of the assays (**Fig. 1**).

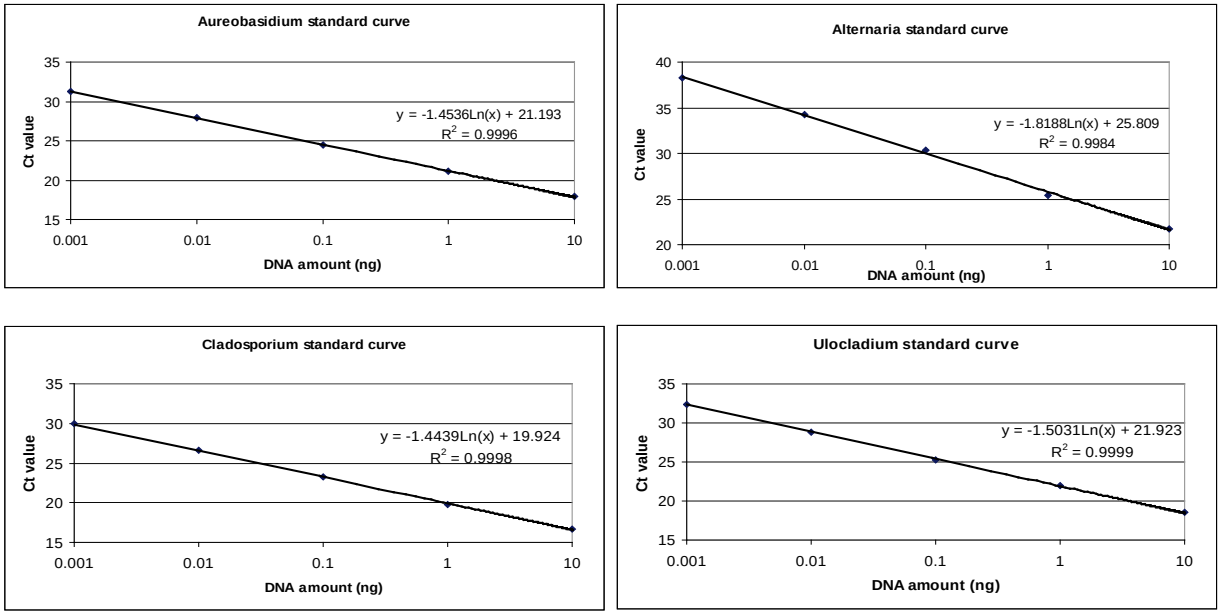


**Figure 1.** Standard curves for the profiled four fungi constructed based on the relationship of Ct values (Ct, cycle threshold, the PCR cycle at which the reporter fluorescence exceeds that of the background) and known fungal DNA concentrations. Note that 100 ng was above the linear detection limit of all the four assays and this data point is not included in the panels.

# DISCUSSION

An efficient and reproducible sampling and extraction of DNA is important to achieve qPCR based quantification of discolouring fungi. The authors have tested multiple commercial DNA isolation kits for the four subjected mould fungi and most of them produce very low DNA yields, below 0.25 ng DNA per mg mycelia, and are thus clearly not suitable for this purpose. The melanized and thick cell-wall of the mould fungi is obviously a major obstacle for DNA extraction. In contrast, the now employed mouse tail protocol involving an extended protease treatment at

60° is obviously very efficient in extracting DNA from these fungi, the kit yielding 5-40 ng DNA per mg from the mycelia of the tested fungi. In addition to high yield, the DNA solution is free of inhibitors to DNA polymerase and thus this kit is very promising for profiling growth of mould fungi.

As the next step to further optimize DNA extraction for profiling mould fungi, we will test adding of an exogenous reference DNA to each sample upon DNA isolation. It is known that DNA extraction efficiency can vary from sample to sample and between different substrates. Adding a standard amount of reference DNA to experimental samples prior to DNA isolation and normalization of the target DNA yield according to the reference DNA yield has been shown as an effective strategy to control stochastic variation in DNA extractability, since the impact of matrix properties on DNA recovery is similar between all DNA pools present in a system, (Hietala et al. 2009; Pilgård et al. 2010). When the DNA extraction method is optimized, a field test evaluation will be performed on coated wooden claddings that have been exposed outdoors.

Studies of host/decay fungi interaction in living trees show that many fungi have adapted tolerance to phytotoxic host defence compounds such as phenols (Hietala et al. 2009). Increased understanding of the mode of action of various wood coatings and the flexibility present within the various species of microfungi that spoil wood in service is needed for further development and process parameter optimisation of wood protection systems. Since the real-time PCR methodology only acquires very small samples, separate assessment can be executed on the surface, in the paint matrix and in the interface between paint and wood. This will provide detailed information about the colonization progress of mould fungi, knowledge that will be of assist in further modification and development of wood protectants.

## CONCLUSIONS

It can be concluded from these experiments that with this new protocol, a new tool has been developed for the quantification of *Aureobasidium pullulans*, *Cladosporium cladosporioides*, *Ulocladium atrum* and *Alternaria alternata.*

## ACKNOWLEDGEMENTS

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# STUDIES OF STEAM EXPLODED FIBRES

Tupciauskas, R.[1], Belkova, L.[2] & Gravitis, J.[3]

A steam explosion treatment was applied to convert grey alder chips to fibrous material. Two vessels of the steam explosion unit were used to receive the exploded fibres. The obtained fibres were pressed to self-binding fibreboard. Structural changes of the chips after the steam explosion were studied by scanning electron microscopy (SEM, Vega TS 5136). Fibre analyzer (L&W) was used to detect changes in measurements of the exploded fibres from the both vessels. Influence on a supermolecular structure of the exploded grey alder fibres polymer components was detected by thermo gravimeter (TGA/SDTA851) and differential scanning calorimeter (DSC822). The studies were necessary to characterise the exploded fibres that were used for the obtaining of the self binding fibreboard.

The images of SEM showed the liberated lignin from the cell wall on the fibres surfaces. The lignin on the fibres surfaces was observed as globular segregated domains, as well as coated by the hemicelluloses film. These natural polymers generated at the steam explosion treatment works as binder during a hot pressing of the fibreboard.

The fibres analysis showed that the smallest particles generally were collected at the second vessel during steam explosion treatment, while the largest particles mostly were collected on the first vessel of the steam explosion unit. This means that the vessels of the steam explosion unit work as fractionation system.

The thermal gravimetric and differential scanning calorimetric curves analyses showed that mass loss of the studied samples was about 25 % and 55 % at the temperature of 300 °C and 360 °C, respectively.

**Key words:** steam explosion, grey alder fibres, structural changes, thermal properties, fibres measurements.

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# DENDROLIGHT PANELS PRODUCED FROM ASPEN WOOD

Iejavs, J.[1], Spulle, U.[2]

Last years the reduced weight cell panel with the trade mark of Dendrolight has obtained the wide world identification due both opening new factory in Austria and intention to open a factory of reduced weight cell panel in Latvia. Up to now Dendrolight type cell panels have been produced from the internal layer of spruce solid timber and plywood, solid timber, particleboard or the external layers of other material. The density of panels of this type is reduced by sawing grooves into the internal boards of the solid timber. As a result of it the internal layer obtains cell structure. The research on the reduced weight cell panel made of aspen (*Populus tremula* L.) wood has been initiated. The reduced weight cell panel of different types has wide application in furniture industry, internal cladding, door production, transport manufacturing industry and construction panel production as well. The essential importance of the research is to make out the usage possibilities of aspen wood which is a common broad-leaved tree in Latvia as an alternative material for spruce in production of the reduced weight cell panel. The aim of the research: to investigate the physical and mechanical properties of aspen cell panel covered by aspen and plywood. In the production of Dendrolight type panel from aspen wood the following raw materials were used: finger jointed aspen half-finished product - for aspen internal layer producing; finger jointed aspen half-finished product and three - layer birch plywood for external layer producing. There were used adhesives of two types for internal and external layer gluing: polyurethane adhesive DANA PU 2116 and polyvinyl acetate adhesive DANAFIX 447. The test of the newly obtained aspen panel was carried out in accordance with the current test standards for panel and timber tests. The following panel parameters were determined: moisture content (LVS EN 322), density (LVS EN 323), swelling in thickness after immersion in water (LVS EN 312), tensile strength (LVS EN 319), three-point bending strength and modulus of elasticity (LVS EN 310), four-point bending strength (LVS EN 408 p.13).

Relevant conclusions: Dendrolight type panels produced from aspen wood obtain the average density of 325 kg $m^{-3}$ (external layer of aspen wood) and 358 kg $m^{-3}$ (external layer of plywood). There are 2 % thickness swelling of aspen cell panels after 24 hour immersion in water, identical as spruce cell panels, with spruce external layer. There are good correlation between three-point bending strength and modulus of elasticity. With good results aspen wood can be used in reduces weight cell panel production.

**Key words:** dendrolight, aspen, panel.

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# INFLUENCE OF CELLULOSE CONTENT ON RHEOLOGICAL AND MECHANICAL PROPERTIES OF POLY(LACTIC) ACID/CELLULOSE AND LDPE/CELLULOSE COMPOSITES

Šumigin, D.[1] , Tarasova, E.[2], Meier, P.[3]

Landfills around the world are full of plastics and packaging materials, some of which may take decades or longer to completely break down. Plastics made from biodegradable polymers are much better for the environment compared to petroleum based/synthetic composites, because they break down substantially faster.

In recent years, the uses of natural fibres as the fillers for biodegradable/synthetic polymers have been increased. Cellulose is one of the prospective fillers to different polymers due to its reduced weight, relatively good stiffness and strength along with a low cost and ease of disposal.

In our work we prepared the cellulosic composites on the base of natural poly(lactic) acid (PLA) and synthetic low-density polyethylene (LDPE). The studied composite materials were manufactured with a twin-screw extruder. The extruded compound was compression moulded to test samples. The weight content of cellulose in PLA/cellulose and LDPE/cellulose composites was varied.

Effect of a small addition of cellulose on the rheological and tensile properties was studied. Tensile tests showed that the incorporation of cellulose into PLA or LDPE matrix lead to stiffer but slightly more brittle and weaker materials, since Young's modulus increases and tensile strength and elongation at break decrease a little. Mechanical results are in agreement with rheological behaviour: the composites exhibit an improvement in the storage and loss moduli of composites compared with matrix polymers. The composite viscosity increases with cellulose content in the same manner as loss and storage moduli.

The processing and material properties of PLA/cellulose composites were compared with those of LDPE/cellulose composites.

**Key words:** cellulose, poly(lactic) acid, biocomposites.

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# COST-EFFECTIVE ANALYSIS OF SCOTS PINE STILBENES

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Extractives of bark, heartwood, knots and wounded xylem provide defense for living trees. In Scots pine (*Pinus sylvestris* L.) heartwood the most important groups of defensive extractives are stilbenes, which consist of pinosylvin and its etherified derivatives. These extractives also make the timber naturally durable against biodegradation caused by fungi and bacteria. Heartwood timber with high stilbene content could serve well in applications where decay resistance is needed. Due to high among-tree variation in stilbene concentration, grading of heartwood timber is needed. The target of our study is to develop and test a fast and nondestructive methodology (UV resonance Raman spectroscopy) to measure the stilbene concentration from solid wood substrate. The methodology could be applied, besides as a research tool, also in practice for example to evaluate the amount and quality of the natural heartwood resources, to grading of timber to produce higher value wood products, and in selecting trees for tree improvement.

Scots pine material originates from progeny tests of Metla (Finnish Forest Research Institute). The method of the chemical (GC-MS) analyses have been fine-tuned and performed in Metla's Laboratory, and the optical (UVRRaman) analyses at the Aalto University.

**Key words:** Heartwood, extractives, gas chromatography, UV resonance Raman spectroscopy, grading

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# IMPACT OF TEMPERATURE AND GRAIN ANGLE ON THE VELOCITY OF SOUND IN MODIFIED OAK WOOD

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Wood modification is carried out in order to improve wood properties or to change its color, aesthetic appearance or design. In addition, there are also changes in wood physical and mechanical properties. When modified with ammonia, wood without vivid texture gains a wide spectrum of colors. Furthermore, while being under moist conditions, wood deformation properties tend to improve, density seems to increase and wood acquires plastic properties. However, in addition to the mentioned advantages, there are number of disadvantages as well. Ammonia breaks down cellulose microfibriles into elementary fibriles, which results in cell walls containing water soluble materials. Wood modified with ammonia tends to absorb larger quantities of moisture than natural wood.

Ultrasound velocity is considered as very sensitive to wood structure variation. Its numeric value depends on many factors: wood species, moisture content, grain angle, temperature, density, etc.

In this work the impact of temperature and grain angle on the velocity of sound in ammonia modified oak (*Quercus robur*) was studied. For measurements special non-destructive test method was used. Temperature influences elastic and damping properties of wood. Consequently, as temperature increases sound velocity decreases. As wood is elastic anisotropic material its` response depends on the direction of the applied stress. Properties parallel to the grain differ considerably from the properties in the transverse direction. In this research measurements were made in three perpendicular directions: longitudinal along grain, radial towards to the growth rings and tangential to the annual rings. Herewith the impact of temperature was evaluated.

**Key words:** wood, temperature, grain angle, velocity of sound

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# ALTERNATIVE WOOD PRESERVATIVE SYSTEMS IN A COMBINED IMPREGNATION PROCESS (CIP)

Liibert, L.[1], Treu, A.[2], Meier, P.[3]

A range of studies has shown that Royal treated wood can provide excellent protection against weathering and decay fungi. This treatment combines the protective properties of a wood protection agent and the hydrophobic properties of a subsequent oil treatment in a wood product.

Copper-based wood preservatives, which are tradidionally used in CIP, are very effective but their long-term future use is questionable because of environmental issues, especially the toxicity against marine organisms. There is a need for new eco-friendly wood preservative systems for a use in CIP.

The substitutes for copper used in this study are natural polymers and organic biocides. The aim of this research is to describe the fixation and antifungal effectiveness of the following compounds: CX-8, Chitosan, Scanimp, Tannin, fire protection agent.

The scots pine sapwood samples (50x25x15mm) were impregnated and oil treated. The treated products were analysed for their preservative-and oil-retention. Preservative fixation time influence on oil treatment was tested. The treated samples were leached according to EN84. Water samples were analyzed for the amount of active ingredient. After leaching the samples were exposed to fungal attack by *Coniophora puteana* and *Trametes versicolor* according to EN113. Treated samples without oil showed less performance against fungi, especially tannin and chitosan.

**Key words**: copper, chitosan, tannin, scots pine sapwood, leaching, EN113

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# HOW DOES SAMPLE POSITION AFFECT THE LEACHABILITY OF WOOD PRESERVATIVES

Kängsepp, K.[1] & Larnøy, E.[2] & Meier, P.[3]

As we move towards more and more eco-friendly society, the wood industries must also adjust to new rules and restrictions. Even though new and greener solutions have been introduced, the leaching of wood preservatives into the nature is still a problem, especially agents that consist copper. Several studies have been conducted on the raw material`s influence on impregnability and it has been found that large variations in sapwood penetration exist which affect a homogeneous distribution of preservatives. This gives reason to believe that the leaching of wood preservatives is also influenced by the raw material. To ensure better economic process conditions which also apply environmentally safe protective agents, it is important to understand material features that influence permeability, retention and leaching of the impregnation agents. This study tries to set the variation of leachability of copper in system, evaluating both the origin of a tree and the origin of a sample.

Samples of scotch pine sapwood (*Pinus Sylvestris*) (20x20x50mm) are treated with the wood protection agents Wolmanit CX-8 and Tanalith. The variation in leachability within trees, between trees and between different stands of Scots pine (from Norway and Denmark) is studied. Within this material, it is possible to trace the individual sample to its original position in the stem. Samples are climatised, impregnated with preservatives and leached according to standard EN_84. Water samples are then sent to ICP machine (Iductively Coupled Plasma Technique) to analyze copper content in the leachates.

**Key words**: copper-containing wood preservatives, leaching, EN_84

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# EFFECT OF BIRCH VENEER PROCESSING FACTORS ON ADHESIVE BOND STRENGTH DEVELOPMENT

M. Piirlaid[1] A. Rohumaa[2], M. Matsi[1], M. Hughes[2] and P. Meier[1]

Birch *(Betula pendula)* is a hardwood which has been used in plywood manufacturing for a long time. The quality of the plywood depends on veneer and plywood processing factors as well as the type of adhesive used. The phenol-formaldehyde (PF) resin was the first synthetic resin used in plywood production and it is still used in the plywood bonding process. The main target of the present study was to evaluate the effect of veneer processing parameters on bond development with PF resin. To evaluate the quality of the adhesive bond in plywood by standard testing methods is laborious and time consuming. This study concentrates on the use of the Automated Bonding Evaluation System (ABES) as an alternative. ABES is miniature hot-pressing device which is equipped with a shear strength testing unit. It is a compact system which allows precise control of the pressing parameters and at same time evaluation of the shear strength properties of the bonds obtained. ABES has been used mainly in studies to characterise the adhesive curing process. The results show that the hydrothermal pre-treatment, drying temperature and the moisture content of veneer has an effect on bond strength development between Birch veneer and PF adhesive.

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# ASSESSING THE POTENTIAL OF FURAN POLYMER-BASED RESIN DEVELOPMENT IN BONDED VENEER PROCESSING FACTORS ON ADHESIVE BOND STRENGTH

M. Matsi[1], A. Rohumaa[2] M. Piirlaid[1], M. Hughes[2] and P. Meier[1]

Plywood manufacturing has so far mostly used phenol-formaldehyde (PF) and urea (UF) resins. Nowadays there is a big demand for environmental friendlier substances, because at this moment widely used resins contain toxic and carcinogenic compounds. Also environmental friendlier substances are key to the future. Therefore studies are being conducted to find new and nontoxic resins. The present study concentrates on a resin system which does not contain formaldehyde and can be applied in the plywood production process without a reduction in strength compared with PF resin. A potential alternative is a furan polymer-based resin. Furan resin has been tested with several different modifications (three different amounts of catalyst) with Automated Bonding Evaluation System (ABES) at different curing temperatures and times. ABES is small precise device equipped with a miniature hot-press and testing device. It is a compact system providing the opportunity to control pressing parameters and measuring the shear strength for overlapped veneer specimens. The test results on Birch *(Betula pendula)* veneers show that furan resin can achieve comparable strength properties with PF resin. The difference is that furfural resin with certain amount of catalytic agent needs higher pressing temperature than pure PF resin, to obtain almost the same shear strength.

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# ANALYTICAL CONTROL OF THE PROCESS OF PREPARING LIGNOCELLULOSE FOR OBTAINING LEVOGLUCOSAN

A. Pazhe, M. Puke, J. Zandersons

The yield of the main product of the thermal destruction of cellulose - 1,6-anhydro-β,D-glucopyranose or levoglucosan (LG) in the fast thermolysis of hardwood increases several times, if pre-hydrolysis of wood in the presence of a sulphuric acid catalyst at the temperature 150 -155°C is carried out, thereby achieving the hydrolysis of the main part of hemicelluloses. The lignocellulose (LC) obtained after washing are also the LG raw material. In the study, the chemical composition of the intermediate products formed in the technological process of preparing LC as well as the degree of polymerisation (DP) of cellulose in wood and the obtained LC are investigated. A possible correlation between the DP and the LG yield is discussed. The component composition is determined, and the applicability and purification potentialities of the obtained intermediate products – prehydrolysis condensates and LC washing waters are evaluated.

The pre-hydrolysis process condensate contains a considerable amount of acetic acid and furfural, namely, 5% and 12% from the oven dry wood mass, respectively. The obtained LC chips are washed with water till the pH 2.0-2.2 or the $H_2SO_4$ concentration from oven dry LC about 0.1% from its mass. 19-21% of oven dry wood organic substances, from which 78-88% are monosaccharides, are diluted in the washing waters. After the washing, the LC yield is 52-55% in terms of oven dry wood.

During the pre-hydrolysis, as a result of the action of sulphuric acid and elevated temperature, the DP of cellulose decreased from 1800-1900 in alder wood to 1200-1400 in LC. Comparing the LG yields from Kuerschner cellulose preparations prepared from the initial wood and LC, a considerably higher LG yield is obtained from the latter.

The thermolysis with the corresponding wood and LC samples, carried out in parallel, has shown that the acid-treated material (LC) demonstrated considerably higher LG yields, which, taking into account the cellulose content in LC (45-55%), actually correspond to the LG yield from the corresponding Kuerschner cellulose preparation. The use of the condensate for obtaining furfural and acetic acid is technically feasible. The applicability of the LC washing waters is still under study, although they do not present any problems in the wastewater biological treatment facilities.

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# INFLUENCE OF TEMPERATURE ON LIGNIN COAGULATION WITH ALUMINUM CLORIDE IN WASTEWATER TREATMENT

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Latvia is the biggest producer of plywood in Eastern Europe. One of the stages of raw material preparation for plywood producing is hydrothermal treatment of birch wood. Wastewater from plywood hydrothermal basin is characterized by the high degree of contamination. The basic contaminating component of this wastewater is lignin, which is the main reason of a high level of chemical oxygen demand (COD) and color of water. Insufficient efficiency of purification of lignin wastewater requires the development of advanced coagulation methods. It is known that the coagulation process is affected by its conditions, among which a temperature of wastewater plays a significant role. It has been assumed that the correct choice of this parameter can considerably improve the process of purification of lignin wastewater from hydrothermal basin, using chemical coagulants.

The main objective of the present study is to investigate the influence of temperature on birch lignin coagulation in the model solution, which imitated the wastewater of hydrothermal basin of plywood industry. The wastewater samples at different temperatures (3, 22 and 70$^{o}$C) were prepared by refrigeration and by warming in a water bath, respectively. The coagulation process was produced by mixing wastewater and water solutions of aluminum chloride with different concentrations. The efficiency of the coagulation within a pH range 3-10 was determined after 2 h of settling and filtration of the system. The method of spectrophotometry was used for determination of a remaining concentration of dissolved solids in a filtrate. COD was measured by total chemical oxidation of the received filtrate by adding potassium dichromate (LVS ISO 6060:1989). The color of the filtrate was determined by the method of photometry at the wavelength 436 nm. The results were related to the Pt – Co reference solutions (ISO 7887:1994).

The optimum dosage of aluminum chloride and pH value for the model solution treatment at a temperature 3°C are 400 mg/l and 6.0, respectively, at which 37.2% reduction of COD, 80.0% of dissolved solids removal and 32.8% of color reduction are obtained. The conducted experiments at varying temperatures have demonstrated that, with increasing a treatment temperature, contaminant removal is enhanced. For the model solution with a temperature 22°C, the optimum aluminum chloride dosage is 130 mg/l and optimum pH is 6.0. Applying these parameters, 45.1% of COD decrease,

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82.1% of dissolved solids removal and 62.7% of color reduction are obtained. It should be noted that, for the model solution treatment at a temperature 70°C, the optimum aluminum chloride dosage decreases fourfold in comparison with the treatment at $3^{o}$C.The system showed the highest efficiency in terms of decrease of COD (54.2%), removal of the dissolved solids (85.7%) and reduction of color (69.0%).

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