Alfred Teischinger, Marius C. Barbu, Manfred Dunky, David Harper, Gerfried Jungmeier, Holger Militz, Maurizio Musso, Alexander Petutschnigg, Antonio Pizzi, Stefanie Wieland, Timothy M. Young (Eds.)

Processing Technologies for the Forest and Biobased Products Industries

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and Biobased Products Industries

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PTF BPI 2010
Salzburg University of Applied Sciences
Kuchl/Austria

edited by

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This conference is dedicated to Prof. DI Dr. Reinhard Lackner

In the year 1995 the academic education in the field of forest products technology and management started at Kuchl under the supervision of Prof. DI Dr. Reinhard Lackner.

He built up the study course and the research department and over 300 students completed their studies successfully under his supervision.

As one of his first alumni I have the pleasure to thank Reinhard Lackner for his collegial way of teaching and working.

We wish Reinhard Lackner and his family all the best for his retirement time and we would very much like to keep contact with him in the future.

Prof. Dr. Alexander Petutschnigg
Head of the degree program 'Forest Products Technology and Wood Constructions'

In your hand you are holding the proceedings of the 1st International Conference on Processing Technologies for the Forest and Biobased Products Industries. The idea for this conference was initiated by Austrian forest products companies which are interested in new developments in processing technologies. The best way to inform scientists as well as industrial decision makers about new developments all over the world is to arrange a scientific conference. This was the starting point and after nearly one year of planning and organizing, the meeting takes place at the Salzburg University of Applied Sciences, Kuchl Campus, where the degree courses for Forest Products Technology and Wood Constructions are taught.

The conference has been organized jointly by the Salzburg University of Applied Sciences, the University of Tennessee, the University of Natural Resources and Life Science Vienna, and the University of Salzburg. Representatives of each constituted the Organizing Committee. The work was supported by the IUFRO and the FPS.

The following topics are covered in the conference:

Innovation in industry
Wood processing technologies and strategies
Process modeling technologies
Wood modification processes
New bonding technologies
Glued laminated lumber and components
Characterization of wood-based panels
Integrated bioenergy
WPC processes

We would like to thank all those people involved in organizing, reviewing and hosting the conference and wish all participants two interesting and successful days.

The Conference Organizing Committee

Table of contents

Session 2A: Wood modification processes
Chair: Dr. Holger Militz

Session 2B: New Adhesive Technologies
Chair: Dr. Antonio Pizzi

Session 4A: Integrated bioernergy
Chair: Johanna Pucker

Session 4B: WPC- Processes
Chair: Dr. David Harper

Biorefineries for Eco-efficient Processing of Biomass – Classification and Assessment of Biorefinery Systems in IEA Bioenergy Task 42 "Biorefineries"

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(www.biorefinery.nl/ieabioenergy-task42)

Classification: The increase of biofuels in transportation sector is the driving factor for the development of advanced processes to produce biofuels in biorefineries, whereas for the co-produced bio-based materials additional economic and environmental benefits might be gained. According to IEA Bioenergy Task 42 a "Biorefinery is the sustainable processing of biomass into a spectrum of marketable products" – (transportation) biofuels and bio-based materials, where other energy carriers (e.g. electricity) might be co-produced". The classification relies on four main features to describe a biorefinery system:

(1) Platforms: e.g. C6 sugars, syngas

(2) Products: transportation biofuels (e.g. FT-biofuels) and bio-based materials (e.g. glycerin)

(3) Feedstock from forestry, agriculture, aquiculture, trade&industry

(4) Processes: e.g. thermo-chemical processes

The platforms might be intermediates from raw materials towards biorefinery´s products, linkages between different biorefinery concepts and already final products. The number of platforms is an indicator for the complexity of a biorefinery. All the platforms, products, feedstocks and conversion processes of the

most promising biorefinery systems are combined in the classification network. A biorefinery is classified by the involved platforms, products and feedstock, e.g.: syngas platform biorefinery for synthetic FT-diesel and methanol from wood.

Assessment: The main question is what the advantages of a biorefinery are as a "multi-product" system compared to conventional bioenergy systems e.g. single product systems. The advantages might be in terms of environmental, economic, technical or social benefits. In IEA Bioenergy Task 42 a methodology is developed to establish a framework for such a comparison, which is already applied to several biorefinery examples. The relevant issues of the comparison are discussed and described.

The analysis of possible "advantages" of biorefinery systems in comparison to conventional systems is done for selected examples in terms of:

(1) Production costs and/or revenues for the energy and material products

(2) Amount of greenhouses gas saving by substituting products from conventional systems with products from biorefinery

(3) ,Amount of fossil energy saving by substituting products from conventional systems with products from biorefinery

Keywords (3 - max. 5): biorefinery, eco-efficient processing, bioproducts, biofuels

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Saving Resources by Advanced Vision-based Automatic Patching of Wood-based Panels

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ABSTRACT

Wood-based panels with a natural wood top layer such as veneered panels, plywood furniture or multilayer mixed-material panels must comply not only to stringent physical quality standards, but still more to very high aesthetic criteria, as the latter are decisive for the purchasing by the customer. The traditional way of manual visual inspection and of sorting out the quality panels with a too low visual quality suffers from serious drawbacks: too slow, too subjective and too costly in terms of loss of a precious natural material.

We present a technology for the automatic inspection and the automatic patching of panels which combines camera-based detection of flaws, automatic patching by NC-controlled putty or dowel injectors and, as an outlook, automatic camouflage of the repaired defects by ink-jet based local post-decoration with matching colour and grain graphics.

1   INTRODUCTION

Natural wood surfaces unavoidably show up local defects such as holes due to missing knots, resin pockets, open joints etc., defects which cannot be tolerated in the final products: multilayer table-tops, parquet, solid wood boards, plywood, shuttering boards, gluelam, furniture etc..   Many companies producing panels with a natural wood top layer therefore use a manual repair strategy: up to 12 workers are placed on both sides of the conveyor belt to perform a visual inspection of every panel; the locate and visually grade every defect and then repair it manually using hand-hold drilling equipment and dowels or putty to fill up the cleared defect zone.

Needless to say that the result of this purely physical repair strategy is far from being ideal:

a)   the required workforce is important and expensive
b)   the result is a the manually patched panel is not documented; its quality grade is fixed in a rather subjective way, introducing noticeable subjectivity in the final pricing
c)   even if the physical properties of a repaired defects may be acceptable (the surface is rather even and closed), the patched defects remain highly visible

patched with circular dowel   patched with elliptic dowel   patched with putty
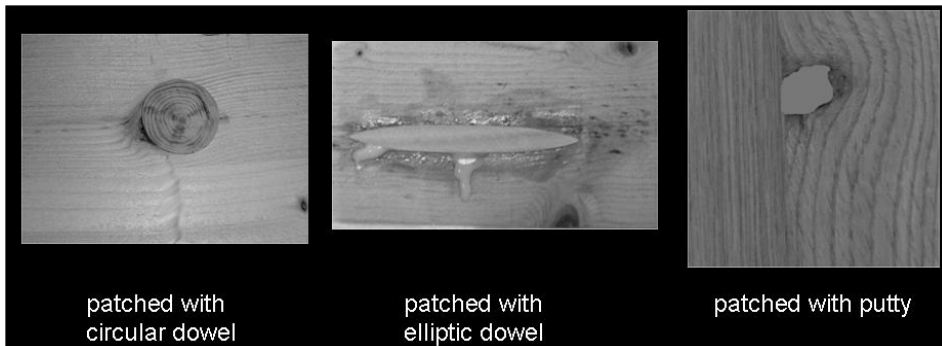
Figure 1. The state-of-the-art patching by manually inserting dowels or b injecting putty performs physical local reparation of a defect, but **not** really an aesthetical one: the repairs are highly visible.

We report on a new technology for a fully automatic and fast patching of large multi-layer wood panels using advanced multi-sensorial image processing and sophisticated numerically controlled XYZ manipulators for either patching by inserting specially shaped dowels or by injection of 1- and 2-component putty.

We finally discuss first ideas to patch panels not only for physical defects, but to use advanced colour image processing and local ink-jet decoration to make the patched defects invisible to the critical eye of the customer, thus restoring an almost perfect first grade quality from lower grade wood.

2   AUTOMATIC PATCHING

Baumer Inspection GmbH, Germany, has taken a more generic approach to the task of repairing panels compared to existing technologies (see f.i. www.rathe.com) able to work with *any type of natural material* (wood, natural stone etc.). We have developed together with the Austrian manufacturer of numerically controlled production equipment FILL GmbH (www.fill.co.at) a highly modular set of imaging devices and numerically controlled XYZ manipulators to embrace any type of panel repair technology (inserting dowels of different size and shape, injecting 1- or 2-component putty of matching colour etc). The system produces in its current 1rst generation version classical physical patching, i.e. it generates from a panel with any number of defects a patched panel with a nicely closed and even surface. The system is however prepared for a further mode which will produce patches which match to the local aesthetics of the panel; it will then produce a final panel where the patches are hardly visible. We call this technology "generic" because it is based on a highly modular architecture comprising different camera/illumination systems, image processing algorithms able to detect a very large number of defects, repair strategies stored in a knowledge base, high-speed/high precision numerically con-

trolled XYZ axes with tools for clearing defects and patching them, either via dowel insertion or putty injection.
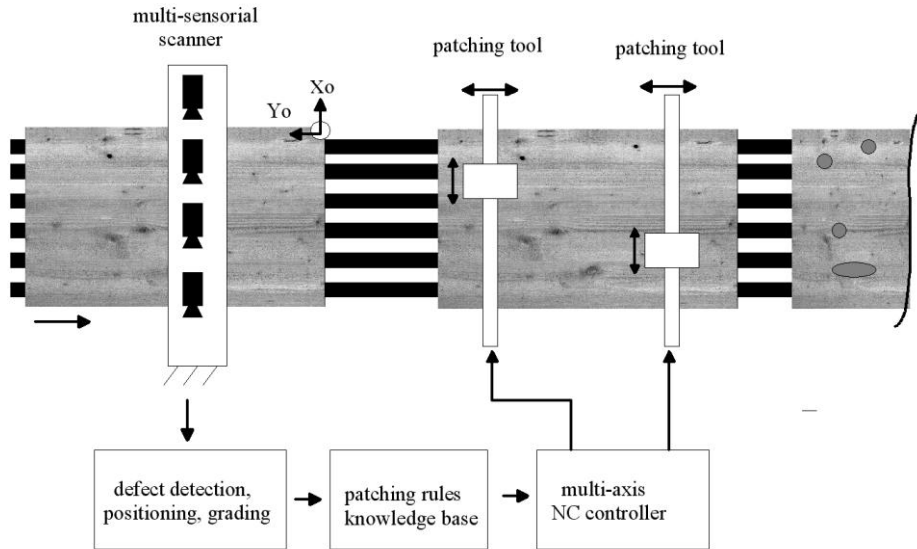
Figure 2. Layout for an automatic patching system

As pictured in Figure 2, the panels are first scanned with a multi-sensorial high-resolution multiple-camera scanner of typ. 01 mm/pixel while moving on a conveyor belt with vacuum gripper. This advanced scanner first optically defines a panel-oriented cartesian XYZ coordinate system with the origin located at one of the front end panel corners; it then detects, grades and locates these defects within that panel-based coordinate system, computes a repair strategy using a knowledge base of repairing rules and then transmits these data to the XYZ working-tool manipulator for carrying out the repair steps.

An arbitrary number of independently operating XYZ tool holders for drilling, putty injection, dowel insertion etc. can be addressed simultaneously to distribute the repair tasks and thus to increase the patching speed. Typically we will use two manipulators in parallel to patch an entire panel in about 90 seconds.

Figure 3. The panels are scanned by the multi-sensorial ColourBrain® scanner (right top) before entering the complex automatic patching plant with several NC patching tools operating in parallel

3   MULTI-SENSORIAL SCANNING FOR A DIFFICULT TASK

As so often in machine vision technology, a task which at the first glance appears rather straightforward becomes more then complex when it comes up to operate reliably in a rough production environment, on panels with an enormous variety of wood species, with high contaminations by dust, wood glue, severe panel non-flatness etc..

A defect to patch must be located with an absolute accuracy of 1 mm on a 5000 mm long panel, which is a 1:5000 absolute accuracy in presence of severe panel non-planarity. Our system takes care of the 3-dim. distortions and measures defect positions mapped to this non-even panel surface topology.

The panel surfaces are severally contaminated by glue and duct from theup-stream hot pressing. We need imaging cameras which can differentiate between real defects (open knots, crack, resin pockets, glue filled holes..) and the very similar looking contaminations. They extract the relevant informations to feed the patching tool controller: position, contour, type of defect, grade, and a patching strategy to achieve a low visibility of the patched areas and a high throughput. Many of these methods are protected by patents of Baumer.

4   PHYSICAL PATCHING AND AESTHETIC RECONSTRUCTION

Figure 1 clearly shows that even the best state-of-the-art automatic or manual physical patching of a panel, be it by doweling or by injection of putty, is not able to reconstruct a natural wood appearance. Patching workers often choose from a small number of different coloured dowels or putties to make the patched defect as poorly visible as possible. But even a carefully patched panel

never reaches the visual quality grade (and price) of a defect-free panel. The same is true for defects patched with a dowel: they remain very visible because of the local mis-match of wood grain.

This aesthetical down-grading is a serious economical loss which is today taken by the wood industry as unavoidable. It is of course also an ecological loss, as lower quality wood species with a large number of knots, resin pockets, cracks etc. cannot be used for high-quality panels for the furniture, flooring and interiors industry.

We have therefore put forward the question, if it would not be both economically and ecologically challenging to develop an automatic patching technology which is able to make the patched defects invisible by using a *local* aesthetic reconstruction of the original wood appearance /1/. By imaging the regions around the defects (typ.a rim of a few cm widths) with colour cameras and by using machine-learning principles to automatically learn the natural wood structure in the neighbourhood of a patch; we are able to synthesize the lost original wood grain and colours.

With a carefully calibrated ink-jet printer head, we could decorate the patch with this synthetic décor to make it almost invisible. Figure 4 shows (in a simulation) an early result of this research project which confirms the validity of our approach.

5   CONCLUSIONS

The fully automatic patching of panels with a natural wood top layer requires a sophisticated combination of advanced machine vision technologies and NC robotics. The substantial amount of contaminations on these panels and the required very high defect recognition and over-detection suppression rates make it paramount to use advanced imaging, pattern recognition and high-speed data processing technologies to compete both in speed and accuracy with the manual working staff. This approach naturally leads to "generic" patching systems, i.e. modular optical, software and NC axis components which can be assembled for the automatic patching of almost any type of materials: wood, natural stone etc.

Our new concept of automatic local aesthetic reconstruction will enable us in a near future to produce almost invisible patches and thus enable the panel industry both to make a better use of actual wood grades and to produce good visual qualities with lower graded wood species. This is a welcomed economic and ecological benefit for this industry.
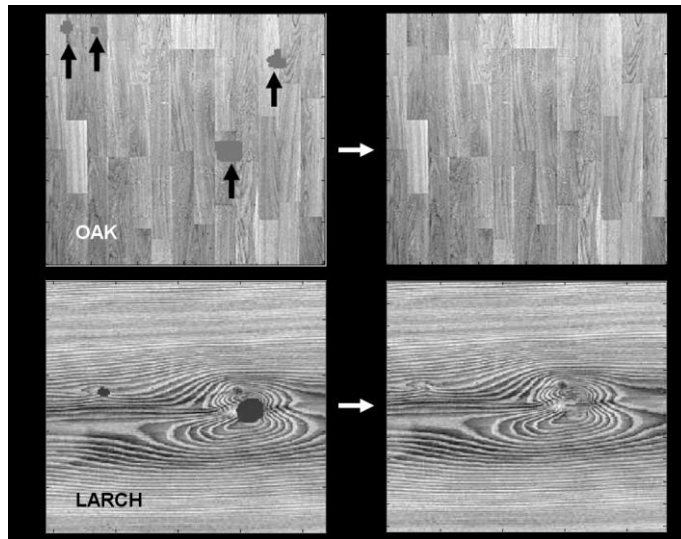
Figure 4. Simulation of the automatic physical <u>and</u> aesthetic patching of local defects in panels: the missing wood grain and wood colours are automatically reconstructed based on the pictural information in the neighbourhood of the defect (patents pending)

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Superior processing of small diameter hardwood

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ABSTRACT

The sustainable management and shortage of limited biological resources has currently become a subject of much discussion. Timber as a renewable biological raw material is used global at a high percentage for low rated utilizations like heating purpose, energy recovery or underrated industrial wood processing. Process value analysis predominantly indicates substandard use of harvested forest hardwood thinnings. The bulk of small sized hardwood timber is graded as industrial timber and processed almost exclusively by the board and paper industry or even restricted to thermal utilization. Industrial assortments are generally low priced with varying proportions of probably "potential wood" relating to total quantity. Raw material out of superior use and high-potential wood provide a kind of technological added value overlapping area. Guidelines for grading the logs and the timber of small diameter hardwood, together with recommendations for its use are developed. Various conventional mechanical tests should encourage the potential of common used hardwood thinnings native in Central Europe. Process and value chains are investigated to show possible alternatives for processing small diameter hardwood.

1   INTRODUCTION

Small diameter hardwood is often not graded regarding wood quality for any superior wood processing, rather qualified as industrial wood due to its dimensions. Board, pulp and paper industry cover themselves with thinnings of various hardwood species up to processable diameters for higher purpose regardless

of wood properties. The mechanical potentials apart from energy production and industrial round wood of hardwoods with low diameter shall be identified.

Process value analysis predominantly indicates substandard use of harvested forest hardwood thinnings. The bulk of small sized hardwood timber is graded as industrial timber and processed almost exclusively by the board and paper industry or even restricted to thermal utilization. The second and especially the third time of hardwood thinnings yield logs up to 3a respectively 3b size class. Furthermore rapid removal of the harvested logs from felling areas and minimized intermediate storage requires a close cooperation of forest and timber industry and are responsible for the grade of log quality at mill decks. For subsequent upgrading wood processing the moisture content of the greenwood should kept as high as possible up to the final cutting. Neglected wood moisture in the paper, board or energy business causes often increasing laying times of logs that results in decreasing moisture content and low wood quality. Contemporary wood processing is able to upgrade sawn timber out of small dimensioned hardwood logs for superior use and applications. Availability, service capacity, range of use equal to conventional sized hardwood dimensions and market potential are some objectives of this study which should be answered.

2 MATERIAL AND METHODS

2.1 Material

To show the potential of this assortment four small diameter hardwood species (*Fagus sylvatica* L., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Quercus robur* L.) from three different growth areas from Lower Austria were investigated. Altogether 122 trees were harvested for the project. The distribution of the wood species was as following, 28 logs of beech, 26 logs of ash, 42 logs of maple and 26 logs of oak. For beech a medium diameter of 28.8 cm and medium tree age of 95 years, for ash 22.8 cm and 32 years, for maple 24.1 cm and 51 years, for oak 28.7 cm and 67 years were constituted.

2.2 Methods

The grading rules of OEHHU [1] for round wood and for sawn timber grading were applied and modifications for small diameter hardwood are suggested.

The through and through sawing of the logs was carried out at the sawmill Frey-Amon, Hetzmannsdorf, Lower Austria. Being cut the boards were marked and stacked for kiln drying. The heartwood boards were used for the drying experiments and the material characterization. The rest of the boards were dried in a convectional drying kiln applying standard drying processes of Frey-Amon for the particular wood species. All boards were dried to a final moisture content of 8.5 %.

After drying clear samples were performed and stored until final testing at a constant climate of 20 °C and 65 % relative humidity. Mechanical characterization was conducted at a Universal Testing Machine according to the following standards: Three-point bending strength (DIN 52186) standard, compression

strength along the grain (DIN 52185) and perpendicular to the grain (DIN 52192), oven dry density (OENORM ISO 3131).

3 RESULTS AND DISCUSSION

Before harvesting the trees the stems have been assessed upright and after felling the logs have been graded at the felling place in the forest.
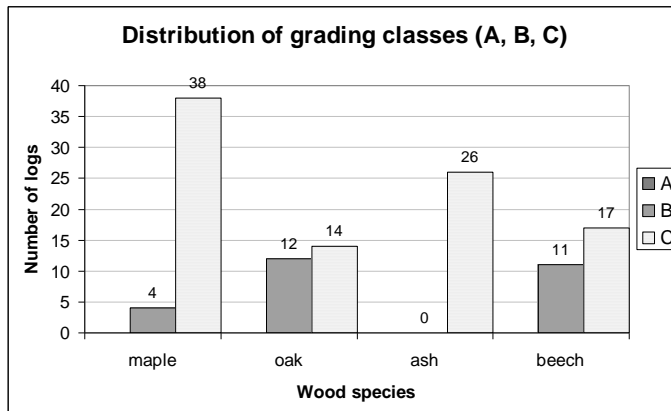
Figure 1. Distribution of grading classes (B, C) following OEHHU

Figure 1 shows the distribution of the log grading classes. There was no log graded in class "A" mainly due to knots. The knots have been the knock-out-criterion for the selected logs. Only 10 logs have been graded due the other criteria (distortion, color).

Besides knots, a limiting grading factor for thinnings is the low diameter. Nevertheless for the project only two logs of ash and one log of maple had been classified in a lower grading class due to the low diameter.

The dried boards were graded as one piece without partitioning them into sections. The medium face width and the length due to end cracks were determined and the "resulting board" was graded.

Figure 2 shows the grading quality of the boards. The grading quality is higher than the grading quality of the logs mainly due to the high quality of the side boards.

Distribution of grading classes (I, II, III, x)
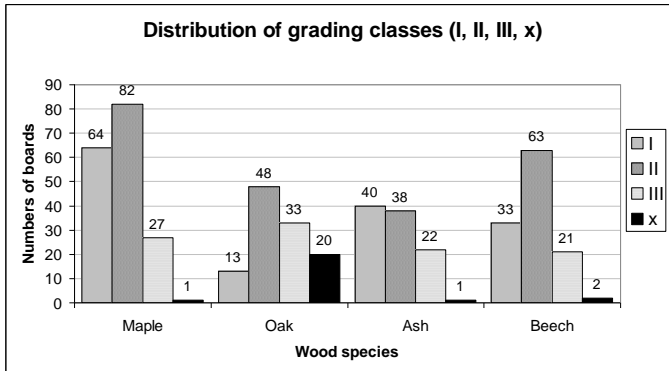
Figure 2. Grading classes of kiln dried timber according OEHHU

The total cut of 20.5 fm of wood resulted in 10.6 m³ of sawn timber in different qualities which equates a yield of 52 %. The average yield for the hardwood industry is about 55 to 60 %. The yield of maple was 67 %, of ash about 52 %, of beech about 45 % and of oak about 41 %. The low yield of beech and oak are due to red heartwood in beech and the high portion of sapwood of oak.

The medium diameter of the logs was 26 cm. The medium diameter in the hardwood industry is around 40 cm. The smaller diameter results in higher processing costs for small diameter hardwood using the same sawing technology. Reducing costs calls for higher processing speed or alternative processing technologies like chipper or circular saws or alternative value chains. These value chains are to be measured and assessed by means of indicators on the process level, for parts of the chain, or entire chains. These basic process chains are assessed by employing the central indicators that reflect economic, environmental and social sustainability aspects on a regional level: gross value added, carbon emissions and employment.

Figure 3 displays a simplified process chain for small diameter hardwood (SDH). Starting from a forest regime in pure and mixed broadleaved forests SDH is gained most likely from thinning operations which imply adapted tree selection and pre-sorting procedures compared to standard management. In the following truck transport is assumed for an average transport distance and a sawmill with band saw technology that can be considered typical for Austria. For the sawmill, sorting, manipulation and sawing as one cumulative process is designed. Subsequent to drying and storage the flow of material follows the assumptions that about 30% of SDH can be transformed to standard assortments while the rest will be used as specific SDH in material use. Manufacturing of SDH is foreseen as parquet (long strip planks) for oak, solid wood chairs for beech, solid wood tables for maple, and interior doors for ash.

FM broadleaved and mixed forests

Thinning — Remaining stand

Forwarding/sorting

Truck transport

Mobile cutting — Saw mill/saw chain

„Holzhof" — Drying

Storage

SDH assortment — Standard assortment

Oak: parquet/long strip planks

Beech: solid chairs

Maple: solid tables

Ash: interior doors
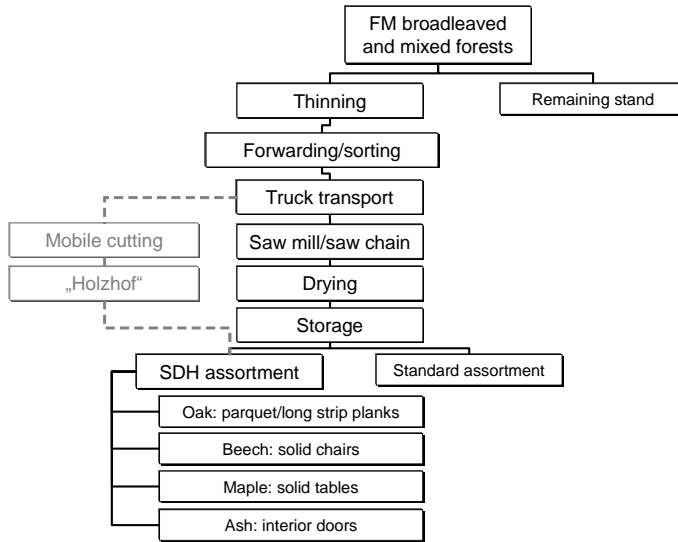
Figure 3. Simplified value process chain for SDH in Austria

The results confirm that small dimensioned hardwood thinnings equal or rather top mechanical properties of conventional timber examined in literature (Kollmann 1982 [2], Wagenführ 1985 [3], Sell 1989 [4]). Quite high average bending strengths and moduli of elasticity of sap- and heartwood could be observed (Table 1). Also compression- as well as tensile strength values were in the upper region as known by literature (Table 1).

Table 1. Mean values and standard deviation (in parantheses) of specific determined mechanical properties of heart- and sapwood

Species	Oven dry density (kg/m³)	3-pt. bending MOR (N/mm²)	3-pt. bending MOE (N/mm²)	Compression strength ⊥ (N/mm²)	Compression strength II (N/mm²)	Tensile strength ⊥ (N/mm²)
Beech	732 (41)	155 (19)	16752 (2147)	17 (2)	69 (8)	14 (2)
Ash	686 (55)	160 (21)	15341 (2300)	13 (3)	71 (10)	13 (2)
Maple	n.a.	121 (21)	12651 (2653)	16 (3)	57 (8)	n.a.
Oak	n.a.	123 (25)	13867 (3127)	15 (2)	63 (9)	n.a.

n.a. = not yet measured

An explanation for surprising high characteristic values could give to some extent growth increment depending basically on site specific conditions like soil composition, particularly for investigated 95 year old beech. Forest management, especially not in time performed thinning, may lead to a minimal increment of growth respectively higher annual-ring density.

Further the increasing share of late wood have a significant influence as well as decreasing lumen on microstructure level, which affect mechanical properties sustainable.

4   CONCLUSIONS

Grading of small diameter hardwood according to the existing standards is not limiting yield and quality. One limiting parameter is the processing itself as the smaller diameter leads to a lower performance and therefore higher costs. Different processing technologies or different processing chains are to deliberate in order to increase material utilization of hardwood thinnings. As the yield of the better qualities is mainly related to side boards which are not suitable for many applications product development for SHD assortments is indispensable.

Mechanical characterization of investigated small diameter hardwoods show unexpected high characteristic values in three-point-bending strength, modulus of elasticity in three-point-bending and compression strength parallel as well as perpendicular to the grain. In comparison to literature mechanical properties of conventional hardwoods are consistently lower than determined values in this study. Small diameter hardwood consists not exclusively of juvenile wood as one might expect concerning small diameters. The fact of equal mechanical properties at least should encourage the superior processing of small diameter hardwood. Potentials in mechanical utilization provide only one opportunity for an upgrading use of this timber assortment beside further applications.

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Increase of material yield in Plywood Production with new Veneer Processing Technologies

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ABSTRACT

Although Germany has a share of 15 % of all plywood consumed in Europe, the German plywood producers have a market share as low as 1 % in Europe. On the other hand, German forests have a high stock of logs suitable for the production of plywood. In order to make plywood production in Germany attractive for investors again, improvements in manufacturing technology are necessary, and new technologies should enable plywood producers to broaden their raw material basis [1].

Material yield using present technology is estimated to approximately 40 % due to losses caused by defects, peeling, drying, trimming etc. During the drying process and due to anisotropic shrinking of the veneer ribbon splits and wavy edges appear. Although several methods are used to achieve an "ironing effect", drying losses cannot be avoided. A possible solution could be processing veneer sheets in a hot press.

An increase in yield seems possible if the peeled veneers are processed in a way which adapts to the real size and frequency of defects: Clipping of fixed sizes and post-grading is one possibility, and cutting of defects and joining the sheets to an endless ribbon free of defects is the other choice. But a decision for one of the alternatives is only possible if the defects on a veneer ribbon typical for the available material are recorded and processing regimes are simulated and evaluated by yield. WKI has developed software for this simulation and tested it for different qualities of beech and spruce logs.

1 ECONOMIC POTENTIAL FOR PLYWOOD PRODUCTION IN GERMANY

In the last decade the plywood production in Germany decreased drastically. From 2002 to 2005 the annual production declined from 36,000 to 24,000 m^3 (hardwood-based) and from 47,000 to 6,000 m^3 (softwood-based). At the same time the plywood imports increased significantly from 460,000 to 598,000 m^3

[1] Aderhold, J., Marutzky, R., Schwitzgebel, F., Duschl, C., Buddenberg, P. A.: Veneer based products made of large diameter timber, Proceedings of the COST Action E40 Conference : Large diameter timber - problem or chance?, p. 43 – 49 (2006)

and from 363,000 to 377,000 m^3 per year, respectively [2]. This discrepancy illustrates the high demand of the German market, but simultaneously it also demonstrates the dilemma of the German plywood industry: Due to high raw material costs and especially high production costs a profitable plywood fabrication seems to be impossible, although the national plywood demand would guarantee high sale volumes. In Germany predominately beech timber from mature tress (> 120 years) is used for the plywood production. Due to a shift in the national silvicultural strategy, i.e. conversion of the dominating softwood stands (spruce and pine) into mixed and pure hardwood stands, especially the volume of beech timber in German forests is steeply rising [3]. Moreover the German sawmill and panel industry is dominated by softwood and due to the comparatively low beech timber demand for substantial uses, only 40% of the sustainably useable beech timber is harvested annually [4]. Therefore from a quantitative point of view great amounts of beech timber suitable for the veneer and plywood production should be available in the forests. On the other hand the political promotion of the energetic biomass use increased the prices for all kinds of timber considerably and therefore from an economic point of view the domestic plywood production appears to be hardly profitable. Otherwise, due to improvements in the manufacturing technology and by the enlargement of the raw material basis a profitable plywood production in other European high wage countries (e.g. Finland) is evidentially possible.

Tree species like birch, alder, poplar, willow and rowan (low density hardwood: LDH) with remarkable growing stocks in the German forests are not commercially used or used for products with low added value. The growing stock of these species amounts to 180 Mio. m^3 and due to a very low harvesting intensity these timber stocks are increasing rapidly [3].

Currently timber from these tree species is neither used for the production of wood-based panels nor for the production of veneer or plywood in Germany, although there are some good reasons for the substitution of beech timber by LDH especially with respect to the plywood production. Contrary to the processing of high density beech timber, steaming of LDH is not necessary before peeling the log. By reason of this the production process becomes more efficient and production costs are declining.

Moreover, currently there is no request for these raw materials on the market, resulting in considerably lower purchase prices. The substitution of beech timber by LDH for the veneer and plywood production is one possibility to revitalize a profitable fabrication in Germany. But to achieve this goal some obstacles have to be removed. Earlier studies indicated that the use of LDH logs (especially poplar) from German natural forests can cause problems in the peeling

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[2] ZMP – Zentrale Markt- und Preisberichtstelle GmbH Bonn (2007): Forst und Holz – Marktbilanz 2007

[3] BMELV - Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (2004): Die Bundeswaldinventur2 (BWI2)

[4] Berthold, D.: Hochwertige Produkte aus alter Buche, Internationaler Verein für technische Holzfragen (2009)

process. Otherwise birch and poplar logs from Scandinavian and South European forests can be processed without any problems. These questions have to be addressed by applied R&D projects.

2 POTENTIAL FOR TECHNICAL IMPROVEMENTS

Other than their competitors in Scandinavia or Southern Europe, German plywood manufacturers use mainly beech as a raw material. This tree species presents certain technological difficulties which have made it impossible so far to benefit from the progress in automated plywood production achieved for soft wood, birch and suchlike. In order to make plywood production on a large scale competitive in Germany, a much higher degree of automation and also improvements in wood yield are necessary due to high wages and energy cost in this country. This requires technological progress in several production steps, with clipping and drying the peeled veneer ribbons being the most promising [5].

2.1 Innovative techniques for veneer drying

Yield losses in plywood production have various reasons. The logs have to be trimmed so that they fit into the peeling machine, which causes losses of around 10 %. In the peeling process itself, further 12 % of the wood is lost due to rest rolls. Veneer processing itself accounts for losses of 15 % due to clipping and 11 % due to shrinkage during drying. After all, the final yield can be as low as 40 %.

The lost veneer volume during the two last-mentioned production steps comprises several components: The reduction in thickness due to shrinkage, the loss in area by clipping, and the loss in area by shrinkage in transport direction (perpendicular to the fiber direction).Shrinkage in fiber direction can be neglected.

The relative shrinkage of wood is different for late wood and early wood. Consequently, drying results in mechanical stresses which would cause buckling of the veneer surface. In order to avoid this, mechanical pressure is often applied perpendicular to the veneer surface during drying. However, the stresses can in this case exceed the strength of the wood, and cracks will appear. This is especially a problem in beech which shows stronger shrinkage than birch or pine and grows more irregular.

Drying in a hot press has been proposed as an alternative drying technology. The main idea is to dry the complete veneer sheet at the same time by hot plates, in such a way avoiding moisture gradients. The applied pressure will prevent buckling. In case the conditions are properly chosen, a plastification of the wood will appear, which reduces the mechanical stresses and prevents crack.

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[5] Marutzky R., Aderhold J., Plinke B.: Hochwertige Verwendung von Starkholz durch Schälfurnierprodukte aus stark dimensionierten Nadel- und Laubhölzern, Teilprojekt 1: Evaluierung und Weiterentwicklung der Technologie zur Herstellung von Furniersperrholz, BMBF Project 0330552A, Final Report, Braunschweig : Fraunhofer WKI, 2008

Press drying increases thickness losses but at the same time avoid shrinkage in transport direction. Furthermore, losses caused by cracked veneer sheets are reduced, and automated handling of the sheets gets possible. Surface roughness of the veneers decreases which can save adhesive.

2.2 Simulation of clipping strategies and yield estimation

Today, the veneer ribbon is clipped across the production line. There are several methods how to determine the width (sheet size in production direction) to be clipped and how to use the material:

- Clip the ribbon into fixed widths and grade each sheet by quality (to be estimated by amount and area of defects),
- Clip out only the defects (to be measured automatically using a defect scanner) and achieve clear areas with different widths,
- Combine the methods (e.g. clip out defects but cut the clear areas again to achieve minimum and maximum sheet widths).

Material losses arise with all methods, depending from several parameters as tolerable defect size, min. and max. width of sheets, limited speed of the cutting knife etc. The overall yield can only be counted when one method is performed and the material has passed the production line. Detailed defect information is not recorded. Therefore, producers decide by experience and by careful selection of the raw material. Effects of alternative processing technologies and their economic impact on material yield can hardly be predicted. E.g., it appears possible that clipping losses can be reduced following a proposal of the Buddenberg agency [5]: The clip length in the production direction of travel is variable; in all cases the maximum length between two defects is used. The clear parts of the veneer ribbon are joined together to form a continuous ribbon. The good areas of the flawed veneer sheets are used once they have been joined together and added to the continuous veneer ribbon which is now free of any defects. The veneer ribbon is cut to the sizes required.

In this way it would be possible to reduce clipping losses, but extra costs would arise from the additional work operations. A decision for one of the alternatives must be supported by knowledge of the amount of defects in the material and by a simulation of the material yield for parameters such as sheet size, defect tolerance for several grades, minimum size of and defect-free veneer area, and minimum distance between cuts due to the inertia of the clipping knife. Simulations are only possible if the defects on a veneer ribbon typical for the available material are recorded and processing regimes are simulated and evaluated by yield. Rotary-cutting trials were conducted in order to obtain by experiment defect statistics for pine and beech [6]. A line scan camera was positioned above the

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[6]Aderhold J., Plinke B.: Opto-electronic evaluation of veneer cutting tests and strategies to optimize the veneer yield, in: 6th European Wood-Based Panels Symposium, 9 October 2008, Hanover

production line and the surface of the veneer ribbons (170 beech and pine peel rolls with a length up to 100 m) was scanned. Calculation of defect and yield statistics from these data required further image processing steps: Contrast and brightness correction, detection of 'dark' image areas as defects and measurement of their size and position, determination of the positions of virtual cuts on the veneer ribbon, according to parameters defect contrast, defect size, min. sheet widths and min. distance between cuts, determination of the overall yield (amount of overall defect-free area to total ribbon area).

WKI has developed software for this simulation and tested it for different qualities of beech and spruce logs. Figure 1 shows the virtual cutting pattern for the case of

- cutting only defects (theoretical – Figure 1 top), and
- cutting defects but consider and min. distance between cuts and a min. sheet width (realistic – Fig. 1 bottom).
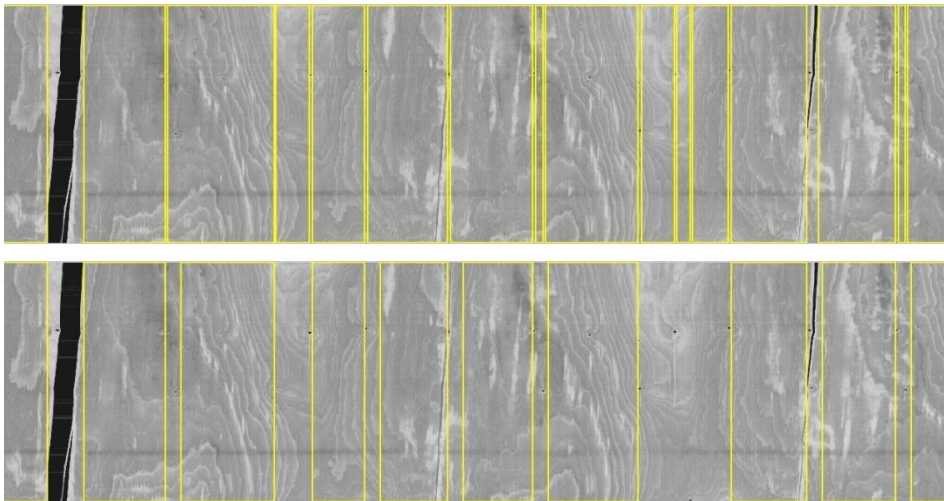
Figure 1. Virtual cutting patterns - Top: Cutting positions around the defects, Bottom: Realistic cutting pattern, considering min. sheet width etc.

The first image shows the areas free of defects and can be considered as quality information about the raw material. The second one shows a realistic cutting pattern and is yield estimation according to the set of parameters (min. defect size, min. sheet width etc.).
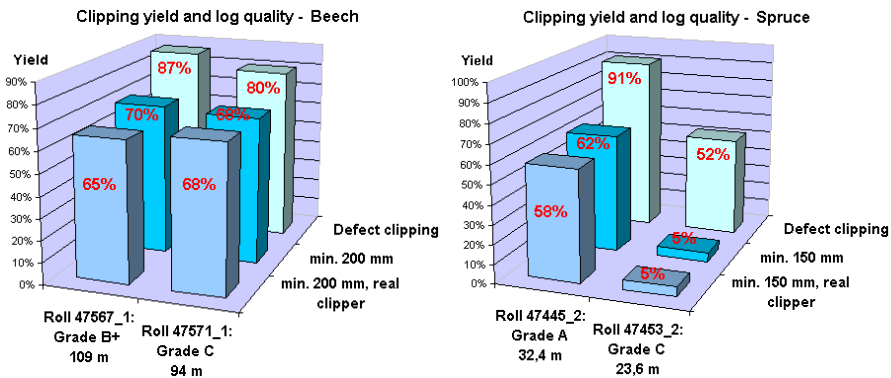
Figure 2. Results of simulated veneer clipping - Left: Yield values for a good and a bad peeling roll (spruce); Right: Yield values for two peeling rolls (beech)

Different processing regimes have been simulated. Some results are shown in Figure 2 for peeling rolls of spruce and beech and of several visual grades: The theoretical yield (defect clipping) decreases if a min. sheet width is demanded, and the real yield reflects different visual log grades.

The tolerated defect size would affect the results as well. More sophisticated simulations are possible - e.g. the yield of cutting sheets of fixed width followed by post-grading.

3   CONCLUSION

Plywood production in Germany has been declining for many years although the consumption in this country is high. On the other hand, a large and still in-creasing supply of mature hardwood trees is growing in German forests. The substitution of beech timber by low density hardwood plywood production could be advantageous for a profitable fabrication in Germany. However, there is also demand for progress in manufacturing technology. This includes innova-tive drying technologies avoiding degradation of veneer quality. The clipping process has room for improvement as well. Novel concepts such as virtual clip-ping and yield prediction derived from test peeling data can open the way to novel clipping strategies based on reliable facts. In such a way, plywood pro-duction in Germany could be revitalized and the existing wood resources be used for high-value products.

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[6]   Aderhold J., Plinke B.: Opto-electronic evaluation of veneer cutting tests and strategies to optimize the veneer yield, in: 6th European Wood-Based Panels Symposium, 9 October 2008, Hanover

Real-time process modeling of wood composite panels

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ABSTRACT

This study focuses on the real-time prediction of mechanical properties such as internal bond (IB) and modulus of rupture (MOR) for a wood composite panels manufacturing process.

As wood composite panel plants periodically test their products, a real time data fusion application was developed to properly align laboratory mechanical test results and their corresponding process data. Fused data are employed to build regression models that yield real-time predicted mechanical property values when new process data are available. The modeling algorithm core uses genetic algorithms (GA) to preselect a meaningful subset of process variables. Multiple calibration models are then built using several regression methods. At one of the test sites, prediction results for the two most manufactured products have been assessed by comparing actual IB and MOR values to their corresponding predicted values. The benefits of using four different regression methods for prediction of mechanical properties are also discussed.

1   INTRODUCTION

The forest products industry contributed \$240 billion to the U.S. economy in 2002 (U.S. Census Bureau 2004). In the same year, 1 009 555 people in the U.S. were employed by 22 231 primary wood products manufacturers [1]. However, this sector has experienced severe downsizings in production and employment since the US housing crisis began in 2007, and is still at risk due to the rise of imported wood products, increasing raw material costs, and the use of non-renewable oil- and cement-derived products in place of traditional wood products.

Wood costs can account for as much as 40% of total manufacturing costs and represent the largest single cost component of total costs for most forest products manufacturers. Wood waste is one of the largest potentially avoidable costs. The engineered wood panel sector produced 64.3 billion square feet of panels in 2003 with wood waste ranging from 3% to 9% [2]. Reducing wood

waste by only 1% can translate into annual savings of almost $700 000 for a typical producer.

Of great importance is the delay between the time a sample is taken for mechanical properties testing at the end of the production line and the time at which the strength of the product is determined in the testing laboratory. This delay can vary between 30 minutes and six hours, during which the quality control (QC) properties of the product are unknown. In the absence of a real-time model that predicts QC properties, it is difficult to optimize production and correct for possible poor mechanical properties or out of target density of the final manufactured product.

Though it has become common for engineered wood manufacturers to separately warehouse real-time sensor data and destructive lab test data, most manufacturers use simple trend charts and reporting tools. Some work has been initiated in data mining and predictive modeling of final product quality characteristics of forest products using statistical methods [3], [4], [5], [6], [7], [8], [9].

Sustaining business competitiveness by reducing costs and optimizing product quality will be essential for the forest products industry. One of the challenges facing this industry is to develop a more advanced knowledge of the complex nature of process variables and quantify the relationships between process variables and final product quality characteristics.

This paper will describe a newly developed real time process modeling software that was installed and tested in a wood composite panel plant to predict real time internal bond (IB) and modulus of rupture (MOR). The quality of the predictions will be assessed by comparing the actual versus predicted IB and MOR values for the two most manufactured products. The impact of using several regression methods instead of only one (multiple linear regression for instance) will be discussed.

2   MATERIALS AND METHODS

The process modeling software was installed in a particleboard panel plant several months ago and is currently predicting. IB and MOR [10] were chosen as the default mechanical properties to be modeled. The plant was producing many products with various thicknesses at different levels of minimum required mechanical properties. Though the process modeling application allows for of all product types to be modeled, results will only be shown for the two major products (in volume) manufactured: 19 mm and 13 mm thick panels. A total of 193 process variables were available for the process modeling algorithm.

2.1 Process data and QC data fusion

A very important procedure deals with the fusion of the process data with the QC data. An automated real time data fusion system was developed to provide the process modeling algorithm with a database containing two important data sets. One data set is populated with the real time lagged process data only, while the other is populated with the QC data and is synchronized in time with

lagged process data. Lagging the process data is a very important step because the plant data warehousing stores all process variables values at an identical time. Yet, when a panel leaves a press at time t_{press}, the fibers, particles or flakes that constitute this panel travelled through the process line before t_{press}. The data fusion program uses the distance from each process sensor (process variable) to the outfeed of the press in conjunction with the forming line speed to calculate a speed dependant lag time for each process variable. An optional constant lag time was also added to take into account the presence of a silo or bunker before a sensor's location on the process line where the raw or processed material can sit for some time before it exits. Each real time lagged process data record is the result of the median of a number of lagged raw process data to avoid possible empty (null) data and to minimize potential noise.

2.2 Process modeling algorithm

The process modeling algorithm works as a Microsoft Windows service. GA [11] is employed to evolve an initial ensemble of randomly selected subset of process variables (among all available) toward an optimized ensemble using genetic operators such as selection, crossover and mutation. Each individual from the ensemble is given a score by computing its Bayesian Information Criterion (BIC) [12] after having built a calibration model using either multiple linear regression (MLR) or partial least squares (PLS) with a sufficient number of fused QC and lagged process data records. Once an optimized subset of process variables has been found, several calibration models based on four different regression methods (MLR, ridge regression {RR}, PLS and feedforward neural networks {NN}) are built. Real time lagged process data are sent through the most current calibration models to generate predicted QC data values. When a new fused QC and lagged process data record becomes available, predicted QC values are compared to the actual QC values to decide if existing calibration models must be recalibrated or kept. The comparison between actual values and the four predicted values allows the selection of the regression method with the best predictive ability whose predicted values will be displayed on the client application real time trending chart.

A unique feature of the process modeling algorithm is the simultaneous use of four different regression methods to build four calibration models for each selected QC property. Multiple linear regression [13], ridge regression [14] and partial least squares regression [15] are well known linear multivariate regression methods while a feedforward neural network [16] constitutes a non linear multivariate regression method.

The process modeling algorithm constantly updates its regression models based on the latest data available while giving predicted values for the selected QC properties. The algorithm allows two QC properties to be modeled simultaneously.

3   RESULTS AND DISCUSSION

Table 1 shows the validation results for the 19 mm and 13 mm products. The number of observations (fused QC and lagged process variable data records) for the 19 mm product IB response, 19 mm product MOR response, 13 mm product IB response and 13 mm product MOR response were 84, 82, 58 and 59, respectively. The observations gathered in these results represent a time span of about two and a half months because many products are manufactured for very short durations. Because of these constant product changes and short runs, it was decided to recalibrate the regression models very often. Recalibration is considered when two fused data records have been accumulated during a product run. If the average error (mean normalized root mean square error) between actual and predicted values for the best performing regression method is greater than15%, new calibration models are generated from the entire set of independent variables (GA process variables selection and calibration models building). Table 1 shows the validation results for IB and MOR for the 19 mm and 13 mm products. The root mean square error of prediction (RMSEP) was used to measure the difference between predicted and actual values. A mean normalized RMSEP (MNRMSEP) in percent was also calculated by dividing RMSEP with the average of the actual values. This statistical measure allows one to compare the prediction errors across products and properties. The linear correlation coefficient is given in Table 1 (r), along with the number of times (in percent of the total number of observations) each regression method (% NN, % RR, % PLS, and % MLR) was selected as the best regression method.

To illustrate the potential of multiple regression methods used in the process modeling algorithm, the first four rows of Table 1 show the prediction results if MLR was the only regression method for all observations (or if the process modeling only had one regression method implemented such as MLR).

IB MNRMSEP was greater than 15% for both of the products when using MLR only. The IB correlation coefficient was of 0.29 and 0.54, for 19 mm and 13 mm products. MOR MNRMSEP was greater than 10% for both products when using MLR only. The MOR correlation coefficient was 0.29 and 0.04, for 19 mm and 13 mm products. Table 1 illustrates that the "2 priors" method produces results that are superior to "MLR" alone. MNRMSEP are reduced and correlation coefficient increased.

Table 2. Process modeling validation results at the plant test site.

QC prop.	Prod.	Pred. Values	RMSEP	MNRMSEP	r	% NN	% RR	% PLS	% MLR
IB	19	MLR	93 kPa	16.8%	0.29	0	0	0	100
IB	13	MLR	118 kPa	20.0%	0.54	0	0	0	100
MOR	19	MLR	1.5 MPa	11.0%	0.29	0	0	0	100
MOR	13	MLR	1.7 MPa	12.8%	0.04	0	0	0	100
IB	19	2 priors	80 kPa	14.5%	0.27	23	32	25	20
IB	13	2 priors	103 kPa	17.6%	0.58	28	22	26	24
MOR	19	2 priors	1.3 MPa	9.1%	0.29	27	35	20	18
MOR	13	2 priors	1.3 MPa	9.8%	0.08	14	27	36	24
IB	19	Best method	51 kPa	9.3%	0.64	23	17	24	20
IB	13	Best method	53 kPa	9.0%	0.83	29	19	22	29
MOR	19	Best method	0.86 Mpa	6.3%	0.64	26	21	29	24
MOR	13	Best method	0.92 MPa	6.9%	0.44	37	24	29	10

The last four rows in Table 1 "Best method" show the prediction results when the regression method whose predicted values are closest to the actual values are selected as method of choice for the 19 mm and 13 mm products. All NMRSEP fall below 10% and the correlation coefficients increase significantly for both IB and MOR. Though picking the best predicted QC value real time is not currently feasible, it shows that the prediction quality has potential for improvement.

4   CONCLUSION

A new process modeling algorithm was developed to predict the mechanical properties (IB and MOR) of a wood composite panel manufacture, real time. A significant amount of work has been dedicated to the development and installation of a process modeling software in several plants. The process modeling algorithm ability to simultaneously develop different regression models based on four regression methods has the potential to bring significant improvements in the IB and MOR prediction quality. Yet, the decision of recalibrating calibration models based on a very small number of historical pairs of actual and predicted QC property results limits the full potential of the four available regression methods and requires further exploration. Future work should focus on finding a more appropriate combination of short term and longer term historical validation results for the choice of real time predicted QC property values.

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On-line determination of material properties in laminates manufacture by Nir Spectroscopy

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Process analytical technologies are widely used in different industries to assure constant product quality and safe production of goods. While being indispensible to for example the chemical or pharmaceutical industries, the forest based industry still is far from exploiting the full potential of on-line measurement techniques to monitor their processes. In the present contribution, recent examples for the successful application of near-infrared (NIR) spectroscopy in the industrial manufacturing of decorative laminates are discussed to illustrate the possibilities of this process analytical tool for the wood-based industry. The presentation is meant to stimulate the interest of the industry to integrate the emerging branch of process analysis in their production equipment to further optimize their processes and to improve product quality which is of special importance in this highly competitive field. Laminates consist of carrier boards like medium density fiberboards (MDF) or particleboards (PB) which are coated with a self-gluing, impregnated decorative paper mimicking real wood or custom design surfaces. Besides carrier board manufacture, the laminates production involves the following steps: (1) Preparation of resin for paper impregnation, (2) Core impregnation with urea formaldehyde (UF) resin and surface coating with melamine formaldehyde (MF) resin of decorative paper, and (3) Surface coating of MDF or PB by lamination in a hot press. Throughout the production of laminates, measurements were performed in the laboratory as well as directly in the process environment at various stages of the composite product. While for analysis of aqueous resins like UF or MF directly in the chemical reactor, mid-infrared measurements are preferable, the quality of paper intermediates and of final coated boards may be beneficially monitored by NIR spectroscopy. Important process variables in paper impregnation involve the moisture content of the impregnated paper prior to lamination or the resin composition used for paper impregnation with respect to the UF/MF ratio.

Quality parameters such as storage stability of impregnated papers can be analyzed by NIR spectroscopy as well. With finished surfaces, technological properties or the degree of cross-linking in the surface resin film are important target responses. As shall be demonstrated in the presentation all these material properties can be targeted by NIR spectroscopy. With laminates, one complicating fact is the wide variability of different decors which are processed at a typical plant. The talk will also address shortly the important issue of calibration and multivariate data treatment.

Keywords (3 - max. 5): Process analysis, near infrared spectroscopy, laminates manufacture

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Speed optimization of CT-based microstructure determination on using matrix decomposition

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ABSTRACT

Using computed tomography in combination with image analyses has been shown to be a valid technique for determining the microstructure of selected derived timber products. In particular images from 3D Sub-Micrometer-Computed Tomography and a combination of erosion and dilatation using arbitrary shaped structuring elements were used to derive the number of microstructures in classes equivalent to the size of the structuring elements. It has also turned out that complexity of the suggested method increases significantly with the size of the used structuring elements in 2D as well as in 3D. As a result very high execution times occur when the algorithm is applied to high resolution image data representing derived timber products with lower density. Our work therefore evaluates the possibilities of decreasing execution time by using decomposition of structuring elements in combination with GPU programming.

The use of GPUs for calculation only yields to better results if the steps of processing can be parallelized. In a first step, a 2D-version using only single slices of the image data and flat structuring elements (disc) is examined; later on, the findings shall be adopted for 3D-data and non-flat elements. First results show that the use of the algorithm proposed by Vaz, Kiraly and Mersereau [7] binds the time complexity of opening an image using an *n*-sized disc-shaped structuring element. Due to the fact that this algorithm is also available as a true 3D-version and can be applied to all 2D and 3D convex and symmetric structuring elements for any binary image data, further investigations on parallelizing the algorithm are made.

1   INTRODUCTION

It has been shown that the characteristics of vertical density profiles can be used to determine the quality of wood based panels [1]. Computed tomography (CT), more precisely sub-micrometer CT (sub-μm-CT), presents a non destructive method to acquire both two dimensional as well as three dimensional images (image stack) of a panel under test [2] Mathematical morphological operations,

namely a combination of erosion and dilatation (opening) using a structuring element (SE), are used to derive the number of microstructures in classes equivalent to a given SE. Figure 1 visualizes the method used.
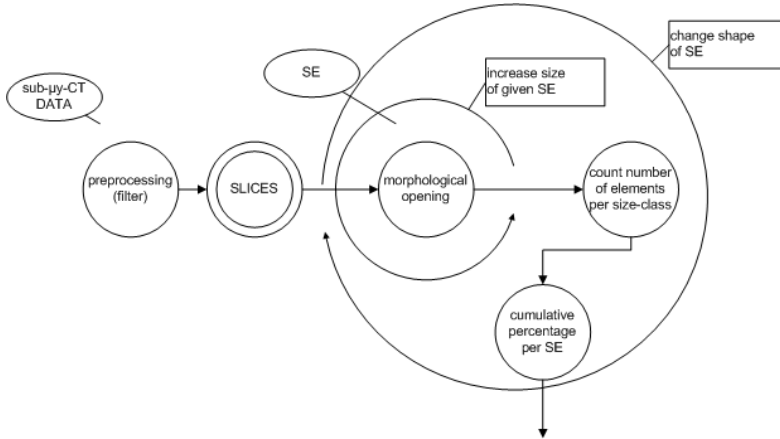
Figure 1. Computing cumulative percentages of size-classes per SE

After images (slices) are acquired by the sub-µm-CT they are preprocessed using standard noise reduction algorithms like Gaussian or median filters. Each slice has a resolution down to 5µm per pixel and the same diameter per voxel. The resulting data is then converted into binary images using a threshold leaving only two density levels. By morphological opening the images with differently shaped SEs where the size of a SE is increased step by step the number of n-sized elements can be summed up per density level.

As the hardware complexity for brute-force implementations of the employed morphological operation is proportional to number of pixels respectively voxels of the SE the time for processing increases polynomially with respect to the diameter of the used SE we faced very high execution times in the high resolution image data [3], [4], [5]. Therefore, this paper evaluates the possibilities of decreasing execution time by using decomposition of structuring elements as evinced in Zhuang and Haralick [6] and discusses a possible combination with GPU programming. As an appropriate algorithm "Multi-level decomposition of Euclidean spheres" by Vaz, Kiraly and Mersereau [7] had been chosen since it can be applied to any isotropic or anisotropic SE. The algorithm is proved to be implementable and faster than other standard decomposition methods.

For the sake of simplicity this paper only deals with disk shaped and ball shaped SEs, respectively. As the proposed algorithm can be used with any other isotropic or anisotropic SE, many different shapes may be applied in later applications. In addition, the first analysis contemplates only the two dimensional case and flat SEs. Due to the fact that this is a special case of the three dimensional

occurrence and as the chosen method is also available in a three dimensional version, results will point to further assertions.

2 MORPHOLOGICAL OPENING BY STRUCTURING ELEMENTS

In mathematical morphology the dilation of an erosion of a set using an SE is defined as an opening. Expression 1 describes that fact, where X is a set of elements of an equal form (e.g. integers) and S is an SE of elements of the same form.

$$open(X, S) = dilate(erode(X, S), S) \tag{1}$$

Opening removes items in size of the taken SE from an image. This is used in the method shown in Figure 1 to remove and count n-sized (actually SE-sized) objects from the image during one iteration.

2.1 Time complexity of morphological opening

As already mentioned above, the complexity of an opening operation increases polynomially with the size of the used SE and thus execution time rises in the same order of magnitude. Without any decomposition of SE, time complexity of dilation and erosion is proportional to the product of the size of the image and SE. Great effort has been taken to reduce time complexity by using decomposition [3], [5], [7], [8], [9] and most of the current image processing software makes use of these algorithms.

3 MULTI-LEVEL DECOMPOSITION OF EUCLIDEAN SPHERES

This section shortly describes the method which has been proposed in [7] and has been chosen to be examined for the analysis of wood based panels, as already described above.

Multi-level decomposition of Euclidean spheres (MLD) decomposes any convex and symmetric SE into a union of partitions (Equation 2). These consist of the largest cube that can morphologically open the partition without changing it and of a sparse factor (Equation 3). To perform an erosion instead of dilatation, dilate has to be substituted by erode in all of the expressions (2-4).

$$SE = \bigcup_{0 < i < n} P_i \quad P_i ... i^{th} - Partition \tag{2}$$

$$SE = \bigcup_{0 < i < n} dilate(C_i, S_i) \tag{3}$$

$$C_i ... i^{th} - Cube, \quad S_i ... i^{th} - SparseFactor$$

Due to convexity of the given SE each cube C_i is a factor of C_{i+1} such that there exists an L_i that C_i is equal to the dilatation of C_{i-1} and L_i. This allows further decomposition of SE (Equation 4).

$$SE = dilate(C_1, (dilate(S_1 \cup L_2, (S_2 \cup (dilate(L_3, S_3))), ...))$$ (4)

If applied to a binary image, Equation 2 yields:

$$dilate(I, SE) = \bigcup_{0 < i < n} dilate(I, P_i)$$ (5)

4 GPU COMPUTING

The most important fact if an algorithm is suggestive to be implemented on a GPU is that its sub steps can be parallelized. It can be seen directly from expressions (2) to (5) and from the nature of decomposition that this applies to any such method. Due to the fact that a resulting image from one iteration is needed to proceed to the next, it is unfortunately not possible to parallelize the whole process (Figure 1). This leaves some parts to stay on the CPU and some that can be moved to the GPU. Therefore future efforts are to be put into deciding whether the rather slow data transfer between those processing units can be compensated by the faster processing.

In general, image processing functions like erosion can be much faster on a GPU. Viney and Green [10] measured a speedup of about 300% on standard Computer Vision algorithms.Figure 2 shows a part (1106x1106 pixels) of a slice of the used sub-µm-CT-data before and after preprocessing described above.
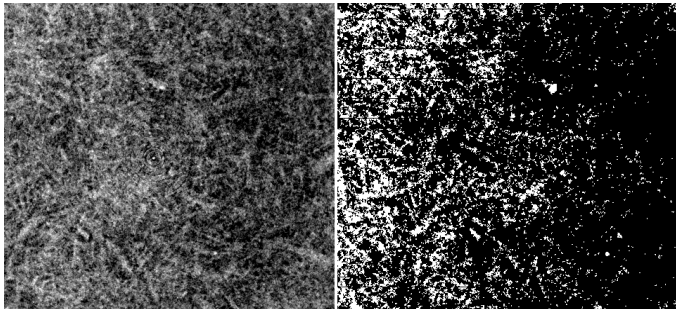
Figure 2. µm-CT slice before - (left) and after preprocessing (right)

5 ANALYSIS AND RESULTS

In order to compare the chosen method to the existing implementation of the process in Figure 1, we implemented two different MATLAB scripts. The first applies no additional decomposition methods and uses the MATLAB function *imopen* [11]. The latter one was implemented following the guidelines in [7] again using MATLAB for morphological opening.

All measurements where carried out on a Intel® Core™ i5 CPU M520 @2.4GHz 2.4GHz laptop using 3.8 of its 4.0 GB RAM using Windows 7 Enterprise Edition x64 and MATLAB R2010a.

In total, the two implementations of morphological opening were applied to 1000 different slices from the data used in [2]. As SE a disc shaped structure was used to measure differences in the implementations. The smallest SE applied to each slice has a radius of 2. Size had been increased by 1 in each of the iterations ending up with a maximum radius of 400 (see [1], [2]). Concerning a resolution of 5μm per pixel this intends a diameter of four millimeter for the largest SE.

5.1 Performance

Figure 3 shows the results of the performance measurements described above. Each calculation was performed twice per slice and the results were averaged using mean score. The same had been carried out to combine the results of the 1000 different slices. In addition, a 1 by 10 median filter was applied to the outcome to smooth the data.
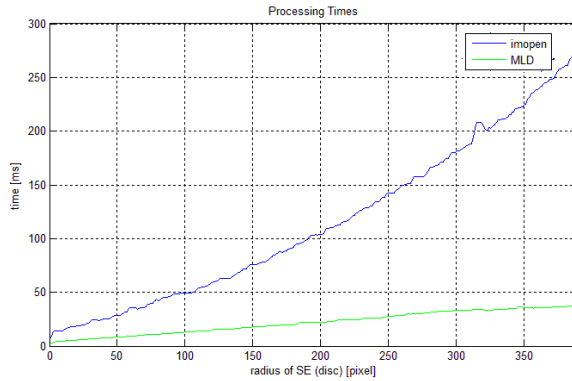
Figure 3. Results of performance measurements

It can be seen that the implementation of MLD is much more stable regarding the size of the SE in that case. As this approved our assumption, further investigations on the method and a three dimensional implementation are planned in subsequent work.

6   CONCLUSION

As the chosen and evaluated method, namely MLD, has proven to be less prone to the size of an SE and as it can be parallelized for computing on a GPU, it presents a valuable addition to the process described in section 1. Due to the existence of a true three dimensional version of the algorithm in [7] and the fact that it is capable of forming all SEs used in the process (star, disk, sphere) advanced analysis is to be conducted.

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The influence of HEAT treatment on the set recovery of compressive deformation

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ABSTRACT

Low density hybrid poplar wood (*Populus deltoides* × *Populus trichocarpa*) was densified under saturated steam conditions at 170°C and then heat-treated at 200°C for either 1 min, 2 min, or 3 min. Densification was performed in a pressurized vessel that was equipped with a heated hydraulic press. After densification, the densified specimens were conditioned in a controlled environment with 65% relative humidity at 20°C and then oven-dried to 0 % moisture content. The density and moisture content after conditioning were determined. Furthermore, in order to determine the influence of heat-treatment on the set recovery of compressive deformation, specimens were soaked in water for 24 hours and again oven-dried. The water soaking - oven drying treatment was repeated five times. After each cycle the percentage of the set recovery was determined. The results showed that the densified specimens after conditioning in a controlled environment room achieved an equilibrium moisture content of 7 % regardless of duration of the heat-treatment at 200°C. Furthermore, the average density of the compressed wood specimens after conditioning was 1.34 g/cm^3 and was not affected by the duration of the heat-treatment. However, the results demonstrated that the heat-treatment influenced the set recovery of the compressive deformation after exposure to water. Longer exposure to 200°C after the compression resulted in smaller set recovery after the first water soaking-oven drying cycle. Subsequent water soaking – oven drying cycles caused increased set recovery in all groups of specimens, and reached a plateau after the third cycle. The results established that considerable fixation of compressive deformation can be obtained by compressing the wood under saturated steam conditions and by heat-treatment at 200°C.

1 INTRODUCTION

The main problem associated with the process of compression is in spite of numerous studies the fixation of compressive deformation. It was found that

wood with the highest degree of compression shows the highest structural recovery [1], [2]. The springback effect occurs because the internal stresses introduced during compression are relieved when the wood is exposed to moisture [3]. The compression-recovery behavior of wood can be attributed to a combination of its cellular structure and the properties of the cell-wall polymers [4]. Steam treatment prior to compression can markedly increase the compressibility of wood and in turn significantly reduce the build-up of internal stresses during hot pressing [5], [7]. The set recovery generally decreases with increasing presteaming temperature and time, and is closely correlated to the percentage of weight loss during the pre-steaming process [8]. Furthermore, in the absence of steam, high temperature can induce permanent fixation of compressive deformation. The high temperature treatment of wood reduces its hygroscopicity, which is due to changes in the polar side groups of the molecular structures of the cellulose, hemicellulose, lignins and extractives [3], [8]. The aim of this paper was to investigate the influence of heat- treatment on the set recovery of the compressive deformation obtained by compression under saturated steam condition.

2 MATERIALS AND METHODS

2.1 Material

The wood of low density hybrid poplar (*Populus deltoides* × *Populus trichocarpa*) from a plantation located in northeastern Oregon was air-dried and then placed in an environmental controlled room (20°C, 65% relative humidity) until equilibrium moisture content of approximately 12 % was achieved. The strips were then planed to reduce thickness to 6 mm (radial), and cut to a length and width of 100 mm (longitudinal) and 60 mm (tangential).

2.2 Compression procedures

The influence of the post heat-treatment at 200°C on the set recovery of compressive deformation was examined. The compression was performed under saturated steam conditions at 170°C after 3 min pre-steaming with saturated steam at 170°C. The specimens were held under compression (5.5 MPa) for 3 min and then the temperature of the platens was raised to 200°C, over a period of 90 s, while the compression load was maintained. When the temperature of the platens reached 200°C , specimens were held under compression at 5.5 MPa for 1 min, 2 min, or 3 min. The process was completed after the specimens were cooled below 100°C while still under compression at 5.5 MPa. Detailed description of compression process is given in [9].

Before and after treatment the specimens weight and dimensions were measured. After conditioning in an environmental room (20°C, 65% relative humidity) the oven-dry density and equilibrium moisture content (EMC) of compressed specimens were determined.

2.3 Set recovery

To measure set recovery as affected by post heat- treatment the specimens (50 mm longitudinal, 15 mm tangential) were cut from compressed wood that had been conditioned in an environmental controlled room (20°C, 65% relative humidity). Specimens were first dried in a convection oven over night at 103°C to establish initial dimensions. The specimens were then soaked in water for 24 h, and again oven-dried. The procedure was repeated for a total of five wet/ dry cycles. After each cycle the percentage of set recovery was determined by expression shown in Eq. (1) below.

$$Set\ recovery = [(t_S - t_C) / (t_I - t_C)] \times 100\ [\%] \tag{1}$$

where t_S is oven-dry thickness after soaking, t_C oven-dry compressed thickness, and t_I initial uncompressed thickness.

All statistical analyses were performed using the multiple range test for significant difference with the 95% LSD procedure (Statgraphics Plus, version 5.0, 2000).

3 RESULTS

3.1 Properties of densified wood

The oven-dry density of wood specimens compressed without post heat- treatment was statistically significantly lower than the oven dry density of post heat-treated specimens (Table 1). Furthermore, statistical analysis revealed the time of post heat- treatment did not significantly affect the oven-dry density of compressed specimens. In addition to increasing density, hygroscopicity of the compressed wood was also influenced. The compression under saturated steam at 170°C significantly reduced the EMC at 20°C and 65% relative humidity, while post heat- treatment at 200°C did not significantly affect the EMC (Table 1).

Table 1. Initial oven-dry density and oven-dry density and EMC of compressed wood specimens (standard deviation shown in parentheses)

Post heat-treatment at 200°C [min]	Initial oven-dry density [g cm^{-3}]	Compressed oven dry density after conditioning* [g cm^{-3}]	EMC* [%]
0	0.381 (0.026)	1.15 (0.045)	6.76 (0.977)
1	0.372 (0.026)	1.34 (0.059)	6.88 (0.869)
2	0.373 (0.024)	1.33 (0.069)	7.21 (0.683)
3	0.378 (0.030)	1.34 (0.055)	6.72 (1.100)

*Conditioning in an environmental controlled room (20°C, 65% relative humidity) until equilibrium moisture content was achieved.

3.2 Set recovery

The duration of post heat- treatment influenced the set recovery of the compressive deformation (Table 2). After the first soaking/ drying cycle the smallest set recovery was obtained in specimens post heat-treated at 200°C for 3 min. With decreased time of exposure at 200°C the set recovery increased. The following soaking/ drying cycles caused increased set recovery in all groups of specimens, but reached a plateau after the third cycle. The statistical analysis of results after the 5 soaking/ drying cycles showed minor significant differences in the set recovery among tested groups of specimens. The set recovery of specimens exposed to the post heat-treatment after compression for 3 min and 2 min was not statistically different from the specimens compressed under saturated steam at 170°C and not post heat-treated, while specimens exposed to temperature of 200°C for 1 min after compression had higher set recovery. The unexpected result could be due to the difference in handling the post heat-treated specimens after compression. The post heat-treated specimens were immediately placed in the environment control room after compression. Whereas, after compression, the specimens without the post heat-treatment were dried in an oven at 103°C over night prior to placement in the environmental control room.

Kutnar and Kamke [9] proposed some explanations of the affect of steam on wood in transverse compression. Perhaps the conditions of compression influenced the build-up of residual internal stresses. Although residual stress could not be measured directly, the amount of thickness recovery immediately after compression was influenced by the compression conditions. The low amount of springback for wood compressed under saturated steam could be the result of a break-down of the cross-links responsible for the memory effect in wood, coupled with softening of lignin and perhaps the formation of covalent bonds in the deformed position [7].

Table 2. Set recovery of specimens compressed under saturated steam at 170°C and post heat-treated for 0 min, 1 min, 2 min, and 3 min; results shown after 1, 2, 3, 4, and 5 soaking/ drying cycles (standard deviation shown in parentheses)

Set recovery [%]	Duration of post heat- treatment at 200°C			
	0 min	1 min	2 min	3 min
1st soaking	3.00 (1.68)	1.47 (1.82)	0.27 (0.880)	0.004 (1.49)
2nd soaking	5.44 (2.61)	5.61 (5.80)	3.21 (1.77)	2.31 (1.78)
3rd soaking	8.23 (3.80)	8.66 (6.53)	5.98 (2.01)	5.36 (1.78)
4th soaking	7.99 (3.85)	10.5 (8.90)	6.56 (1.91)	6.05 (1.78)
5th soaking	8.09 (4.43)	11.1 (8.05)	6.86 (2.09)	5.75 (1.55)

The photomicrographs (Figure 1) also indicated recovery of compressive deformation after water soaking. The wood post heat- treated at 200°C for 3 min showed the smallest structural recovery. Microscopic examination revealed that all applied compression treatments were performed without cell wall fracture. In all applied treatments the wood was at or above the glass transition temperature of the amorphous polymers in the cell wall. It should be noted that the test material was fast-grown plantation poplar wood that contained considerable amount of tension wood, which storage modulus and softening temperature are known to be lower than those of normal wood [10].
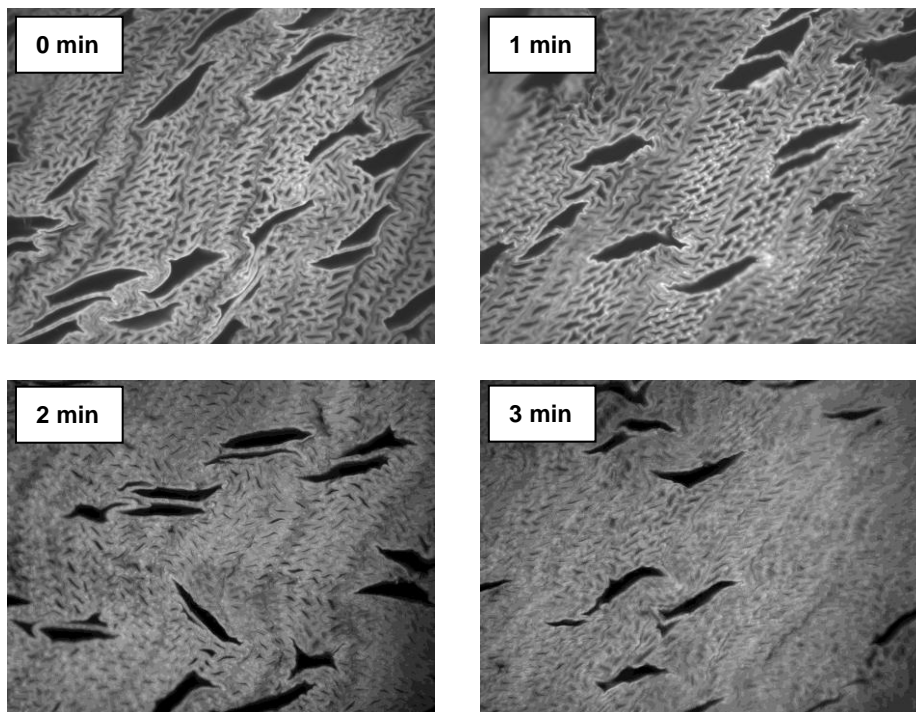
Figure 1. Photomicrographs after water soaking of specimens compressed at 170°C in saturated steam and post heat- treated at 200°C for 0, 1, 2, and 3 min

4 CONCLUSION

The results suggested that considerable fixation of compressive deformation can be achieved by wood compression under saturated steam conditions at 170°C. Heat treatment at 200°C adds some marginal improvement to dimensional stability. In specimens compressed under saturated steam at 170°C and post heat-treated at 200°C for 3 min only 6 % set recovery was obtained after five water soaking/ drying cycles. Furthermore, the compression under saturated steam at 170°C significantly reduced the EMC of wood specimens, while the heat-

treatment did not significantly affect it. Note that the compression treatments were performed without cell wall fracture in all specimens examined.

5 ACKNOWLEDGMENTS

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LbL treatment of wood surfaces to improve bondline performance

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Adhesion is the surface phenomenon which assures the success of any bonding. Due to the recent developments in nanoelectronics, nanoscale electrostatic layer set up was made available. In order to optimize bondline performance samples of different wood species were LbL treated and bonded with structural and non structural adhesives. The objective was to create by means of layer by-layer technology an ordinate film coating in thickness ranging from 5 to 500 nm in an adsorption process consisting of several steps to influence wetting and adhesion of adhesives. Negative charged PSS and positive charged PDDA polyelectrolytes were alternately absorbed on the wood surfaces.

Standard loading tests as three point bending and tensile test with both structural and non-structural adhesives were carried out to evaluate the results in comparison with the performance of conventionally bonded samples.

Keywords: LbL treatment, adhesion, bonding performance

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Impact of heat treatment on the wettability of wood

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ABSTRACT

The heat treatment of wood – which is primarily used to increase the durability, reduce the hygroscopicity, and improve the dimensional stability of wood – also causes some unfavourable effects. The wettability of heat-treated wood is typically reduced, which may impact adhesion in the case of bonding with waterborne adhesives. Heat-treated wood accepts less water at a slower rate, so the hardening of adhesives that cure by water removal is slower. The objective of this study was to determine the impact of heat treatment on the wettability of several wood species, and to evaluate the effect of aging in different environments on the wettability of untreated and heat treated Norway spruce. The industrial Plato® process was used for the heat treatment of the investigated wood. Wettability was evaluated in terms of contact angle measurements by the Wilhelmy plate method on a Krüss K12 Tensiometer. In the first experiment, the wettability of untreated (control) and heat-treated specimens made from poplar, birch, Douglas fir and Norway spruce was determined. In the second experiment, only untreated (control) and heat-treated Norway spruce were examined. Half of the test specimens were exposed to environmental conditions in surrounding air, and the other half to a nitrogen environment. The effect of aging on the wettability of wood was evaluated at certain time intervals: immediately after surface preparation, and 1, 7, and 14 days later. It was found that, in the case of all the investigated wood species, the contact angle was always larger for the heat-treated specimens when compared to the untreated (control) specimens. The effect of aging in air was evident – the contact angle increased with time exposure, whereas aging in a nitrogen atmosphere did not impact the wettability of the wood.

1 INTRODUCTION

The heat treatment of wood reduces its hygroscopicity and improves its dimensional stability. Additionally, heat-treated wood is more durable, and thus more resistant to decay [1]. However, the heat treatment of wood also causes some unfavourable effects, such as diminished strength and toughness, and reduced wettability.

The industrial Plato® process for the heat treatment of wood improves the dimensional stability and durability of wood while maintaining its mechanical properties. Plato®Wood is mainly utilized in exterior applications, such as garden furniture, fencing, claddings, window frames and doors [2]. Adhesive bonding is often involved in the production of such products. Because adhesion between wood and adhesives is related to surface wettability, the aim of this study was to determine the impact of heat treatment using the Plato® process on the wettability of several wood species, and to evaluate the effect of aging, in different environments, on the wettability of untreated and heat-treated Norway spruce.

2 MATERIALS AND METHODS

The industrial Plato® process [3] was used for the heat treatment of the investigated wood. Wettability was assessed in terms of contact angle measurements, using the Wilhelmy plate method on a Krüss K12 Tensiometer. In the first experiment, the wettability of untreated (control) and heat-treated specimens made from Birch (*Betula pendula*), Poplar (*Populus species,* I214), Douglas fir (*Pseudotsuga menziessii* Franco), and Norway spruce (*Picea abies* Karst) was determined (Table 1).

In the second experiment, untreated (control), hydro-thermolysed (intermediate) and heat-treated Norway spruce were examined. Half of the test specimens were exposed to the environmental conditions of the surrounding air, whereas the other half samples were exposed to a nitrogen environment. The effect of aging on the wettability of wood was evaluated at certain time intervals: immediately after surface preparation, and after 1, 7, and 14 days.

Table 3. Treatment of the wood specimens

Specimen	Wood species	Treatment
B-C	Birch	Untreated (control)
B-PHT		Heat-treated
P-C	Poplar	Untreated (control)
P-PHT		Heat-treated
DF-C	Douglas fir	Untreated (control)
DF-PHT		Heat-treated
NS-C	Norway spruce	Untreated (control)
NS-HyT		Hydro-thermolysed (intermediate)
NS-PHT		Heat-treated

3   RESULTS AND DISCUSSION

The Plato® heat treatment affected the wettability of all the investigated wood species (Figure 1). The contact angle was always smaller (better wettability) in the case of the untreated-control (C) specimens, and larger in the case of the Plato heat-treated (PHT) specimens. Intermediate treatment (HyT) also caused an increase in the contact angle. These findings are in agreement with results obtained in previous studies [4], [5], [6], [7], which showed that the wettability of wood with water is decreases (with a larger contact angle) after heat treatment. This is mainly because the surface of heat-treated wood is hydrophobic, less polar and significantly repellent to water. Consequently, this might hinder waterborne adhesives from adequately wetting the surface.
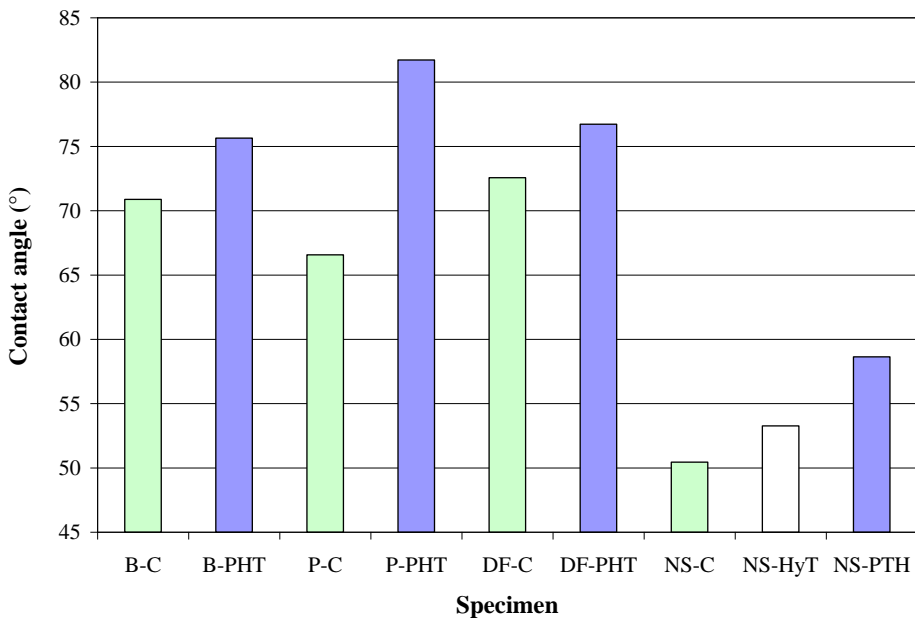
Figure 1. The influence of heat treatment on the contact angle of water for different wood species

It is evident that the heat treatment affected the wettability of the Norway spruce specimens, which were exposed in both air and in nitrogen (Figure 2). The contact angle was the smallest in the case of the control wood (NS-C), whereas it increased with hydro-thermolysis (NS-HyT) and heat treatment (NS-HT). The effect of aging in air was clearly evident – the contact angle increased with time exposure, whereas aging in a nitrogen atmosphere did not impact the wettability of wood. Oxidation of the wood surface was main reason for the reduced wettability of the specimens which were exposed in air.
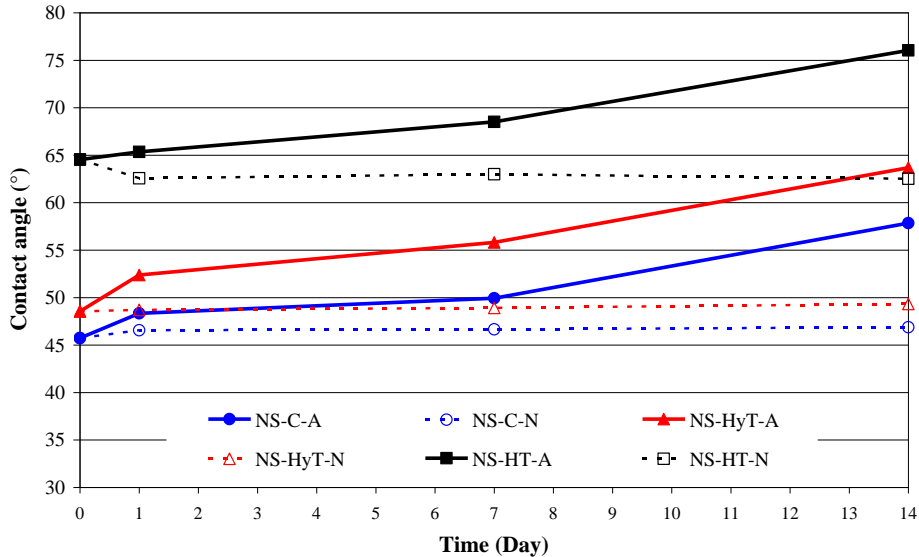
Figure 2. The effect of aging of Norway spruce specimens exposed in air (A) and in nitrogen (N) on the water contact angle.

4 CONCLUSIONS

Plato® heat treatment reduced the wettability of the investigated wood species. The contact angle was always larger in the case of the heat-treated specimens when compared to that of the untreated (control) specimens. The effect of aging in air was clearly evident – the contact angle increased with time exposure, whereas aging in a nitrogen atmosphere did not impact the wettability of the wood.

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Use of valuable by-products from leather production for new applications

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ABSTRACT

The Authors report on the results of a research project focused on the development of panels made of leather fiber, a by-product of the leather production, especially for interior applications (e.g. furniture). First possibilities for the production of leather fiber panels (LF) and leather wood fiber panels (LWF) were examined and their material properties were determined. The experimented adhesives were evaluated in laboratory scale in order to study their gluing and pressing parameters as well as their technical performances. During the panel production the influence of different resin contents and material densities were examined as well as the influence of the pressing parameters on the material properties. The results of the internal bond of the LF panels were higher for the use of the EVA dispersion adhesive (EVA nanocuir R). In thickness swelling panels produced with the PVAc powder adhesive (PVAc nanocuir 25) obtained better results. If one considers however the fact that during the production of the panels with dispersion adhesive a smaller resin load is used, results advantages for this adhesive system.

1   INTRODUCTION

By new material development with consideration of the resources utilization or advancement of characteristics of existing materials, important product innovations can be developed. Resulting by-products can be revalued under the criteria „upcycling". In this field also the development of panels made of leather fibers is located, a by-product of the leather production. The search for new value-added uses for the special, nanocuir® processed leather fiber, resulting from leather cut remains deriving from steering wheel production, led to experiment possibilities of producing leather fiber panels (LF), leather-wood fiber panels (LWF) and the three-dimensional shaping of these panels, especially for interior applications (e.g. furniture).

The development of such LF panels will have several advantages as they would distinguish from real leather e.g. by their consistency of color and other attributes because they possibly would not suffer inevitable natural variations.

The purpose of this research project was to investigate first gluing and pressing parameters for the production of such panels as well as their technical performances, like the internal bond (IB), formation of the density profile and its ability for three-dimensionally shaping. Therefore two thermoplastic adhesive systems were selected; an EVA dispersion adhesive (vinyl acetate/ethylene copolymer, 45% solid content (SC)) due to its specifications like high flexibility, even at low temperature, flexural strength and mechanical resistance of finite products and a PVAc powder adhesive (vinyl acetate/ethylene copolymer powder, 98 - 100 % SC), due to its properties like soft and flexible blending with natural fibres such as wood and cork.

The overall goal of the work was to evaluate the possibilities of producing LF and LWF panels based on MDF laboratory production characteristics, to create properties good for bending, machining (e.g. laser cutting) and finishing performance (e.g. embossing). Moreover, parameters for the up-scaling of the production of large-scale panels were to determine.

2 EXPERIMENTAL METHOD

2.1 Panel production

The leather fiber used was from leather cut remains mainly deriving from steering wheel production, resulting from the special nanocuir®- finishing procedure. The fiber was collected after the nanocuir® finishing procedure, bagged in plastic bags, delivered to the lab and there pressed into panels. The fiber moisture content before pressing was about 17 %. In one series of experiments an EVA dispersion adhesive (EVA nanocuir R, 45 % solid content), and in another series a PVAc powder adhesive (PVAc nanocuir 25, 98 - 100 % solid content), was applied to the fiber using a laboratory ploughshare mixer. The target panel density for both series was 0.65 g/cm³ and 0.8 g/cm³. The target thickness of the panels was 4 mm. The mat size was 45 cm by 45 cm. The panels were produced using an automated hot press (Höfer HLOP 280). After pressing and prior testing, the boards were conditioned in a climatic chamber (RH 65%, T 20°C) during 3 days.

2.1.1 Phase 1: Preliminary study on the determination of the best pressing program per adhesive system

To determine important pressing parameters of the different adhesive systems, preliminary tests were performed for the pressing temperature, step-closure time and pressing time. These showed that for the production of LF panels with the PVAC powder adhesive system a pressing program with a two step closure was necessary to achieve good bonding results. In the first step the press was closed from a mat heights of 22 mm to a thickness set to 10 mm kept for approximately 8 min pressing time. This was done to let the PVAc powder "pre-melt" be-

fore closing in a second step to the final panel thickness of 4 mm for another 5 min pressing time. The pressing programs are shown in Figure 1.
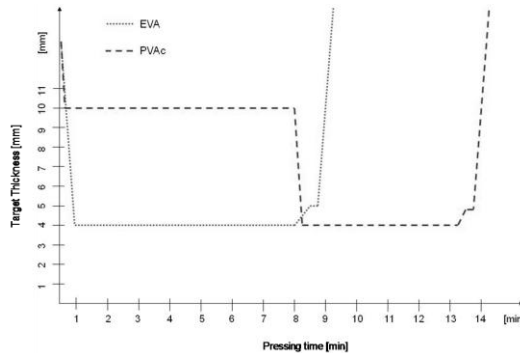
Figure 1. Differences in pressing program for LF panel production using EVA nanocuir R and PVAc nanocuir 25

2.1.2 Phase 2: Determination of the influence of the materials density, resin load and pressing temperature

The overview of the parameters selected for the determination of the influence of the materials density, resin load and pressing temperature are show in Table 1.

Table 1. Overview of the panel and pressing parameters

Adhesive System	EVA nanocuir R			PVAc nanocuir 25		
Target Density [g/cm³]	0,65 / 0,8			0,65 / 0,8		
Resin Load [%]	10	15	20	20	40	60
Press Temperature [°C]	100			140 / 180 / 200		

2.2 Testing

After pressing, three 50 mm wide sample strips were cut from the middle of each panel. The strips were cut into five 50.0 mm by 50.0 mm specimens for the determination of the internal bond (IB), thickness swelling (TS) and measurement of the vertical density profile.

2.2.1 Measurement of the vertical density profile

For the measurement of the vertical density profile an x-ray densitometer (Dense-Lab X, Electronic Wood Systems) was used. The average density profile was calculated from five samples of each panel. The average density profile reflects the density change throughout the panel thickness.

2.2.2 Determination of the internal bond (IB)

The density of each panel was individually measured at current conditioned storage (RH 65%, T 20°C) before testing the internal bond according to DIN EN 319 (1993) [1] with a universal testing machine Zwick Roell Z 250.

2.2.3 Determination of the thickness swelling (TS)

The swelling in thickness after immersion in water was determined according to DIN EN 317 (1993) [2]. The properties evaluated in the 24-hours water storage (T 20°C) defined as the change in thickness of the absorbed water divided by the initial thickness, TS is given in percent.

3 RESULTS AND DISCUSSION

Internal bond strength is one of the most important indications of the internal bond quality of mat-formed panels. The IB test normally indicates the weakest bonding strength within a panel, and was used for criteria evaluation.

For the PVAc nanocuir 25 adhesive various pressing temperatures (140-180-200°C) were analyzed for the best curing conditions. The highest IB values (mean of 0.46 N/mm²) were determined at a pressing temperature of 200°C. However, resulting from thermal degradation of the leather proteins at high temperatures the smell during the production process was displeasing, and also the panel smelled unpleasant. Therefore, the pressing temperature for the production of the LF panels was fixed at 180°C. However, the LWF panels were produced at a temperature of 200°C.

3.1.1 Resin Load on Internal Bond

Three different resin contents of the LF panels with a target density of 0.65 g/cm³ were investigated for each adhesive system.
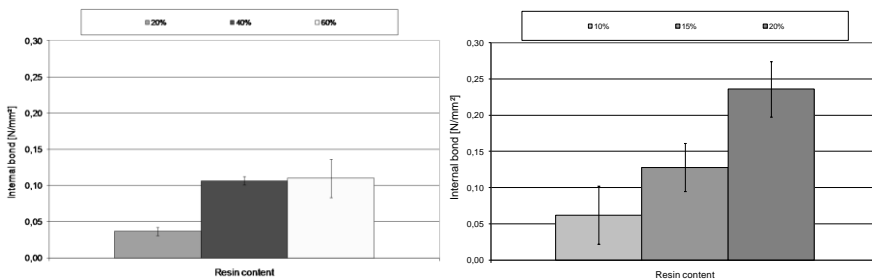
Figure2. Influence of resin load [%] on IB (left) for PVAc nanocuir 25 (target density 0.65 g/cm³) and (right) for EVA nanocuir R (target density 0.65g/cm³)

For the PVAc nanocuir 25 adhesive the highest IB values (mean of 0.11 N/mm²) were determined for a resin content of 40 and 60 %, with no significant difference between both strengths (Figure 2, left). Virtually the effects of higher resin content of the panels could also be observed by haptic perception; resulting in a plastic-like haptic of the panel's surface.

The results of the IB analysis of the panels with EVA nanocuir R adhesive showed a significant increase of the IB for a higher resin content of the LF panels (Fig. 2, right). The highest IB values with EVA nanocuir R adhesive (0.24 ± 0.04 N/mm²) for a resin content of 20 % were 114.6 % higher than the IB values with PVAc nanocuir 25 adhesive (0.11 ± 0.03 N/mm²) for a resin content of 60 %.

3.1.2 Resin Load on Thickness Swelling

The TS values of panels after the 24-hour water soak test are presented in Figure 3. For all investigated samples, the average values of TS were consistently improved by higher resin content; moreover, the panels with EVA nanocuir R system show an obvious influence of the resin content on the TS values. However, the comparison of the results from the water soak test show a clear reduction for all determined TS values of the PVAc nanocuir 25 adhesive. The results indicate that both adhesive systems are not usable for immersion in water or for high air humidity (e.g. exterior applications).
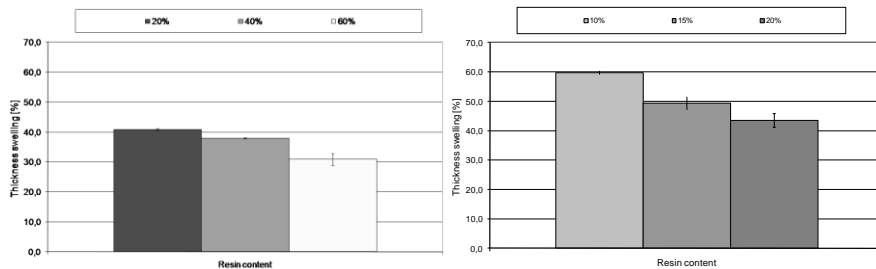
Figure 3. Influence of resin load [%] on TS (left) for PVAc nanocuir 25 (target density 0.65 g/cm³) and (right) for EVA nanocuir R (target density 0.65 g/cm³)

3.1.3 Influence of wood fiber content on panel properties

Standard MDF wood fiber was used for the modification of the leather fiber panels. The change in properties of the leather panels was investigated for the addition of 30 % wood fiber, whereas the IB values of the leather fiber panels are the reference for comparison. For the leather-wood fiber panels with PVAc adhesive (60 % resin content), the IB strength was reduced to 52 % from the reference. However, the IB values of the LWF panels with the EVA system (10 % resin content) were increased by 70 %.

The results of the TS test of the panels are presented in Figure 4. For all LWF panel series, the TS values were increased through the addition of the wood fibers. Specifically the TS values of the LWF panels with the EVA adhesive system were increased by 100 % from the initial thickness (Fig. 4, right). In this way the panels show a similar behavior like normal wood based panels (e.g. particle boards) where the influence of a higher resin content resulting in better thickness swelling characteristics has often been reported [3].
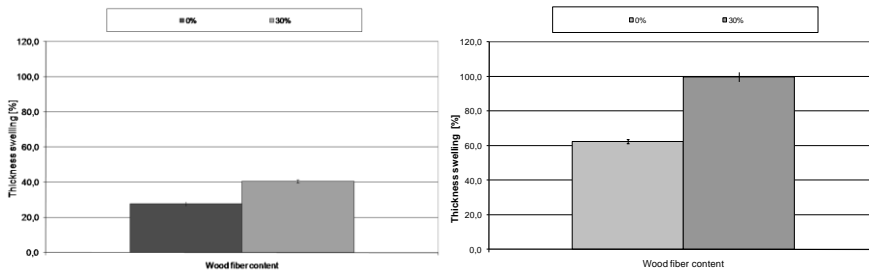
Figure 4. Influence of resin load [%] on TS (left) for PVAc nanocuir 25 (target density 0.80 g/cm³, 60 % resin content) and (right) for EVA nanocuir R (target density 0.80 g/cm³, 10 % resin content)

4 CONCLUSION

Within the scope of the project several important panel properties and processing parameters for the production of LF and LWF panels, based on MDF lab production characteristics, were evaluated. The produced LF and LWF panels were fabricated in laboratory scale in order to study their gluing and pressing parameters as well as their technical performances and properties.

It was found that the results of the internal bond of the LF panels were higher for the use of the EVA dispersion adhesive (EVA nanocuir R). In thickness swelling better results were obtained using the PVAc powder adhesive (PVAc nanocuir 25). In case of the LWF panels the addition of 30 % wood fibres showed a negative effect to the IB of PVAc adhesive panels (60 % resin content). The IB strength was reduced to 52 % from the reference. However, the IB values of the LWF panels with the EVA system (10 % resin content) were increased by 70 %.

Anyhow, with a view to a future industrial application, further investigations are still required, particularly on the improvement of processing parameters and characteristics for the production of large-scale panels. Also the examination of other important properties is necessary like the study of the UV resistance, resistance to tearing, color fastness and treatment properties e.g. embossing. These are important properties for future applications that allow the material to be used e.g. as a covering material for chairs and the like.

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ASWOOD™ ADHESIVE SYSTEMS for furniture and flooring applications

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ABSTRACT

Dynea has developed the AsWood™ technology for the furniture and flooring industry. The AsWood™ adhesive systems are two component systems consisting of a melamine formaldehyde adhesive combined with a PVAc adhesive. Both adhesive components, and the mixture of the two, are comparable to traditional formaldehyde-based adhesives with respect to physical properties, such as viscosity, pH, solids content, shelf life etc.

The AsWood™ technology is in use for production of solid wood panels and curved plywood and in the trial phase for production of parquet. The systems give unchanged or improved bond quality as well as improved moisture resistance compared to traditional formaldehyde-based tech-nology. The As-Wood™ systems are used without any significant changes in the production parameters, production efficiency and reject rates.

Dynea has shown that formaldehyde-based adhesives can be used to produce products with emission at the same level as natural wood. This can be done without major changes in production equipment and without adverse effects on product quality and production efficiency.

1   INTRODUCTION

The focus on formaldehyde has increased significantly since IARC's reclassification of formaldehyde as a group 1 "Human Carcinogen" in 2004 [1]. As a consequence the formaldehyde based adhesives are under increasing pressure from alternative technologies such as Polyvinylacetate adhesives (PVAc) and Emulsion Polymer Isocyanate adhesives (EPI). These dispersion based adhesive solutions may however involve certain challenges compared to the formaldehyde based technologies:

- Short assembly times
- Long setting times compared to very fast setting formaldehyde based adhesives
- Reduced production capacity
- Increased reject rate

- Short pot lives (EPI adhesives)
- Handling of isocyanate (EPI adhesives)

Thus, despite the formaldehyde issue, formaldehyde based adhesives are often preferred due to technical advantages and high robustness. The challenge for the producers of formaldehyde adhesives is on the other hand to develop formaldehyde based technologies with negligible formaldehyde emission.

The formaldehyde content in the formaldehyde based adhesives and, as a result, the emission from the glued products has been reduced tremendously during the last 20 – 30 years. During this work the difficulty has been to maintain properties like bond quality, pressing time, production efficiency, reject rates, shelf life of the adhesive etc. Thus, when discussing even lower emissions, the natural question is whether further reduction is possible without serious negative effect on the adhesive properties and bond quality of the glued product.

2   RESULTS AND DISCUSSION

The AsWood™ solutions for furniture and flooring applications are two-component adhesive systems. The first adhesive component is a melamine formaldehyde (MF) adhesive whereas the second adhesive component is formaldehyde free and based on a modified polyvinyl acetate (PVAc) adhesive. Several systems based on different MF adhesives and different formulations of the PVAc component are developed. The mixing ratio of the two adhesive components varies from 100/50 up to 100/150 depending on the molar ratio of the melamine adhesive. Table 1 gives the physical properties of the most reactive AsWood™ system but systems with significantly lower reactivity is also available for those production lines where long pot lives are a necessity.

Table 1. Physical properties of AsWood™ 7000 and AsWood™ 7502

Adhesive system	AsWood 7000	AsWood 7502	Glue mixture (100:120)
Polymer	MF	PVAc	MF/PVAc
pH	ca 9,5	ca 2,5	ca 4
Viscosity (mPas, 25°C)	ca 4500	ca 2500	ca 2000
Solids content (%)[1]	ca 67	ca 53	ca 65
Shelf life	3 months[2]	3 months[3]	Not applicable
Pot life (20°C)	Not applicable	Not applicable	1 h

[1] drying in a ventilated oven for 2 h at 120°C

[2] 20 – 25°C

[3] 10 – 25°C.

Both adhesive components, and the mixture of the two, are comparable to traditional formaldehyde-based adhesives.

The AsWood™ systems are comparable to traditional urea formaldehyde systems (UF) with respect to bond quality, but they surpass the UF adhesives with respect to moisture resistance. This can be seen by testing according to the European standard EN 12765 [2]. This is a standard for classification of thermosetting wood adhesives for non-structural applications. The adhesives are classified into durability classes (C1 to C4) based on the dry and wet strengths (tensile strength/shear strength) of bond lines measured under specific conditions after various conditioning treatments. The range of results obtained with the AsWood™ systems are given in Table 2 together with typical results obtained with standard UF systems.

Table 2. Comparison of shear strength of typical UF system and the AsWood™ systems, tested according to EN 12765

Adhesive system	Dry test (N/mm^2)	Cold water test (N/mm^2)	Hot water test (N/mm^2)	Boil test (N/mm^2)
Typical UF systems	11 - 18	7 – 9	0 – 9	0
AsWood™ systems	11 - 18	8 – 10	11 – 13	7 – 10
C2 requirement	≥ 10	≥ 7	-	-
C3 requirement	≥ 10	≥ 7	≥ 4	-
C4 requirement	≥ 10	≥ 7	-	≥ 4

Cold water test: 24 h in cold water (ca 20°C)

Hot water test: 3 h in water of 67°C, 2 h in cold water.

Boil test: 3 h in boiling water, 2 h in cold water.

2.1 Solid wood panels

Solid wood panels are produced by edge gluing of wood lamellas. Figure 1 gives examples of products produced from solid wood panel.

Figure 1. Different products produced from solid wood panels

The AsWood™ technology is used by several producers of solid wood panels. The bond quality is the same or exceeds the bond quality they used to have with the traditional technology. The production process is unchanged, the production efficiency and reject rates are unchanged and the emission is at the level of solid wood, see Table 3 for comparison.

Table 3. Comparison of emission of solid wood panels of pine and beech glued with AsWood™ and untreated solid pine and beech, tested according to ASTM D 6000-2 [3], EN 717-1 [4], ISO 12460-4 [5] and EN 717-2 [6]

Emission test	Construction	Pine	Beech
ASTM D 6000-2 (ppm)	Solid wood panel	0,03	
ASTM D 6000-2 (ppm)	Solid wood	~0,03	
EN 717-1 (mg/m^3)	Solid wood panel	0,010	
EN 717-1 (mg/m^3)	Solid wood	~0.009	
ISO 12460-4	Solid wood panel		0,03
ISO 12460-4	Solid wood		~0,03
EN 717-2 (mg/m^{2}h)	Solid wood panel		0,10
EN 717-2 (mg/m^{2}h)	Solid wood		~0,10

The samples of solid wood were tested without any pretreatment, conditioning or storage, i.e. the samples were prepared for testing and placed in the test equipment immediately after the purchase in the local lumber store. For solid wood the emission varies from sample to sample. For example, emission values from 0.006 – 0.015 mg/m^3 have been measured in the European chamber test for different samples of pine. Hence exact values for emission from the different wood species can not be given.

2.2 Curved plywood

In production of curved plywood (form pressing) a number of veneer sheets are glued together in parallel in a shaped press. The resulting panels are commonly used as furniture parts. The producers using the AsWood™ systems for form pressing are producing exclusively designed furniture for the high end market where brand protection is essential. An example of this is the Scandia chair produced by Kistefoss AS in Norway, see Figure 2.

Figue 2. Scandia chair produced by form pressing by Kistefoss AS

The bond quality of the curved plywood produced with the AsWood™ systems is very good, the systems are used without any changes in the production process and the production efficiency and reject rates is unchanged The curved plywood has emission on the level of solid wood, see Table 4.

Table 4. Comparison of emission of curved plywood of beech glued with AsWood™ and untreated solid beech, tested according to ASTM D 6000-2 and EN 717-1

Emission test	Construction	Beech
ASTM D 6000-2 (ppm)	Curved plywood	0,02
ASTM D 6000-2 (ppm)	Solid beech	~0,01
EN 717-1 (mg/m^3)	Curved plywood	0,009
EN 717-1 (mg/m^3)	Solid beech	~0,006

ASTM D 6007-2t: Requirements for non formaldehyde adhesives – 0,04 ppm

2.3 Parquet

Three layer parquet (Figure 3) can also be produced with the AsWood™ systems.

Figure 3. Three layer parquet

The AsWood™ systems are in the trial phase by a number of parquet manufacturers. The trials have confirmed that the systems are viable replacements for the traditional UF systems. Table 5 shows the emission of oak parquet glued with the AsWood™ technology.

Table 5. Comparison of emission of parquet glued with AsWood™ and untreated solid oak, tested according to ASTM D 6000-2 and EN 717-1

Emission test	Construction	Oak
ASTM D 6000-2 (ppm)	Oak parquet	0,02
ASTM D 6000-2 (ppm)	Solid oak	~0,01
EN 717-1 (mg/m^3)	Oak parquet	0,009
EN 717-1 (mg/m^3)	Solid oak	~0,006

ASTM D 6007-2t: Requirements for non formaldehyde adhesives – 0,04 ppm

The AsWood™ systems can be used to produce parquet both by warm pressing and by use of radio frequency pressing. The AsWood™ systems will even cure at room temperature and are ideal for production with relatively low pressing temperature. The most reactive system allows pressing temperatures down to 60°C while maintaining reasonable pressing time.

3   CONCLUSION

Dynea has shown that formaldehyde-based adhesives can be used to produce products with emission at the same level as natural wood. This can be done without major changes in production equipment and without adverse effects on product quality and production efficiency.

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Comparison of Formaldehyde Emission Potentials for Binders and Additives

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ABSTRACT

For the development and modification of low-emission binder-systems, a fast and simple determination method of the formaldehyde emission potential is essential. Up to now, the evaluation of glues has been complicated by long-winded and laborious methods.

During particleboard manufacture, the hot-pressing parameters (e.g. pressing time and -temperature) significantly affect the long-term formaldehyde emission. Consequently, a comprehensive optimization of the pressing process is necessary to enable statements on the binder's emission potential. Hence, this production step is skipped in primary binder development. Furthermore, the determination of the long-term formaldehyde emission in a chamber according to EN717-1 is too time-consuming for a quick assessment of the response of emission to small changes in the binder system.

For the Wood K plus modified flask method, glued particles are hardened in a conventional laboratory drying chamber without pressing. Afterwards, the samples are analyzed in a bleached tea bag following the flask method standardized in EN 717-3. With this approach, a quick determination of the formaldehyde emission potential of binders and additives (relative to a reference system, e.g. urea formaldehyde) is possible. From these results, a ranking of binders can be established, based on which an experimental design for subsequent measurements including chamber tests can be set up.

1   INTRODUCTION

Formaldehyde emission research and thereto related topics have been raising great interest in the wood working industry during the last few years. The main driving force behind this is the ongoing development towards lower legal limits concerning the long-term formaldehyde emission of composite wood products. Among others, the most rigorous regulations are found in the final regulations order of the Californian Air Resource Board (CARB), in the Japanese F****

standard and in the intra-corporate supply-regulations of a Swedish multinational furniture company.

In order to fulfill these regulations, a standardized emission test has to be performed. Due to historical reasons, no internationally standardized testing method is established. An overview of the different formaldehyde emission measurement methods, including a short classification regarding time-consumption and required equipment, influencing analysis costs, as well as the results' informative value (IV) is shown in table 1.

Table 1. Overview of formaldehyde emission determination methods for wood based panels

Method	Standard	Equipment	Time	IV
Chamber	DIN EN 717-1, ASTM E 1333, JIS A 1901	-	-	+
Perforator	DIN EN 120	+	+	-
Desiccator	JIS A 1460	+	+/-	+/-
Flask	DIN EN 717-3	+	+	+/-
Gas Analysis	DIN EN 717-2	-	-	+/-

IV…informative value

In general, the approved reference method for determining a material's emission is the chamber method (as described in European Standard EN717-1). The main disadvantages of this method are the high technical effort and the time consuming analysis (up to 30 days). Another widespread analysis technique for formaldehyde emission is the extraction with toluene in a perforator (EN120). The informative value of perforator results on possible long-term formaldehyde emissions is uncertain, especially with low-formaldehyde resins. In spite of this, the perforator method is commonly used in panel board production plants, as the equipment needed is rather cheap and not very complicated.

The most auspicious method for rapid formaldehyde emission analysis is the flask method, as published by Roffael [1] and standardized in EN 717-3. The great advantages of this method are its quickness and the low equipment requirements.

2   WOOD K PLUS MODIFIED FLASK METHOD

When developing a low-FA emission binder system, many factors affect the final result, such as free formaldehyde, resin reactivity, type of wood, or the resins' stability towards hydrolysis. To enable evaluation of many systems in a short time, there is a strong need for a very fast screening method with low equipment requirements. Based on the screening's preliminary results, a ranking for the accurate analysis of selected binders and additives can be set up.

2.1 Choice of analysis parameters

As shown in Table 1, the only quick analysis method which is feasible with simple equipment is the flask method. Therefore, this method has been chosen as a basis for the following method development.

One hindrance to a rapid screening is that all of the formaldehyde-emission analysis methods known, among them the flask method, are based on panels. A closer look on the factors affecting the formaldehyde emission shows that the hot press step in panel production plays a key role. By regulating temperature and / or pressing times, the panel properties, such as the formaldehyde emission, can be controlled over a wide range, limited only by production costs. Hence, when developing a new binder system, a complete characterization based on panels has to be carried out, employing a design of experiments with variation of many parameters, for example the pressing time and temperature, moisture content or amount of glue used.

For a quick emission potential check, this elaborate work can be skipped by hardening glued wood chips in a conventional laboratory dryer. In method development, temperature has been kept at 180°C, and hardening time is varied from 4 to 8 minutes. Longer hardening times turned out to be unsuitable for determination of slight differences in formaldehyde emission between the binder systems. Gluing of wood chips (technical particle board middle layer chips) is performed in a Drum Hoop Mixer using a conventional oil spray gun.

The glued and hardened chips are sealed immediately and have to be analyzed within 76 hours in bleached tee-bags, which have no significant formaldehyde-emission themselves. The sample bags are then analyzed as described in EN717-3 in a closed 500ml bottle over 50ml of distilled water at 40°C for 180 minutes. The formaldehyde content is determined by performing the Hantzsch reaction with acetylacetone followed by a photometric quantification of formaldehyde content in the absorption liquid.

2.2 Method evaluation

During method evaluation, several uncertainties in the method have been clarified. First, the evenness of glue application has been proven, by taking samples from different spots in the glue application barrel (bottom, lower and upper middle, top). The results are displayed in Table 2 and show good consistency. Therefore, the rather primitive technique of glue application can be regarded as suitable to make significant statements on the binders' emission.

Table 2. Consistency check of glued chips

Sample No	Origin	value [mg/kg]
A	Bottom	51.15
B	Lower Middle	51.57
C	Upper Middle	54.01
D	Top	57.87
	Mean value	53.65
	Standard dev.	3.08 (6%)

Then, the reproducibility has been checked by analyzing industrial urea-formaldehyde glue several times. The results are shown in table 3 and show a mean standard deviation of 4%. Obviously, there is a tendency to lower formaldehyde emission with longer hardening times for this particular system.

Table 3. Reproducibility of Wood K plus modified flask method

Hardening time [min]	Sample A	Sample B	Sample C	MV [mg/kg]	SD [%]
4	55	53	58	55	4.0
6	54	50	52	52	3.5
8	40	43	40	41	4.2

SD…standard deviation

MV…mean value

Due to the usage of industrial chips, different glue batches and glue ages, the standard deviation found can be regarded as quite low. Moreover, the natural, inconsistent raw material wood contributes to the deviations observed.

3   EXAMPLES

3.1 Influence of binder reactivity on formaldehyde emission potential

One of the first experiments performed dealt with the effect of glue reactivity on formaldehyde emission. As reported before, the resin's degree of curing has a great impact on formaldehyde emission. Free formaldehyde in the glue has a great share in the overall emission, as well as unbound methylol-groups which are unstable towards hydrolysis. Both of these effects are significant when glues are incompletely cured.

Figure 1 shows how these effects can be demonstrated employing the modified flask method. To achieve different degrees of curing within the same periods of time, the amount of hardener in the binder formulation is varied. Despite other results based on other methods, the resulting FA-emission determined by the modified flask method is found to be lower at higher degrees of curing.
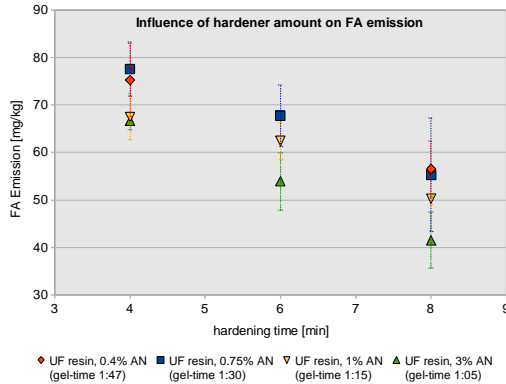
Figure 1. Influence of hardener amount on FA emission

It has to be considered that a comparative examination of different binder systems is only meaningful when analyzing glues of the same reactivity. A simple method for checking the binder's reactivity is the gel-time test in boiling water [2].

3.2 Influence of formaldehyde reduction attempts

The main target of the modified flask method is, without controversy, the monitoring of the effects of formaldehyde reduction attempts on the binder's emission potential. This is possible only by comparing glues of similar reactivity, in order to minimize the effects mentioned before. Potential approaches to reduce the formaldehyde emission are the addition of pure melamine to the urea-formaldehyde glue, the use of precondense melamine-urea-formaldehyde glue, or, for example, the addition of a formaldehyde scavenger, as described in [1]. The effects of such strategies on the emission potential are shown in Figure 2.
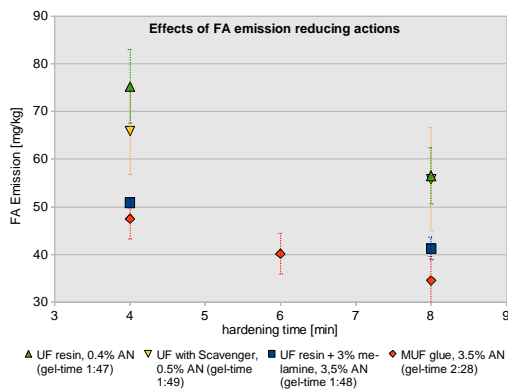
Figure 2. Influence of additives on FA emission

Disregarding the loss in reactivity and production efficiency, the use of industrial MUF glue seems to be the most effective way to reduce formaldehyde emission. Despite being of scientific interest, this solution is up to now economically impossible in industrial particle board production.

3.3 Comparison to panel-based emission analysis

To check the significance of the modified flask method, compared to the panel based analysis technique according to EN 717-3, a design of experiments has been set up, varying pressing time and –temperature ceteris paribus. The "UF with Scavenger" binder system, already presented in Figure 2, serves as an example. A three-dimensional plot of the resulting emission values is shown in Figure 3. The emission scavenging effects at medium curing levels correlate well with the results from Figure 2.
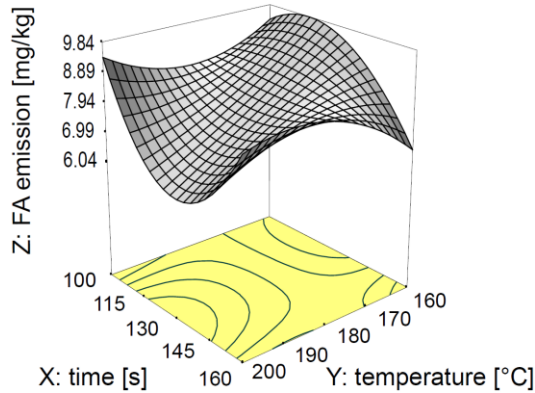
Figure 3. Test of FA Scavenger in panels with flask method

4 CONCLUSION

Based on the flask method, EN 717-3, a rapid screening procedure for the formaldehyde-emission potential of binders for wood based panels has been established. The hot-press step in panel manufacture has been replaced by hardening glued chips in a lab-dryer. Significant dependence of emission from the resin curing rate has been found. Hence, for comparative investigations of additives, similar reactivity of the binder system has to be ensured. The emission values found with the modified flask method based on glued chips correlate well with results from the panel based analysis according to EN717-3. The preliminary information from the screening can serve as a basis for decisions on a further testing program.

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Branch wood, from secondary wood resource to value added Eco-Products

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ABSTRACT

One of the most ignored secondary resources, the branch wood, mainly used as firewood, is insufficiently known and exploited in spite of limited natural resources. This could be used in new value added products as an alternative to stem wood, providing its characteristics are known and understood.

An initiative to increase the degree of conversion of branch wood was considered in this paper and consisted in manufacturing branch panels of maple (*Acer platanoides* L.) from crosscut branch prisms that can be used in small articles of decorative furniture.

The panels were subjected to bending tests and their MOR and MOE were determined. The results were interpreted by examining the microscopic structure, the MOR, the MOE and the compression strength of the raw material, maple branch wood, in relation with those of mature stem wood of the same species.

The mechanical tests of the raw material showed that the MOR of maple branch wood was slightly higher than that of the maple stem wood, which may be linked to the higher density of the former. A reason of the higher density in branch wood could be the presence of smaller cell lumens compared to those of the stem wood as found when processing the microscopic images with an image analysis software.

The MOE and compression strength of maple branch wood were slightly lower than those of the stem wood and this was perhaps due to the greater number of medullary rays and to the higher proportion of pores found in branch wood.

Since maple branch wood had similar strengths to maple stem wood this makes likely similar strengths of wood panels with the same orientation. However, the maple wood panels proposed in this study had a crosscut grain orientation driven by aesthetic considerations, which had clearly reduced their MOE and MOR compared to those of some conventional composite panels reported in the literature. This makes them applicable only for small articles of decorative furniture which are not subjected to bending stresses.

Further work is under way for testing the dimensional stability and finishing of these panels.

1 INTRODUCTION

Wood secondary resources, including wood branches, represent about 25-32% of the total harvested wood and are mostly destined for firewood and coal. Approximately 10% can be recovered by redirecting them, thus becoming an alternative resource. Most commonly, branch wood is recovered by being chipped for wood based panels. However, branch wood, could be used in new added value products as an alternative to stem wood, providing its characteristics are known and understood.

In a recent project [2], panels were manufactured from crosscut branch wood that can be further used in small furniture articles (Figurea). Compared to reconstituted solid wood panels, which have the grain parallel to the panel surface, the proposed new structures show the end grain on panel faces, displaying an attractive design.

Fir branch wood panels, were tested for bonding quality [5] and for their surface roughness, which showed a good bonding strength complying with the standard DD CEN/TS 13354:2003 [6] and a surface roughness app.30% smaller than for a conventional orientation parallel to the grain [3]. Nevertheless, hardwood branch panels were not studied.

This paper is investigating the MOE and MOR of maple branch eco-panels with crosscut grain. To compare the results with the characteristics of the raw material, specimens of branch wood and stem wood of maple (*Acer platanoides* L.) were tested for their compression strength parallel to the grain, MOE and MOR. For completeness, SEM and optical microscopy of maple branch wood and stem wood together with image analysis with a specialized software were used to interpret the results.

2 METHOD

Straight maple (*Acer platanoides*) branch pieces of app. 500-600 mm and with diameters ranging between 6-10 cm resulted from delimbing operations were randomly taken from a local forest base warehouse. Two maple branch panels with crosscut grain were manufactured from maple branch prisms of 30 x 30 mm section, cut from the above branches. The prisms were further crosscut into slices 20 mm thick and then glued edge to edge with polyvinyl acetate by means of screw clamps to form panels of 510 x 270 x 20 mm. Out of two panels, 6 specimens were prepared for testing their MOR and MOE according to EN 310 [7].

Specimens of maple stem wood available as sawn timber and maple branch wood were cut for testing their compression parallel to the grain [10], their MOE [9] and MOR [8].

To better understand the behaviour of maple branch and stem wood specimens subjected to mechanical testing, two microslides for each category of material were prepared for examination with an optical microscope BIOSTAR OPTECH B5 fitted with an image capture system. Four images for each type of material

were further analyzed with an image-analysis software, ImageJ [11]. This was used for obtaining a quantitative evaluation of the investigated parameters. ImageJ identifies wood cells (eg. pores) as objects, selects their contour and returns a mask image where only the objects (anatomical cells) of interest are kept (Figure 1 b,c) and it provides numerical data about the measured objects such as: area and perimeter of each object, total and average area of objects, percentage and number of objects detected in an image.

Separately, small cubes about $3 \times 3 \times 3$ mm of maple branch and stem wood were prepared and examined in a Cambridge 150 Scanning Electron Microscope using secondary electron imaging.

3   RESULTS AND DISCUSSION

Microscopic SEM examination of maple showed the presence of smaller cell lumens in branch wood than in stem wood (Figure b,c), which may explain the higher density of the branch wood of maple compared to that of the stem wood (Table 2). Image processing with ImageJ confirmed this result (Figure 2 and Table 1).

| a | b | c |
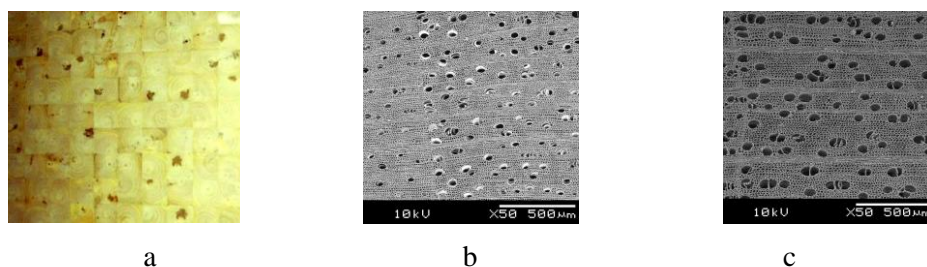
Figure 1.   a- maple branch panel; Transverse SEM micrographs of maple (magnification x 50) b- branch wood; c- stem wood

The mechanical tests of the raw material showed that the MOE and compression strength of maple branch wood were slightly lower than those of the stem wood (Table 2) and this was perhaps due to the greater number of medullary rays (Figure 1b,c), which according to [4] citing Koch (1972) can lower compression strength parallel to the grain, and to the higher proportion of pores found in branch wood (Figure 2 and Table 1). The MOR of maple branch wood was slightly higher than that of maple stem wood which may be linked to the higher density of the branch wood (Table 2).

Compared to the MOE and MOR of the raw material, maple branch wood, which was tested parallel to its grain, the values for the maple branch panels with perpendicular grain orientation decreased more than 11 times for the MOE and 17 times for the MOR (Table 2).

The maple branch panels had lower stiffness and bending strength than other composite panels. Chipboard is the material with the lowest MOE and MOR of

the composite boards presented in the analysis in Table 3. The MOE and MOR of the maple branch panel were app. 50% of the values for chipboard, but this result is attributed mainly to the grain orientation of the branch wood panel (Figure 1a) rather than to the material.
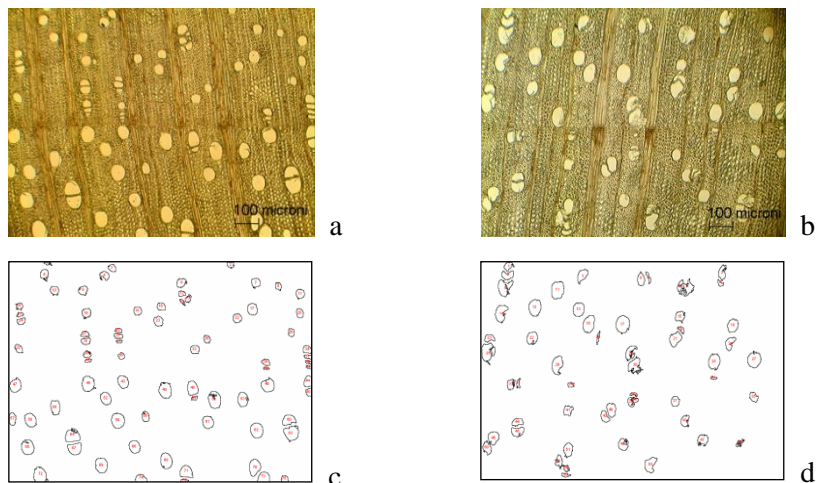
Figure 2. Microscopic cross-sections taken by means of an optical microscope BIOSTAR OPTECH B5 with 100x magnification **(**a,b) and their processing with ImageJ software (c,d). a, c- maple branch wood; b, d- maple stem wood

Table 1. Image processing analysis with ImageJ software for pores of maple branch wood micrographs compared with those for maple stem wood (mean values)

Pores/mm^2		Mean pores lumen diameter (μm)		Mean area of pores lumen (μm^2)		Percentage of total lumen pores area (%)	
B	S	B	S	B	S	B	S
61	52	42	43	1260	1429	8.5	7.5
(6.3)	(13.1)	(1.6)	(2.6)	(12.1)	(5.3)	(6.5)	(9.4)

Coefficients of variation (%) in parenthesis; B-branch wood; S-stem wood

Table 2. Comparison between some mechanical properties of maple stem wood, maple branch wood and maple branch wood panels

Wood type	Density (kg/m^3)	Compression strength (MPa)	MOR (MPa)	MOE (MPa)
Stem wood	609 (1.9)	55 (8.7)	106 (11.5)	10764 (4.9)
Branch wood	689 (2)	52 (11.8)	118 (9.9)	9265 (8.4)
Branch panels	639	-	6.8	800

| with crosscut grain | (1) | | (10.1) | (7.3) |

Coefficients of variation (%) in parenthesis.

Table 3. Mean values of MOE, MOR of maple branch panels determined experimentally compared with the range values of other composite panels from the literature (from related standards and Schniewind et al (1989) as cited by [1])

Material/ Test	Maple branch Panel (20)	Chipboard (13-20; 20-25)	OSB (18-25)	MDF (19-30)	Block-board (<20)	Softwood Panels (≤ 24)
Source	tests	EN 312	EN 300	EN 622	Schnie-wind	Schnie-wind
MOE (MPa)	800	1500-1600	1400-3000	2100	4500-6500	6000-8000
MOR (MPa)	6.8	11.5-13	8.00-16	18	20	50-70

Values in parenthesis represent the panels thickness in mm.

4   CONCLUSION

An initiative was considered in this paper to increase the added value of wood branches, consisting in new panels with an enhanced design, assembled by gluing crosscut maple branch wood prisms. The main destination of these panels is for manufacturing small decorative furniture parts, rather than structural elements. The new panels were tested in bending and the results were compared with those reported in the literature for other composite panels.

Since maple branch wood was the secondary resource used in the panels, their microscopy and some mechanical properties, as compression parallel to the grain, MOE and MOR, were tested and compared with those of the maple stem wood.

The mechanical tests of the raw material showed that the MOR of maple branch wood was slightly higher, while the MOE and compression strength were slightly lower than those of the stem wood, which seemed to correlate with the smaller cell lumens, with a greater number of medullary rays and a higher proportion of pores in the branch wood observed when comparing the microscopic views and when processing the images.

Since maple branch wood had similar strengths to maple stem wood this makes likely similar strengths of wood panels with the same orientation.

As expected, the new panels with the grain perpendicular to the surface did not perform as well in bending as other wood based composites reported in the literature, which suggests a destination of those panels strictly to small decorative eco-products that are not subjected to bending.

Further work is needed to test other properties of those panels that will enhance their value, such as their dimensional stability and finishing.

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Development of a wooden I-Joist using Corrugated Veneer Web Panels

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ABSTRACT

The increasing need for construction materials coupled with the decreasing quality and quantity of available raw materials triggered innovations and re-search works to meet challenges of demand and supply. Wood composite I-joists represent an efficient use of materials for structural applications. Howev-er, the buckling characteristics of these composite panels discourage the use of I-joist under heavy concentrated loads. This presentation summarizes the results of an ongoing research project to increase the lateral torsion and in-plane stabili-ty of these materials. The focus of the article is on experimental phase of the study where different sources of potential raw materials, elaborates on physical and mechanical properties of the proposed furnish, composite formulation me-thodologies, different end joint types of the web panels and web-flanges con-nection are discussed.

1   INTRODUCTION

Prefabricated wood I-joists consist of solid-sawn or structural composite lumber flange members connected with structural panel webs usually using moisture resistant adhesives. They are well suited for long-span joist applications like roof and floor systems in both residential and commercial applications and represent an attractive economical alternative to traditional beam products (Hindman et al., 2005). Engineered wood I-joist composites are highly efficient, lightweight structural elements with a shape that maximizes the bending stiff-ness while minimizing the material used.

However, the buckling characteristics of these composite panels discourage the use of I-joist under heavy concentrated loads. In case of increased spans, if the joist is not supported in the lateral direction (i.e., perpendicular to the plane of bending), and the flexural load increases to a critical limit, the joist will fail due to lateral buckling of the compression flange (Zhu et al., 2005). Furthermore the

78

slender web elements having relatively large depth-to-thickness ratios and webs with holes (Afzal et al., 2006) are particularly susceptible to local buckling also. Lateral instability can be prevented by providing lateral support at the top flanges. Local buckling is usually eliminated by using filler blocks at the locations of heavy concentrated loads acting on the beam. Profiling the web generally increase the stability of the I-joists and avoids the buckling failure of the beam (Hindman et al., 2005). Different profiles have been developed, the most commons being the corrugated and trapezoidal ones. The corrugated profiles like sinusoidal shapes have the advantage over trapezoidal profiling of eliminating the local buckling of the flat portions.

The primary objectives of this research was to investigate the effects of construction parameters such as joist's depth, web-to-web or web-to-flange joint's strength, web panel's thickness, etc. on bending performance of the I-joists. Specific objectives of the study were to: determine the bending strength and stiffness of the I-joists made of hardwood veneer clippings analyze the load bearing capacities of different web-to-flange joints, determine the tensile strength of various web-to-web joints.

2   MATERIALS AND METHODS

The furnish material for the corrugated web panels were White Ash (*Fraxinus Americana*) rejected full size veneer sheets. The brown discoloration prevented the application of these sheets as decorative veneers. The dry veneer sheets did not undergo any modifications and were used exactly in the form as they come from an Appalachian decorative veneer manufacturing plant. Sheets were covered with phenol formaldehyde type adhesive using a laboratory roller coater based on a 5% resin to veneer ratio on dry weight basis. The resin spread determination was based on a previous research work (Dénes et al., 2006, Lang et al., 2008). Hand mat forming in a 760 by 760 mm forming box ensured high degree of control in parallel alignment of long sheets. The pressing schedule was setup on load control with three pressure release steps before press opening. The panels were pressed for 12 minutes at 190 °C. The corrugated shape of the panels was provided by a set of 455 by 760 mm aluminum templates (Figure 1a).

Figure 1. a) Corrugated press templates; b) Web panels with different thicknesses; c) Prefabricated I-joists

The conditioned panels (Figure 1b) were trimmed and finger jointed in length. Two types of flange-web joints were used to fix the web panels to the flanges: tongue and groove and finger joint. The I-joists were produced in two lengths 3,65m and 2,45m using various structural composite lumber (SCL) as flange materials (Figure 1c). Table 1 describes the dimensions of the flange and web materials as well as the joint type used for flange-web connections.

Table 1. Prefabricated I-joists characteristics

Spec.	Length, m	Depth, mm	Flange width, mm	Flange thick., mm	Web thick., mm	Flange material	Joint type
1	3.65	231.8	42.9	33.3	5.1	PSL	FJ[1]
2	3.65	273.1	44.5	42.9	7.9	LVL	FJ
3	3.65	301.6	55.6	39.7	6.4	PSL	TG[2]
4	3.65	287.3	50.8	34.9	7.9	LVL	FJ
5	3.65	292.1	50.8	34.9	11.4	PSL	FJ
6	3.65	306.4	57.2	44.5	4.4	LVL	TG
7	2.45	236.5	57.2	44.5	12.7	LVL	TG
8	2.45	266.7	57.2	38.1	9.1	PSL	TG
9	2.45	417.5	85.7	34.9	10.2	LSL	TG

Bending strength and stiffness determination was completed in accordance with ASTM D198-05. Each sample was laterally supported to minimize the off-axis buckling. Due to the short specimen's length and different joist depths, the span-to-depth ratio for the 3,65m joists was 12-15:1, for the 2,45m joists 6-10:1 as compared to the recommended 17-21:1 ratio. A linear displacement transducer recorded the mid-span deflection between the load points. Load was applied by a hydraulic testing machine at a constant rate of 2,5mm/min. The experimental setup is shown in Figure 2a.

Because of press size limitation the corrugated web panels had to be joined in length as well as the flange materials. Two joint types were prepared, finger and dovetail joint for the web-web connection and finger joint for flanges end joint. The pure tensile strength of joints were determined on 150/200 mm wide flat veneer panels and compared with the panel's similar properties without joint. Tensile tests were performed in accordance with ASTM D3500-05, Method B, except specimens' length which ranged between 305-405 mm instead of 1220mm prescribed by the standard. A fixture apparatus was designed and built with striated plates and fixing bolts at both ends of the specimens (Figure 2b). Loading rate was set up to 0.635 mm/min.

3   RESULTS AND DISCUSSION

Moment capacity, bending strength and modulus of elasticity results are shown in Table 2. The moment of inertia of the web panels were approximated based on the unit volume, i.e. the thickness was increased in order to compensate for the higher web length. Despite high variations of the joists geometrical charac-

teristics the modulus of rupture and modulus of elasticity values show consistency except one extreme data for MOE. The obtained values are comparable with conventional I-joist's similar values however, the possibility to increase them by the optimization of web-flange connection strength exists.

Table 2. Mechanical properties of the prefabricated I-joists

Spec.	I, cm^4	F$_{Max}$, kN	M, Nm	MOR, MPa	MOE, MPa
1	2862	6.6	3856	15.19	12548
2	5856	8.3	4823	11.44	8687
3	8085	17.7	10369	19.14	13169
4	6382	6.6	3843	8.60	12824
5	6920	8.3	4823	10.07	11997
6	9356	8.9	5190	8.54	12962
7	5075	25.5	10134	23.46	-
8	5801	22.1	8776	19.45	-
9	25387	44.5	17715	14.40	-

I, second moment of inertia, F$_{Max}$, maximum force at rupture, M, bending moment capacity, MOR, modulus of rupture, MOE, modulus of elasticity

I-joists with tongue and groove web-flange joints proved to have higher load bearing capacity than finger joints. Depth, web panel's thickness, flange material type had low influence on the flexural properties. Figure 3. shows some typical failures occurred during the bending tests.

Figure 2. Typical joist failures

I-joists with finger joint connection between flanges and web failed in finger's rolling shear at the top or bottom flanges followed by the web-web joint shear failure (Figure 3a,b,c). This can be explained by the chipping outs the finger jointing cutter head made on corrugated panel portions with perpendicular grain orientation.

For I-joists with tongue and groove web-flange joints characteristic failure mode was the horizontal shear of web panels (Figure 3e,f). Specimen 3 failed in tension of the bottom flange at finger joint followed by web shear at joint simultaneously with the top flange failure in tension (Figure 3d). Joist 7 with the highest web thickness failed in crushing of both bottom flange and web panel at end reaction. The corrugated panel had a loose part in that region contributing significantly to the failure. The top flanges of Joist 9 crushed locally at one of the load application points and the skewed load caused lateral buckling.

Table 3. Tensile strength of joined veneer panels

Joint type	F_{max}, kN		Tensile strength, MPa	
	Mean	CV, %	Mean	CV, %
Dovetail joint	14.9	32	9.2	20
Finger joint	39.9	26	25.3	25
Without joint	67.4	34	66.6	17

Table 3 shows the tensile strength values of the flat panels made from white ash veneer sheets. High variation of the measured values characterizes all of the joint types. During the tests several finger jointed specimens failed in shear at bolt connection. Finger jointing in length of the veneer panels reduced the axial load bearing capacity by 60% on the average while the dovetail joint diminished the tensile strength with 85% (Figure 3).
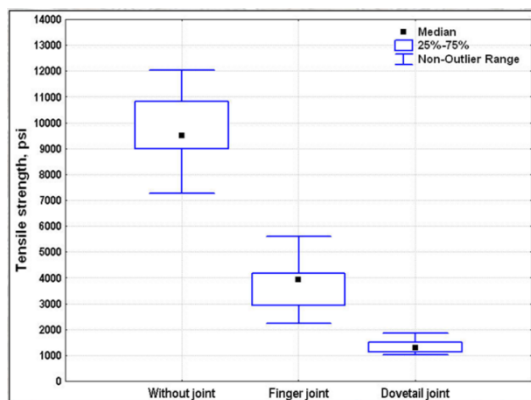
Figure 3. The effect of joint type on tensile strength

4   SUMMARY AND CONCLUSIONS

- The results showed that an efficient corrugated structural panel with a moderate wave geometry can be successfully produced from hardwood veneer side clippings using conventional mat forming and pressing methods
- Flexural properties of I-joists using corrugated web panels from hardwood veneers were comparable with conventional joist's similar properties
- I-joists with finger joint web-flange connection failed in shear of glue line at the top or bottom joint while tongue and groove jointed beams failed in horizontal web shear.
- Web-web finger joint connection decreased by half the tensile strength of the web panels, while dovetail joints reduced with almost 90 percent
- Further work needs to be done to optimize the web-flange finger joint strength and to evaluate the local and global buckling behavior of the I-joists with corrugated veneer web panels

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Gluing of European hardwoods for load bearing timber structures

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ABSTRACT

Durable und reliable bonding of lamellas is essential for the production of glulam. To ensure that requirements are met, adapted bonding parameters are necessary for gluing beech and ash. One goal of this study was to examine wood characteristics of beech and ash which have the potential to influence curing, and to compare them to spruce. With regard to the frequency of occurrence, coloured heartwood of beech and ash was also taken into consideration. First of all, water absorption coefficients were determined. Furthermore, pH on surfaces was analyzed, because it might influence curing of acid-catalyzed adhesives. In addition to the fundamental research of species characteristics, the overall goal was to gain knowledge of interactions of adhesives and varying wood species during the curing process. Therefore, a novel method was developed, allowing for monitoring real-time curing of assembled adherends. First results suggest that this is a promising method to contribute to a better understanding of the curing process and how it is influenced by wood species.

1 INTRODUCTION

The stumpage volume of hardwoods in European forests has been increasing since decades, while the utilization has been declining. Promising efforts are to enhance the load bearing capacity of glulam by using European beech (Fagus sylvatica L.) and ash (Fraxinus excelsior L.) lamellas. Since load bearing products are safety relevant, reliably and securely bonded joints are mandatory. With regard to European beech several investigations have been carried out in the past years, [1]. These studies focused primarily on melamine-urea-formaldehyde resin (MUF), which are the most widely used adhesives for the production of glulam in Europe. Positive results regarding bonding quality with beech could be achieved by [2]. Outstanding performances were achieved for different MUF adhesives with a prolonged closed assembly time. Since for spruce also shorter assembly times are leading to positive results, it was assumed that the curing process might be retarded by beech. In preliminary investigations similar results were obtained for ash. Understanding the curing process

84

and how it is influenced by wood species is considered an important contribution to enhanced bonding of European hardwoods.

2   OBJECTIVES

The overall goal was to gain knowledge of the interactions of adhesives and varying wood species during the curing process. Therefore, the study was aimed at developing a new method, allowing for monitoring real-time curing of adhesives between assembled adherends. One specific goal of this research was to examine characteristics of beech and ash in comparison to spruce. Coloured heartwood, which may have the potential to influence curing was also included. Because MUF adhesives are dispersed in water, the rate of water absorption by wood has an influence on hardening. So far, little has been reported on differences in water absorption of European hardwoods. This study was aimed at obtaining water absorption coefficients for beech and ash. Another factor influencing curing is the pH of wood, because hardening of the examined MUF systems is initiated by acid. Since pH of the wood surfaces is crucial for bonding, another objective of the study was to reveal differences in pH on the surfaces of the above-mentioned wood species.

3   MATERIAL AND METHODS

3.1 Water absorption

To obtain the water absorption coefficient w_t, the standardized method according to [3] was used. The determination of water absorption was carried out for 64 beech and 35 ash specimens without coloured heartwood and for 36 beech specimens and 19 ash specimens containing coloured heartwood. As a reference 10 spruce specimens were included in the study. The specimens had an MC of about 12 % and stored in water for 24 hours. Since for bonding the tangential surfaces are relevant, the water absorption of freshly planed flat sawn specimens was analyzed. The lateral surfaces of specimens were sealed with an impermeable epoxy resin. Water was absorbed by the specimens only in a defined area of 103 cm². Mass increase was measured after 11 predefined time intervals and plotted versus square root of time.

3.2 pH-value

To measure pH on wood surfaces a specially designed pH electrode with a flat membrane was used. The specimens were situated in a closeable teflon container as illustrated in Figure 1. An opening in the container allowed for placing the pH electrode accurately on the specimens. The distilled water required for measuring pH was applied by means of an injection through a drilled hole in the container in order to minimize contact with atmospheric CO_2. Measurements were carried out on the surface of veneers which were cut off from planed solid boards. Prior to starting measurements the boards had been stored in a climate room (20/65) for several weeks. From each board two veneers were obtained. One veneer had an aged surface, while the surface of the corresponding veneer

was freshly planed. In total 50 (46) veneers of beech and 8 (12) veneers of ash without coloured heartwood (containing coloured heartwood) were analyzed.

To minimize external effects and to enhance comparability, the specimens with and without coloured heartwood were in nearly all cases obtained from the same tree. As a reference, 18 veneers of spruce were included in the study. Since 6 to 10 separate pH values per veneer were determined, in total 983 pH values were measured.

Figure 1. Teflon container with inserted veneer

3.3 Monitoring curing behavior

For monitoring the curing behavior of adhesives in dependence of wood species, it was necessary to develop a new method. The method provides informa-

tion about the curing process of adhesives between assembled adherends without pressure applied. Therefore, a standard rheometer was used. In Figure 2, the device used for the tests is illustrated. A freshly planed wood specimen (ws_1) was fixed to a special base plate (1). Another planed wood specimen (ws_2) was fixed to a probe (2) with a screw. By means of an electronically controlled motor it was possible to define an exact gap between the two wooden surfaces.
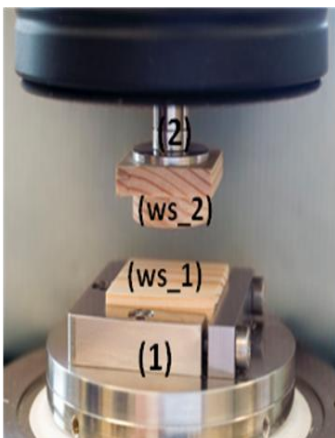
Figure 2. Device for monitoring curing between assembled adherends

After applying adhesive on ws_1, a distance of 0.2 mm was adjusted between ws_1 and ws_2. Thereby intimate contact between adhesive and wood was secured. By means of normal force measurement it was possible to control and readjust the position of the probe. By recording the position of ws_2 in intervals of 1.0 seconds the decrease in adhesive layer thickness during assembly time could be documented. After predefined closed assembly times the two wood specimens were separated by driving the probe with ws_2 back into the upper direction. A load transducer measured the required forces and the rate of separation is also registered. The required maximum tensile force F_{max} and the dissi-

pated energy *w* for debonding allows for characterizing the curing process. Tests were carried out with a commercially available MUF adhesive system.

4 RESULTS AND DISCUSSION

4.1 Water absorption

For all specimens, an even mass increase by square root of time was seen and could be described by linear regressions ($r^2 \geq 0.95$). The slope of each regression model provided w_t. In Table 1, mean values and standard deviations of water absorption coefficients w_t are given in dependence of wood species. Data reveal that the rate of water absorption for beech and ash was considerably higher than for spruce. W_t is also significantly influenced by the occurrence of coloured heartwood. While for beech a decrease of roughly 40% was obtained, for ash a reduction of nearly 30% was observed as compared to non-coloured heartwood. The reduction of w_t might be due to closed intercellular pathways within coloured heartwood.

Table 1. Water absorption coefficients w_t in $kg/m^2h^{0.5}$

wood species	mean	standard deviation	number of specimens
beech white	0.201	0.036	64
beech coloured	0.119	0.024	36
ash white	0.136	0.018	35
ash coloured	0.097	0.012	19
spruce	0.084	0.009	10

4.2 pH

In Figure 3, the pH values for freshly planed and aged surfaces are illustrated in dependence of wood species. It is obvious, that pH of ash is considerably higher compared to spruce, while pH of beech is intermediate. The occurrence of coloured heartwood in beech wood did not lead to changes in pH, while for ash a decrease was observed.

Direct measurement of pH on the wood surface showed that freshly planed surfaces always had considerably lower pH values than aged surfaces. This aging effect might be considered, when acid-catalyzed adhesives are used. However, obtained data contradict results by [4], who observed a decrease in pH during storage. Reason for this might be differences in methods and specimens preparation by [4].
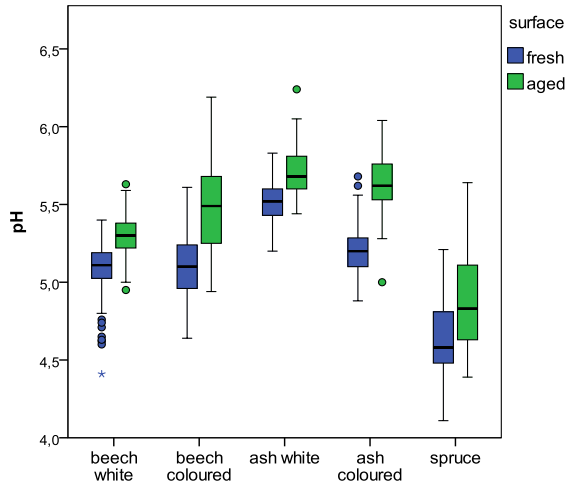
Figure 3. pH in dependence of wood species and age of surface

4.3 Monitoring curing behavior

4.3.1 Decrease of adhesive layer thickness

During closed assembly time a continuous decrease of the predefined adhesive layer of 0.2 mm could be observed when wood specimens were tested. In Table 2, the absolute decrease of adhesive layer is given for varying assembly times and wood species. It is obvious that the decrease of the adhesive thickness depends on the wood species. While a decrease of adhesive layer is accelerated for spruce and beech (white), shrinkage is lower for ash and beech containing coloured heartwood. Those results correspond to some extent to the results presented in chapter 4.1. The influence of coloured heartwood on water absorption, for example, can be confirmed with the given data.

4.3.2 Maximum tensile force F_{max} and dissipated energy *w*

Table 2 also shows data for F_{max} and *w*. Besides an increase of F_{max} and w with increasing assembly time, an influence of wood species and coloured heartwood can be seen. F_{max} and *w* are always higher for beech, data for ash are found on a considerably lower level. Results for spruce were intermediate. Disregarding the influence of wood species, a more detailed analysis of data revealed, that a tight correlation exists between F_{max} and *w*. On the other hand decrease of adhesive layers did not or only marginal correspond to increased values for F_{max} and *w*. It has to be considered though that the results are based on a low number of specimens.

Table 2. Mean decrease of adhesive layer thickness, F_{max} and w in dependence of assembly time and wood species

assembly time in min	wood species	n	decrease in µm	F_{max} in N	w in J
30	beech white	6	43.4	16.7	1.3
	beech coloured	8	24.1	11.4	1.3
	ash white	3	25.6	6.9	1.1
	ash coloured	3	15.2	5.8	0.9
	spruce	6	26.1	17.9	1.3
60	beech white	7	52.4	37.6	6.1
	beech coloured	9	33.9	33.6	6.1
	ash white	3	31.8	17.5	3.0
	ash coloured	2	20.3	13.8	2.1
	spruce	6	36.7	27.4	4.1
80	beech white	2	48.2	50.4	12.2
	beech coloured	2	27.0	37.3	7.4
	ash white	3	36.9	40.9	12.8
	ash coloured	2	26.3	24.5	5.1
	spruce	6	41.4	38.9	9.0

5 CONCLUSIONS

Significant differences were found in water absorption of ash, beech and spruce. An influence of the occurrence of coloured heartwood was also observed. The extent of differences has to be considered if maximum assembly times of water based adhesives are defined. On the other hand, determined pH values of analyzed wood species are not considered to have a significant impact on the curing of acid-catalyzed adhesives. However, the validity of this assumption has to be verified by means of ongoing experiments. Furthermore, a reliable and effective method to monitor real-time curing of MUF adhesives was developed. This method can be used to monitor curing processes and could be an effective method for optimizing adhesive systems.

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Advanced NMR based characterization of wood and wood products

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ABSTRACT

The chemical and physical properties of wood and wood products relate strongly to their molecular and super-molecular structures. Today, nuclear magnetic resonance spectroscopy represents one of the most important and versatile tools for the structural analysis of lignocelluloses and their derivatives. We present a collection of efficient NMR technologies for the reliable and accurate characterization of wood-based materials.

Solid-state ^{13}C CP-MAS NMR has proven particularly useful in the analysis of (ligno-) cellulose morphology and the non-destructive determination of lignin, polysaccharides and protein contents of raw and processed plant materials. We demonstrate the time and sample efficient discrimination between plant and wood samples with respect to supermolecular order and chemical composition. The effects of moderate thermal treatment as well as artificial ageing of wood have been investigated by ^{13}C CP-MAS NMR spectroscopy and corroborate with ATR-FT-IR spectroscopy results.

Whole-wood dissolution in various solvent systems, derivatization and consecutive ^{1}H, ^{13}C, and ^{31}P NMR analysis have been used to determine the composition of different lignocellulose samples with high accuracy. Discrimination between cellulose and hemicelluloses can be afforded by acid total hydrolysis to yield the corresponding sugar monomers. These can be quantified directly and accurately by ^{1}H NMR spectroscopy in strongly acidic medium. Solution-state NMR methodologies have also been applied to study the amount of solvent-accessible reactive hydroxyl and acid moieties within lignocellulosic samples. This parameter has proven to be important for chemical wood processing (e.g. dissolution, derivatization).

1 INTRODUCTION

Wood is a complex composite material, which exhibits unique physical and chemical properties. The main constituents of wood are cellulose (38-50%),

hemicelluloses (23-32%), lignin (15-25%) and non-cell wall components (1-5%). Cellulose is a linear biopolymer, which derives from β-1,4 linked glucose monomers. The super-molecular organisation of cellulose chains influences significantly on the physical properties of wood. Beyond that, cellulose morphology also impacts strongly on wood reactivity, processability and mechanical resilience. Hemicelluloses are heterogenous polysaccharides lacking a higher degree of order and deriving from mainly xylose and arabinose. Their role with respect to wood chemistry and physics is not particularly well understood. Hemicelluloses play, however, an important role in contemporary biorefinery concepts. Lignin is the third polymeric main constituent of wood and structurally derives from p-hydroxycinnamyl alcohols. It forms large three-dimensional networks embedding and "glueing" the polysaccharides together. As a consequence of its complex structure, chemical and morphological wood analysis is not a straightforward task. On the other hand it forms a prerequisite for deducing advanced structure-property relationships.

Nuclear magnetic resonance spectroscopy offers a wealth of experimental methodologies for the characterization of wood, wood components and wood products. Here, we detail a toolbox for the efficient and reliable quantification and structural analysis of all major wood components in a range of different samples. Figure 1 illustrates principle approaches for sample preparation and analysis enabling the extensive NMR based characterization of wood and wood products.
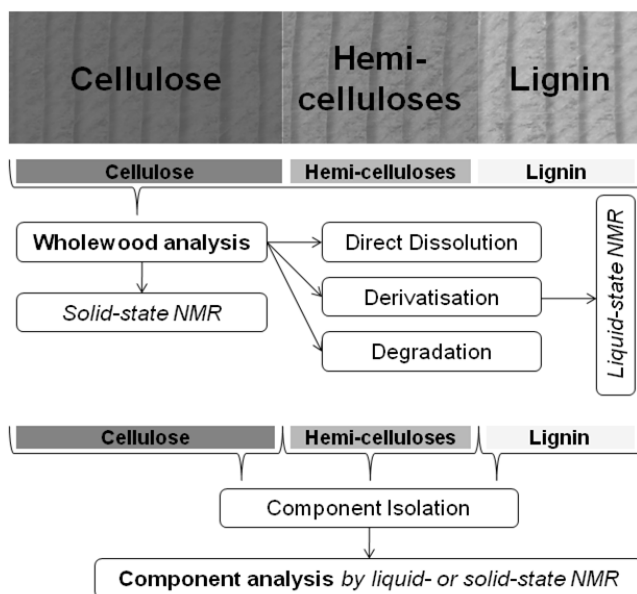

Figure 1. Principle approaches towards efficient NMR based wood analysis

2   SOLID-STATE NMR OF WOOD AND WOOD COMPONENTS

Solid-state NMR spectroscopy of wholewood offers a good deal of structural information at minimal expense of sample amount, sample preparation, and measurement time. Resonances of lignin, carbohydrates and aliphatics are separated and provide quick and reliable compositional information [1]. Further parameters, such as cellulose crystallinity [2], the degree of lignin etherification, estimates on lignin syringyl/guaiacyl ratios, carbohydrate acetyl content, and lignin methoxyl content are accessible via resonance lineshape analysis (Figure 2).
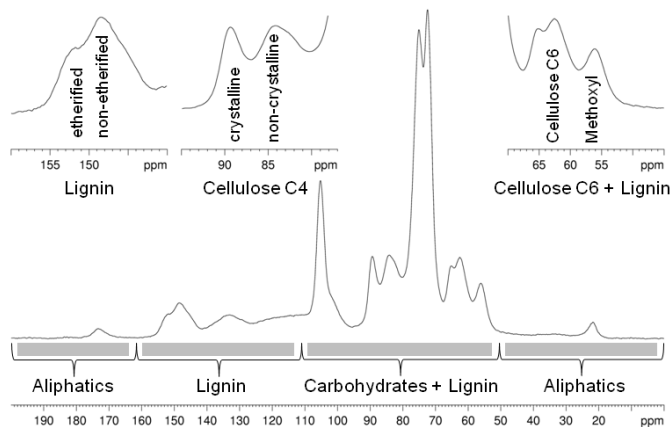
Figure 2. Solid-state ^{13}C CP-MAS NMR spectrum of air-dry, untreated, blade-cut wood with enlarged views of resonances providing specific morphological and structural information, accessible via signal deconvolution or integration routines

We have applied solid-state ^{13}C CP-MAS NMR spectroscopy to study the effects of artificial ageing and moderate temperatures on the chemical structure of wood. It has been shown, that artificial ageing leads to an increase in cellulose crystallinity [3]. Lignin structures remain largely unaffected by the treatment. ATR-FT-IR spectroscopy results corroborate the findings from ^{13}C CP-MAS NMR. It is summarized, that the changes due to ageing mainly affect the polysaccharide fraction of wood. Similar trends of increased cellulose crystallinity have been observed on aged natural fibres, too.

For pulp and regenerated cellulose fibre samples, i.e. analytes composing mainly of cellulose I or II sophisticated methods for morphology assessment have been described [4]. Typically, the shape of the particularly well resolved AGU-C4 resonance is investigated. Larsson et al. employ deconvolution routines to separate up to eight individual contributions to the experimental cellulose I lineshape. These include signals associated to crystalline cellulose I_α and I_β, paracrystalline cellulose, and lines attributed to accessible and inaccessible fibril surfaces. In combination with physical models, these contributions allow also

for the evaluation of lateral fibril and fibril aggregate dimensions. Results obtained from such computations are strikingly comparable to those obtained from electron microscopy. Note here, that cellulose I analyses according to Larsson et al. involve wet-state measurements for resolution enhancement, and typically also hemicelluloses-removal by acid hydrolysis.

3   LIQUID-STATE NMR OF WOOD AND WOOD COMPONENTS

Solution-state NMR spectroscopy typically yields much narrower resonances and thus greatly enhanced resolution as compared against solid-state NMR. Additionally, numerous – often multidimensional – spectroscopic techniques correlating neighboring nuclei with each other are routinely used. Liquid-state NMR is therefore a highly versatile tool for chemical structure analysis and also well-suited for minor component identification and quantification. With respect to wood and wood component analysis it is however often challenging to obtain homogenous and representative solutions of the analyte. Three main approaches to wood and wood component dissolution are: a) direct dissolution or gelation, employing organic solvents [5], [6] or ionic liquid media, b) sample-derivatisation, e.g. acetylation or phosphitylation [7], and concomitant or subsequent dissolution, and c) polymer degradation through e.g. total acid hydrolysis [8].

We have investigated lignin composition and bonding structure in directly gelated and dissolved phosphitylated wood. Results corroborate with those obtained for isolated lignins. Homogenous gelation of ball-milled wood is easily afforded in (deuterated) dimethyl sulfoxide (DMSO) [5]. The resulting gel can be studied by two-dimensional ^{1}H/^{13}C HSQC NMR, which aids in identifying numerous lignin structural elements. N-Methylimidazole (NMI) [6] can be added to achieve complete dissolution and to enable quantitative high-resolution ^{13}C NMR. Another particularly convenient dissolution technique includes phosphitylation of hydroxyls and acid moieties with 2-Chloro-4,4,5,5-tetramethyldioxa-phospholane (2-Cl-TMDP) and concomitant dissolution into ionic liquids, e.g. 1-Allyl-3-methylimidazolium chloride ([amim]Cl) [7]. Phosphitylated wood and wood components can be studied at high resolution and good sensitivity by quantitative ^{31}P NMR. Phosphitylation with TMDP may also be conducted in heterogenous non-swelling environment [9], i.e. without dissolution of the carbohydrate analyte. Then, the consumption of TMDP is proportional to the amount of solvent accessible and thus reactive hydroxyls and acid moieties – another important parameter for wood and cellulose processing.

Common to the previously described wholewood NMR analysis techniques is the difficult distinction between cellulose and hemicelluloses. Their structural similarity results in overlapping resonances, which complicates the reliable quantification of both carbohydrate fractions. One particularly well suited approach in separating the contributions of both polymers lies in their complete degradation through acid hydrolysis with subsequent monomer analysis. Hemicelluloses mainly compose of pentoses, like xylose and arabinose, while cellu-

lose derives solely from glucose. Monomer analysis is commonly achieved by HPLC separation, but recently also ^{1}H NMR spectroscopy in strongly acidic medium (40% H_2SO_4) has been employed to this goal [8]. It has been shown, that ^{1}H NMR spectroscopy offers excellent resolution for separating resonances attributed to commonly encountered sugar monomers. Further important advantages of ^{1}H NMR based monomer quantification lie in its good accuracy, relatively short experiment times, the potential for automation, simultaneous detection of furfural, hydroxymethylfurfural, and acetyls, and simple sample preparation. In Figure 3 sample spectra from the C1-β anomeric proton region of an artificial mixture of frequent sugar monomers and a wood hydrolysate are shown. Note, that in typical wood hydrolysates the resonances of glucose and xylose dominate, which results in significantly reduced spectral overlap. Note further, that at fixed pH the ratio of alpha versus beta anomers is constant and known from the literature [8].
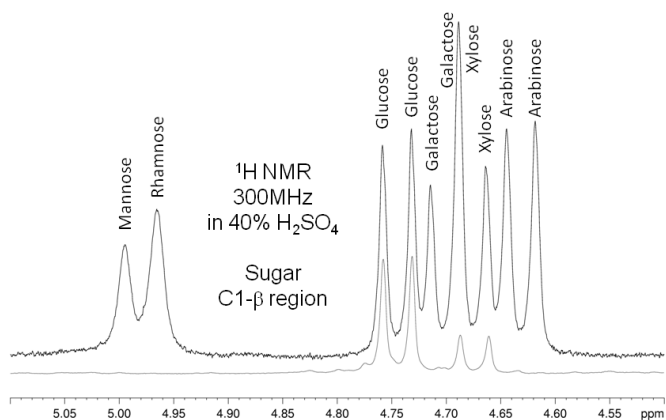
Figure 3: 300MHz ^{1}H NMR plot of the C1-□ anomeric proton region of a synthetic mixture of sugars commonly encountered in wood hydrolysates (black, top) and a typical wood hydrolysate (grey, bottom)

4   CONCLUSIONS

We have summarized contemporary solid- and liquid-state NMR techniques for the efficient compositional and morphological analysis of wood and wood products. Detailed structural information is accessible from small sample amounts in short experiment times and with minimal sample manipulation requirements. Even directly analyzed wood particles yield solid-state NMR spectra of considerable information content, including cellulose crystallinity relating strongly to macroscopic mechanical and physical properties. Several options for derivatizing and/or dissolving wood for subsequent NMR analysis have been discussed, too. Solution-state NMR spectra of wood can provide detailed information with regard to its reactivity, chemical composition, lignin structure and hemicelluloses content.

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3D Microstructure Characterization of Wood Based Panels

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ABSTRACT

The work presented here deals with the microstructure characterization of wood based panels, in particular of oriented strand board (OSB), particleboard (PB) and medium density fiberboard (MDF). A non-destructive method, sub-micrometer computed tomography (sub-µm-CT), was used in order to achieve threedimensional image stacks of the panels investigated. Qualitatively it was possible to differentiate between wood material and air in the panels. For quantitative analysis some more appropriate steps in the microstructure determination were necessary. With adequate image analysis tools it was possible to reduce noise in the image stacks and to cut the image stacks to sub-volumes in order to avoid edge effects. This enabled to differentiate between material and void and to calculate the volume fraction of these phases. Additionally the virtual data enable splitting of existing sub-volumes in the samples into smaller and representative sub-volumes without destroying their edges by mechanical cutting forces. In order to investigate the influence of microstructure parameters on physical properties, e.g. the local density as determined using a conventional x-ray method, the virtually cut sub-volumes were analyzed separately. Finally it was possible to determine the pore size and the type of the pore size distribution. Results of the analysis of the sub-volumes show good correlations between local density and pore size.

1 INTRODUCTION

The microstructure of wood based panels is one of the most important parameters concerning their performance. The most promising technique for microstructural characterization of wood-fiber-based composites is the x-ray micro computer tomography (μCT). This method was successfully used in some of the first investigations concerning material characterization and microstructure related properties, like fiber orientation [1], [2]. High resolution synchrotron x-ray microtomography was also used for the characterization of fiber based panels [3], [4], [5]. Nondestructive x-ray computed tomography and image analysis techniques were also applied on OSB in order to characterize the panel microstructure [6]. More recent investigations concerning strand based wood products dealt with the void structure and the influence of voids on the density of the panel [7]. For particleboard only a very limited number of microstructural characterizations exists. Recently Sackey and Smith [8] investigated the macro voids of uncompressed particleboard mat using x-ray tomography and response surface methodology.

This paper deals with the microstructure characterization of wood based panels using sub-micrometer-computed tomography as well as adequate image analysis tools. One of the biggest challenges during the investigations was the determination of a representative sample size concerning the different wood based panels and with this of the maximum achievable resolution pro volumetric pixel. The different sizes of the structuring elements in a wood based panel (strands, particles and fibers) request different representative sample sizes. The image stacks were then segmented into different phases (e.g. for OSB and particleboard: voids, low density regions, high density regions; for MDF void and cell wall material). With classical tools derived from mathematical morphology the threedimensional pore sizes and the pore size distribution within the panel were evaluated. The reconstructed images from the CT data then enabled both, qualitative and quantitative characterization of wood based materials and the reconstruction of volume models, which might be in future the basis for modeling such types of wood based panels.

2 MATERIAL AND METHODS

2.1 Panel Material

Industrially produced panels were used for this investigation, in particular OSB (18 mm thickness), particleboard (19 mm thickness) and medium density fiberboard (19 mm thickness). According to the size of the various structuring elements (strands, particles and fibers), different sample sizes were used for computed tomography: for OSB 50 mm x 50 mm; for PB 30 mm x 30 mm; and for MDF 4 mm x 4 mm; the samples were stored under standard climate conditions (20 ° C, 65% rel. humidity) to constant weight.

2.2 Vertical Density Profile

Before the samples were scanned with sub-micrometer computed tomography the vertical density of each sample was measured using a vertical density measuring device (Dense-Lab X, Electronic Wood Systems, Hameln, Germany). The measurement increment was set to 10 µm.

2.3 Sub-Micrometer-Computed Tomography

Scanning of the samples was done using an industrial CT device Nanotom 180NF (GE Phoenix|x-ray, Wunstorf, Germany) at the Upper Austrian University of Applied Sciences. This unit has an 180kV nanofocus x-ray tube and a digital detector array (2300 x 2300 pixel). The measurements were carried out with 1500 projections and voltages between 60 kV and 85 kV.

2.4 Image Analysis

Before image analysis was done, image noise had to be reduced in all image stacks. Then the image stacks were virtually cut into subvolumes of certain size. Before starting the analysis the images were segmented to gain binary information (0 and 1). For MDF the Otsu method [9] showed high potential in dividing the image in material and void. For OSB and PB an image segmentation algorithm based on the analysis of variance was chosen, which was already presented elsewhere [10]. This procedure enabled to distinguish between void, low density regions (e.g. early wood) and high density regions (e.g. latewood).

In order to obtain the pore size distribution of the investigated panels procedures of mathematical morphology were used [11]. The main procedures are erosion of a set of voxels I (1) with a certain shaped structuring element H, followed by dilation (2) with same structuring element. Both procedures together are called opening (3). With this procedure it is possible to find regions which fit to the structuring element.

$$(1)$$

$$(2)$$

$$(3)$$

With a series of morphological openings with structuring elements of growing size the pore size distribution can then be obtained.

3   RESULTS AND DISCUSSION

3.1 Resolution

Table 1 shows the achieved resolutions of the investigated wood based panels according to their sample size. For MDF a resolution of 3.2 µm pro voxel (volumetric pixel) was reached. The presence of larger particles shows the need for larger sample sizes.

Table 14. Achieved resolutions depending on sample size

Panel	Sample size [mm³]	Achieved Resolution [µm/voxel edge length]
MDF	4 x 4 x 19	3.2
Particleboard	30 x 30 x19	17.0
OSB	50 x 50 x18	31.1

3.2 Pore Size

The evolution of the pore size distributions according to different sub-volume sizes is shown in Figure 1. The investigated sample sizes do not influence the pore size distribution of MDF; small volumes for OSB and particleboard show different pore size distributions until a certain volume is reached (~2000 mm³). A maximum likelihood estimation in MATLAB® showed that the pore size distributions follow Γ-law (Figure 2).
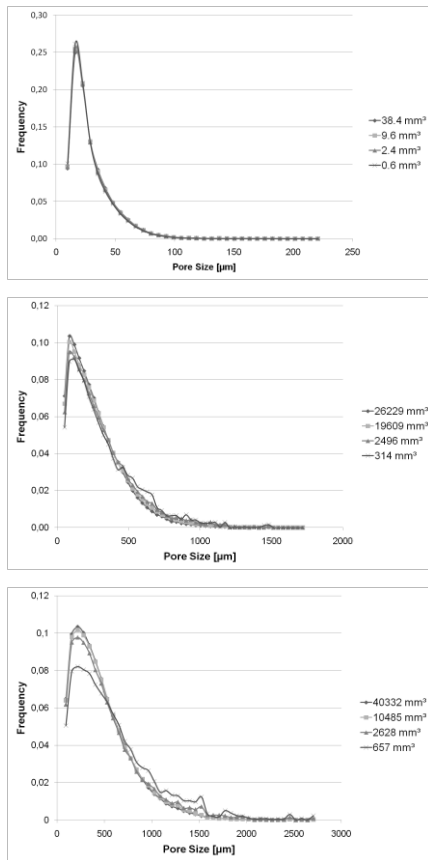
Figure 1. Pore size distributions according to different sub-volume sizes: MDF (top left), particleboard (top right) and OSB (bottom)
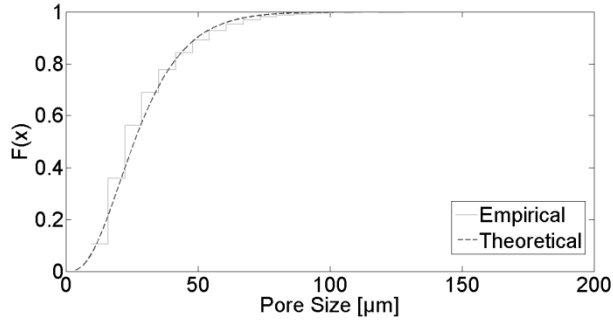
Figure 2. Cumulated density function (cdf) plot of the pore size distribution of MDF. A maximum likelihood estimation showed that the pore size distribution follows Γ-law

3.3 Density and Pore Size

The analysis of sub-volumes enabled the comparison of pore sizes and local densities as well as the analysis of cell wall material and volume fractions of the different phases. Exemplary results for MDF are shown in Figure 3.
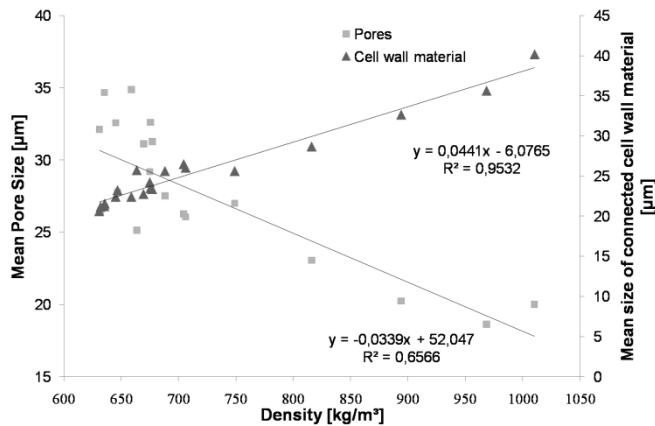
Figure3. Correlation between mean pore size and mean size of connected cell wall material and local density. The two lines show the linear regression

4   CONCLUSION

The work presented here describes the possibility to qualitatively and quantitatively analyze the microstructure of wood based panels. All investigations were carried out using sub-µm-CT and image analysis. The information provided by this work can in future be used for a further understanding of the structure of wood based panels. Based on the achieved results wood based panels can be modeled in order to optimize the microstructure of the panel and to save of raw material.

5 ACKNOWLEDGEMENTS

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Tangential penetration of UREA-Formaldehyde adhesive resins into beech and fir wood tissue

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ABSTRACT

Adhesive penetration into the adherent is an important process during wood bonding. Both, the formulation of the adhesive and the bonding conditions influence the penetration behaviour. The main objective of this study was the evaluation of the influence of the degree of condensation of urea-formaldehyde (UF) resins on the tangential penetration into beech and fir.

Radially cut beech (*Fagus Moesiaca*) and fir (*Abies Alba*, Mill.) wood plies and three types of UF resins with different degrees of condensation were used. Microtome slides of 20 μm thickness were cut from each bonded sample, showing the tangential penetration of the resin between two adherents. Epi-fluorescence microscopy was used for measuring the depth of adhesive penetration.

The results show a significant correlation between the penetration behaviour and the degree of condensation of the adhesive resins. The higher the degree of condensation, the lower the penetration, expressed as average penetration depth (AP) and as total interphase region (IR) including the unfilled lumen area. AP and IR into beech were higher than into fir. The filled interphase region (FIR) was calculated as percentage of the size of the filled interphase region (A) related to the size of the whole interphase region (IR). FIR increases slightly with a higher degree of condensation whereas A decreases for both wood species. FIR and A into fir were higher than into beech.

Key words: penetration, beech (*Fagus Moesiaca*), silver fir (*Abies alba Mill.*), degree of condensation, urea-formaldehyde (UF) adhesive, epi-fluorescence microscopy, fluorescence confocal laser scanning microscopy (CLSM).

1 INTRODUCTION

The use of condensation resins [1], [2] for bonding wood components like veneers, particles, or fibres plays a dominant role in the wood based panels industry. An adequate penetration of the resin into the wood surface enables forma-

tion of a sufficient large bonding interface; this penetration must have taken place before curing of the resin has occurred.

The interphase region of the adhesive bond is defined as the volume containing both, wood cells and adhesive. It is created by the penetration of the adhesive into the wood surface, partly filling the lumens; it is determined by wood related parameters, by the properties of the resin and the adhesive mix, and by various bonding processing parameters. The temperature of the wood surface and of the bond line and, hence, the viscosity of the resin (which itself also depends on the already reached degree of hardening) influence the penetration behaviour of the resin and hence the bond performance.

Higher condensated structures (higher degree of condensation) of UF resins exhibit a higher viscosity at a given solid content and, hence, a reduction of the flowing ability, causing worse distribution of the resin on particles or fibres [3]. Penetration into the wood substance decreases for higher condensated UF resins [4], [5]; a clear correlation is given between the viscosity of the resins and the initial rate of penetration into the surface, shown as slower decrease of the droplet volume on the surface with time using the static contact angle measurement for higher viscosities.

The extent of the penetration is preferably determined by examination of the cross section of a bond line, mainly using various microscopic methods; an overview was given recently [6].

In two earlier papers of the authors [6], [7] for the first time the influence of the degree of condensation of a UF resin on the penetration into a wood surface had been investigated; this study was performed using fir and beech as wood material, but only in radial direction.

The objective of this study presented here was the evaluation of the influence of the degree of condensation on the penetration into beech and fir in tangential direction and the resulting distribution of UF resins within the wood substance by means of microscopic investigation.

2 MATERIALS AND METHODS

2.1 Wood raw material

Beech and fir logs were cut from the trunks at the height of 1.3 m in a length of 1100 mm. The boards of 42 mm thickness were cut using a band-saw. After initial air drying the boards were further dried in a laboratory kiln drier and planned to the final dimensions of 1000 mm x 150 mm x 30 mm. These boards were cut then into radial blocks of 100 x 30 x 5 mm in order to investigate the penetration of adhesive in tangential direction. Furthermore, these radial blocks were conditioned at the relative air humidity of $65 \pm 5\%$ and the temperature of $20 \pm 2^{o}C$.

2.2 Urea-formaldehyde (UF) resins

Three UF resins with different degrees of condensation according to recipes described in the literature [8],[9], were provided by DUKOL Ostrava, s.r.o.

(Ostrava, Czech Republic) as already reported earlier [6]. The degree of condensation (DOC) increases with the duration of the acidic condensation step from resin UF I (lowest DOC) to resin UF III (highest DOC). The viscosity of the three resins increases due to the increasing size of the molecules presented in the resin from 218 mPa.s for UF I to 281 mPa.s for UF II, and, eventually, to 555 mPa.s for UF III.

In order to keep the same gel time of the adhesive mixes, the addition of ammonium sulphate as hardener was 0.5% for UF I and 0.3% for UF II and UF III, both values expressed as solid ammonium sulphate on resin solids. An equal gel time was considered to be essential for the comparison of the penetration of the various adhesive mixes into wood, since the length of hardening process influences the penetration behaviour due to increase of the molecular size.

The adhesive mixes were prepared by addition of 10 % (by mass) of wheat flour as extender and 0.05 % (by mass) of Safranin (Superlab, Belgrade) as marker, both based on solid resin. A similar increase in viscosity as for the resins themselves is seen for the adhesive mixes (UF I: 545 mPa.s; UF II: 745 mPa.s; UF III: 1644 mPa.s), measured just after mixing.

2.3 Bonded samples and determination of penetration

The experimental procedure except the special arrangement of the plies in order to achieve tangential penetration was the same as already reported earlier [6]. Microtome specimens of 20 μm thickness cut perpendicular to the bond line were used for microscopic evaluation using epi-fluorescence microscopy and confocal laser scanning microscopy (CSLM) [6].

Individual depths of penetration (μm) were determined from each photomicrograph of the microtome slide at 45 positions within the 1400 μm width of the bond line. The depth of penetration within this paper is defined as the sum of the distances the resin could penetrate into the two plies starting from the bond line. No separate evaluation was done for the two plies, even there might be some small difference in the individual penetration between the ply where the adhesive mix has been applied and the other ply without application of adhesive mix.

The average penetration depth (AP) is determined as the mean value of penetration depths calculated from all 150. The total interphase region (IR) was calculated using the maximum value out of the 45 values for the depth of penetration in each photomicrograph. IR includes the unfilled lumen area and the area of all filled lumens or filled rays (A). The filled interphase region (FIR) was then expressed as percentage A/IR (%).

3   RESULTS AND DISCUSSION

3.1 Average penetration depth (AP)

The average tangential penetration depth AP into beech and fir decreases with higher degree of condensation (viscosity) of the used resins (Figure1).
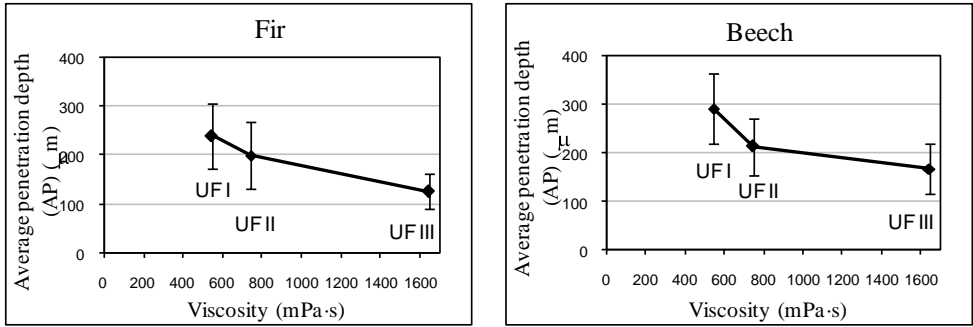
Figure 1. Average penetration depth as a function of viscosity of the adhesive mixes (as measure for the different degrees of condensation); the bars represent the standard deviation

For all degrees of condensation the tangential penetration is higher for beech than for fir. However, the increase of viscosity causes the same average decrease of penetration depth in both species. This is the consequence of the different permeability based on the different anatomic structure of the two wood species, which fact also clearly can be seen on the microphotographs taken by epi-fluorescence (Figure 2 and 3).
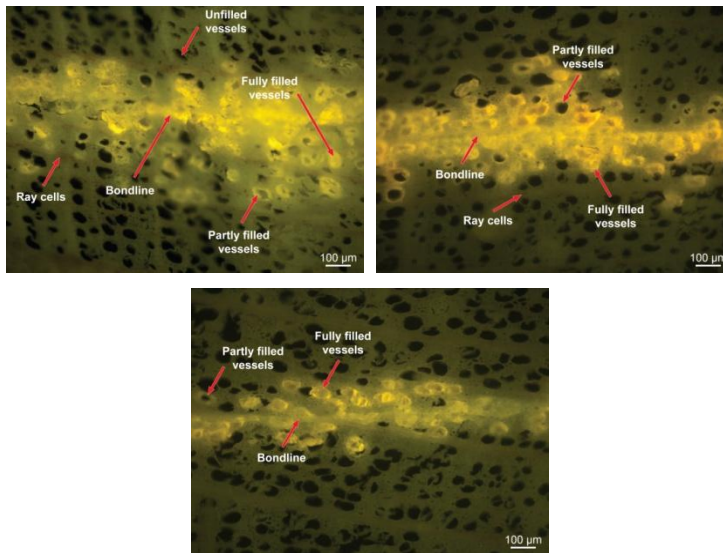
Figure 2. Photomicrographs for the tangential penetration of the three adhesive mixes (with Safranin) into beech, using epi-fluorescence. Left side: UF I; middle: UF II; right side: UF III

Comparing the light coloured sections on both sides of the geometrical bond line it is clearly visible that the UF I adhesive mix penetrates to a greater extent and deeper into the tissue of the two wood species, beech and fir, due to the smaller size of the molecules before the hardening reaction starts.
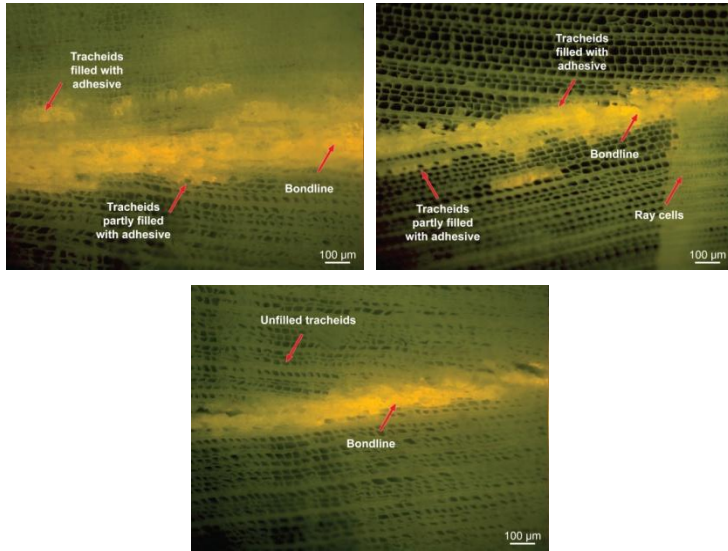
Figure 3. Photomicrographs for the tangential penetration of the three adhesive mixes (with Safranin) into fir, using epi-fluorescence. Left side: UF I; middle: UF II; right side: UF III

The basic elements of the anatomical structure of fir consist of axial tracheids mutually connected by bordered pits, comprising about 93 % of the xylem mass. Thus, the adhesive penetrating into fir tends to fill these transport elements with wide lumens sequentially as they are arranged in the annual ring, passing to the next row mostly after filling the prior one.

In beech the transport elements (vessels) are surrounded by mechanical elements with narrow lumens and lignified walls with small pits. Vessels comprise only about 37 % of the total wood tissue, while the mechanical elements (wood fibres and fiber tracheids) amount to 50 - 70 %. During penetration into beech, the adhesive tends to fill the transport elements with their 3 – 5 times wider lumens and, hence, providing better fluidity as far as possible starting from the bond line; therefore higher penetration depth appears in beech than in fir, because even the tracheids in early wood of fir are smaller than the vessels in late wood in beech.

The main flow path in tangential direction, as in the radial, occurs through pits and rays. Tangential penetration is increased by the fact that there are much more pits on the radial cell walls. Even it was tried to keep the cutting line parallel with the longitudinal axis, still cut cells will occur, where the adhesive can

penetrate some distance in front or behind the level of the photograph and then feign tangential penetration, which in fact is rather longitudinal penetration in a cell or a vessel inclined to the axis perpendicular to the photograph. This just depends from the distance between the open end of the tracheid or the vessel and the position of the microtome slide.

The adhesive mix also penetrates into the mechanical elements of beech; this, however takes places in much lower extent. This can be clearly noticed on photographs (Figure4), taken by confocal laser scanning microscope (CLSM)enabling optical sectioning into 20 µm depth of the microtome specimen.
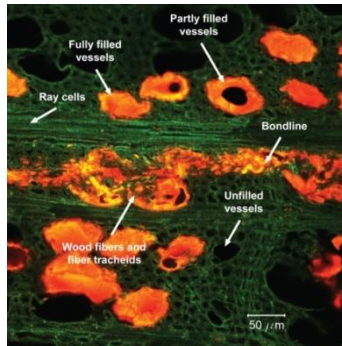
Figure 4. Confocal laser scanning microscopy (CLSM) photograph of UF I (with addition of Safranin) bond line (reddish) showing that adhesive mix also penetrates into the mechanical elements in beech tissue

The average penetration depth (AP) in tangential direction is slightly higher compared to the radial direction for both wood species and with all three applied adhesives (Figure 5); results for radial direction had been already reported earlier [6],[7]. The reason for this might be addressed to the pits located dominantly on the radial walls and, hence, enabling higher penetration of adhesive in tangential direction.
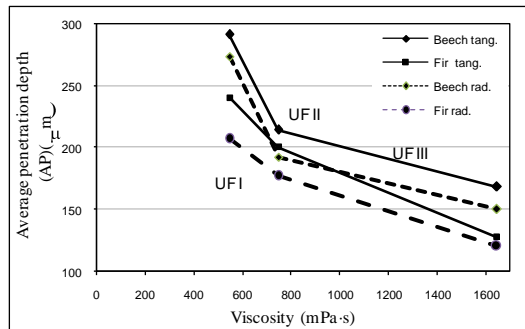
Figure 5. Comparison between tangential and radial penetration for beech and for fir as a function of the viscosity of the three adhesive mixes, representing the different degrees of condensation.

For radial penetration much higher differences between maximal and minimal values of penetration are given than for tangential penetration, even these differences are not always statistically significant; tangential penetration is more uniform concerning the penetration depths.

3.2   Interphase region (IR)

The interphase region (IR) decreases with higher degrees of condensation of the resins (Figure 6). It is directly determined by the maximal penetration depth, showing that there is not much discrepancy between the maximal and the average penetration depth.
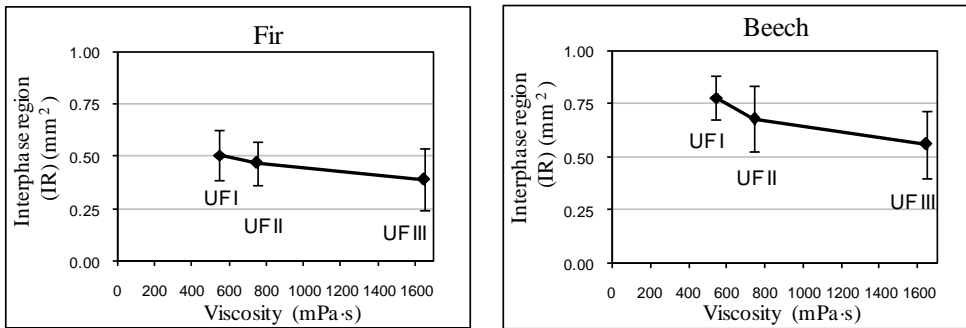
Figure 6. Average size of the interphase region (IR) as a function of the viscosity (different degree of condensation) of the UF adhesive mixes. The bars represent the standard deviation

IR is greater for beech than for fir for all three adhesives mixes applied, which result confirms the greater values for AP for beech compared to fir. Also the difference between highest and lowest value (at the different degrees of condensation) is greater for beech than for fir, due to the anatomical differences in beech and fir. In addition, this influence is more pronounced than for the average penetration depth. The lowest value for beech (for UF III) is still higher than the highest value for fir (for UF I).

3.3 Area of filled lumens and rays (A)

The area of filled lumens and rays describes the penetration of the adhesive mixes into wood tissue and depends on the viscosity (degree of condensation) of the resins in the adhesive mixes, on the wood species, and on the direction of the cutting plane (causing radial or tangential penetration). The evaluation of A is important in the determination of the optimal adhesive loading level for various wood species.

Area A decreases with increasing viscosity; this decrease is more pronounced for beech compared to fir. The values for A are higher for fir compared to beech, and the differences between the values for fir and beech increase with a higher degree of condensation of the resins for the used adhesive mixes (in-

creased viscosity). The highest value for A, hence, is given for fir for the adhesive mix based on the UF resin with the lowest degree of condensation. The reason for this fact is the high porosity of fir (71%) compared to beech (56%), which especially enables the penetration of adhesives with even bigger molecules.

No statistically significant differences are given for the various areas of filled lumens and rays (for a certain adhesive mix) between tangential and radial penetration and for the two wood species.

3.4 Filled interface region (FIR)

The Filled Interface Region FIR is oppositely proportional to the average Adhesive Penetration Depth AP and to the size of the Interphase Region IR. With higher values for AP and IR, FIR decreases at constant adhesive loading levels, as they had been maintained through all experiments.

FIR changes only little with the viscosity (degree of condensation) of the resins. Since FIR is the ratio between A and IR, and since both these values decrease with increasing viscosity (restricted penetration), FIR as ratio between A and IR might not undergo big chances for different adhesive mixes; this also is the case for the measurements reported here. The slight increase (even it is not statistically significant) indicates that, most obviously, lumens and cells more or less close to the bond line are filled up rather than the maximum penetration depth is increased.

FIR for tangential penetration is significantly higher for fir compared to beech. Statistical tests showed significant differences. Due to the higher porosity of fir, the adhesive preferably fills the cell layers close to the bond line.

Comparing the data of tangential penetration and of radial penetration [6], [7] it is evident that for fir FIR is the same in both directions for a given adhesive mix; for beech the tangential penetration is slightly higher for all three adhesive mixes used. This can be explained by the smaller interphase region (IR) for tangential penetration into beech.

4   CONCLUSIONS

As expected, AP, IR, and A decrease with higher viscosities of the adhesive mixes (higher degree of the resins in these mixes), since these values mainly depend on the ratio between the average anatomical diameters of tracheids and vessels on the one side and the average size of the adhesive molecules in liquid state on the other side. IR decreases more strongly than A, which means that predominantly the long penetration paths are restricted due to the higher viscosity; hence, FIR increases slightly.

   AP and IR are higher for beech compared to fir; this means that the adhesive can penetrate easily deeply into the wood tissue of beech. For the case of tangential penetration the influence of early wood and late wood adjacent to the geometrical bond line is less.

5 ACKNOWLEDGEMENTS

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Wood for good – serving the needs of the industry

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1   TIMBER – RENEWABLE NATURAL MATERIAL

- Forests
- Functions
- Sustainability (Forestry Act of 1975)

2   AUSTRIA – FORESTS & PRODUCTS, TRADE

- Statistics
- Forest products industry
- Branches
- Products

3   EDUCATION SYSTEMS , R & D

- Education system & institutions
- R & D institutions

4   SALZBURG UNIVERSITY OF APPLIED SCIENCES, CAMPUS KUCHL

- Forest Products Technology & Management (diploma) 1995 - 2010
- R & D activities
- Partners

5   THE BOLOGNA DECLARATION OF 1998

- Bachelor - Master programs (>2007)

6   OUTLOOK

IUFRO - Highlights of the Organisation

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ABSTRACT

The International Union of Forest Research Organizations (IUFRO) is the global network for forest science cooperation. lt unites 15,000 scientists in 650 Member Organizations in over 110 countries. Currently, IUFRO is a non-profit, non-governmental association based on Austrian law.

IUFRO is the only world-wide international organization devoted to forest research and related sciences and has an unique membership which brings together research organizations, universities and individual scientists, as well as decision-making authorities and other stakeholders with an interest in and focus on forests and trees [1].

IUFRO supports the sustainable management of forests through its network of institutions and individual scientists. IUFRO promotes collaborative research to solve current and potential future problems and it provides technical expertise for the implementation of research results, taking into account, inter alia, the status and appropriateness of current technologies.

Research coordinated by IUFRO is applied in all dimensions of the globally accepted concept of sustainability and as defined in, e.g. "Forest Europe" [2].

Keywords: IUFRO, forest, research, environment, sustainability

1   INTRODUCTION

IUFRO's mission is to promote global cooperation in forest-related research and to enhance the understanding of the ecological, economic and social aspects of forests and trees; as well as to disseminate scientific knowledge to stakeholders and decision-makers and to contribute to forest policy and on-the-ground forest management.

ln the more than 110 years since its establishment lUFRO has developed a culture that involves dedicated voluntary work towards achieving lUFRO's mission.

2   DIVISIONS

The scientific activity of lUFRO is spread over eight permanent divisions, sub-divided in research groups and working parties, as well as a number of task forces that are established for a limited period of time. This thematic structure brings together scientists who have a similar interest but work under different economic, political and environmental conditions. Scientific knowledge is generated, exchanged and disseminated by means of international meetings, collaborative research networking, as well as joint publications and state-of-knowledge reports.

lUFRO's current divisions are: 1 – Silviculture, 2 - Physiology and Genetics, 3 - Forest Operations Engineering and Management, 4 - Forest Assessment, Modelling and Management, 5 - Forest Products, 6 - Social, Economic, Information and Policy Sciences, 7 - Forest Health, 8 - Forest Environment [1].

3   MEETINGS

Approximately every five years IUFRO organizes a world congress with about 2,000 participants. The latest congress was held in Brisbane, Australia in 2005 and the next one will be in Seoul, Korea in 2010. In between the world congresses, meetings are organized by the individual IUFRO research units (i.e. divisions, research groups and working parties, task forces, special programs, projects and chapters) all over the world. All conferences are listed in an on-line calendar on the IUFRO website www.iufro.org.

The Union organizes approx. 70 meetings annually, 20% thereof are held in developing countries. The proceedings are available at the IUFRO secretary and from the organizers of the meeting. The IUFRO world congresses reports and proceedings are sent free to IUFRO members.

IUFRO also organizes interdivisional conferences and world congresses to enable scientists to present research results and to offer a discussion forum to bring about a better understanding of different forms of forestry and research.

4   PARTNERSHIPS

In the field of forestry and forest science several regional and sub-regional networks of individual researchers and institutions have emerged, notably the Asia Pacific Association of Forestry Research Institutions (APAFRI) and the Forestry Research Network of Sub-Saharan Africa (FORNESSA). These networks maintain close cooperation with IUFRO. In Latin America, a strategic cooperation has been initiated with the Tropical Agricultural Research and Higher Education Center (CATIE). In Europe, IUFRO cooperates with, among others, the European Forest Institute (EFI), e.g. in the organization of meetings such as the IUFRO Regional European Conference held in 2002, and with the European Forest Genetic Resources Programme (EUFORGEN) of the International Plant Genetic Resources Institute (IPGRI) [1].

5   INTERNATIONAL SCIENCE-POLICY INTERFACE

In recent years, IUFRO has gradually increased its participation in international forest policy processes and contributed its scientific and technical expertise to the development of forest policies aimed at advancing sustainable forest management at the local, national and international levels. For example, it has provided thematic contributions to the United Nations Forum on Forests (UNFF), the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC). Also IUFRO's long-standing cooperation with the Food and Agriculture Organization of the United Nations (FAO), and its membership in the Collaborative Partnership on Forests (CPF) has significantly facilitated the provision of scientific information and advice for international policy-making and on-the-ground applications.

REFERENCES
[1]   www.iufro.org
[2]   www.fao.org

Innovative production of wood-based lightweight panels

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ABSTRACT

Lightweight boards in the wood-based panel and furniture industry are not a new topic. First trials to reduce the density of PB and MDF boards were mentioned more than one decade ago. Sandwich panels with faces from thick veneer, plywood, thin PB or MDF and cores made from honeycomb paper, very light wood species or foams are also state of the art since at least two decades. The fast growing market of knockdown furniture on the one hand and the increasing costs for energy and raw materials on the other hand are additional factors that make weight saving a primary economical objective for most panel producers. Moreover, customers demand more for ergonomically solutions regarding packaging and transportation.

A new one-stage production process for sandwich panels with wood-based facings made from veneers, wood particles or fibres and a core consisting of expandable particles is presented. It could be integrated in existing continuous pressing lines for PB and MDF manufacturing keeping the advantages of this production technique in matter of efficiency. The manufacturing of lightweight sandwich panels in a continuous one-stage process should combine the production of the dense facings and the very light core layer. During the first stage of the hot pressing process, the mat surfaces are compacted to high densities and the resin cures in this state. In a second stage, the press is opened to the final panel thickness. In this stage, the foam material expands and forms the lightweight core. The core material itself acts also as a bonding matter to the facings. The lightweight panels that were produced at lab scale reveal mechanical prop-

erties that are comparable to recently used wood-based panels while obtaining a weight reduction of 30-50 %.

1   INTRODUCTION

The lightweight wood-based panel industry developed in the last two decades in different ways. The reduction of density for particleboard (PB) and medium density fibreboard (MDF) using light available wood species, increased resination and optimized board density profiles is well proved as an industrial technique. This way allows a reduction by maximum one third of the initial density and keeps the main properties like internal bond (IB) and bending strength (MOR) in an acceptable range. The production costs could be a problem for manufacturers not having available light species or no facilities to produce their own resin, because of their increased resination. The costs for material make up for more than 50 % of the total manufacturing costs. The new generation of light panels (especially >19 mm) reaches densities of 500 kg/m³ for MDF and 450 kg/m³ for PB but their fields of application became limited [2].

Despite the booming development of MDF in the last two decades and its excellent properties and processability, PB continues to keep in first place in terms of market shares in the world (36%) and in Europe (61%) [4]. Main advantages of PB compared to MDF or plywood that can explain this situation are the possibility to use 100% recycled wood, to produce low weight panels at a low price. In some regions the processing and finishing technologies, which are limited only to PB might also be a reason for its supremacy. The European furniture industry is processing 54 % of PB (38 mill. m³) and 55 % of the MDF (13 mill. m³) production. The high densities of these panels cause high end product weights. Especially the fast-growing market for knockdown furniture demands low weight furniture [3]. New considerations imposed by take-away furniture chains limited the package weight in order to meet dimensions that match the ergonomic abilities for the end-users. Heavy pieces of furniture have to be split into more than one package. A maximum weight of 25 kg per unit seems tolerable in this context [11]. However, by decreasing the weight of the individual pieces of furniture, handling can be also simplified once the product is assembled. This reduces the risk of damages and extends the service life of the product [6].

In the early 20th century, the weight of pieces of furniture decreased significantly. The reason was not the demand for lightweight materials but rather the shortage of wood after World War II. With the apparition and use of PB and MDF, the weight of furniture increased. Only in the recent years, lightweight design has become its own, independent subject that aims at improving functionality, reducing cost and ecological impact [14].

2   OBJECTIVES

As the production of lightweight panels is more elaborate and raw material costs like foams or expandable materials are often higher compared to most standard boards. The advantage of lightness is counterbalanced by the increased prices for the final panel [8] and [9]. If production processes become more efficient by innovative solutions up to 30 % of the produced thicker wood-based panels (> 20 mm) could be substituted by lightweight panels [6]. The recent decrease of classical board prices (especially PB and MDF) is still an impediment for a short-term market implementation of the modern lightweight boards independent of their performances.

Some furniture design developments of the last three decades like thin elements, straight surfaces, local joints and the use of melamine or veneer-coated surfaces allow and request again the use of lightweight wood-based panels. The established technology for producing honeycomb sandwiches with timber frames and thin faces was optimized and reused recently to reduce weight by up to 50%. Some shortcomings of the honeycomb sandwiches still are limitations for the market success: sizes, fix frame position in the panel, low resistance to parallel loads and low price performance for thin boards (<24 mm) [11] and [13].

However, classical wood-based panels like PB with partially reduced weight (>450 kg/m³) represent a strong competitor in terms of volumes and low prices. Some lightweight sandwich panel producers using classical discontinuous processes could not penetrate all possible application fields because of this situation [12].

Different techniques to save weight in wood-based panels show individual downsides. Either the production of lightweight panels is too laborious, which in many cases means too costly, or the mechanical and physical performances of the panels are significantly decreased. With a growing number of benefits that lightweight panels are supposed to deliver, i.e. decreasing weight and material costs and an increasing flexibility, the challenges increase. Lightweight panels with large cells in the core request very sophisticated solutions concerning fittings, edge processing and –lamination. One solution is the use of sandwich panels with a foam core. As cell sizes of the foam material are very small compared to tubes or honeycombs, problems with the heterogeneity of the core, like edge-processing or "telegraphing" effect on the surface are negligible. Moreover, foam cores often introduce thermal insulation properties. However, the material input increases constantly with increasing thickness of the boards, while the use of thicker honeycomb panels introduces growing empty spaces in the panel, which decreases the relative costs. This is one reason why honeycomb panels become cost effective in thicknesses greater than 24 mm [12]. For standard thicknesses from 15 to 19 mm, foam core panels can present a competitive alternative.

This paper describes recent techniques and presents a new technique for the production of foam core panels with wood-based facings. Additionally, some characteristics of panels produced at lab scale are presented.

3   RECENT PRODUCTION TECHNIQUES

A sandwich panel generally comprises of three layers. The core, a comparative-ly thick layer, separates two thin surface layers, or facings. The main function of the core is to keep the facings at a certain distance. The core only bears lower shear stresses and thus can be very light [1]. The compression and tension stresses are highest in the facings, thus the facing structure has to be very strong. This provides very good static properties with respect to weight.

Two recent ways of producing lightweight sandwich panels are described. Dis-continuous production techniques use pre-expanded foams for the core and thin boards or foils for the facings. The core material is usually foamed and then sliced from a block. The slices are glued on prefabricated and coated thin panels like thick veneers, thin PB, plywood or MDF. In consequence, three individual steps are necessary to produce a foam-core sandwich panel. By using this tech-nique, however, it is possible to use wood fibres based facings, because prefa-bricated wood-based facings cannot be further processed in a continuous man-ner as of their fixed dimensions [5]. The high production costs caused by the discontinuous batch process and limited sizes are counterbalancing the impor-tant weight reduction that is possible using this technique.

Continuous processes are used when it comes to materials that can be fed into a processing unit in a virtually endless manner, like from a coil. Compared to the discontinuous process, this technique uses less individual steps for the assembly of sandwich panels. Here, only prefabricated facings like foils or impregnated papers are used, while the core is in most cases foamed between the facing dur-ing the production process. Due to the adhesion properties of the foam - usually PU-foams are used - no additional gluing layer is needed. This technique is preferable not only from an economic point of view, because the output is high-er and the input of labor and material is less. In addition, quality aspects reveal that a continuous manufacture generates more stable panel conditions and more diverse sizes (Fig. 1).
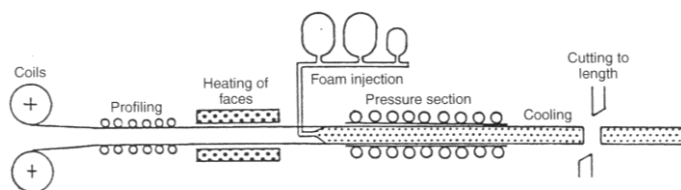

Figure. 1. Principle of a continuous foam core panel production [5]

4   NOVEL FOAM CORE PANEL PROCESS

Recently, the authors reported about a novel approach for the continuous pro-duction of foam core sandwich panels with wood-based facings [9]. In this ap-proach, the manufacture of the facings and the core takes place during the con-

tinuous hot pressing of the sandwich panel. The approach is derived from the conventional production technique of wood-based panels (PB and MDF) and was designed with a continuous production in mind although not limited to.

Figure 2a shows the principle of a conventional PB process. A three-layered mat composed of resinated wood particles, coarse particles in the core and fine particles in the surface layers, is formed using three individual forming heads. The mat is then pressed in a continuous hot-press. In comparison Fig. 2b shows the novel foam core process. A three-layered mat is formed consisting of two resinated yet not compacted face layers and one unexpanded core layer. The face layers comprise of resinated wood fibres or particles. The core layer is composed of a dry expandable thermoplastic material, which is triggered by temperature. After the compaction of the facings, the temperature in the core initiates an expansion.

Shortly after, the press is opened to the desired panel thickness. After a consolidation phase, the panel is ready for cut-to-sizing.
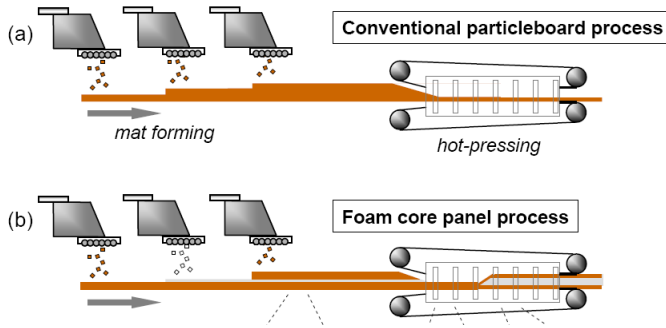
Figure 2. Principle of the one-stage process, (a) conventional particleboard process (b) foam core panel process [13]

5   LIGHT WEIGHT SANDWICH PANELS PROPERTIES

Sandwich panels were produced at lab scale according to the new continuous production technique with a target thickness of 19 mm. The surface layer was made from UF resinated softwood particles used in the PB industry. The manufacture of the samples was done on an 800x600 mm² lab hot-press following the process described above. The surface thicknesses of the panels were varied in three steps between 3 and 5 mm. During the trials, the amount of foam material in the core was unchanged. The UF resin content in the surfaces was set to 12 % (solid) for all sandwich panels. The tested properties were bending strength (MOR) according to EN 310 and internal bond (IB) according to EN 319.

Figure 3 shows a cross-sectional density profile of a 19 mm thick sandwich panel with 4 mm facings and an 11 mm core layer. The average panel density is 380 kg/m³. The facings density is up to 880 kg/m³, while the core shows an average density of 160 kg/m³. The graph shows that the cross-sectional profile

of the panels is highly symmetrical. Other variations with 3 mm and 5 mm thick facings hold average densities of 310 and 510 kg/m³, respectively. The same applies for the thickness of the core.
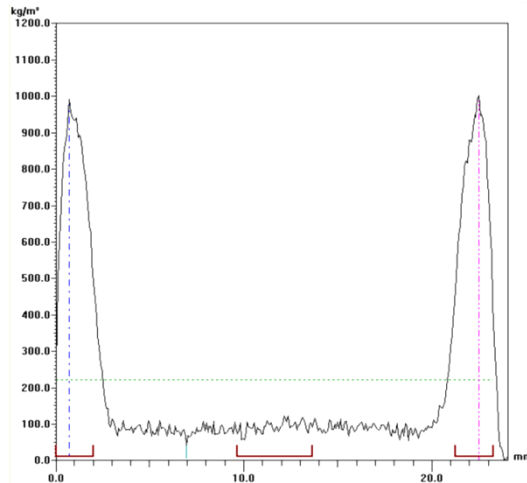
Figure 3. Density profile of a sandwich panel with wood-based facings [7]

The overall density can be adjusted from 200 to 600 kg/m³. This is possible since the thickness of the facings can be as low as 0,5 mm while there is no technical upper limit.

Figure 4 shows the development of MOR and IB with increasing facing thickness. Due to the increasing planking effect of the surface layers, the MOR increases significantly with facing thickness. The average MOR for 3 mm surface layers reaches 6,5 N/mm², for 4 mm surfaces 7,7 N/mm² and for 5 mm surfaces 12 N/mm². The higher compaction of the foam with thicker facings resulted in a more shear resistant core. The crack formation changed correspondingly from shear failure to face yield in the lower facing. The IB test revealed a similar trend. Thicker facings resulted in superior internal bond values as 0,17 N/mm² for 3 mm facings, 0,21 N/mm² for 4 mm and 0,28 N/mm² for 5 mm surfaces, respectively. All samples failed at the interface between the wood particle facing and the foam core.
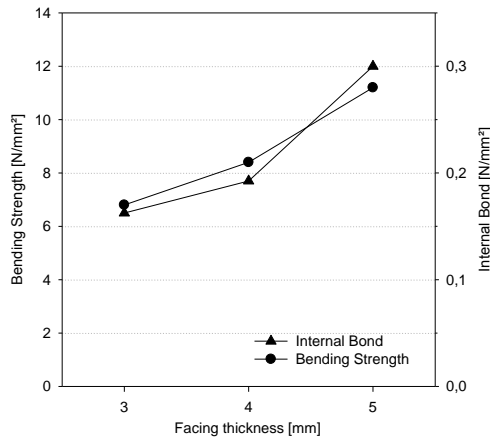
Figure 4. Development of bending strength and internal bond strength with increasing surface thickness [7]

6   CONCLUSIONS AND OUTLOOK

The growing demand for lightweight panels is met by the wood-based panel industry with the development of different weight saving opportunities. One way of saving weight is the reduction of raw material and adjusted gluing systems (also increased resination); another way is the breakup of the structure. Lightweight design as its own discipline contributes several concepts in this context, like the structural advantages of sandwich layouts. The new one-stage process improves the efficiency and can be used to produce light sandwich panels with wood-based facings continuously. The mechanical properties of the panels are, with respect to weight, comparable to classical wood-based panels. The panel composition can be varied in wide ranges. At the same time, the panels are not depending on a frame construction. Against the background of a growing freedom in design for furniture manufacturers and the need for efficient production techniques, this development does seem to be an alternative for recently used production techniques.

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121

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Thermo-Hydro-Mechanical behavior of wood and Processing, Cost Action FP0904

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ABSTRACT

The polymeric components of wood and its porous structure make it possible to seek new technological processes for wood transformation without changing its ecological character. These techniques are generally called Thermo-Hydro-Mechanical (THM) treatments. THM treatments can improve the intrinsic properties of wood, produce new materials and acquire a form and functionality desired by engineers. There are numerous THM processing techniques which can be divided into two major categories; Thermo-Hydrous treatments (TH) and Thermo-Hydro-Mechanical (THM) treatments.

During TH/THM treatments some unwanted effects on strength of the wood, its brittleness, the ageing kinetics, the dispersion of the mechanical properties and shape-memory can happen. Better understanding of wood chemico-mechanical behavior needs knowledge exchange on processing and wood characterization during treatments. The main objective of this paper is to report briefly the current state of knowledge on the wood TH/THM treatments and the role of new COST Action FP0904 "Thermo-Hydro-Mechanical wood behavior and processing" in knowledge transferring and experiences among the R&D and the industry through European COST networking of nationally funded research activities.

1   INTRODUCTION

One of the emerging eco-friendly methods in wood modification is the application of combined heat, moisture and mechanical action-so-called Thermo-Hydro-Mechanical treatments.THM processing can improve the intrinsic properties of wood, produce new material and give desired form and functionality without changing the wood eco-friendly characteristics. Recently, several THM processing techniques have been developing which can be divided into two categories; Thermo-Hydrous treatments and THM treatments. These treatments can be made in close or open system. Some of these treatments are given in Table 1.

TH treatments are implemented to enhance some of the wood properties, stress relaxation during forming of wood based composites, veneer production, wood

cutting, wood artificial ageing and improving wood fracture resistance. THM on the other hand, is employed in the producing of new materials by densification, forming by molding, welding of wood by friction, embossment, bending of wood, wood folding and chip-less manufacturing. During THM treatment wood undergoes large deformation, stress relaxation and chemical degradation as well shape memory. Several TH and THM processes have recently been developed in Europe, Japan, the USA and Canada, but only some of them have been scaled–up until industrial production.

Table 1. Wood Modification by Thermo-Hydro-Mechanical treatments

(**TH**)	(**THM**)
- Reduction of wood hygroscopicity. -Improvement of resistance to decay - Relaxation of wood internal stresses -Producing accelerated aged wood - Drying of wood by high temperature	-Wood densification (open/closed system) -Wood molding -Wood surface densification -Embossment -Wood friction welding -Wood folding -Chip-less Manufacturing

To overcome the problems associated with TH/THM wood processing at the laboratory scale, during scale-up and controlling the end use properties, a detailed knowledge on wood behavior (large deformation, chemical degradation, mass and heat transfer) becomes important, which requires a close collaboration between experts in wood chemistry, wood mechanics and material sciences from both academia and from industry.

2 BACKGROUND AND STATE OF RESEACH IN THE FIELD

Following, a brief description of the current state of art on the wood densification, wood TH treatments and wood friction welding is given.

2.1 Wood densification

In 1886 the idea of densification of massive wood by applying compression force existed, [1]. By 1922, the Pflumes brothers in Austria had developed a method for densification of wood through its impregnation with rubber. This type of densified wood was used in the aviation industry until 1945. Initially, the main aim of wood densification was to improve the mechanical behaviour of wood by eliminating its porosity. In spite of the modification of material proper-

ties however, densified wood showed an undesirable behaviour called "shape memory" or "compression-set recovery". To eliminate this phenomenon,[2] developed a process of impregnating of densified wood with a phenol formaldehyde resin. This was industrialized under the name of "Compreg wood". The fabrication of Compreg wood is still carried out on an industrial scale. Eliminating the shape memory of densified wood partially was achieved through the use of thermo-hydrous treatments by [3]. Thin plates of birch were densified under different moisture contents at 180°C for various heating times. They showed that their shape memory is correlated with the heating time. Emanating from these findings, a product presenting very small set-recovery called "Staypak", was developed.

Recently, [4] adapted the same process as [3] to eliminate the shape memory of densified wood. Advanced investigations of the densified wood treatments by THM processing have been reported by [5] and [6]. These studies have shown that the THM post-treatment of densified thin wood at 200°C for only 4 minutes is sufficient to totally eliminate the shape memory.

The primary goal of recent research on wood densification techniques as well as the development of new techniques in THM post-treatments is to extend them to elements of large dimensions. In Japan closed systems for studying transversal densifications of elements with large dimensions were constructed with four distinct processing stages: (1) wood plasticization by high temperature steam, (2) compressive moulding (two-directional shaping), (3) THM post- treatment, (4) cooling and drying.

Two technical procedures have emerged from these studies. In the one developed by [5], small trunks of wood with round sections are transformed into trunks with square section. The second process is designed to obtain structural timber of high quality from wood with weak density. Their results show that the problems like cracks and exfoliation which are produced during densification process have not yet been solved in practice. These problems are originally related to scale-up (size-effects). They have suggested that the acquisition of more fundamental knowledge on wood THM behaviour is necessary to overcome the issues that currently stand in the way of developing a new manufacturing system for "compressive moulding of wood under high-pressure steam techniques".

Since the 1990s, various investigations and research works have been initiated in Europe, in the United States and most recently in Canada. on the molding, densification and THM post- treatments of wood. For example in Denmark, a machine was developed for pre-compression of wood in the longitudinal direction. In Germany, a system for wood heat treatment was developed using oil with high temperature (OHT). In this system, oil is used as a medium which can be heated above 200°C. An application of this system was used by [7] for eliminating compression-set recovery of large, industrial-scaled densified woods. The resulting product has also shown improved resistance of TH wood against micro-organism, which allows the product to be used for outdoor services.

In the USA commercial interest in the harvesting of fast grown wood with innate low density, has driven the wood-research community to investigate possible opportunities for employing densified wood in construction of composite materials [8]. Numerical simulation of wood-molding processing is complex and is currently at an early stage of development. Only a few elementary works are published in the literature like [9] and [10].

The primary focus of current research in the field of wood-molding, wood- densification as well as in THM post- treatments is to broadening their application to large-size wood elements for structural application in the construction industry.

2.2 Thermo-Hydrous wood treatments

Heat treatment of wood is a wood modification technique since during the treatment wood constituents undergo chemical changes. The reason for heat-treatment is the enlarged demand for environmentally friendly high-durability wood. During the 1980s, French and Japanese industries began to heat-treat wood in closed system in order to increase the microbial durability. Since then, the interest for heat-treatment has increased all over the world. The process essentially involves a controlled degradation of wood, primarily resulting in the destruction of hemicelluloses. The heat-treatment of wood includes several different methods. In most cases, it involves temperatures between 180 and 240°C. The high temperature is achieved with overheated steam, in vacuum, or with an inert gas, for example nitrogen. Also, pre-heated oil can be used in the process. A simplified picture of the results of the heat treatment methods is 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.

Industrial heat treatment processes typically aim on improving the biological durability of less durable wood species and furthermore on enhancing the dimensional stability of wood or wood based products, e.g. particle boards. The properties of industrial produced heat treated wood in general were intensively investigated in the recent past.

On the European market several industrial heat treatment processes have been introduced during the last few years. The common processes are:

The Thermowood process, the Plato wood process, Retification process, le Bois Perdure and OHT-process (oil-heat treatment).

The basic diversity of the different processes is indicated by their oxygen-excluding and heat-transporting media: steam is used by the Thermowood process, the Plato process uses liquid water in a first step followed by a conditioning phase, nitrogen gas is used by the Retification process and rapeseed oil by the OHT-process. However, a substantial similarity in treatment conditions is that these processes run in a temperature range between 180 and 240°C to change the chemical composition of the cell wall. Due to severe degradation of

the strength, TH treatments of wood at elevated temperatures above 300 °C are limited, [11].

Modified heat treatment processes are also emerging in Denmark; the WTT process working at 160–180°C and in Austria; the Huber holz process working at 170–230°C. Both processes have heated steam as heat-transporting medium.

2.3 Wood friction welding

The idea of joining wood pieces by means of pressure and frictional heat is very recent. In 2002 the first attempt for wood welding by linear oscillatory movement was carried out in Switzerland at BFH in cooperation with University of Nancy (France). Since then many works have been carried out in both universities and in the Swiss Federal Institute of Technology-Lausanne. Some of the research results on the topic can be found in [12] and the others. The majority of the welded wood by friction is Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) and mostly the work has been carried out on small samples about 150x20x15 mm^3. The samples were welded on the surface of 20x15 mm^2. Experimental results have shown that the maximum average tensile strength obtained was about 10 MPa for beech and 2 MPa for Norway spruce samples. Currently, in Switzerland at BFH a multilayered of poplar was fabricated by linear friction welding, where dimension of each lamella is 160x4x2 cm3 with a welded surface of 160x4 cm^2.In this method the temperature and wood moisture content are not controlled as in wood treatment by the closed system. In this technique the temperature of wood between the welded surfaces may rise to more than 400°C during welding causing locally wood chemical degradations. The welding processing time is short – about 10-20 seconds. Current investigation into the interfacial strength of welded wood connections shows that the strength achieved by this method is inferior to that obtained by using conventional glues, and the strength of friction welded joints decreases at high humidity. These techniques have attracted industrial interest.

3   CONCLUSION

There is a need to better understand the processing needed, allowing treatments to meet product needs. Altering the way in which wood is treated is known to dramatically alter the way it performs. During the treatments some unwanted effects can happen. Examples of unwanted effects are strength loss of the wood during treatment particularly in the transverse direction, embrittlement, rapid ageing and high dispersion of the mechanical properties. Establishing a greater understanding through knowledge exchange will allow effective processing of wood. This is particularly the case in transferring knowledge and experience from the R&D sector to the industrial sector. Considering the key aspects of the scientific problems encountered in the THM-closed system and THM-open system leads to three principal research areas which will be coordinated in the COST Action FP0904 through 3 Working-Groups:

WG1: Chemical degradation of wood under TH treatments and its effects

WG2: Modelling and characterization of THM behaviour of wood during treatment

WG3: New Products by THM-open system and internal stress relaxation

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Characterization and potential recycling of home building wood waste

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ABSTRACT

Construction waste represents a significant portion of landfill waste, estimated as 17% of the total waste stream. Wood construction waste of a 2000 square foot single family home we found to be 1500-3700 lbs of solid-sawn wood, and 1000-1800 lbs of engineered wood products (EWP). Much of the solid-sawn lumber and EWPs could be recycled into several products. Through a partnership with an EarthCraft House (A "Green" housing system) certified builder, the authors have determined the wood construction waste generated for recently built houses at a new green housing development. The purpose of this study is to quantify the construction waste and explore options for the reuse or recycling of these wood products. The EarthCraft House certification system rewards these activities and discourages landfilling. Wood products studied included solid-sawn lumber, oriented strand board, particleboard, LVL, and preservative treated wood. We will present the results from 6 houses including solid and grinding recycling options. We will mention some other national certification systems such as LEED for Homes and the NHBA system.

1   INTRODUCTION

Construction waste from home building represents a significant portion of landfill waste in both Construction and Demolition Landfills (C&D) and in Municipal Solid Waste Landfills (MSW). The waste can be 17% of the waste stream. Wood construction waste of a 2000 square foot single family home from our research can be 1500-3700 lbs of solid-sawn wood, and 1000-1800 lbs of engineered wood products (EWP). This is extremely wasteful and not good for the environment. It needs to be addressed with practical solutions.

We have a history of working together to reduce wood waste and increase wood reuse and/or recycling. Our R&D team includes the US Forest Service wood utilization research project in Blacksburg, VA and faculty in the Department of Wood Science and Forest Products at Virginia Tech also in Blacksburg, VA.

129

For this effort, we worked with a local home building company to evaluate their wood construction waste and develop and recommend recycling options to keep wood waste materials out of landfills. We had previously successfully worked on wooden pallet recovery, repair, reuse, and recycling R&D for over 20 years. We have also completed R&D on the recovery, reuse, and recycling of used preservative treated wood from demolished outdoor decks.

We entered into a partnership with the EarthCraft House (A "Green" housing system) certified builder, to determined the wood construction waste generated for each house at their new green housing development. The builder is using advanced wood and engineered wood products and systems as well as advanced energy systems. The purpose of this phase of our study was to quantify the construction waste and explore options for the reuse and/or recycling of these wood products. A second phase will be to analyses the construction processes, and resulting waste and work with the builder to reduce his overall wood waste for future homes.

2   WHAT IS "GREEN" BUILDING

Green building is the practice of increasing the efficiency with which buildings use resources (energy, water, and materials) while reducing building impacts on human health and the environment during the building's lifecycle, through better siting, design, construction, operation, maintenance, and removal. Waste material recycling is a preferred and rewarded practice in green building (you get points for doing it).

3   WHAT IS EARTHCRAFT HOUSE?

EarthCraft House is a residential green building certification program that serves as a blueprint for energy- and resource-efficient homes. The EarthCraft House certification system rewards energy- and resource-efficient homes and recycling activities while discouraging landfilling of waste. EarthCraft House is considered a regional program and can be compared to national programs such as LEED for Homes by the US Green Building Council (USGBC) and the National Green Building Standard by the National Association of Home Builders Green Program (NAHB Green). EarthCraft House was developed by the Atlanta Home Builders Association and the Southface Energy Institute in Atlanta, Georgia.

To be certified in Virginia, the building has to complete training from EarthCraft Virginia. Next they must plan and build a home to meet the minimum requirements for an EarthCraft House with oversight and inspections by an EarthCraft Technical Advisor. This would include a pre-drywall inspection and a finished house inspection to include home and heating and cooling system tightness inspections. There are three possible levels of certification. The building expenses go up as the certification level goes up.

4   STUDY OVERVIEW

With an EarthCraft House certified developer in Blacksburg, VA, we are quantifying the amount of OSB, treated lumber, and spruce (spruce/pine/fir) dimension lumber waste during home construction and determining potential uses for discarded material as an alternative to landfilling. As the homes are being built, we are collecting the wood waste and storing it in a used container were we can collect separately the waste for three homes. After the three homes are finished, we move the trailer to our laboratory setting and analyze and in some cases process the waste. We take another trailer to the housing site to continue to collect more waste from other homes.

5   WOOD WASTE RESULTS

Initial results are presented in Table 1 for the first 6 homes in the development. Figure 1 shows the house on Lot #47 during construction and the waste by major wood products used. To help normalize the results waste per square foot of building construction is presented in Table 1. The spruce lumber and OSB pounds per square foot results are very variable. Spruce lumber has a range of .58 to 1.98 pounds of waste per square foot of living space in the homes. OSB has a range of .5 to .9 pounds of waste per square foot of living space. Preservative treated wood waste ranged from .03 to .29 pounds per square foot.

From a little over a 2000 sq. ft. house
Total wood waste – 5,059 lbs.

- OSB waste – 1,419 lbs.
- Treated wood waste – 417 lbs.
- Spruce structural lumber waste – 3,134 lbs.
- LVL – 64 lbs.
- Paralam – 25 lbs.

Figure 1 Example of the amount of wood waste generated from new home construction on Lot #47

The treated wood range of waste values can be explained by the size of the decks and needed stairs by house. Some homes needed far less wood to build the stairs and deck. The treated wood was also used for sill plates, but normal waste for sill plates is low.

The range of waste for OSB and spruce is more complicated. The biggest factor other than the fact that the homes being built were new designs for the builder was the fact that different framing subcontractors were used for some of the homes. The builder had could not control much of the waste. Repeat building of a house and precutting in a central area could help reduce the waste per square foot of living space.

Table 1. Weights of spruce, OSB, and treated wood waste material from the first six homes

Lot #	living space (Sq. Feet)	Spruce Weight (lbs)	Spruce (lbs/sq. ft.)	OSB Weight (lbs)	OSB (lbs/sq. ft.)	Treated Wood (lbs)	Treated Wood (lbs/sq. ft.)
1	2,634	3,100	1.18	2,380	0.90	214	0.08
34	2,634	1,540	0.58	2,287	0.87	71	0.03
41B	1,936	2,770	1.43	1,685	0.87	375	0.19
43	1,685	1,985	1.18	1,048	0.62	496	0.29
47	2,036	3,134	1.54	1,419	0.70	417	0.20
48	1,840	3,641	1.98	915	0.50	392	0.21

6   RECYCLING OPTIONS

The two major recycling options are to make solid-wood and fiber products as shown in Figure 2. Solid-wood products range from converting waste OSB (structural plywood substitute) into shelving, pallet parts, treads for stairs, and many other uses. The waste structural and treated wood can be finger jointed for reuse in other home building or to make finger jointing molding products. We used a minimum length when determining if the structural lumber waste could be finger jointed. The remaining waste would be sent to a grinder to be reduced to fiber.

The second option is to grind the waste with horizontal or tub grinders to various forms of mulch. The mulch can be used to control erosion at the building sites and then mixed with the soil after the home is completed. The mulch could also be used for temporary driveways and walkways during construction to reduce mud transfer into the home under construction. The mulch could also be sold as bioenergy or animal bedding.

Most of the shelving that we produced from the waste OSB as shown in Figure 2 was donated to a local Habitat for Humanity store. They sold the pieces for $.50 each to help raise funds to build homes for underprivileged families.
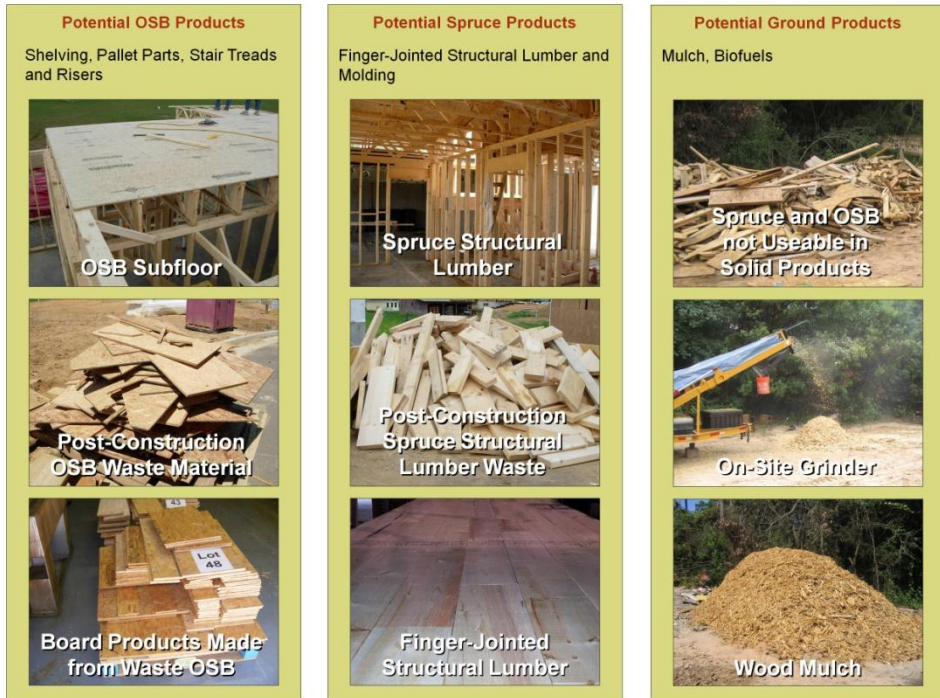
Figure 2. Wood products and wood waste generated from new home construction and some recycling options

7 RECYCLING RESULTS

The two major Initial results indicate that 50-60% of the OSB waste material (Figure 3) as well as 35-50% of the treated lumber waste can be recycled into solid useable products (This project is in the second year of a five year project and much more recovery, reuse, and recycling data will be generated). The spruce lumber pieces were on average much shorter and we estimates that only 8-18% could be finger jointed for solid useable products. If other potential products of different sizes and shapes are developed, the recovery yield could increase significantly. The remaining materials (OSB and lumber) can be processed for biofuels and mulch.
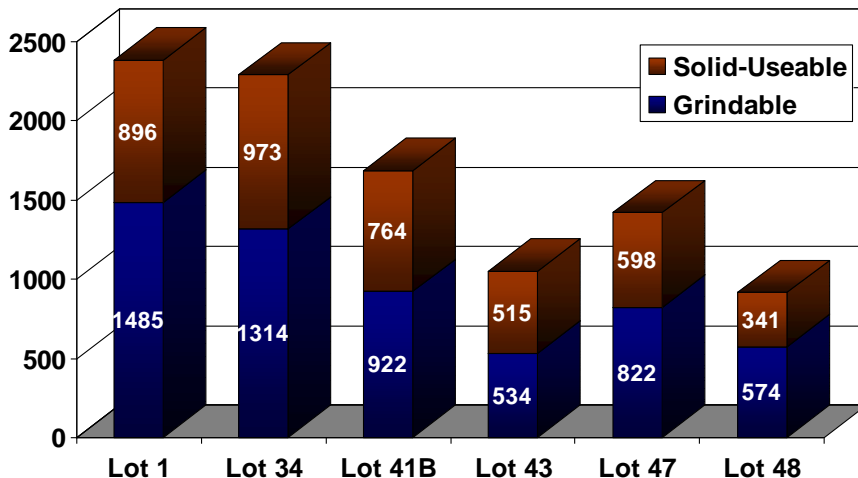
Figure 3. Weights of solid useable and grindable OSB material from new home construction

8   SUMMARY AND CONCLUSION

Wood construction waste from home building can be a major burden on landfills in the United States. To discourage this practice "Green" building systems are rewarding builders that recycling wood construction waste. To aid in this practice we have been working with a "Green" builder (EarthCraft House) to quantify the construction waste and explore options for the reuse or recycling of these wood products. Wood products studied included solid-sawn lumber, oriented strand board, particleboard, LVL, and preservative treated wood.

We presented the waste results from the first 6 houses and solid and grinding recycling options for the waste materials. The wood construction waste of a 2000 square foot single family home was found to be 1500-3700 lbs of solid-sawn wood, and 1000-1800 lbs of engineered wood products (EWP). Oriented strand board was the major engineered wood product used in the home building. Wood waste ranged vastly from house to house due to different subcontractors, house design and that fact that these were not repeat building of a home design.

Solid and fiber recycling options were presented. The materials can be used and not landfilled. We recommend a central recycling facility and a central cutting facility together to reduce waste and to process the construction waste. We plan to start working with the builder on the next step of reducing the construction waste.

Extraction of nutrients from biomass ashes with varying extraction times

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ABSTRACT

During the incineration of biomass (e.g. wood) the organic material is decomposed whereas the inorganic components remain as ashes. The coarse fraction of the ash remains at the bottom of the furnace (bottom ash) and the fine fraction is collected from the flue gas (fly ash). Both ashes contain valuable plant nutrients like N, P, K, Ca, Mg, S, and other trace elements. Therefore these ashes can be used as a kind of fertilizing agents for soil. The plant availability of the nutritive components (which are absorbed in form of ions) depends on their solubility at the environmental conditions in the soil.

In this study bottom ash and fly ash from an Upper Austrian biomass incineration plant has been used to investigate the leaching behaviour of the contained nutritive components. Leaching experiments were performed in a sequential extraction procedure starting with distilled water and followed by salt-solutions (ammonium acetate solutions) at different pH values simulating different environmental soil conditions. Also the length of the leaching period was varied from eight to forty eight hours (namely 8, 16 and 48 hours) in order to optimize the extraction time. All leachates were analyzed by ion chromatography (IC).

For the calculation of the leached amount of components, all investigated biomass ashes were analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES) after a microwave digestion with HNO_3 and HCl.

The experiments showed that high portions of plant relevant components were already dissolved in the first leaching step with deionized water, especially K^+, Ca^{2+}, Cl^-, SO_4^{2-} and also NO_3^-.

Increasing the leaching time did not significantly influence the results. Therefore shorter extraction procedures can be used for the determination of nutritive components in biomass ashes.

Compared to distilled water salt solutions released more Ca^{2+} and Cl^- but less K^+ and SO_4^{2-}.

From the performed experiments it can be summarised that the nutritive components contained in biomass ashes are quite soluble and biomass ashes can therefore be used to reduce the necessary amount of synthetic fertilizers.

1 INTRODUCTION

By incineration of biomass (e.g. wood chips) organic material gets decomposed. The remains after the incineration process are ashes (inorganic residues). The ashes consist of e.g. Ca^{2+}, K^+, NO_3^- and PO_4^{3-} which are valuable plant-components. Therefore these ashes are interesting for the use as fertilizing agents for soils. On the other hand, biomass ashes also contain heavy metals (e.g. Cd and As). As many heavy metals are harmful for the environment, animals and men, the entry of these elements must not be above certain concentrations limited by laws. Table 1 gives an overview of the limit concentrations of heavy metals in biomass ashes when being used on grasslands or on fields in Austria. [1]

Table 1. Relevant limit values [mg/kg] for heavy metals [1]

elements	limits	elements	Limits
Zn	1,500	Ni	100
Cu	250	As	20
Cr	250	Mo	20
Pb	100	Cd	8
Co	100		

It is also very important that heavy metals from ashes are not set free through humidity. In general mobility and bioavailability of metals and the related eco-toxicity to plants strongly depend on their specific chemical forms (exchangeable, carbonate bound) or binding. [2] Exchangeable forms are bioavailable and mobile, organic forms are fixed and immobile. [5] Also the pH plays an important role [5] for migration (e.g. chromium can be migrated from ash to water at pH 5 to 7. [4]).

Nutrients, however, should be easily dissolvable through water and slightly salty solutions (rain water).

In order to determine the plant-available amounts of leachable ash components, conditions close to real environmental conditions can be investigated by extraction experiments with distilled water or salt solutions. In the same way also the leachable fractions of the heavy metals can be determined. Extraction procedures for soils are very common procedures and well described in literature. But still it is in discussion which extraction procedure describes best natural conditions – regarding the extraction time, the extraction media (e.g. which salts in which concentrations) and the relationship of solid material to the leaching agent.

Only few extraction procedures are reported for biomass ashes. One example is an investigation of Hansen et al who investigated the mobility of Cd in fly ashes from biomass incineration using wood and straw as input materials. They found that only very small amounts of cadmium could be mobilized and washed out with mild extractants. [3]

In the present study the mobility of metals and of ions important for plant growth as well as of the heavy metals listed in the Austrian recommendation for the use of biomass ashes on fields and grassland [1] has been investigated.

2 EXPERIMENTAL

The extraction procedure described by Peijnenburg et al [5] was taken for the investigation of plant-available components for this work. Peijnenburg et al used a six step extraction procedure – for the present investigation the focus lay on the first three extraction steps (see Table 2) as they represent best natural environmental conditions. The extraction times in the original procedure was in the first three steps always 16 hours – in this work different extraction times (8, 16 and 48 hours respectively) were tested. The objective was to find optimal extraction times – just long enough for representative results.

Table 2. Extraction procedure [3] showing the first three extraction steps

Step	Extraction procedure	Speciation
1	4.0 g dried biomass ash + 40 ml deionized water shaking for 8,16 or 48 h at room-temperature	water soluble components
2	+ 40 ml 1 M NaAc (pH 8) shaking for 8,16 or 48 h at room-temperature	exchangeable components
3	+ 40 ml 1 M NaAc (pH 5 with HAc) shaking for 8,16 or 48 h at room-temperature	components associated to carbonates

Therefore to the ashes from biomass incineration distilled water or salt-solutions at different pH-values were added as extraction media and then shaken according to the described extraction procedure.

Then all leachates were analyzed with ion chromatography (IC) and inductively coupled plasma optical emission spectroscopy (ICP-OES).

Also, the biomass ashes itself have been analyzed after a microwave digestion with HNO_3 and HCl.

3   RESULTS

Figure 1 shows the results for 8, 16 and 48 hours extraction time with deionised water.
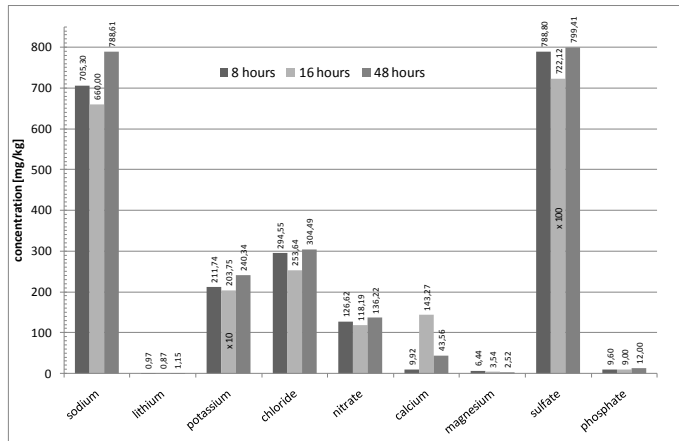
Figure 1 Extracted plant-available ions at 8, 16 and 48 hours extraction time of the first extraction step with deionised water

The values for potassium in diagram 1 have to be multiplied by 10 and the ones for sulfate by 100.
Sulfate, potassium and sodium are set free tin high amounts in the first extraction step with deionised water. Furthermore, it can be seen that the three tested extraction times show comparable results. So shorter extraction times can be used which allows faster analyses. These results could also be found for the extraction steps 2 and 3.
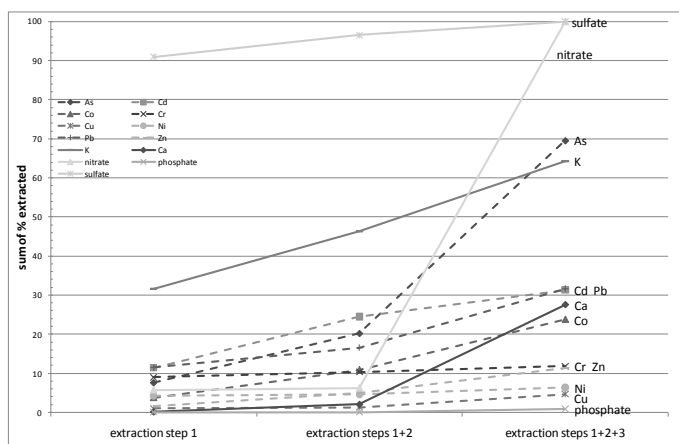
Figure 2. Cummulative amount of % extracted in the three extraction steps

138

The figure above shows that nutrients are leached in a high amount with the three extraction solvents, whereas heavy metals are only set free to a low degree. These are good results as plant relevant ions are easily bioaccessible – harmful heavy metals on the other side are only leached in small amounts (far below the limit values of the Austrian recommendation for the use of biomass ashes [1]).

4   DISCUSSION AND CONCLUSIONS

Different extraction times showed no significant influence on the leachable amounts which allows the use of shorter extraction times.

Essential components for plant growth are mostly extracted by mild extractants (water or NaAc) and are so easily bioavailable.

Harmful heavy metals are only set free in small amounts through distilled water or salt-solutions. The dissolved amounts are well below the maximum allowed values from the Austrian recommendation [1].

The use of biomass ashes on grassland seems to be useful as fertilizing agent and also in terms of closing the cycle from growing plants, using them for heat generation and returning nutrients back to the soil.

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Bio-Ethanol potential from Lignocelluloses – Potentials in Austria

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ABSTRACT

Several methods for the production of bioethanol from lignocelluloses (2nd generation bioethanol) from wood and mainly from straw are mentioned in the literature. But only few exact numbers are available concerning the yield and its potential for replacing the conventional fuel sources. Therefore, the basic data for the evaluation of the potential of this renewable energy form from biomass are missing.

The authors have examined the bioethanol production from lignocelluloses on a lab scale. The used method involves the following steps: thermo-mechanical pretreatment, enzymatic hydrolysis, bioethanol fermentation and downstream processing.

Lab scale experiments show, that steam explosion is a very suitable method for the pretreatment of lignocelluloses. The cellulose can then be converted by means of enzymatic hydrolysis to sugars. The yields fluctuate between 80 and 90 %. The resulting sugars can be more or less completely fermented to ethanol. On the basis of these results, the ethanol yield per ton of biomass can be calculated as well as the potential for the bioethanol production in Austria.

1   INTRODUCTION

The EU-committee defines in the exhibited draft directive for advancement of renewable energy sources (January 2008) biofuels as liquid and gaseous transport fuels, which are produced from biomass.

The expressed critism of human population concerning "First generation biofuels" (food versus fuel?) often refers to their energy- and environment balance in relation to their possible saving of green house gases, to sustainability of feedstock source, to the demand of agricultural area for crop growing, as well as to possible usage competition to foodstuffs, resulting in price increases of agricultural products.

While for production of 1st generation biofuels only one part of the crop is used (e.g. biodiesel is processed from the oil of seeds and fruits), the development of a production technology for complete crop conversion to synthetic biofuels is

intensely studied. For those „Second Generation Biofuels" or Advanced Biofuels, energy crops, straw, wood, vegetable garbage and other biological remnant materials can be used. The utilization of those feedstocks is less competitive to food production.

Several methods for production of bioethanol from lignocelluloses (e.g. from wood and mainly from straw) are mentioned in the literature. But only few exact numbers are available concerning the yield and its potential for replacing conventional fuel sources. Therefore, the basic data for the evaluation of the potential of this renewable energy form from biomass are missing.

The authors have examined the bioethanol production from lignocelluloses on a lab scale. On the basis of laboratory tests and of existing statistical data concerning cultivable land, production of straw, amounts of waste paper and reforestation efforts, the bioenergy potential of 2nd generation bioethanol has been calculated.

2   SHORT PROCESS-DESCRIPTION OF „2ND GENERATION BIOETHANOL"

The process is composed of the following sub-steps: Milling, thermophysical pretreatment (Steam Explosion), hydrolysis, fermentation, distillation and product separation/processing (Figure 1).
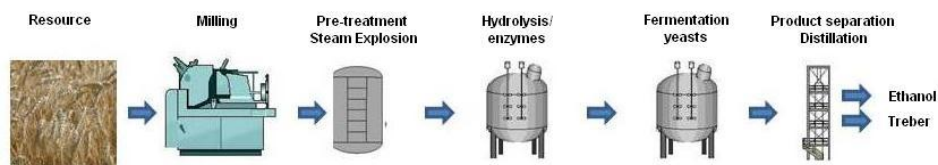
Figure 1. Schematic illustration of 2nd generation bioethanol production [1]

In order to make lignocellulosic remnant biomass accessible for production of bioenergy sources, it is necessary to decompose it in an operating step. A promising technology for this decomposition is the thermophysical "Steam Explosion"-process. In this process, the milled biomass is heated at temperatures of 120 – 200 °C for 5 – 60 minutes. After pressure release, the fibre structure is broken down and the microfibrillae are exposed, inducing, that lignocellulosic biomass is made accessible to subsequent enzymatic hydrolysis. This Steam Explosion method is based on the so-called VABIO-process developed from Steinmüller [1].

a. Material and Methods

i. Enzymatic Hydrolysis

For cellulose conversion into C6-sugars, the enzyme mixture Accellerase TM1000 from Genencor® has been used. Enzyme activities accounted for 43.00 FPU/mL and 390 IU/mL, respectively. A volume of 5 to 20 FPU/g dry

straw has been tested. With the pre-treated straw, a 5 to 20 % suspension has been produced and enzymatically solubilised at a temperature of 50 °C for 24 to 96 hours.

ii. Determination of sugars and ethanol

The sugars have been determined with HPLC from Jasco, RI-2031 Plus Detektor and BioRad AMINEX® HPX87H, Ion Exclusion Column

iii. Fermentation

Fermentation process has been conducted in a buffered solution at temperatures of 30 to 45 °C, as described by Hofer [2].

iv. Yeasts

Exclusively, wild-type strains of *Saccharomyces cerevisiae* have been used.

v. REM-photographs

Photographs have been taken, using a scanning electron microscope (Tescan VEGA LM).
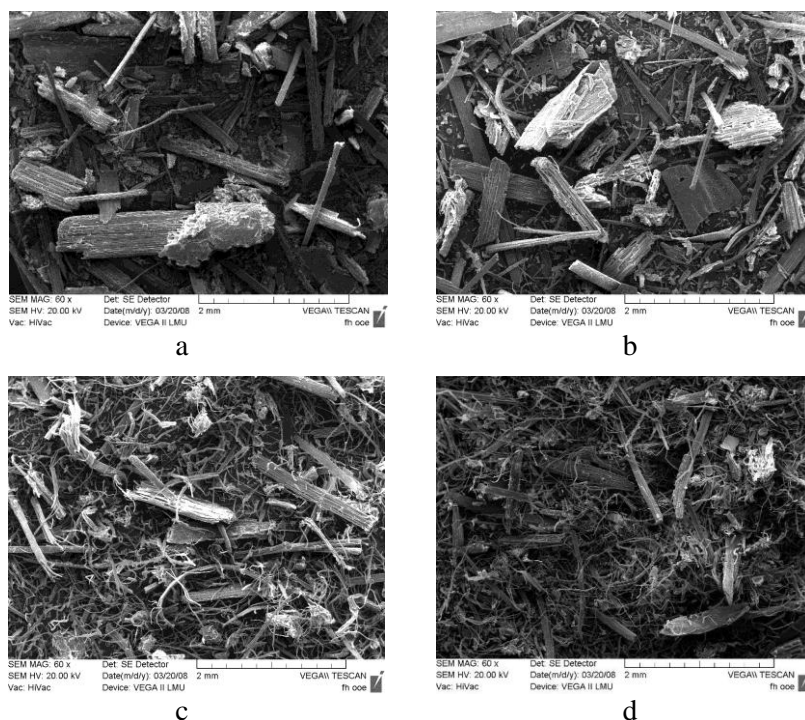
3   RESULTS

a. Steam Explosion

Figure 2 Scanning electron microscopical pictures of a) untreated straw, b – d) straw, pre-treated with increasing temperatures [3]

The process of thermophysical pretreatment has been largely adopted from the so-called VABIO-procedure. Scanning electron microscopical photographs show the extensive decomposition of straw up to microfibrillae (Figure 3a – 3d). Therefore, the cellulose is sterically made accessible for conversion by the multi enzyme complex.

b. Enzymatic Hydrolysis and Fermentation

Laboratory results have shown that lignocellulosic material can be pretreated efficiently with Steam Explosion. During enzymatic hydrolysis, cellulose can be saccharified to more than 90 % of the theoretical yield. The obtained sugar solution is converted to bioethanol to more than 95 % of the theoretical yield. Therefore, the sub-steps 2 and 3, namely hydrolysis and fermentation, have been largely optimized concerning product yield.

Results have shown, that the cellulosic proportion of straw with a TS input of 10 % (w/v) could be saccharified to more than 90 % of the theoretical yield (Table 1). Thereby, the calculations are emanated from a cellulose yield of 40 % in straw. The high yields are additionally remarkable, as the used yeast strain currently only can convert C6-sugars.

However, with increasing substrate concentrations, sugar yield decreases up to 70 % of the theoretically possible yield. Reasons for this purpose are currently analyzed.

Table 1. Sugar and ethanol yields, depending on different substrate concentrations

Straw concentration	Cellulose	Total sugar	Sugar yield	Ethanol	Ethanol yield, depending on sugar	Ethanol yield, depending on cellulose
% weight	g/l	g/l	%	% Vol.	%	%
10	40	36.0	90.0	1.8	90	80.5
15	60	44.0	73.3	2.9	97.3	71.3
20	80	56.3	70.3	3.8	93.8	65.9

The obtained sugar has been converted to more than 90 % of the theoretical yield. Also sugar concentrations of up to 60 g/L can be quantitatively digested into ethanol. Recent analyses have shown that sugar yields of more than 100 g/L are possible. During these approaches, a significant inhibition of the fermentation process has been observed. Possible inhibitory components (furfural, hydroxymethylfurfural) will be identified, as well as strategies for the removal of those metabolits will be developed.

c. Calculation of bioethanol production

For calculation of bioethanol potential from remnant straw, the average efficiency factor of 90 % during hydrolysis and 95 % during fermentation has been

taken. By usage of waste paper (own data) and old wood (theoretical estimations), yields are somewhat lower.

Based on the laboratory results, an alcohol yield of 324 L/ton of straw up to 648 L/ton of waste paper can be reached.

The capacity factor of those 3 feedstock components has been estimated with 25 – 50 % (Table 2). For the use of remnant straw, currently no business market is available. However, straw is an important soil conditioner and therefore, a part should be plowed into the fields.

For the calculation approach of bioethanol potential, straw usage of 50 % is estimated rather conservatively. The use of waste paper will compete against waste paper recycling. Currently, there is an oversupply of waste paper. It has to be noted, that all 3 feedstocks will be subjected to a certain competition.

Table 2. Bioethanol potential from lignocelluloses

	Remnant straw	Unused refore-station supply	Waste paper	total
Tons pa	2,000,000	6,000,000	800,000	8,800,000
Capacity factor	50%	25%	50%	
Tons pa	1,000,000	1,500,000	400,000	2,900,000
Amount of cellulose	40%	45%	80%	
Eta saccharification	95%	80%	90%	
Eta fermentation	90%	90%	90%	
l Bioethanol / t	342	324	648	
m^3 Bioethanol pa	342,000	486,000	259,200	1,087,200
Substitution rate	6.08%	4.28%	3.24%	13.59%

Summing up, for Austria, a production potential of about 1 million m^3 of bioethanol per year can be calculated. At present, Austrian fuel consumption accounts for 8,000,000 m^3 per year (source: BmWFJ3). If 50 % of the available straw in Austria would be used, only 4 % of petrol will be substituted by bioethanol of 2nd generation. By the use of available waste paper as well as previously unused old wood, the substitution rate remains under 14 %. Therefore, bioethanol potential from currently not used remnant materials is largely overestimated. However, the low substitution rate of conventional motor fuels into bioethanol of previously unused remnant materials could be drastically increased, if grain or lignocelluloses, respectively, were specifically cultivated for energy production.

4   DISCUSSION AND CONCLUSION

This study demonstrates, that straw and old wood can be converted to bioethanol with an high degree of efficiency. A cost-effective production will only be possible, if inhibitory effects (by inhibitory compounds) at high substrate con-

centrations are eliminated. The authors attribute more importance to the removal of such inhibitors than in the conversion of C5-sugars, which other authors are investigating (Boles 4). Hydrolysis procedure is lasting relatively long, compared to other enzyme processes; therefore an optimization of the cellulase complex is advisable. One possibility could be the production of cellulases onsite the actual with Steam Explosion pretreated substrate. Further investigations concerning use of other previously unused remnant materials or energy crops, such as maize, which have higher yields per hectare than wheat or wheat straw, respectively, could further increase bioethanol potential.

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Markets, Applications, and Processes for Wood Polymer Composites (WPC) in Europe

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ABSTRACT

This paper gives an overview about the production processes for WPC (Wood Polymer Composites), various application fields, and current market situation in Europe. Depending on the applications and needs, respectively, there are different processes for the production of WPC. The most common are extrusion and injection molding, but also rotomolding, continuous compression molding and thermoforming are appropriate processes for WPC.

During the past decade in Europe there has been a great deal of research and development focused on WPC material performance. The number of European research and development institutes and machinery companies involved in the WPC business in Europe is very high on a global scale. This results in a variety of commercial applications of WPCs. Today the broadest variety in the application of WPCs is in Europe, although the largest producers concentrate on decking.

There is very little data available about the European Decking market. In order to enhance the poor data situation Wood K plus conducted a survey among WPC-actors in May and June 2009, 124 European WPC companies and 59 research institutes in 13 countries were approached by an email survey.

We did a comprehensive characterization of WPC-materials to be able to draw comparisons, particularly with our own developments. Thus, we conducted extensive market survey - which led to a multi-client study - as well as to an extensive analysis of commercially available European deckings to get an impression of the technical and commercial performance of WPC-materials. A short overview of these results is given here. The most common solid wood deckings in Europe (e.g. Larch, Bangkirai) are included for comparison.

The paper closes with a forecast about the market development of the European Decking market until 2015.

1   INTRODUCTION

The use of wood fibers as a filler in polymers goes back to the early 1900s. With the introduction of thermoplastics, the first commercial use of Wood-Polymer Composite (WPC) appeared in the mid-1950s with the manufacturing of a wooden flooring tile (PVC and wood flour). Nowadays, the most common technology for producing WPCs is extrusion although injection molding and other technologies are in use.

By linking the joint scientific and technological resources with several academic institutes and some of the leading companies the developing of specific properties of wood products for various applications, an increase of their consumption and upgrade of their image in the market - which is presently often perceived as "low-tech" – should be achieved.

2   PRODUCTION PROCESSES

For WPC, the most frequently used production processes are extrusion and injection molding. The composites can be extruded either in a one step-process, so called "direct extrusion", or in a two step-process. The two step-process is an advanced development in extrusion technology. First, granules are produced by employing an extruder combined with a hot pelletizing- or under water granulation system. Second, these granules are extruded to profiles. In Europe, direct extrusion is the most frequently used method, followed by processing in a Heating/Cooling Mixer. Besides these, compression molding, deep drawing, continuous- and discontinuous pressing are in use.

3   MARKET SITUATION

The most frequent application of WPC in North America, Europe and also in Asia is decking. Wooden decking is something new in Europe; the traditional material in Central European gardens used to be stone. Currently tropical wood (mostly bangkirai) has the majority market share, followed by domestic timber like larch and pressure treated pine. In Addition to these traditional decking materials, WPC-decking is gaining on market share throughout Europe. To get more information about this relatively new market, the Austrian Competence Centre for Wood Composites and Wood Chemistry (Wood K plus) carried out a survey among the WPC actors (R&D, manufacturer, sales, compounder, machine manufacturer, supplier of additives) in the European market in June 2009 [1].

According to the survey, the European WPC decking market currently amounts to about 68,000 tons. This is an average estimation of the most important actors in Europe. The market of WPC-siding is still in the initial stage and it is estimated to be 13,600 tons in Europe in 2009 with very few producers. According to announcement in May 2009 from the German wood working industry, the growth of the German WPC production amounted to 78 %.

a. Companies dealing with WPC in Europe

124 companies operating in Europe deal with WPC in 2009 (see Figure 1). That constitutes an increase of over hundred new companies since 2003 and an increase of 20 companies since 2007. This figure includes the most important suppliers of additives and polymers as well as the producers of machinery and tooling. In addition, 27 producers of WPC decking and/or siding are included in this number.
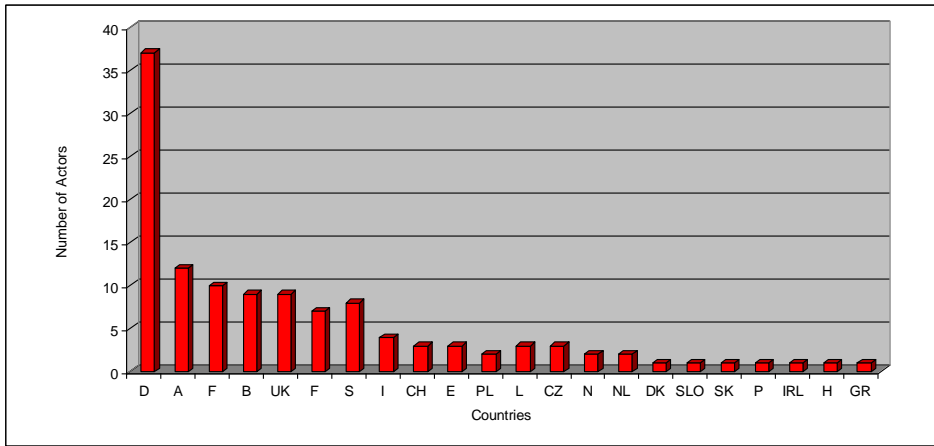
Figure 1. WPC-actors in Europe in 2009 [1]

The largest European manufacturers are Deceuninck, Werzalit, Kosche, UPM-Kymmene and Rehau although no reliable production figures are available. Werzalit, Kosche, and Rehau are Germany-based companies. Also the Finnish UPM-Kymmene's biggest production unit is in Karlsruhe, Germany, whereas production unit of Rehau is located in Austria. When taking into consideration the growth opportunities in Europe, German markets appear most attractive with a lot of players, scientific conferences and fairs taking place. In terms of production volumes, Germany is a leading market, followed by France and Benelux-countries. The largest WPC producer of the German wood-based industry and Deceuninck from Belgium both increased their turn over by 25% in the year 2009 [3].

b. Other WPC Applications beyond decking

The wide application range of WPCs in Europe spans from decking and siding to sophisticated musical instruments, furniture, table ware, toys and pallets. In the spring of 2006, the company IKEA released the first chair completely made of a WPC. The injection molded chair is made in six pieces that can be put together without tools. "Ellan" is available in three colours (black, turquoise and white) and in Austria costs € 39.95. "Ögla", the second IKEA WPC chair, has been on the Austrian market since the beginning of 2007. In Europe and Japan, several companies already use WPC for furniture parts. The chair material con-

sists of both recycled and virgin polymer. The wood share amounts to more than 50%.

Following construction, consumer goods and house wares is another large opportunity for growth in WPC materials. In Europe there are also companies producing injection-molded consumer goods such as pencils, watches, golf tees, music instruments, tableware toys and decorations. The clarinet of grenadill composites e.g. was developed by Fasal and is produced out of the production waste from solid Grenadilla wood clarinets.

Oil price speculations and shortage of oil supply influence polymer prices. This can be both a threat and a chance for the WPC industry. Rising polymer prices can lead to substitution of pure polymers with filled polymers, and fuel the use of WPC in traditional polymer applications.

4   WPC BENCHMARK [2]

WPC-decking was purchased via standard ways of distribution (DIY stores, wood products-wholesale companies) to make sure that standard products, just like those bought by normal consumers, were obtained (and not, potentially, some superior material fresh from R&D). The process of acquisition of the samples was not as easy as we had imagined. Therefore, we were not able to test all European products. In particular, some decking from French manufacturers is missing. Nevertheless, 17 products were characterized extensively (see Table 1).

Table 1. List of properties determined for material and component, respectively

Material		Component	
Property	**based on standard**	**Property**	**based on standard**
Composition	-	Geometry	-
Density	ISO 1183	Weight/Running Meter	-
Water absorption, Swelling	EN 310	Coefficient of sliding friction (CSF)	EN 13893
Flexural Modulus	ISO 178	Flexural Modulus	EN 310
Flexural strength	ISO 178	Flexural strength	EN 310
Impact strength	ISO 179	WA by Boiling-test	EN 1087-1
VOC	headspace-GC	Coefficient of Linear Thermal Expansion (CTE)	ASTM D 6341
HDT-A	ISO 75	Xenon-artificial weathering 1500h	ISO 4892
OIT	ISO 11357		

Both material- and component-properties were determined. Specimens for mechanical materials characterization were obtained by CNC-milling of the deck-

ings. This was not an easy task due to the un-even surface and the sometimes complex geometry of the profiles, but delivered specimens of consistent geometry.
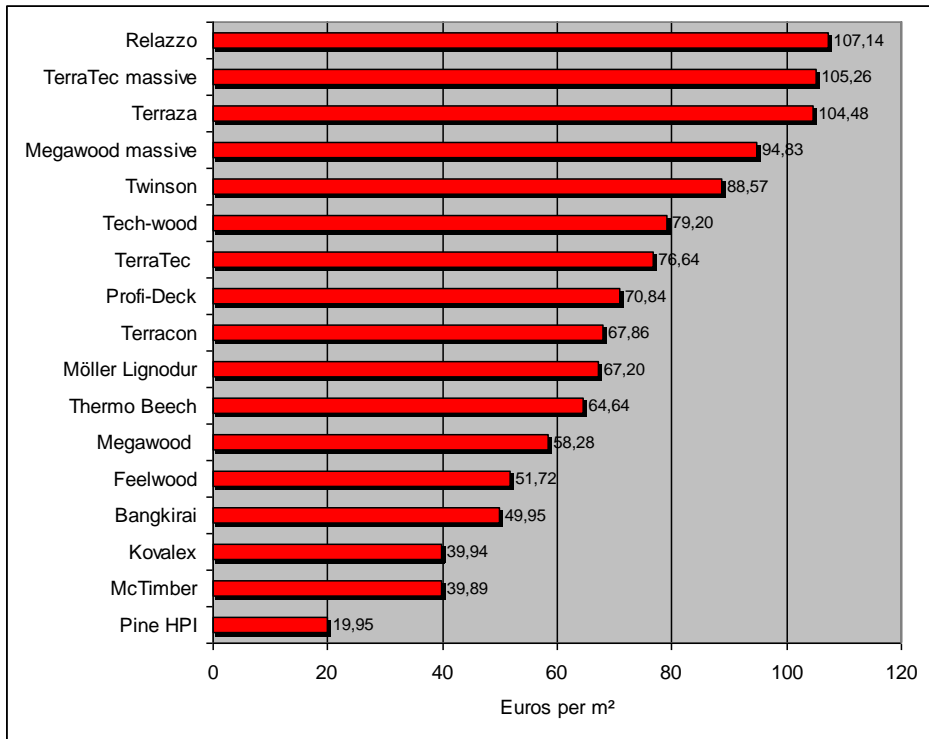
Figure 2. Chart of evaluated prices of the deckings

Figure 2 shows a price-ranking of the deckings tested. It includes common wood-deckings plus Thermo Buche, which is thermally treated beech wood. Obviously, all WPC materials are significantly more expensive than European wood species, and most are still more expensive than tropical hard-wood or thermally treated wood. In regards to the matrix, PP deckings are generally a bit more expensive than PE ones, but the correlation is not too distinct. PVC deckings are in the mid.

More details about the results regarding the analyses listed in Table 1 one can find in [2].

5 CONCLUSION AND FORECAST

European WPC markets are growing although the construction market as such is struggling. A stable growth for the WPC production is forecasted until 2015. The respondents of the Wood K plus study reported that the European decking and siding market will continue to grow. The majority of the respondents share

an optimistic view about rapidly growing decking markets. However, the views about the future size of the decking market vary. The estimated amounts, to be produced in 2015, vary between 101 000 and 150 000 tons decking [1], [3].

Although European public is very cautious toward new materials, large WPC producers could change this through joint marketing activities. At the moment, marketing is taking place at a low level, for example through the use of different quality signs. As a raw material that is based on renewable resources, WPC is far too unknown among the decision makers as well as the end consumers. The definitely self-confident pricing of the WPC-deckings [2] shows that they are meant to be sold as a "premium" product. Therefore, the customers will probably expect premium properties, also.

WPC are used neither by the wood-working nor the polymer industry, with the consequence that companies from both sides lack the adequate knowledge about the use of wood or polymeric side and vice versa.

Nevertheless, companies with a polymeric background seem to have more advantages due to their know-how of production processes. The prices of licenses are high, and the alternative is to develop own recipes. Investments in product development should increase and cooperating with different disciplines and companies is an appropriate tool for successful product development.

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Effect of finishing agents on the mechanical performance of wheat and flax pulp fiber-Polypropylene (PP)-composites

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ABSTRACT

This study is focused on the improvement of mechanical properties of cellulosic wheat- and flax- pulp – polypropylene composites through enhancement of the dispersion of the fibers. Ten different sizing-and finishing agents, including fats, starches and poly-siloxanes were used as surfactants for the cellulosic pulp. As a result of surface treatments, impact strength of the wheat pulp compounds was increased by 85 %. An improvement in tensile strength of 25 % was also achieved. The enhancement of several properties is attributed primarily to the improved dispersion of the cellulosic fibers. The results did not follow the classic trend where any factor which enhances strength and stiffness is detrimental to toughness.

1   INTRODUCTION

Natural fibers are an attractive alternative to synthetic reinforcements for thermoplastics. The advantages include renewable resource origins, predominantly lower costs, low densities and high specific properties. However, these fibers are distinguished by hygroscopicity, because they contain polar hydroxyl groups. Thus, incorporation of cellulose into hydrophobic-nonpolar polyolefins results in poor interfacial fiber-matrix adhesion. Consequently, the stress transfer from the matrix to the stronger fiber is restricted and the full potential of the reinforcement cannot be fully utilized. A very effective way to solve this contradiction is the addition of suitable polyolefins, which are grafted with maleic anhydride [1]. Further methods, which are used to improve the performance of composites, are based on surface treatments of the fibers. Additionally, limits for the use of cellulose- composites in structural applications may arise from the tendency of natural- and in particular of pulp fibers to agglomerate and stick together. Additives, which are traditionally used by the textile industries to facilitate manufacturing and to improve the performance of natural fiber based products, are agents for fiber sizing and finishing.

This study is focused on the improvement of mechanical properties of pulp PP composites through enhancement of fiber dispersion and fiber strength as a result of the application of chemically different surfactants. To compare the cellulose- reinforcements with conventional fillers three composites containing glass fiber, talcum and wood flour were produced.

2   MATERIALS AND METHODS

a. Materials

The flax and wheat-celluloses were provided by the Delfort group AG (Traun, Austria). The basic recipe was composed of 30 wt% fibers, 67 wt% of the high-melt flow polypropylene (MFI 230°C/2.16kg = 50g/10min 222CC50 (Ineos Polyolefins, Brussels, Belgium) and 3 wt% of the coupling agent Scona TPPP 8112 FA (Kometra GmbH, Neugattersleben, Germany).

Ten different chemicals which were used for fiber finishing are stated in Table 1. The agents were applied to the fibers in concentrations of 0.3 and 0.15 wt% based on total composite weight. Modified and untreated fibers were mixed in the laboratory kneader, IKA-Duplex HKD-T0.6D, at an adjusted moisture content of 60 wt% for half an hour. Due to a change of raw material, certain modification had to be processed in a second run. All of these samples, including the new references, are marked with an asterisk. Three further recipes, based on the same formulation and % weight using traditional fillers, were made. These contained glass fiber (Chop Vantage 3660/ PPG- industries Inc., Pittsburgh, Pennsylvania, USA), talcum St 30 (Luzenac c/o Naintsch Mineralwerke GmbH, Graz, Austria) and wood flour E 35 (La Sole Est Srl, Pavia di Udine, Italy) as reinforcements.

b. Processing

Compounding of the cellulose-polypropylene composites was carried out on a Collin ZK 25 counter rotating, parallel twin screw extruder. The barrel temperatures of the extruder were set to 80 °C in the feeding section, to 180°C in the succeeding two heating zones and to 160 °C in the die. Manufacturing of the tensile test bars (ISO 527; model 1A) was performed by a Battenfeld HM 60/210 injection molding machine. The barrel temperatures were adjusted to 185 °C in the metering section and to 190°C in the consecutive three heating zones.

c. Environmental scanning electron microscopy (ESEM)

Fracture surfaces of the reference- composites were sputter coated with gold by use of an Edwards Scancoat Six sputter coater. These surfaces were observed with a Phillips XL 30 environmental scanning electron microscope.

d. Tests and analysis

After two weeks storage at 23°C and 50% relative humidity tensile properties and impact properties were determined according to ISO 527and ISO 179/1fU.

Table 1. Composition and recommended applications of the modifiers

Code	Company	Description	Applications
A	Wacker Chemie	nonionic/anionic silicone resine oil in water	care products, release agents
B	Wacker Chemie	emulsion of polysiloxane-functional silicone resin	masonry water repellents
C	Agrana	esterificated polysaccharides	sizing agent for textiles
D	Wacker Chemie	alkyl-modified polysiloxan	care products (polishes)
E	Wacker Chemie	silicone wax	skin protection, skin care
F	Wacker Chemie	silane/siloxane microemulsion	water repellents for buildings
G	Peter Greven	diisotridecyl adipate	lubricant (high temperature)
H	Wacker Chemie	nonionic, aqueous emulsion of a silicone wax	car polish
I	Wacker Chemie	poly(dimethylsiloxane) dispersed in water	release agent for ironing aids
J	Clariant	cationic distearyl dimethyl ammonium chloride	for fabric softener formulations

3   RESULTS AND DISCUSSION

a. Impact properties

The effects of the surfactants on the impact strength of the cellulose-polypropylene composites are summarized in Table 2.

Table 2. Unnotched Charpy impact strength of cellulose composites, including the percentage change (Δ%) related to the unmodified references.

	Unnotched impact strength in kJ/m²							
	Wheat cellulose				Flax cellulose			
Untreated	12.9				16.0			
Untreated*	20.8 *				17.8			
Agent	0.15 % Finish		0.30 % Finish		0.15 % Finish		0.30 % Finish	
	kJ/m²	Δ%	kJ/m²	Δ%	kJ/m²	Δ%	kJ/m²	Δ%
A	12.3	-5	13.2	3	14.7	-8	17.5	10
B	19.6	52	15.1	17	16.8	5	18.8	18
C	17.1	32	14.5	12	17.5	10	17.5	10
D	17.6	37	17.5	36	18.7	17	17.6	10
E	16.4	27	18.0	40	18.7	17	18.8	18
F	15.4	19	17.8	38	14.6	-9	17.7	11
G	14.6	14	15.3	19	15.3	-4	16.2	2
H	25.8*	19*	19.0	48	17.4	-2*	19.4	22
I	26.6*	28*	23.9	85	20.0	12*	19.0	19
J	24.5*	18*	18.9	47	21.3	19*	21.4 *	20*

* Values obtained in the second run are marked with an asterisk

Debonding, pull-out and fracture of the fibers are the three mechanisms of energy absorption during impact [2]. This energy depends on various factors like toughness of the matrix and the fiber alone, defects in the packing of fiber/matrix and crystalline morphology, among others [3].

Strong increases in impact performance could be achieved by use of most of the surfactants. For wheat cellulose, the impact strength could be improved by 85% by use of the poly(dimethylsiloxane) (I) in a concentration of 0.3%. In contrast, the impact strength of the flax cellulose composites was, at best, increased by 21% through modification with 0.3% siliconewax (H). A fact significantly improving the Charpy impact strength is the enhanced dispersion of the fibers.

Figure 1 displays fracture surfaces of unmodified wheat- and flax pulp references and selected modified compounds. The flax pulp reference revealed less fiber agglomerations compared to the unmodified wheat pulp composite. The fracture surfaces of the treated wheat composite showed a uniform and regular distribution of the cellulosic fibers. Lower improvements in fiber dispersion were obtained with flax pulp reinforcements. This resulted in lower augmentations of the impact strength of flax fiber composites.

1- Dispersed fibers; 2-Fiber agglomerations
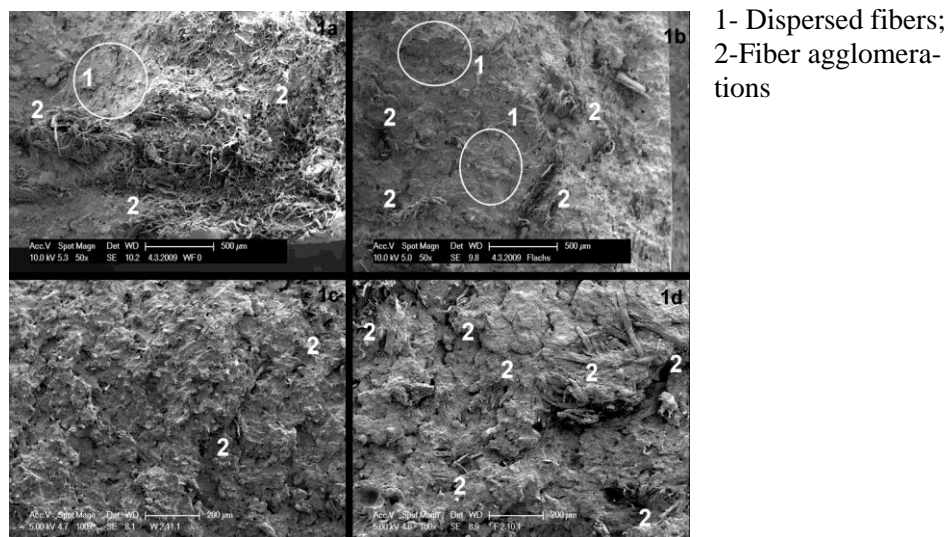
Figure 1. ESEM micrographs of the wheat (a) and flax references (b), of wheat pulp composites (c) modified with 0.3% poly (dimethylsiloxane)-water emulsion and of flax pulp composites (d) treated with 0.3% of silicone wax

The impact strength of selected cellulose composites and compounds with traditional reinforcement such as talcum, wood flour and glass fiber are compared in Figure 2. As expected, the reinforcement with wood flour brought the lowest impact strength about. This can be primarily attributed to the geometry of the particles. The impact values of the untreated wheat- and flax references ranged

slightly above the ones of the wood flour composite. They were, however, strongly below the toughness of the glass fiber and the talcum composites. Through modification with poly(dimethylsiloxane)-water dispersion (I), the impact strength of the wheat- composite was elevated above the range of the glass- and talcum composites. Lower surface area effects of the treatments were found for the flax- cellulose. The impact strength of latter could, at best, be increased to the level of talcum and glass fiber composites, by use of silicone wax (H).
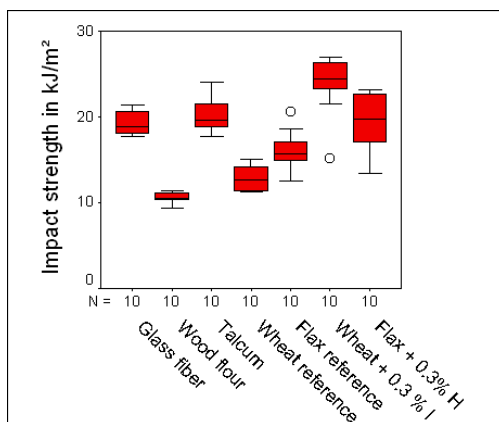

Figure 2. Box- and Whisker diagram of impact strength of different composites

b. Tensile strength

The results of tensile strength are stated in Table 3.

Table 3. Tensile strength of cellulose composites, including the percentage change (Δ%) related to the unmodified references.

	Tensile strength in MPa							
	Wheat cellulose				Flax cellulose			
Untreated	33.8				37.3			
Untreated*	31.0*				31.5*			
Agent	0.15 % Finish		0.30 % Finish		0.15 % Finish		0.30 % Finish	
	MPa	Δ%	MPa	Δ%	MPa	Δ%	MPa	Δ%
A	33.3	-2	34.	1.4	36	-4	41.0	10
B	41.0	21	37	9.1	41	11	45.2	21
C	37.6	11	35	3.3	42	12	40.4	8
D	38.9	15	39	15.2	44	17	43.3	16
E	38.0	12.	39	16.5	43	16	44.6	20
F	37.1	10	40	18.6	37	0	45.5	22
G	35.9	6.3	37	8.6	42	13	42.7	15
H	35.0*	13*	39	16.1	34 *	9*	42.5	14
I	38.7*	25*	42	22.9	37*	17*	44.5	19
J	37.6*	21*	42	25.0	36*	14*	36.1*	15*

Values obtained in the second run are marked with an asterisk

With the exception of the silicone- resin oil-in-water emulsion (A), tensile strengths could be increased by use of all other modifiers (B to J). The tensile strength of the wheat composite could be improved by poly(dimethylsiloxane) (I)-treatment, or modification with ammonium chloride (J) by about 25%. Tensile strength of the flax composites was improved by 22% by using silane-siloxane microemulsion (F) as treatment in a concentration of 0.3%. Primarily, the augmentation of tensile strength is attributed to the improved dispersion of fibers. Although, further effects provided by surfactants such as enhanced shear resistance of the fibers and further improvement of the fiber-matrix interfaces cannot be ruled out. The comparison of the tensile strengths of selected pulp composites with those of conventional reinforcements is displayed in Figure3.
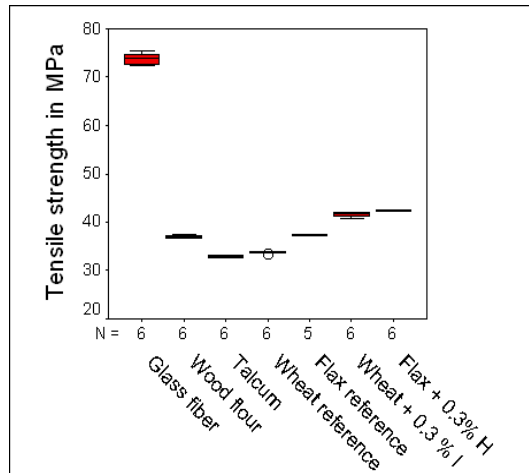

Figure 3. Box- and Whisker diagram of tensile strength of different composites

A clear superiority of the glass fiber composites over the rest of the compounds becomes visible. This outcome is a result of the higher strength of glass fibers in comparison to that of natural fibers [4].
Furthermore the glass fibers used are distinguished by significantly lower diameters (10μm) compared to the dimensions of the wood particles (180-500μm).

4. CONCLUSIONS

Applying surfactants to cellulose fibers is a simple and cost effective way to enhance impact strength and tensile strength of cellulose –composites. The effectiveness of the finishing agents depends strongly on the applied concentration and on the type of cellulose. Impact strength of the wheat pulp composites could be improved up to 85 %, tensile strength was increased for 25 %. The increase in mechanical properties is primarily attributed to an upgraded dispersion of the cellulose fibers which increases the surface area of the fibers. Further

investigations should be carried out to optimize concentrations of the surfactants and to adapt this method of surface modification for industrial use.

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Post industrial wooden raw material as natural fiber base for wood plastic composites based on PVC and PP matrix material

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ABSTRACT

Wood plastic composites are mainly produced from natural wood fibers (pellets or pre-treated wood fibers). Within this project – which was supported by the EU under the CORNET directive – it was investigated how post industrial wooden raw material such as MDF/HDF, OSB or plywood waste can be used for WPC products and what typical physical properties can be expected. Such products are often available in large quantities, quite homogenous and stable in quality (particle size, humidity), but have restrictions for their thermal recycling due to their resin content.

To ensure realistic processing conditions, the investigated WPC-profiles are close to a typical decking profile and manufactured with direct extrusion on a conical counter-rotating twin screw extruder to ensure representative sampling. PVC as well as PP was used as polymer matrix materials. However, due to its typical outdoor use, the main focus was on PVC.

Results of those WPCs have shown significant advantages over "conventional" WPCs. A wide variety of material combinations such as fiber content (50% to 80%) and different additives were examined. Those samples were tested for their typical performance indicators such as bending strength, creep behavior, thermal expansion, water absorption and weatherability.

It has been shown that, in principle, the use of post industrial wooden raw material has its advantages not only in the availability of resources, but also in achievable physical properties. Commercialization and the up-scaling to real production will have its difficulties and need more than only material development. Taking the outstanding physical characteristics of this WPC into account, a potential to use this WPC-material for products close to constructive applications – to replace or complement wood - is visible.

1 INTRODUCTION

Wood plastic composites (WPC) are mainly produced from natural wood fibers (pellets or pre-treated wood fibers) together with polymer matrix materials such as Polyethylene (PE), Polypropylene (PP) and Polyvinylchloride (PVC). Considering the market share and application of different products (see figure 1), the profile extrusion process is the primary method of manufacturing. Within the WPC-profile applications, decking is by far the biggest market. Technical characteristics for this application such as weatherability, bending strength, E-modulus, and water absorption are key criteria for most of the new developments.
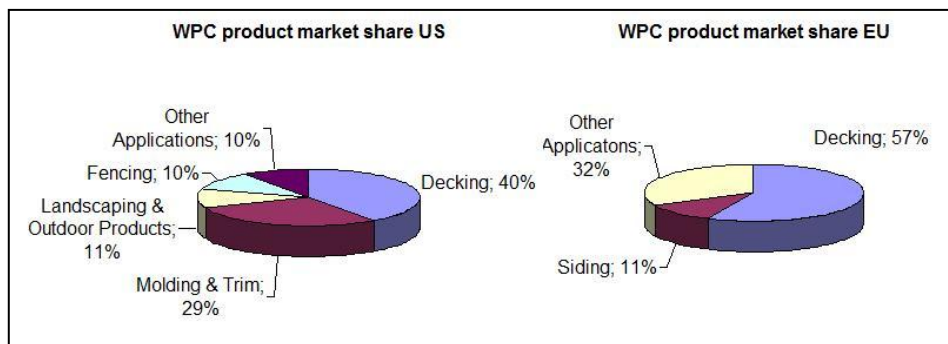
Figure 1. Market share of WPC products in the US [1] and EU [2]

Most of the latest developments were based on natural – some times specially treated – wood fibers from standard wood production sites such as wood mills. But these sources are also used more and more extensively to generate pellets for biomass energy production. Although wood prices do not trend in the same way as standard crude materials like oil, as indicated in figure 2, a steady demand will keep prices relatively high and a further growth can be expected.

Figure 2. Development of energy prices in Germany and price of wood-pellets [3]

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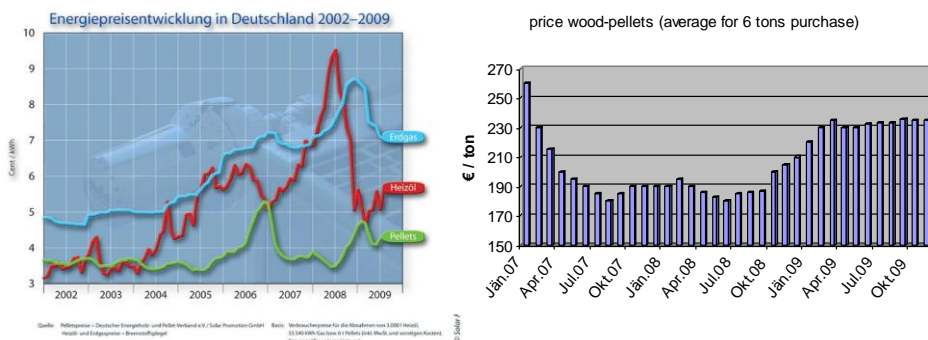Based on these circumstances, the project has evaluated alternatives to typical wood fibers for the production of WPC for outdoor applications.

2   THEORETICALLY BACKROUND

Various studies [4], [5] have described WPC as natural fiber hybrid composite materials containing fine wood particles with certain standard polymers as matrix materials. Although products with low wood contents or other natural fibers than wood might be classified as WPC, for European WPC it is different. Especially due to ecologically considerations, the fiber should be wood and the fiber content should exceed 50%.

Major selection criteria for matrix materials for outdoor WPC applications are on the one hand technical characteristics and on the other hand the ability to withstand natural weathering. Besides fiber dispersion, the final performance characteristics of WPC are mainly influenced by adhesive forces between the natural fiber reinforcement and the polymer matrix. Typically non-polar materials such as polyolefins have to use expensive coupling agents to provide necessary interaction, whereas PVC is becoming more and more popular due to its good binding qualities based on its polarity as well as the outstanding performance [6]. Ecological objections are still there. However, due to its wide spread applications for long-life products in the construction industry, its acceptance will grow.

In contrast to polymers, the consistency of wood fibers is challenging the WPC production. Not only the kind of wood, but also the size distribution and moisture content are critical for the production and the end-product quality. Standard wood fibers have to be well selected and pre-treated – mainly with high energy input - prior to use and therefore have an impact on cost and availability. Alternative materials, like cardboard or paper waste, are also based on wood fibers and available in sufficient qualities and quantities. However, existing recycling strategies at production sites are mainly being opposed for their use in WPC. Another possible fiber source is the waste of preprocessed wood, such as oriented strand board (OSB), plywood, or MDF/HDF production. Due to its condition (particle size, consistency in moisture, well documented origin), MDF waste especially is a possible consistent and therefore suitable source. Cost wise it is below other wood fiber raw materials due to its limited thermal recycling capability at bigger energy plants or consumers with sufficient filtering technologies based on resin contents up to 12%.

3   PROJECT EVALUATION CONDITIONS / EXPERIMENTALS

Much research and development work has been done on existing lab-scale extrusion equipment in Austria. Standard PP from BOREALIS with different MFI values as well as PVC from SOLVIN are utilized as polymer matrix materials. MDF pre-processed wood waste from a big MDF-converting plant was taken directly from their silo stations at moisture levels of 6%, pre-sieved at 2 mm to cut the fraction and avoid bigger particles and used as wood fiber. Those mate-

rials were fed directly together with relevant testing components (color master-batches, UV-Stabilizers, coupling agents for PP) by gravimetrically controlled feeding devices into a conical counter-rotating twin-screw extruder with 38 mm outlet diameter. Within the extruder, melting and mixing at various process conditions have been evaluated to form stable WPC melt conditions at the extruder outlet before entering the die. The cooling of the extruded profile was done under vacuum on standard WPC-profile extrusion down-stream equipment. Typical melt temperature was around 185°C and outputs on lab scale extruders were up to 40 kg/h. Counter checks and up-scaling was done with similar bigger extruders up to 100 kg/h and special conical co-rotating twin-screw extruders up to 250 kg/h.
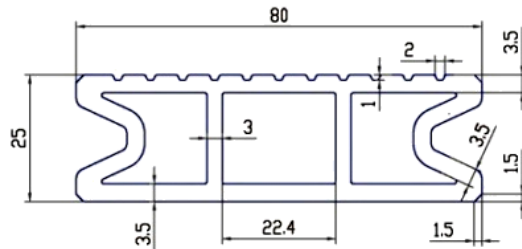

Figure 3. Test profile for the production of material samples on lab scale

To come as close as possible to realistic material values for further scaling-up an adapted small decking profile was extruded (figure 3). Material samples were prepared by grinding and milling mainly at the lower side of the decking profile. Besides wood fiber load, the influence on different UV-Stabilizer, coupling agent and color master-batch ratios were analyzed statistically. Fiber content for PVC based WPC was examined from 50% up to 65% and for PP based from 60% up to 80%. Due to processing conditions (e.g. melt viscosity), PP usually has a higher wood fiber content; therefore this study also reflects this circumstance. However practical experience has shown that PP based WPC with a higher wood fiber content (above 70%) is not usable for outdoor applications due to bad overall performances in decking applications.

4   DISCUSSION

As mentioned in [7], various studies have published multiple data for polyolefin based WPC products.   Therefore, the focus of the discussion will be on test results of PVC based WPC products. PP based test results are shown as a control for getting a full range of possibilities. Typical standard as well as special technical data – which are usually not often checked for outdoor profiles - were examined to prove the use of pre-processed wood waste based WPC.

a. Standard technical data for decking profiles

i. Mechanically properties (bending strength, E-Modules; DIN EN 178)

Figure 4 shows the influence of different additives and fiber content to strength. The bending strength of PVC based WPC varies little with the fiber content as well as the UV-stabilizer ratio. The variations for PP based WPC are much bigger. Especially the amount of coupling agent has extensive influence on the bending strength due to the non-polar property of PP. Similar results were found for standard polyolefin based WPC [8].
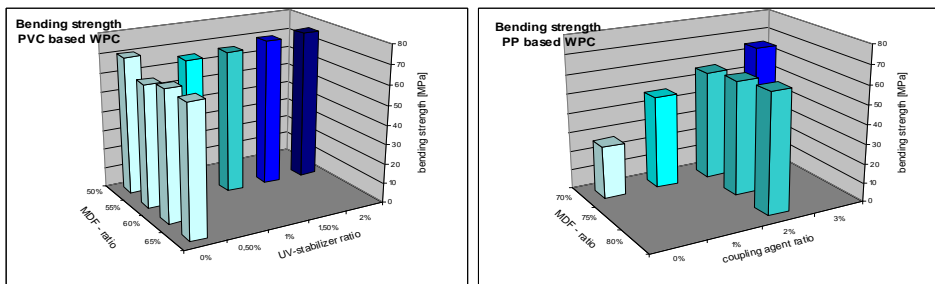

Figure 4. Bending strength of PVC based and PP based WPC in reliance of specific additives

Generally, it has been observed that pre-processed wood based WPC reached a higher level of bending strength as well as E-modulus than typical standard WPC. With values of up to 75 MPa in bending strength and up to 7GPa in flexural modulus, the PVC based WPC will be close to the highest values mentioned in [9] as the maximum for WPC.

ii. Water absorption (DIN EN 317)

The water absorption (up to 28 days) for material combinations without adhesion aids is shown in figure 5. The observed offset between PVC- and PP-WPC is based on the different polar behavior of matrix materials. Coupling agents for PP-WPC will reduce water absorption to PVC-WPC levels on short time. On long-term levels, it seems that typical coupling agents do not exceed electrochemical binding forces. Therefore, polar polymers offer advantages due to their efficient and economical (cost reduction to add chemical coupling agents) binding forces.
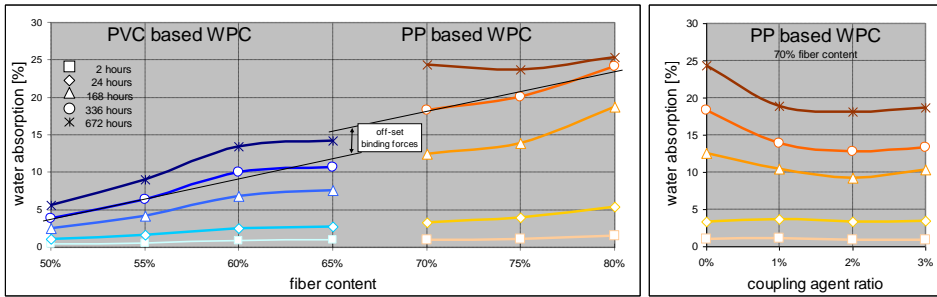
Figure 5. Water absorption of PVC and PP based WPC at different fiber contents

iii. Artificial weathering (XENON-Test)

To investigate outdoor performance, artificial weathering tests were examined for visual appearance. An exemplary result is given in figure 6. It was observed that the tested UV-stabilizers are unable to stabilize wood fibers and protect them against fading at surface levels. Only sufficiently stabilized color master batches obtain the original color and visual look of WPC. Slight color changes will happen – within the first 100 hours – even with good color stabilization due to the fact that the surface color is a mixture between matrix material color and wood fiber.

WPC-sample 55% MDF and   **WPC-sample 55% MDF;**
1,5% UV-stabilizer   **1,5% UV-stabilizer and 2% color**
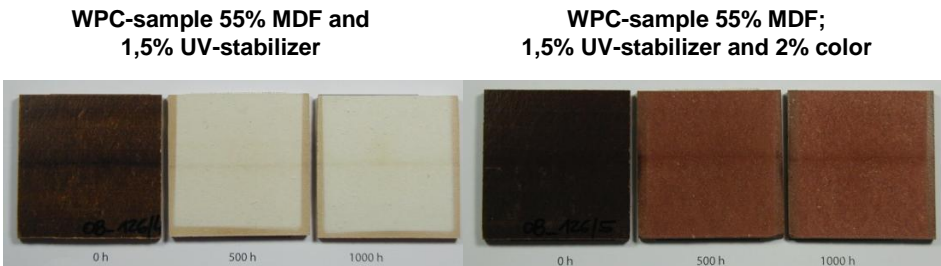
Figure 6. Influence of UV-stabilizer content on artificial weathering of WPC

b. Special technical data

This section reflects technical parameters usually not measured for outdoor profiles.

i. Creep behavior (ÖNORM ENV 1156)

Depending on the polymer matrix material, WPC will face similar problems to plastics concerning deformation under load. Therefore creep behavior for WPC is important for stress loaded outdoor profiles. As shown in figure 7, PVC based WPC has significant advantages over PP based WPC. Although it is not as good as wood, PVC WPC will closer reflect wooden behavior.
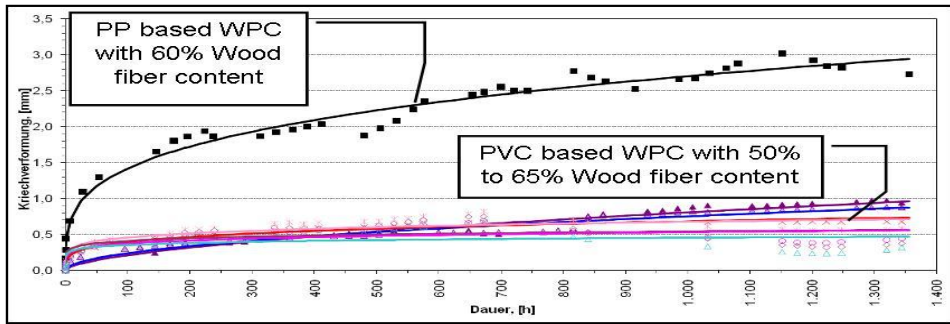
Figure 7. Creep behavior of PVC and PP based WPC

5 Change of mechanical properties after artificial weathering

Like wood WPC will also lose mechanical properties after weathering. This study also scanned the possibility to improve aged WPC by adding usual UV-stabilizers. Figure 8 displays selected results of this study. Unfortunately, no significant effect to improve loss of strength was observed. The reduction in mechanical strength of preprocessed wood fiber WPC is similar to other WPC.
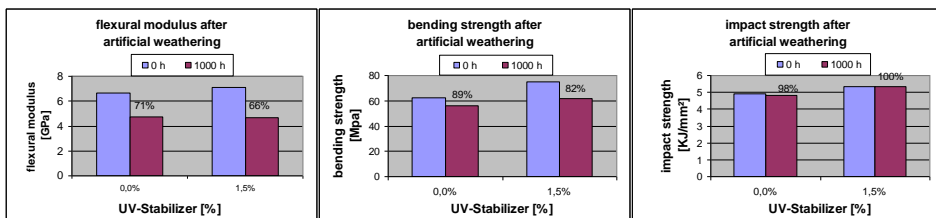
Figure 8. Change of mechanical properties such as flexural modulus, bending strength or impact strength after artificial weathering depending on UV-stabilizer content

6 Thermal coefficient of expansion

The coefficient of expansion of WPC is mainly based on polymer matrix materials and its typical thermal behavior of expansion. Results of the study are given in Table 2. These results correspond with other studies. Due to process-based homogenization of the material the thermal coefficient of expansion is almost applicable for all 3 dimensions. Based on the wood fiber reinforcement the thermal expansion of the matrix polymer itself is reduced by a factor of 2.5.

Table 1. Range of tested WPC-profiles

WPC base	thermal coefficient of expansion α
PE	$38 - 42 \times 10^{-6}$
PP	$35 - 38 \times 10^{-6}$
PVC	$18 - 21 \times 10^{-6}$

7 Optimization of mechanical strength by processing and recipe

Elated by the good results, further optimization was done at the processing level of PVC based WPC to improve the dispersion quality of fibers. With pre-homogenizing as well as adjusted venting and process technology a better homogeneity of the PVC based WPC could be reached. This results insignificantly better mechanical strength levels (Figure 9).
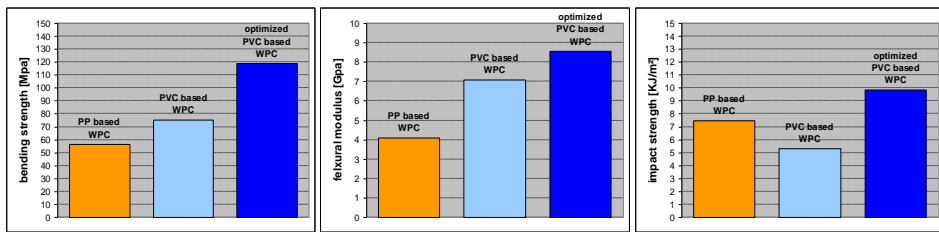
Figure 9. Improved strength levels and impact resistance for optimized PVC based WPC

8   CONCLUSIONS

Pre-processed wood fiber waste – especially from MDF/HDF sources - will represent an ecologically and economically worthwhile raw material source for WPC production. Material as well as process know-how is needed to up-cycle this raw material source and convert it into value added products. PVC as polymer matrix material will have many technical advantages over polyolefins such as PP. The principal production of pre-processed wood fiber (MDF) based WPC were evaluated as well as specific characteristic values were measured. The tested WPC profiles show significantly higher mechanical strength behaviors – especially at optimized levels - than standard WPC where mostly pre-treated but standard wood fibers are used as a fiber source. PVC based WPC is superior to PP based WPC in most of the related technical values applicable for typical profiles used outdoors.

Figure 10. Improved strength levels for optimized PVC based WPC [10, 11]

With optimized production and recipe formulations, PVC based WPC will come close to natural wood in many properteries, especially for bending strength as shown in figure 10. It will also be equal to (sometimes even surpass) the so-called "thermo-wood" which is also used for outdoor applications.
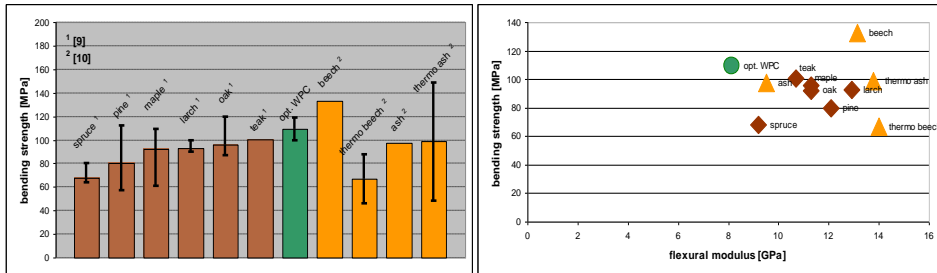
Taylor made WPC - a hybrid material that is beginning to form a new material group - will show potential for the outdoor use. Its mechanical values might even open possibilities to use WPC in constructive wood engineering applications. First scaling-up results have been realized at the company Extruwood GmbH, in Austria and further R&D work based on the initial results will be supported by the Österreichische Förderungsgesellschaft mbH, Wien.

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Assessing the particle structure of Wood Based Panels through Mode 1 fracture test

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ABSTRACT

The aim of this study is the evaluation of the suitability of an adapted version of the fracture double cantilever cleavage test for the characterization of different wood based panel types. Special regard was given to the analysis of particle size effects on the shape of the fracture curve, peak force, and fracture energy, respectively. The gained results confirm the good suitability of the method for the characterization of particleboards.

1   INTRODUCTION

A major characteristic of wood based panels and construction materials is the resistance against fracture. Assuming that wood based materials contain propagable fracture structures, mainly the adhesive bond strength dictates the fracture behaviour. On the other hand the density of the board, adhesive content and particle size and geometry determine the bond area between the particles. Due to the low density the weakest area of fracture resistance can be found in the core layer. The new developed fracture resistance testing method is optimized to observe effects of the particles, adhesive content and density on bonding strength of the board.

2   MATERIAL AND METHOD

In total 660 fracture energy test samples, e.g. OSB, particleboard and MDF, were tested. Test samples can be divided into four different groups concerning particle size and particle structure: i) OSB with big flat particles [1], ii) P5 particleboard (PB) [2] composed of fresh particles, iii) particleboard containing recycled wood [2], and iv) MDF [3] boards with fibres and fibre bundles. Each group is divided in two subgroups with first axial orientation and second transverse orientation. In this elaboration only axial fracture samples are presented. All boards showed a nominal thickness of 19 mm. Rectangular specimen of

25 mm width and 250 mm length were cut off the boards gaining 100 to 200 specimens for each group. In order to initiate the crack within the core layer, specimen were cut in the core layer to a depth of 25 mm. Figure 1 shows the crack initiating cut and a schematic crack propagation. The samples were glued with a rapidly curing cyanoacrylate adhesive between two stiff, metallic T-beam braces which guarantee the force application mainly into the core layer.
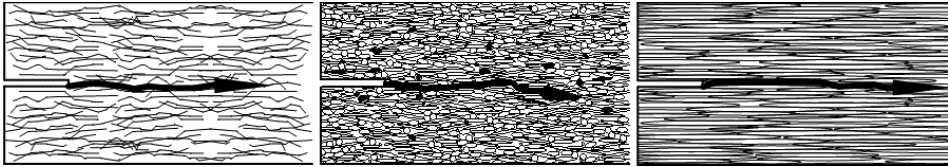

Figure 1. Scheme of the crack initiating cut and fracture progress in different woodbased panels: MDF (left), PB (middle), OSB (right)

Fracture tests were performed on a Zwick/Roell Z100 universal testing machine equipped with a 2.5 kN load cell. The cross head speed was 1 mm/min until the remaining force dropped to one third of the maximum. These settings guarantee fracture within 60 ± 30 sec similar as for the internal bond test [4]. By implication, cross head speed increases progressively up to 10 mm/min and the test ends with a remaining force of 5 N after a maximum testing time of approximately 150 sec.

3   RESULTS AND DISCUSSION

For the qualitative description of the fracture behaviour four representative samples were selected. Characteristic force-displacement curves for all tested board types are shown in Figure 2. The fracture energy curves show a steep increase of the load up to the maximum load. Maximum load was reached for the OSB sample at 1263 N, for the PB P5 sample at 850 N, the "PB recycling" sample at 628 N, and for MDF at 604 N.

With the force drop after the maximum load the curve follows more or less an asymptotic progression until the panels failed or a minimum force of 5 N was reached. This part of the curve is strongly influenced by the particle geometry and particle size. The enlarged area of interest (AOI) of Figure 2 is shown in Figure 3. The OSB curve shows an irregular pattern with several abrupt force drops due to the large particles. In comparison MDF shows a very smooth curve and low energy absorption, which can be seen in the horizontal out fading zone. "PB P5" absorbs much more energy than "PB recycling" which can be attributed to the higher adhesive content. Due to the inhomogeneous particles of "PB P5" and "PB recycling" the fracture energy curves showed irregularities after the abrupt force drop, which was less pronounced for the more homogeneous PB P5. From the fracture energy curves it is assumed that greater particles lead

to irregularities and abrupt force drops in the coasting part of the curve, whereas the first part of the curve is more attributed to the bond strength of the board.
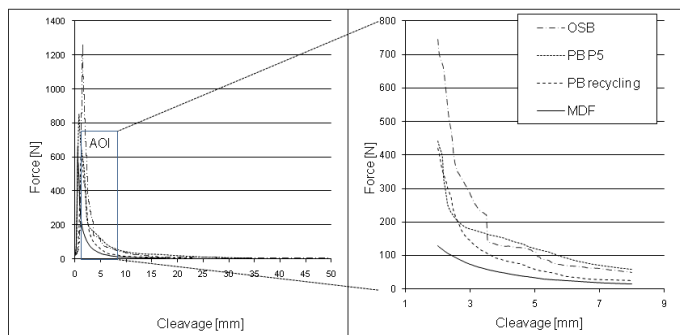
Figure 2. Fracture curves of selected wood based panels
Figure 3. Enlarged area of interest (AOI) for fracture curves of selected woodbased panels

4   CONCLUSION

The novel double cantilever cleavage test convinced with an easy hand-ling of the specimens and the testing process. The test itself is sensitive for the analysis of board characteristics and is clearly usable for the interpretation of board properties.

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Quality Control of Impregnated Papers with a Multiple Regression Model

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ABSTRACT

The company M.Kaindl produces at its plant in Salzburg, urea – and melamine – formaldehyde impregnated papers, as a basic raw material for the lamination of particle boards. To guarantee high and consistent product quality, different sensors and processing technologies for process and quality control are required. This publication deals with the analysis and the modeling of the essential material and process parameters considering their influence on the essential output parameters basis weight and moisture content (MC) of the impregnated papers.

1   INTRODUCTION

The findings of [1] show the importance of constant properties of impregnated papers and in [2] different models for quality control are compared. These findings are a basis for this paper.

The production of impregnated papers is done according to the process chart in Figure 1. The raw paper control and processing is shown in orange color, the resin and chemicals control and processing is shown in green color and the film production processes and control systems are shown in blue color.

Within this paper the question, whether it is possible to improve the accuracy of the existing measurement system by predicting the output parameter using a multiple regression model or not, is answered.
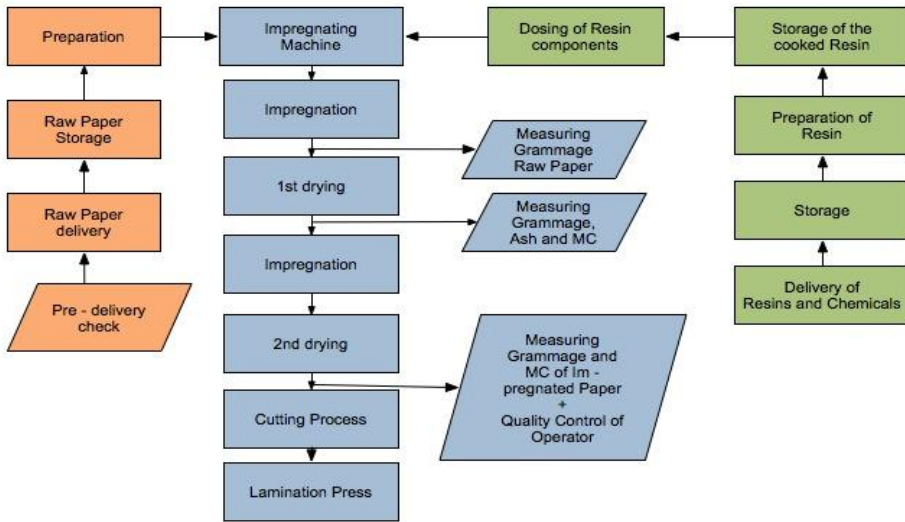
Figure 1. Process chart of Impregnated paper production

2 METHODS AND RESULTS

The modeling was done in two steps. In the first step data were collected over a time period of six weeks during the current production process. In this process automated measureable data were collected in the facility and additional data from possible predictors, which have been analyzed in a laboratory, were also collected. On the basis of the collected data, predictors that were statistically significant were identified using multiple linear regression analysis.

In the second step the determined significant output parameters were collected over a time period of six weeks and a multiple linear regression (MLR) model to verify the results of the first experimental model was developed. For the MLR models only automated statistically significant parameters were used to ensure a high and steady quality of the final product. In Figure 2 the improvements in quality control are shown for the two optimized models. In Table 1 all model parameters are shown, as well as the model summary.

Table 1. Model Parameters and Model Summary of the two Models

	Model 1				Model 2			
	Model Parameters				Model Parameters			
	B	Std Err	t	Sig	B	Std Err	t	Sig
Constant	7,084	0,51	12,19	,000	5,257	0,25	20,623	,000
b1	0,046	0,006	7,588	,000	-	0,001	-5,441	,000
b2	-0,029	0,003	-8,875	,000	,033	0,003	10,466	,000
b3	-0,73	0,022	-3,265	,002	-0,04	0,019	-2,128	,035
b4	-0,008	0,001	7,546	,000				
	Model Summary				Model Summary			
R	0,92				0,786			
R2	0,851				0,618			
Adj. R2	0,838				0,610			
Std Err. of Estimates	0,16926				0,34261			
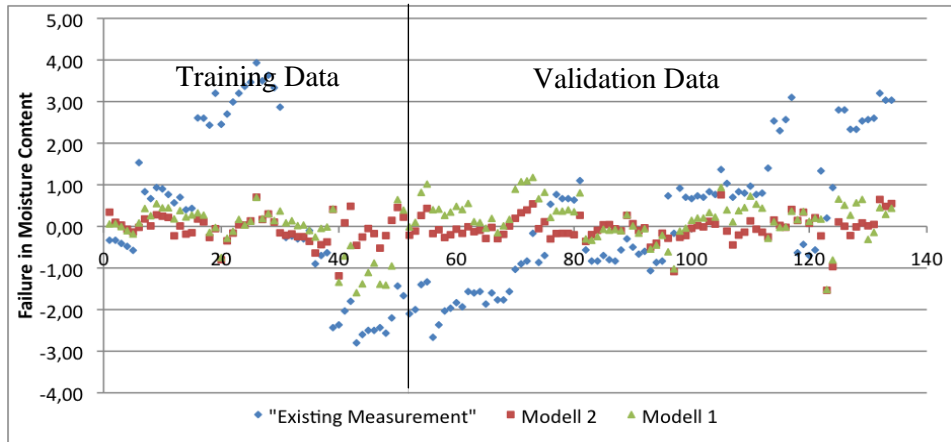
Figure 2. Improvements in Quality control

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Enhancing southern pine plantation timber value yields via integration of Lumber Product Systems

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ABSTRACT

This paper provides invaluable insights into the economic desirability of horizontally integrating a chipper-canter mill with a dimension lumber mill in converting plantation-grown southern pine timber into lumber and marketable chips. In this study, the chipper-canter mill produces squared timber products (e.g., 4x4, 4x6, 6x6, etc.) and chips from about 20,566 cu.ft. of logs per 8-hour shift . About 56% of this log input comes in the form of tree-length logs with a maximum dbh (inside bark) of 10 in. and 44% comes as top logs with a maximum large-end diameter of 8 in. from the existing dimension mill which produces dimension lumber and wood chips from about 37,500 cu.ft. of sawtimber per 8-hour shift. On average, the estimated weighted average incremental value yield engendered by the integrated production system (compared to a dimension mill) could be about $0.30 per cu. ft. of log input, based on 3rd quarter 2009 prices. There is a reasonably high probability (approximately 68%) that it could be as low as $0.20 or as high as $0.41 per cu.ft. of log input. About 60% of this could be attributed to the conversion of re-routed (from dimension mill) tops into wood chips and squared timber instead of dimension lumber, and the other 40% to improvement in conversion efficiency due to the processing of relatively larger sawlogs (with minimum small-end diameter of 8 in.) at the dimension mill. Assuming that the dimension mill was operated at 80% capacity, the potential incremental value yield of the integrated lumber production system could be about $6,465 per 8-hour shift, on average. And there is approximately a 68% chance that it could be as low as $4,162 or as high as $8,768 per 8-hour shift. Additional increase in expected net revenue in the form of log input cost savings (about $0.29/cu.ft. of log input or $2,825 per 8-hour shift, on average) could accrue if "super pulpwood" instead of chip-n-saw logs were purchased for the chipper-canter mill. The estimated maximum rational investment (MRI) for the chipper-canter mill operating at 80% capacity most likely could be about $38.5 million, assuming a minimum acceptable rate of return of 8%, a 10-year life, and 3 daily shifts for 300 days per year. There is approximately a 68% chance that it could be as low as $24.8 million or as high as $52.2 million. As

determined via regression analysis, MRI increases (or decreases) with investment life by about \$1.5 million per year, on average. Clearly, such an integrated system of producing lumber could potentially enhance sawmill profitability and competitiveness and provide increased revenues for timber producers and suppliers/forest landowners from otherwise undervalued or underutilized plantation-grown timber, particularly those that are known to have high juvenile wood content. In the final analysis, this will lead to forest conservation through more efficient use of timber resources.

Keywords: sawmill integration, chipper-canter mill, dimension mill

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Tannin based foams and its derived carbon foams

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ABSTRACT

Tannin-based rigid foams are networked structures obtained by polycondensations of polyflavonoid tannins and furfuryl alcohol.

Carbon foams have been obtained by pyrolysis of such a natural precursor. Physical and chemical properties of both, tannin foams and derived carbon foams have been evaluated.

Tannin foams have shown interesting properties such as their strong resistance to fire, their high water uptaking and their remarkable low thermal conductivity. During the carbonization process (900°C for 2h under nitrogen flow), the foams rearrange to "glass-like" carbon foams. This vitreous carbon material has good electrical conductivity, low thermal conductivity and good mechanical strength.

All the most important features of these organic and carbonized foams are reported and discussed in this poster. Some suggestions about future applications are also proposed.

1   INTRODUCTION

Tannin-based rigid foams are obtained from polycondensation of a formulation containing 95% natural products. These materials are resistant to fire to the same extent as synthetic phenolic foams. They are already known for their application as floral foams [1] and more recent studies have shown their properties as insulation material and heavy metal scavenger [2].

Carbon based tannin foams are obtained from carbonization treatment of tannin foams. This process is a thermal treatment of the organic sample at 900°C for 2 hours under nitrogen flow. The carbonized foam presents all the characteristics to be considered "vitreous" [3].

The goal of this poster is to classify these new materials related to the actual market and to introduce further suggestions for increasing properties and for industrial scaling up.

2 RESULT AND DISCUSSION

Tannin and carbon foams are extremely porous (ca 95%) and light materials (0,05-0,15 g/cm³), with high amount of open cells. Dimension of the cells is 100-300 μm for the organic and 50-150 μm for the carbon foams. Surface area is quite low (0,8 m²/g). Intrinsic properties of tannin-based and derived carbon foams are similar [2].

Conversely, extrinsic properties are often different. Mechanical properties such as compression resistance and elastic modulus shows that the carbonized foams are around double stronger than the organic. Thermal conductivity tests have shown that both the foam have a very low conductivity of 0,02 to 0,04 W/m.K. Electrical conductivity of carbon foams is around 1,3 S/cm while the organic foam do not conduct electricity.

All these properties have allowed to better understand the behavior of these new foams and to propose these materials for several applications.

3 CONCLUSIONS

Tannin based rigid foams can be proposed as insulation material, heavy metal adsorber, floral foam or shock absorber. Low cost (ca 2-4 €/Kg) and natural formulations have created a strong industrial interest on this tannin based foams.

The derived carbon foams are also remarkable. They have a competitive price compared with the other vitreous carbon foams. Such foams can be used as porous electrodes, catalyst supports, adsorbent materials for liquid or gas purification, impact, energy or acoustic absorbers. Additional applications could be resistance to thermal shock, electromagnetic interference shielding, vibration damping or ablation in space programs for protection of re-entry vehicles.

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Determination of some influencing Parameters in the Rotational Wood Dowel Friction welding process for the use in handcrafted solid wood furniture production

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ABSTRACT

Wood welding is probably the most innovative system to obtain wood-to-wood joints of the last decays.

Rotational welding basically consists on induced heat produced by friction of high-speed rotation dowel in a drilled hole with smaller diameter.

Oligomeric and polymeric materials begin to melt when temperature increases over 180°C. Solidification of the melted wood after cooling and pressure leads to densification of the bonded interface [1], [2].

Nonetheless this technique is not reported used industrially because the industrial machineries and processes are not yet optimized and adapted to the rotational dowel welding characteristics.

This poster shows advantages and disadvantages in the joint when welding is produced by manually operated cordless screwdriver instead of the classic static drill. The most important factors for quality of the joint are mentioned and analysed.

1   INTRODUCTION

Welding of wood is caused by melting and flowing of lignin and hemicelluloses at a temperature of over 180°C. It has already been observed that the temperature increasing rate is one of the most important parameters in wood welding [3]. There are two effects that participate to create the welding-joint: Physical and chemical one. The physical effect is due to melting and a subsequent solidification of the glue line whereas the chemical effect consists in cross-linking of wood oligomers and polymers.

Previous work has shown that the tensile strength of wood welded bond- lines can even achieve better results than the ones glued with polyvinyl acetate [4].

In our work, the rotational friction to weld the dowels is applied using cordless screwdrivers (Bosch GSR 18 VE-2LI, PROTOOL DRC 18-4 TEC LI) with

1800-1850 rpm in manual mode. Beech wood fluted dowels of 10mm in diameter are used.

The two-block joining of several wood species has been tried and beech has been selected as the most meaningful one.

The goal of this poster is to show which results can be achieved by easy-handling manually operated cordless screwdrivers instead of the classic static drills.

2   RESULT AND DISCUSSION

Tensile strength depends essentially to relation of dowel/substrate hole diameter. A further notable parameter is the welding time. In two-block beech samples the combination dowel/substrate hole diameter 10/9-8 with welding time of 3 sec gives values in of Ø 3,11 ±0,47 N/mm².

This result is slightly higher than the one of the samples glued with polyvinyl acetate (Ø 2,88 ±0,26 N/mm²), according with results reported in literature for static machines [4].

When dowels are impregnated with furfuryl alcohol, tensile strength increase up to Ø 3,21 ±0,53 N/mm². Despite the longer welding time of 10 sec needed in this case, the value has to be considered interesting because the process uniformity seems to be much better.

The characteristics of this joining technique and the most influencing parameters related to the process when using manually operated cordless screwdrivers can be seen after these series of tests. Data analysis confirms that several applications can be proposed.

3   CONCLUSIONS

The rotational wood dowel friction welding process can be recommended for joints of wooden elements in cabinetry, furniture, wooden walls, ceilings and interior constructions.

This easy-handling technique is considerably fast and it has almost no waiting time after the formation of the bond line (the strength of the joint can be considered complete after 5 min conditioning time).

Welding drills can be successfully used after a few recommendations.

The whole process is up to 100% environmentally friendly, since only wood is used and no additional materials have to be introduced.

Increasing interest is recently coming out for furniture made by 100% wood because they are easy to manage also for recycling issues.

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Thermal modification of particleboard for dimensional stable product

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ABSTRACT

Thermal modification of wood proved to impact the dimensional stability, the property that is criticized when particleboards are in question. In this paper we are going to present the impact of thermal post-treatment of particleboards on 24-hour thickness swelling. Melamine-urea-formaldehyde bonded commercial particleboards were exposed to the temperatures 180, 210 and 240° C for 10, 20, and 30 minutes. Thickness swelling was studied. We determined that there is a difference between thickness swelling with regard to the temperature and time of exposure. We determined better dimensional stability (lower thickness swelling) of thermally modified particleboard. Such a treatment can be recommended as a method for improvement of particleboard performance when exposed to the high humidity environment.

1   INTRODUCTION

Dimensional stability is among formaldehyde emission among most criticized properties of particleboards. When particleboards are exposed to water or environment with high moisture content, they tend to swell and expand in all directions. The degree of swelling or expansion depends on the type of wood species used for particles, type and share of adhesive used, and the time of exposure and pressure used in hot pressing. Due to hygroscopic behavior of particleboards its usage in a humid environment is often limited.

Thickness swelling of particleboard is affected by wood itself (reversible swelling) and pressing conditions (irreversible swelling) [1], [2], [3]. In order to minimize thickness swelling we have to find a way to minimize both or at least one of mentioned factors. The hygroscopicity of wood can be reduced by chemical modification or even degradation. Such degradation can also occur when wood is exposed to high temperature. [4], [5]. With thermal treatment the internal compression stresses generated during hot pressing of the board can be released. When wood polymers such as lignin are exposed to temperature below viscoelasticity transition temperature (Tg) they are in a glossy state, but when they are exposed to the temperature above Tg they are in a viscous state – they

183

perform as a viscous polymer. Dou to less stiff particle matrix compression stresses can be released hence lower swelling. [5]

There are many reports on improvement of dimensional stability of board by thermal modification. Some of them are focused on treatment of particles prior blending and pressing (pre-treatment) and some of the to post-treatment of consolidated boards. [5], [6], [7], [8]

The aim of this paper is to present the impact of thermal post-treatment of commercial particleboards on 24-hour thickness swelling.

2   MATERIALS AND METHODS

Ten melamine-urea-formaldehyde bonded particleboards samples, size 500×500 mm, thickness 22 mm and density 650 kg/m^3 were obtained from industrial batch.

Boards were treated at three different temperatures (190° C, 210° C and 230° C) and three exposure times (10, 20 and 30 minutes) in a laboratory single opening hot-press. To prevent compression of boards during exposure distance bars were used. After the treatment boards were kept at room temperature to cool down, afterwards 8 samples 50×50 mm^2 were cut out for thickness swelling determination.

Thickness swelling was determined by 24-hour immersion in water. [9]

3   RESULTS

We have determined that thickness swelling is influenced by the time and temperature of thermal treatment (Figure 1).

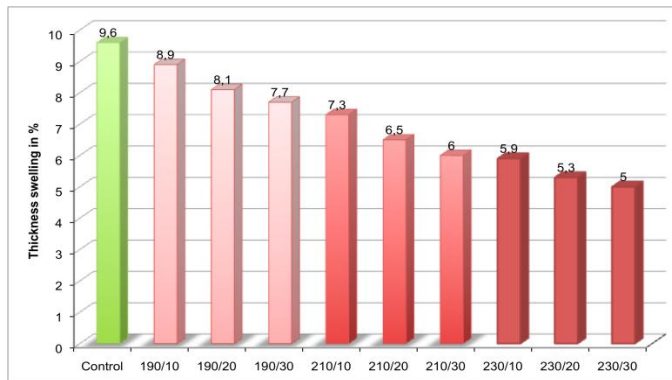**Figure 1.** Thickness swelling with regard to the time and temperature of treatement

As we can see the thickness swelling decreases with increasing temperature of treatment and time of exposure. It can be seen that even "low" temperature and short time of exposure reduces thickness swelling. At higher temperature the time of exposure doesn't affect the thickness swelling as much as at lower temperature.

4   CONCLUSION

We can see that thermal post-treatment of particleboards can be used to decrease their thickness swelling.
We have determined that thickness swelling decreases with increasing temperature of treatment and time of exposure.

5   ACKNOWLEDGEMENTS

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Estimation of firewood usage in Kosovo – Perspectives for future development

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ABSTRACT

This poster deals with the allocation of forest resources and the customers of firewood in Kosovo. It is shown that the demand of firewood as an energy source is higher than the sustainable firewood quantities available from the forest. Kosovo has to solve the upcoming shortage of firewood ressources to be able to guarantee a sustainable forest management and the economic development of the country.

1 INTRODUCTION

For the year 2008 the primary energy consumption of Kosovo is balanced with 2,353 ktoe by the Ministry of Energy and Mining of Kosovo. The main source is coal, as there are important lignite sources in Kosovo. The amount of wood as primary energy source is estimated to be 417 ktoe and amounts to more than 17% of the total primary energy consumption. Forecasts of the Ministry of Energy and Mining of Kosovo predict that the consumption of biomass will decrease until 2018 down to 138,1 ktoe per year. This decrease will be due to lower availability of fire wood as a result of recent over utilization of the forests. This estimation is alarming and for the Ministry of Agriculture Forestry and Rural Development of Kosovo the question of ressource planning for firewood supply is vital.

2 METHOD

This paper starts the discussion of strategies to improve the firewood supply in Kosovo. The recent situation of energy demand and usage is analysed by a questionaire of 1204 households in Kosovo. This study delivers the basic data to know the demand and the allocation of demand of firewood.

To estimate the need of wood for technical use a representative sample of 124 companies of the forest products industries are asked about their wood and energy consumption. Based on the data a linear optimization model is devel-

oped to optimize transport from the region where the wood is growing to the region where it is needed.

3 RESULTS

The data shows qualitatively, that the firewood resources are not situated where the main demand is allocated (see Figure 1). The highest undersupply with values of 100.000m³ is within the districts Prishtine, Prizren, Ferizaj and Peje while the districts with reasonable oversupply are Leposavic and Zubin Potok (approx. 100.000 m³).

| (a) | (b) | (c) | (d) |
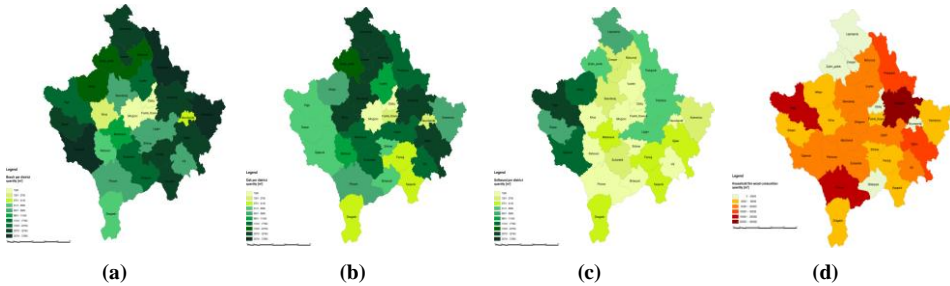
Figure 3. Qualitative comparison of firewood resource (a-beech, b-oak, c- softwood) and demand allocation(d) (the darker the color the higher the quantity)

Most of the wood is heated in wet conditions and according to the questionaire, the majority (90%) of the population is not interested in more efficient thermal insulation of the buildings. This leads to an increasing demand in the future even if the recent need cannot be satisfied in a sustainable way. No pellets or wood chips are used for heating. It is shown that most of the waste wood is used within the companies to cover their own demand. So it is expected that the increasing energy demand of private consumers cannot be satisfied by industrial waste wood in the future. One investigated company stated interest to invest into a briquette press.

As the demand succeeds the quantity of sustainable harvested wood, for the linear optimization model, find the objective function in Eq. (1), a pseudo supplier is included (to achieve the linear equation system).

$$\sum_{j=1}^{n}\sum_{i=1}^{m} c_{i,j} * x_{i,j} \longrightarrow min$$

j ... resource locations, $\quad i$ ... destinations, $\quad c_{i,j}$...cost factors, $x_{i,j}$... transported quantities

(1)

4   CONCLUSION

The results show that Kosovo is in a critical situation concerning the energy supply. The lack of energy resources is leading to illegal cutting by the citizens of Kosovo. To guarantee a stable development these problems have to be solved by forest management and reduced energy consumption (especially by improved building standards).

A model to predict bond strength during hot-pressing of Particleboard

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ABSTRACT

The development of procedures for monitoring the hot-pressing process is very important to identify the best pressing conditions to meet a certain objective, without compromising board quality. A simple dynamic model, which predicts the evolution of elasticity modulus and viscous component along the press cycle, was developed. The compression stress, thickness and temperature were monitored. Fitting the model to this data, it was possible to detect important events that occur within the mat, as resin hardening, as well as to predict the internal bond of the final panel.

1   INTRODUCTION

Environmental requirements and new products specifications, have forced producers to find new taylor-made gluing solutions, without loosing productivity and quality. To ensure the success of those tailored gluing systems, the correct scheduling and rigorous control of the hot-pressing process should pursued. Commonly, the scheduling of pressing cycle is made empirically, through trial and error trials in the production line to adjust the pressing program to changes in resin binder. This process is expensive, slow and validates only a set of equipment/material [1]. A phenomenological approach can overcome these limitations, but experimental data is still needed for parameter estimation and model validation. A few models can be found in the literature for the rheological behavior during hot-pressing [1], [2], [3], but also to predict resin cure [4]. The mattress rheological behavior during pressing involves complex phenomena that are dependent on mat internal conditions. Bond strength development during hot pressing will be dependent not only on resin characteristics, but on

the operating conditions. The panel will fail, at least locally, when internal stress (including densification stress and steam pressure) exceeds the bond strength of partially cured adhesive joints.

2   MODEL DEVELOPMENT

From the experience already acquired in the modeling of the hot-pressing process [3], a dynamic model was developed to predict the evolution of compression stress, strain, modulus of elasticity along the press cycle. This model is based on Maxwell model (viscoelastic behaviour) and the parameters were estimated from experimental data obtained during the hot-pressing (compression stress and thickness versus time).

3   EXPERIMENTAL

Three-layer particleboard (PB) panels were produced in a laboratory scale hot-press, controlled by computer. A standard wood mix, for face and core layers, was provided by a PB manufacturer. Three different formulations of UF resins were used as adhesive (see Table 1).

Table 5.   Technical data for UF-resins

Resin	Origin	Molar ratio F/U	Reactivity (s)	Viscosity (25°C) (mPa.s)
UF1	commercial	1.0	80	200
UF2	laboratory	1.0	48	210
UF3	laboratory	1.0	45	130

The pressing cycle was scheduled in order to simulate a typical particleboard continuous pressing operation. Using a pressure transducer, LVDT and thermocouples, the compression stress, thickness and temperature were monitored during the press cycle. After pressing, the internal bond (IB) was evaluated (EN 319).

4   RESULTS

Figure 1 presents the variation of the elasticity modulus and viscous component, as well as internal stress changes (corresponds to events occurring in the mat) along the press cycle for a good quality and for a lower quality panels.
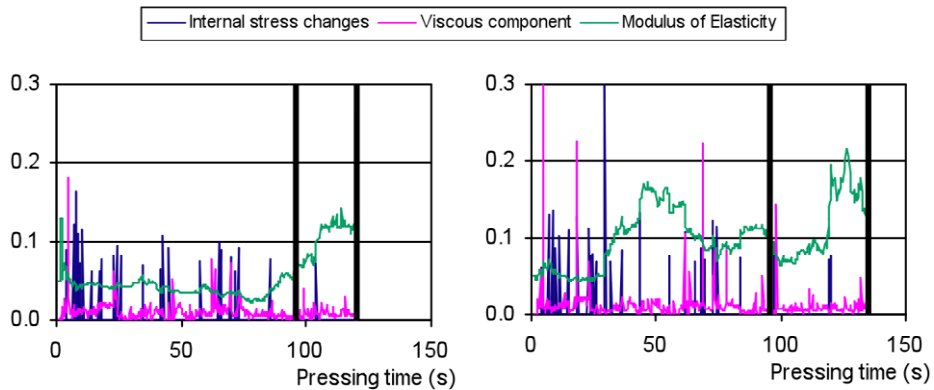
Figure 1. Variation of the elasticity modulus, viscous component and mat strength development for two panels (left: IB=0.26 MPa right: IB=0.41 MPa)

In Figure 2, mat strength development predicted by the model versus IB of the final panel is presented for three different resin formulations and four pressing cycle times (platen temperature was constant). The model seems to fit well the internal bond of the final panel.
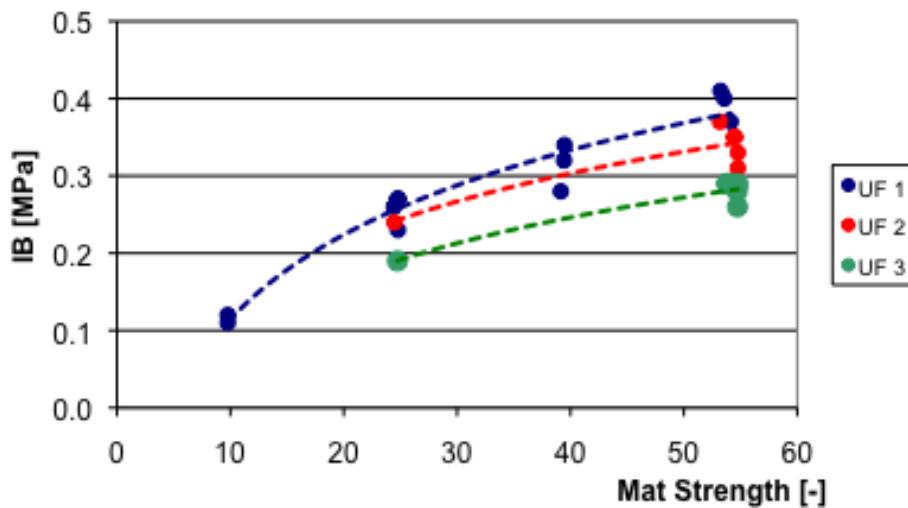
Figure 4. IB of the final panel versus mat strength development

5   CONCLUSION

The model was able to detect important events that occur during the hot-press, not only inside the panel (compactation, steam formation and resin cure), as well as in the press (closing, venting, intermediate compression and opening). The model also permits to predict board quality (internal bond) using the in-

191

crease of an apparent elasticity modulus, calculated using experimental data obtained during the hot-pressing (compression stress and thickness along the press cycle).

6   ACKNOWLEDMENTS

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Characterization of reinforced adhesives for Particleboards

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ABSTRACT

The bonding strength of two component binder systems based on melamine resins was analyzed due to the fact that these binder systems are able to show lower formaldehyde emission than common urea formaldehyde resins. For a rapid evaluation of their bonding strength the tensile shear strength of longitudinal adhesive bonds was measured. To reduce the reported occurrence of wood failure [1] the method was optimized. It is shown that the measured shear strength correlates with the corresponding flexural strength of prepared particle boards.

1   INTRODUCTION

The particle board industry is looking for cost-effective binders which, on the one hand, conform to standards of low formaldehyde emission and, on the other hand, meet the specifications of mechanical strength for load bearing boards in wet conditions. The answer to this problem could be a combination of different binders with complementary properties.

2   METHOD IMPROVEMENT

The shear strength of different adhesives was measured in tensile mode related to European Standard EN 205. For reduced wood failure the adhesive application was reduced to 50-60 g m^{-2} and beech veneer with a smooth surface and a thickness of 2.5 mm was used. An overlapping area of 300 mm² minimizes deviation. Furthermore wood failure is reduced by increasing the length of restraint to 180 mm. Pressing temperatures were varied at a fixed pressing time of 60 s and bonding pressure of 0.25 MPa. Series of one-layer laboratory particleboards of 350 x 350 x 10 mm³ dimension were prepared with 10% solid resin content by hot-pressing for 120 s at 2 MPa pressure using industrial middle layer wood flakes. Flexural strength was tested according to EN 310.

3   RESULTS AND DISCUSSION

Blended adhesive systems need much lower pressing temperatures than single adhesive systems based on thermosetting resins. Figure 1 shows the shear strength of an adhesive system consisting of a melamine resin A and a formal-

dehyde free binder B. At lower temperatures the shear strength is increasing by adding binder B. Shear strength of the pure melamine resin is also increasing at higher pressing temperatures as it has been expected.
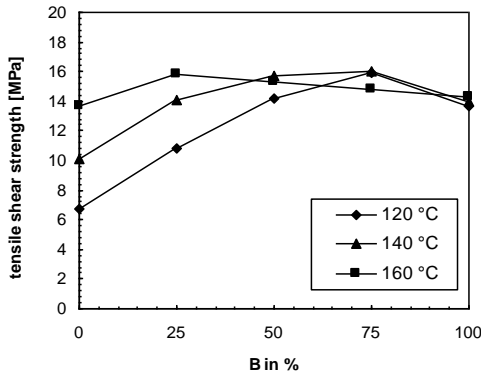
Figure 1.   Shear strength of two component adhesive system (melamine resin A + binder B)

In contrast to automated bonding evaluation system (ABES) test [2] tensile shear strength shows a better correlation with particleboard properties (Figure 2), because the test specimens were tested after post-curing. However the corre-

lation is strongly depending on the used adhesives. Blends of melamine resin with formaldehyde free binders were tested.
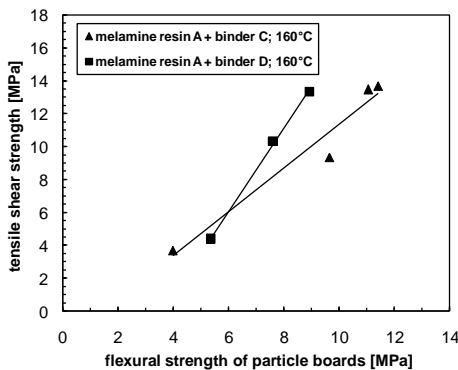
Figure 2.   Correlation of tensile shear strength of adhesive bonds with flexural strength of particleboards at a pressing temperature of 160 °C (melamine resin A + binder C or D with different melamine and binder contents)

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Bio-adhesives based on lupine proteins for Green Building

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ABSTRACT

Formulations of bio-adhesive based in lupine protein (BALP), without formaldehyde, were prepared. The compositions of the BALP formulations were 7/14/1/30 (w/w) for lupine/urea/Poli(amide epichlorohydrin) (PAE)/waters, respectively. Initially, lupine flour is denatured with urea at $80^{\circ}C$ subsequently; the products of denaturalization are crosslinked with PAE. The BALP bio-adhesive can be considered as an aqueous dispersion of modified lupine flour with a crosslinking agent. The synthesis was realized in batch system and the characterisations of the dispersion are determined by solids percentage 30-43%, viscosity 100-1100cPs and pH in the range of 10-8.0. Particle boards (PB) with density $640Kg/m^3$ and 15mm of thickness were made using 8.1% (w/w) of lupine-urea precursor and lupine-urea-PAE. These PB were used to determine the emissions of formaldehyde, Internal Bond (IB) and swelling. The results were compared to PB made from urea formaldehyde resins (UF). The results indicate that it is possible to obtain PB with low formaldehyde emission using BALP bio-adhesive and the board properties are comparable to those obtained from traditional UF resins.

1 INTRODUCTION

At present the LEED legislation and CARB standards guidance is focalized on technology and quality requirements for PB that are used inside homes in green construction[1-2]. The orientation is to obtain boards that emit formaldehyde comparable to that emitted by the pure wood, using raw materials from renewable sources. To answer this guidance the adhesive industry has incorporated new technologies including; innovative gluing systems of resins and chemical addi-

195

tives, advanced technology for resin synthesis and efficient monitoring and control of the synthesis parameters. However, the higher innovation is mainly based on the development of adhesives made from biomass or by-products agro-industrials, free of formaldehyde, NAF system. The first adhesive of this new generation is prepared with proteins presents in soy flour[3]. Similarly, this paper explores the possibility to use lupine protein for making adhesives without formaldehyde, NAF system, enabling manufacture PB useful for building green.

The Table 1 shows the composition of amino acid reactive present in soy and lupine flour.

Table 1. Amino acid reactive for Soy flour and Lupine flour

Soy Flour			Lupine Flour	
Amino acid reactive	%		Amino acid reactive	%
Aspartic/Asparagine	6	COOH	Aspartic/Asparagine	4.6
Glutamic/Glutamine	9		Glutamic/Glutamine	9.8
Serine	2.8	-OH	Serine	2.2
Theonine	2		Theonine	1.4
Cysteine	0.7	-SH	Cysteine	0.8
Methionine	0.7		Methionine	0.2
Lysine	3.3		Lysine	2.0
Arginine	3.7	Amine	Arginine	5.3
Tyrosine	1.7		Tyrosine	2.2
Histidine	1.4		Histidine	0.8
Total Reactive	31.3		Total Reactive	29.3

The presence of –COOH, –OH, –SH and amine groups in amino-acid can be used to promote reaction with the functional groups of cellulosic component present in wood fiber. It can be also used for promote cross linking reaction with specific reactive (PAE). The Table 1 does not show significant differences in the total amount of amino acid reactive (a.a.r.). Differences are observed between proportions of each type of a.a.r. The quantity of a.a.r. with -OH and -SH groups are lower in lupine flour, around 25 and 28%, respectively. However, it presents more a.a.r. with –COOH and amine group, around 25% more. This feature should allow the use of lupine proteins as raw material for making adhesive, because the presence of functional group such as; carboxylic acid and amine is also very important to produce covalent and no-covalent interactions among the adhesive and functional group present in the components of wood fiber. The Table 2 present the characteristic of adhesive and properties of PB obtained with these adhesive.

Table 2. Characteristics of adhesives and properties of PB

	UF	Lupine-Urea	Lupine-urea-PAE
Solid (%)	65	43	32
Viscosity (cPs)	350	1060	108
pH	8.2	10	8.3
IB (N/mm^2)	0.68	0.2	0.68
Swelling 24h (%)	17.4	57.9	17.7
Emission (mg H_2CO/100g board)	8.0		0.07

The precursor of bio-adhesive, lupine-urea (7/14 with 30 water), has a high viscosity for a relative low percentage of solid. Nevertheless, the addition of crosslinking agent PAE to lupine-urea to obtain the bio-adhesive lupine-urea-PAE (7/14/1 with 30 water) allows to use adhesives with lower percentage of solids in order to reach the adequate viscosity. The results of mechanical properties between PB obtained from UF and Lupine-urea-PAE do not present significant differences. The difference in swelling essay between the Lupine-urea precursor and the lupine-urea-PAE bio-adhesive is attributed to the presence of PAE. This better response is attributed to the formation of hydrophobic bond promoted by PAE. However, the bio-adhesive allows to produce PB with emissions 110 times lower than those emitted by PB made with UF. This feature is attributed to the absence of formaldehyde in the formulation of bio-adhesive.

2 CONCLUSION

Lupine flour could be a very interesting alternative as raw materials from renewable sources for making adhesives free of formaldehyde. However, it is necessary the presence of cross linking agent to improve the properties. Bio-adhesive based in lupine protein can be used to produce PB with low emission of formaldehyde. These PB can be use in green building for interior use.

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Automated grading, upgrading, and cuttings prediction of surfaced dry hardwood lumber

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1   INTRODUCTION

In today's hardwood sawmills, most cutting and grading decisions are performed manually. Edger and trimmer operators typically make sawing decisions based on fast visual examinations of each board, or the processors have scan-controlled saws that base decisions on just wane and void (incomplete information). Each board is then assigned a grade manually, based on a visual assessment of the board by a person. A board's grade depends on estimates of its surface area, the type and placement of defects, grade cuttings and current market prices for lumber [2].

Automation is essential to create high value accurately graded products, and for conservation of raw materials. We have developed a prototype system that scans wooden boards and automatically detects wane and defects. Using defect information and board dimensions, the system grades, and edges and trims the board to upgrade a higher value if possible. We also processed the results in a lumber-to-cuttings simulator to predict cutting yields for products such as flooring, furniture and cabinets. This paper presents an evaluation of our scanning system.

2   PROTOTYPE SCANNING SYSTEM

We developed the scanning system used in this study. The camera is aimed vertically downward, and is positioned to capture a field of view that is 16 inches (41 cm) wide. Image resolution is 96 pixels/inch, which is approximately 0.26 mm per pixel.

The system operates by first detecting wane, and then identifying clearwood and defects on the non-wane portion of the board. For defect detection and identification, the system uses a modular approach that employs several different artificial neural networks (ANN). The system analyzes shapes of defects to distin-

guish splits from voids and also to determine mechanical stains. Edging and trimming locations are determined using a branch-and-bound search technique. The result is not guaranteed to be optimal, but is typically close to optimal and is found in about 4 seconds on average. The hardwood lumber grades are illustrated [1] using the National Hardwood Lumber Association grading rules [2]. The assignment of the correct grade is important because each grade has a vastly different monetary value.

3 EXPERIMENTAL RESULTS

Figure 1 shows some example scanned images and the defect-detection results. Table 1 shows the results of the lumber grading part of our system. Eighty-six yellow poplar board faces were scanned and analyzed. Almost 50% of the board faces received the same or a higher grade than the company grades, and 43% of the boards could be upgraded to a higher and more valuable grade by additional edging or trimming as determined by our software.

For the 90 red oak board surfaces analyzed, 64% received the same or a higher grade. Upgrading was possible for 41% of the boards, through additional edging or trimming. While most of the higher grades are debatable, as the grading outcomes may vary from one grader to another, the reasons for lower grades assigned by our system are clear. The system occasionally classified natural stains as defects such as knots or decay. The other major cause of downgrades was mechanical stains. We also used the ROMI-RIP software [3] to simulate production of cuttings from the boards. This analyzes how the boards can be used to produce parts for flooring furniture, cabinets and other products.
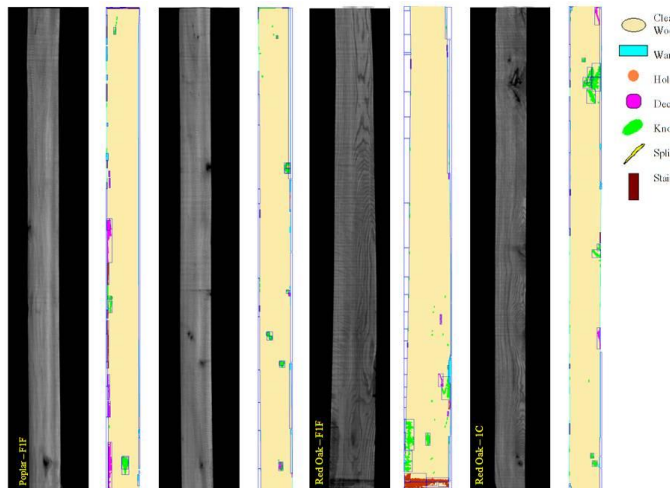

Figure 1. Experimental results for poplar and red oak boards

Table 1. Lumber grading results from the company grading and from our automated system

Species	Company Graded Board	No. of Boards	Same Grade	Higher Grade	Lower Grade	Upgrade Possible
				Scan & Grade vs. Company Grade		
Yellow Poplar	FAS	36	17	0	19	15
	1C	29	1	8	20	15
	2C	21	14	2	5	7
	Total	86	32	10	44	37
Red Oak	FAS	27	22	0	5	3
	1C	39	1	14	24	21
	2C	24	16	5	3	13
	Total	90	39	19	32	37

4   DISCUSSION AND CONCLUSIONS

Our system has successfully scanned, reconstructed, graded, and processed yellow poplar and red oak planed kiln dried lumber.

Additional work is needed to fully evaluate the reasons for a significant number of the boards (43%) to be graded lower by our system than had been graded by company graders. Natural stain, in particular, presents a difficult problem because it can be difficult to distinguish from defects based on shape and intensity alone. The ability of our system to accurately measure grading cuttings may be better than can be performed by human graders. We need to recheck the boards to see if the human graders were wrong in their assessment, or if the software has a problem in scanning, reconstruction, or another area.

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Effect of recycled wood and alternative species on Particleboard machining

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ABSTRACT

The aim of this work is to assess the impact of recycled wood and two alternative wood species (*Eucalyptus globulus* and *Populus alba*) on machinability and edge quality of particleboard (PB). Three-layer boards were produced using several wood mixes and then cut using an instrumented multi-function machine. An ANOVA was performed in order to evaluate the significance level of the effects of several factors, wood mix and operating conditions, on machining conditions (power consumption and cutting forces) and particleboard edge quality.

1 INTRODUCTION

In Portugal, due to the shortage of raw materials, wood-based panels companies were forced to the use of alternative species and recycled wood. This situation leads to an increase raw-material supply fluctuation, demanding a more rigorous control of the production processes in order to fulfill the specifications/properties of these products. The evaluation of the performance of PB is traditionally based in the measurement of its physico-mechanical properties, but for end users (furniture and joinery industries), the machinability is gaining importance. In fact, this operation often endangers the prestige of these products causing the crumble of the edges. An important aspect is thought to understand the effects of panel composition and operating conditions on edge quality of PB. Several works have been presented in the literature about the machinability of solid wood, but the machinability wood-based panels is less studied [1], [2].

2   EXPERIMENTAL

Three-layers boards were manufactured using different wood mixes with euca-lypt, *Eucalyptus globulus* (mostly bark) and poplar, *Populus alba*. For the face layer (FL), a standard mix, provided by a PB producer was used. For the core layer (CL), two kind of mixes were prepared: Mix1-standard mix (25% *Pinus pinaster* + 15% *E. globulus* + 30% sawdust + 30% recycled wood) + *E. globulus* (0, 10, 20, 30 %); Mix2- *P. alba* (0, 10, 20, 30 %)+recycled wood (45%)+ *Pinus pinaster*. Urea formaldehyde resin was used as adhesive (the gluing factor was 6.3% for FL and 6.9% for CL based on oven-dry weight of wood). Boards were hand-formed in metallic containers with 220x220x80 mm and pressed in a laboratory hot-press controlled by computer and then tested for several physi-cal-mechanical properties. For cutting the boards, the sawing element of a semi-automatic 5 heads multi-function machine was used. The machine was instru-mented with a high performance vector AC drive, a current transducer and a pair of low-cost Murata piezoelectric sensors. Their data were collected using a high-speed data acquisition system permitting to measure the power consump-tion and the cutting force. For edge quality evaluation, an innovative artificial vision system was constructed, which permits, after numerical treatment, to establish an edge quality criterion [3].

3   RESULTS

Table 1 presents the results of ANOVA for the *Eucalyptus globulus* mix.

Table 6. ANOVA table for the *Eucalyptus globulus* mix (Mix1) – mean (NS-not signifi-cant, +5%, ++1%, +++0.1%)

Factors	DF	SS	F ratio	p-value	Significance level
Internal Bond (MPa)					
Pressing time (s)	1	0.1166582	154.5532	<0.0001	+++
Gluing Factor	1	0.0601262	79.6574	<0.0001	+++
Mix Eucalypt (%)	3	0.1390204	61.3932	<0.0001	+++
Feet per Tooth (mm)	1	0.0006360	0.8426	0.3606	NS
Density (kg/m^3)	1	1.1872207	1572.875	<0.0001	+++
Edge quality					
Pressing time (s)	1	0.0079239	0.3022	0.5836	NS
Gluing Factor	1	0.1327058	5.0610	0.0264	+
Mix Eucalypt (%)	3	0.2679818	3.4067	0.0201	+
Feet per Tooth (mm)	1	0.0007739	0.0295	0.8639	NS
Density (kg/m^3)	1	5.1497718	196.3980	<0.0001	+++
Power consumption					
Pressing time (s)	1	0.0582182	1.1044	0.2955	NS
Gluing Factor	1	0.1409440	2.6737	0.1048	NS
Mix Eucalypt (%)	3	0.1478567	0.9349	0.4263	NS
Feet per Tooth (mm)	1	0.0989907	1.8779	0.1733	NS
Density (kg/m^3)	1	4.6403731	88.0281	<0.0001	+++

Figure 1 presents the effects of the several factors (pressing time, gluing factor, mix and feed per tooth) on internal bond, power consumption and edge quality of particleboard. As expected, for internal bond, the pressing time, the gluing factor, the *Eucalyptus globulus* mix and density are very significant. For edge quality of boards, the gluing factor, the mix and density are significant. For power consumption, only density is significant.

Table 2 presents the results of ANOVA for the *Populus alba* mix. The feet per tooth is very significant, but not the mix. In Figure 2, the effect of *Populus alba* mix on power consumption and edge quality can be observed.
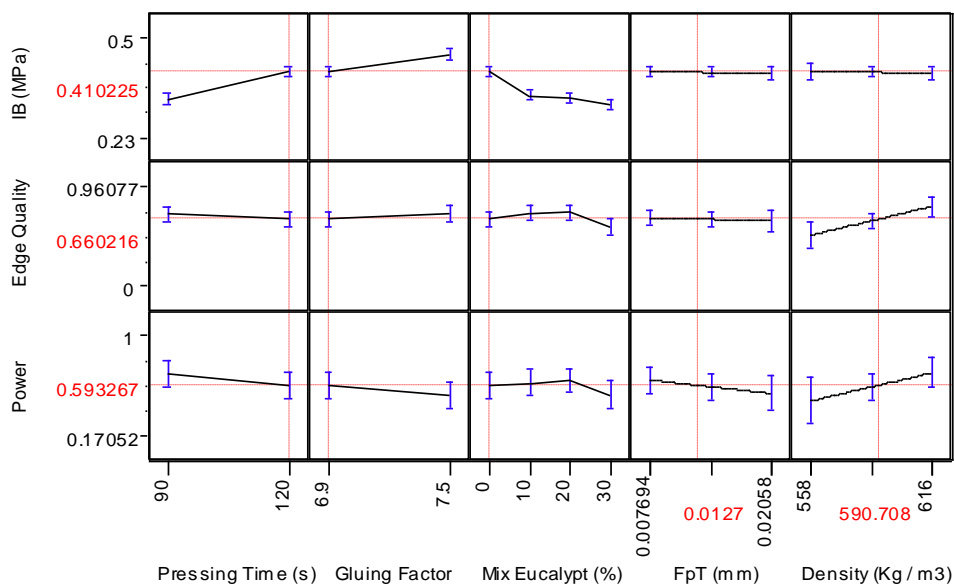

Figure 1. Effects of factors levels on internal bond, edge quality and power consumption (mean) for the *Eucalyptus globulus* mix (Mix1)

Table 2. ANOVA table for the *Populus alba* mix (Mix2) – mean (NS-not significant, +5%, ++1%, +++0.1%)

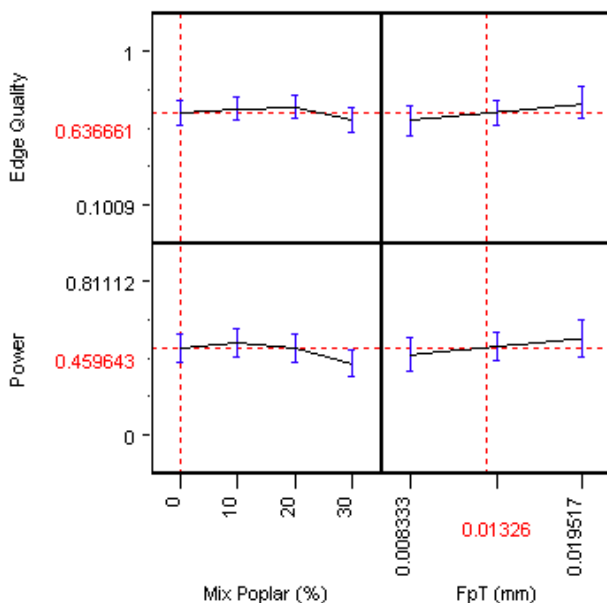| Factors	DF	SS	F ratio	p-value	Significance level
			Edge quality		
Mix Poplar (%)	3	0.122487	0.7730	0.5120	NS
Feet per Tooth (mm)	1	37.621223	712.2451	<0.0001	+++
			Power consumption		
Mix Poplar (%)	3	0.197764	1.5556	0.2055	NS
Feet per Tooth (mm)	1	18.309712	432.0617	<0.0001	+++

Figure 5. Effects of factors levels on edge quality and power consumption (mean) for the *Populus alba* mix (Mix2)

4   CONCLUSION

The use of different wood mixes has an important influence in both edge quality of sawed particleboard and machine power consumption (and consequently on tools wear). The use of these wood species (*Populus alba* and *Eucalyptus globulus* bark), with lower density and lower stiffness than pine, enhance the machinability of particleboards, but reduces their internal bond.

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Improving by reinforcement the deflection of shelves made of Particleboard and MDF

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ABSTRACT

This study was undertaken to determine the effect of the reinforcement on the deflection under static loading of cabinet furniture shelves constructed from wood based panels. The new method was developed on the basis of vertically inserted and glued in grooves elements of plywood with thickness of 6 mm and width of 10 mm. Deflection was calculated theoretically by using FEM and compared by experimentally obtained.

This new method for improving the shelves deflection gives an opportunity (i) for increasing the load capacity or the length of the shelves or (ii) for reducing the thickness of the shelves; it also can be used for other elements of furniture like worktops and desktops.

1   INTRODUCTION

During the last decades wood based panels (WBP) have been widely used in furniture constructions. Shelves in case furniture are often loaded with a high weight, which leads to unacceptable deflection. Studies in related areas have been done by many authors. Eckelman et al. [1] provided a theoretical analysis for the deflection of shelves, case tops, and bottoms. Other authors like Albin [2], Denizli-Tankut et al. [3] and Nikolaeva [4] investigated experimentally the deflection of wood based panels and compared it with the theoretically evaluated deflection. Effect of cyclic humidity on the creep behaviour was investigated by Ozarska et al. [5]; the effect of rail support was studied by Tankut et al. [6]. But only rare information was found in the literature concerning the possibility to improve the deflection of wood based material by using any kind of reinforcement.

2   MATERIALS AND METHODS

In the present study test specimens were prepared from laminated particleboard (PB) with density 673 kg/m^3 and MOE 3464 N/mm^2 and medium density fibreboard (MDF) with density 736 kg/m^3 and MOE 4632 N/mm^2. The size of the shelves was 864 x 280 x 18 mm, most common used for shelves in bookcases. Six series of each 10 samples were prepared: particleboard ("PB") and medium density fiberboard ("MDF") without reinforcement, with two ("PB 2"

and "MDF 2") and three reinforcement strips ("PB 3" and "MDF 3"). The strengthening strips were beech plywood and were vertically inserted into a groove with a width of 6 mm and a depth of 10 mm and glued by PVAc adhesive. Shelves were freely supported and loaded for 28 days with a distributed static load related to 100 kg/m^2, which corresponds to L 50 according to DIN 68874. The elastic deflection was measured immediately after the load was applied and hourly for the first 8 hours; after that the readings were taken daily. Additionally by using the FEM software program SAP 2000 the deflection was evaluated theoretically for six different types of construction of the shelves.

3   RESULTS AND DISCUSSION

The data of the initial and the final deflection as well the theoretically evaluated elastic deflection are given in Table 1. The greatest effect was obtained with MDF and a reinforcement with three elements of plywood, where the deflection was 33 % less compared to the standard shelf. A significant improvement was found also for shelves with two stripes, where the deformation decreased by 20 %. Test samples made by laminated particleboard showed that the reinforcement decreased the deflection with 20 % for three stripes and 13 % for two stripes, both compared to particleboards without reinforcement. The difference of the final deflection between panels with and without reinforcement was slightly higher. It is concluded from this study, that FEM gives a good opportunity for predicting the deflection performance of reinforcement wood based panels; especially in MDF the difference between calculated and obtained values was in a small range of only 15 %.

Table 1. Initial, final and theoretical deflection values of reinforced PB and MDF

No	Type of WBP	Initial elastic deflection (mm)	Final elastic deflection (mm)	Creep deflection (mm)	Percent of initial creep deflection (%)	Theoretical elastic deflection (mm)	Difference initial to theoretical deflection (%)
1	PB	4.58	6.11	1.52	33.2	3.98	15.2
2	PB 2	3.99	5.67	1.67	41.9	3.50	14.0
3	PB 3	3.65	5.18	1.53	41.9	2.87	27.2
4	MDF	3.29	4.17	0.88	26.7	2.95	11.7
5	MDF 2	2.63	3.25	0.62	23.5	2.70	-2.6
6	MDF 3	2.21	2.86	0.65	29.5	2.32	-4.7

The curves for the creep deflection in dependence of time for each type of WBP are plotted in Figure 1. It is clear visible that MDF has a better deflection stability compared to particleboard and shows better long term stability.
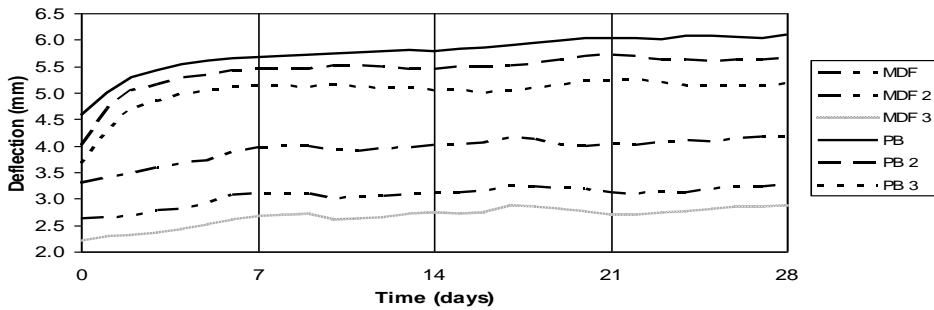
Figure 1. Creep deflection of the wood based panel shelves

4 CONCLUSION

Results from FEM calculations and from the performed tests clearly indicate the considerable improvements of shelf deflection performance of wood based panels under static loading by reinforcement with plywood strips. For MDF the improvement is between 20 to 30 % and for particleboard between 12 and 20%. MDF has about 30 % better deflection stability without reinforcement and up to 40% with three stripes compared to the tested particleboards. In order to develop a better utilization of improved wood based panels as structural elements of furniture, additional research is needed for optimizing the parameters of the reinforcement stripes and some other factors like fit of the joint, adhesive type and quantity applied.

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U.S. Wood Pallet Material Use Trends

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1 INTRODUCTION

A series of five studies conducted by the Virginia Tech Department of Wood Science and Forest Products, in collaboration with the USDA – Forest Service (Blacksburg, Virginia), have tracked activity in the U.S. wood pallet and container industry between 1992 and 2006. The studies determined trends in wood use and pallet production within the industry, both new and recovered. Each of the five studies attempted to include all U.S. companies that were primarily or secondarily involved in the production of pallets and/or containers. For a variety of reasons, not all firms provided data. Therefore, we estimated industry totals using the data collected and an independent measure of industry size.

2 NEW PALLET TRENDS

Most recently over 450 firms, representing over 590 production facilities, provided information about business activity in 2006. Approximately 57 percent of the firms reported that new pallet production was their primary source of revenue in 2006. Recovered, repaired, and/or remanufactured pallets were the primary source of revenue for 25 percent of the firms. Regardless of the primary source of revenue, over three-quarter of responding firms (78.3%) reported that they produced some new pallets and more than one-half (55.5%) were involved in pallet recovery, repair and/or remanufacturing.

On average, production of new pallets was 304,160 per firm in 2006. Approximately 21 percent of the pallets produced in 2006 were heat treated by the manufacturer and less than one percent were fumigated due to export restriction. However, heat treatment or fumigation may occur after the manufacturer sells the pallet.

Over 70 percent of firms utilized hardwood lumber and/or cants in their operations and approximately 62 percent utilized some softwood lumber and cants. Overall, the industry used 63.6 percent (by volume) hardwood and 36.4 percent softwood material in 2006 (Figure 1). This compares to an estimated 68.8 percent hardwood in 1992 and a high of 71.7 percent in 1995. Within the hard-

wood category, 61.2 percent (by volume) of the lumber, cants, and parts used was of mixed species (i.e., no species separation) in 2006. The most commonly utilized single species was oak (26.9% of total hardwood use by volume). Maple accounted for 7.2 percent and other hardwood species accounted for 4.7 percent. The southern pine species group accounted for 53.5 percent of soft-wood lumber, cant and part use in 2006. The spruce/pine/fir species group accounted for another 35.5 percent of use by volume.

We estimate that the industry produced 441 million new pallets in 2006. This level represents a modest 2.8 percent increase over estimated production of 429 million in 1999 and a 7.3 percent increase from production in 1995 (estimated to be 411 million units). The majority of the estimated 441 million pallets produced in 2006 were of the stringer type. Block pallets were approximately 6 percent of production.

While increases in new wood use are associated with increased pallet production, looking only at the use of new wood material can be misleading as it does not illustrate an important trend in the industry that occurred during the period of the studies – increased wood recovery and reuse. This activity will be described next.

3   PALLET RECOVERY, REPAIR, AND REMANUFACTURING

Recovered, repaired, and/or remanufactured pallets were the primary source of revenue for 25 percent of the firms surveyed. Regardless of the primary source of revenue, over one-half (55.5%) of responding firms were involved in pallet recovery, repair, and/or remanufacturing. Clearly, pallet recovery is no longer the peripheral activity it may once have been. Rather, the processing of used pallets has become a large part of many firms in the industry. Industry-wide, the production of used (i.e., recovered, repaired and/or remanufactured) pallets averaged 208,375 units per firm in 2006. We estimate over 357 million pallets sold in 2006.

Firms were asked to indicate how the pallets they received in 2006 were utilized. The majority (67%) were repaired. Almost 16 percent were un-nailed and 10 percent were reused without repair. We found that less than one-quarter of one percent of the pallets received were landfilled. Of pallets that are un-nailed, the largest portion (83%) of the parts was reused in repairing or remanufacturing pallets. Ground or chipped pallets or parts had many uses. Colored landscape mulch is the most common use of ground material at the equivalent of 39 percent of ground/chipped pallets. Almost half (47%) of the firms that grind or chip pallets, used the material for colored mulch. The equivalent of 29 percent of the ground/chipped pallets was used for fuel and 23 percent were used for other (uncolored) landscape mulch. The smaller but potentially profitable animal bedding market accounted for the equivalent of 4.4 percent of the ground/chipped pallets.

4   IN TOTAL

By combining information regarding the use of new wood and the use of re-
covered pallets, we get a picture of how the U.S. wood container and pallet
industry is utilizing a mix of these sources of material to serve its customers.
Figure 2 provides our estimates of the use of new and recovered (used) wood by
the industry from 1992 to 2006. Two trends are evident. First the total amount
of wood material (both new and used) utilized by the industry increased steadily
between 1992 and 2006. The second trend evident in the data is the increasing
importance of recovered material to the industry. In 1992, recovered material
accounted for 13 percent of the wood material utilized by the industry. This
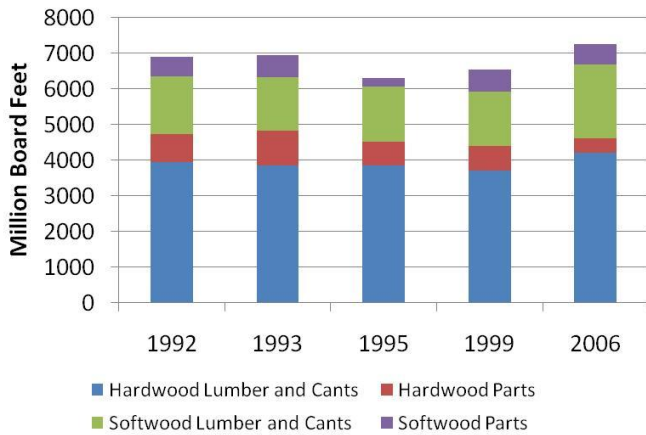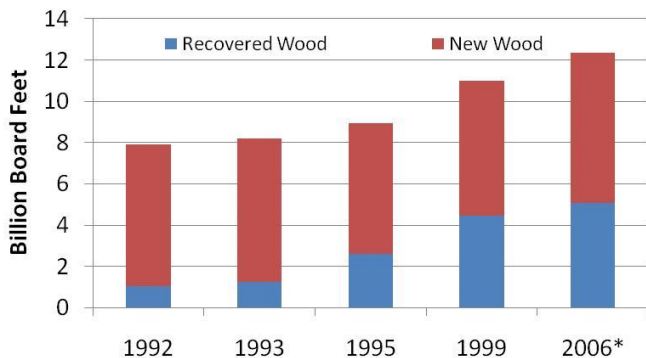grew to 41 percent in 2006.

Figure 1. Estimates of New Wood Volumes Used by the United States Wood Pallet and
Container Manufacturing Industry: 1992 to 2006

Figure 2. Estimates of New and Recovered Wood Use by the United States Wood Con-
tainer and Pallet Manufacturing Industry: 1992 – 2006

Chairs

Marius Barbu

After his studies at the Faculty for Wood Industry, University "Transilvania" Brasov, Univ.-Prof. Dipl.-Ing. DDr. Marius C. Barbu (born in 1967) continued with ÖAAD/DAAD scholarships to be involved in several research projects about wood composites at "Boku" Vienna as well as at the "Ludwig-Maximilian" Munich. He received his first Ph.D. in 1995 in Brasov for his work about wood composites and other materials. In 1997 he received his second Ph.D. at the "Boku" for his work about the manufacture of low-density MDF. Dr. Barbu holds lectures at several European universities and universities of applied sciences and represents Austria and Romania in international technical committees. Furthermore two technical books within the field of wood-based panels have been published. From 2001 on he was in charge of R&D within the Binder Holz Group, Austria. In 2002 he received his call as a professor for the technology of wood-based composites at the University of "Transilvania" Brasov and has worked as a visiting professor at the "Center for Wood Science" at the University of Hamburg, Germany since 2006.

Manfred Dunky

Dipl.-Ing. Dr.mont., Univ.-Doz. at the University of Natural Resources and Applied Life Sciences, Vienna. Study of "Plastics Technology" at the University of Leoben, Austria; during thesis analysis of UF resins as used in the wood based panels industry. In total up to now nearly 30 years experience in the chemical industry (producer of adhesive resins for the wood based panels industry) and directly in the wood based panels industry. Main working topic: connection between adhesives and the properties of the wood based panels produced thereof. Besides these activities in research, publications and presentations at conferences. Chairman of COST E34 and of WG1 in COST E13. Habilitation (venia legendis) at the University of Natural Resources and Applied Life Sciences, Vienna, for Wood Sciences. Author of a standard textbook on adhesive resins and wood based panels. Since 15 years lecturer at the University of Natural Resources and Applied Life Sciences and the University of Leoben. Current research topics: (i) Computer tomography on wood based panels, and (ii) Penetration behaviour of adhesives in wood.

David Harper

Dr. Harper is an Associate Professor at the Tennessee Forest Products Center at The University of Tennessee where he has been since 2004. He possesses a B.A. in Physics from West Virginia University and M.S. and PhD in Civil Engineering from Washington State University. In addition, he was a Post Doctoral Fellow at the Forest Products Laboratory in Madision, WI. His primary research interests include polymer fiber interfaces and adhesion, carbon and fiber products from lignin, and mechanics of renewable composite materials.

Holger Militz

Master in Wood Science and Technology at University of Hamburg. 10 years director of SHR Timber Research Institute in Wageningen, Netherlands. Since 2000 head of Wood Biology and Wood Products Group, Forestry Faculty, Göttingen University. Main fields of research are : wood protection, wood modification, wood adhesives, wood building products. Member of International Academy of Wood Science, International Association of Wood Anatomists, USA Forest Products Society, International Research Group on Wood Protection.

Alexander Petutschnigg

FH- Prof. Dr. nat. techn., studied Forest Products Technology and Management as well as Mathematics. He has been working at the University of Applied Sciences Salzburg since 2002. There he has been a Professor since 2006 and Head of Department since 2008. Previously he was a research scientist at the JOANNEUM RESEARCH in Graz. He is author of numerous scientific publications, member of the Austrian Society of Operations Research and achieved the Christian Doppler Prize in 2005. He is a reviewer for several scientific journals and conferences and adjunct professor at the University of Tennessee. Prof. Petutschnigg was project leader of several fundamental research projects as well as research projects in the field of material-, product- and process development with industrial partners.

Antonio Pizzi

A.Pizzi, is full professor of industrial chemistry at the ENSTIB. Prof. Pizzi, who holds a Dr.Chem. (Polymers, Rome, Italy), a Ph.D.(Organic Chemistry, South Africa) and a D.Sc.(Wood Chemistry, South Africa), is the author of more than 500 research and technical articles, patents, contract reports and international conference papers as well as 7 books on adhesion and adhesives published in New York, and the recipient of numerous international prizes for new industrial developments in his fields of specialization. His best-known area of specialization is on wood and fiber glueing and wood adhesives chemistry, formulation and application, in particular to composite products based on natural materials.

Johanna Pucker
Johanna Pucker holds a masters degree from the University of Applied Sciences FH Joanneum in the field of Urban Technologies. During her course of studies she specialized on energy and environmental engineering (degree in 2004). She collected her first experiences in research at the Trenchless Technology Center at LA Tech University, Ruston, LA, USA, where she did research work on social costs associated with trenchless projects (2005 - 2006). From 2006 to 2008 she was employed at the EnergyCabin Produktions- und VertriebsGmbh in Gleisdorf, Austria. Since 2008 she has been a research associate at the Institute of Water, Energy and Sustainability at JOANNEUM RESEARCH. There she works in the area of energy research. Her main research tasks are performing life cycle assessments (LCA). She is involved in several projects dealing with the evaluation of transportation systems, of biogas systems, synthetic natural gas and FT-biofuel production systems as well as biorefinery concepts.

Alfred Teischinger
Dipl.-Ing. Dr., Professor of Wood Technology at the University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Head of the Institute of Wood Science and Technology at BOKU and scientific director of the Competence Centre for Wood Composites and Wood Chemistry (Wood K plus). Editor of the LIGNOVISIONEN Series, chair of the Austrian Standard Committee for wood and wood-based materials and board member of various national and international organisations and editorial boards as well, such as INNOVAWOOD, Wood Research, Holztechnologie, European Journal of Wood and Wood Products etc.

Timothy M. Young
Timothy M. Young is a Full Professor in the Forest Products Center at the University of Tennessee. He has a Ph.D. (concentration Statistics) and a M.S. in Statistics (minor in Operations Research) from the University of Tennessee; M.S. (Forest Economics) and B.S. (Forestry) from the University of Wisconsin. He teaches highly successful workshops and courses in industrial statistics and data mining for the forest products industry.

He has 103 scientific publications of which 42 are refereed journal articles and has contributed two chapters to the International Encyclopedia of Statistical Science. He has made numerous invited and keynote lectures at professional meetings. His grantsmanship from the private and public sectors have exceeded $2.5 million dollars with an additional $500,000 currently in review. He has been awarded the U.S. Southern Growth Policies Board 2009 Innovator Award, George G. Mara Award of Excellence in research and writing in 2007, and Awarded Meritorious Effort in Preparing and Presenting Scientific and Industrial Information at the 33rd and 41st International Wood Composites Symposium. He is past chairman of the Process Control and Quality Control Technical Interest Group of the Forest Products Society (FPS), former President of the Mid-South Section of the FPS, former Chair of the International FPS meeting (2007), and member of the American Statistical Association.

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The Deepwater Horizon oil spill in April 2010 has showed us that increasing risk and costs have to be accepted to satisfy the increasing demand of material and energy resources from a worldwide perspective. Increasing the recovery of raw materials is one possibility but another one is increasing efficiency in processing and production. Therefore the development and improvement of processing technologies is a crucial factor for economic progression. This conference should give and overview of new developments in processing technologies in the forest and biobased products industries.