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Using Wood Composites as a Tool for Sustainable Forestry

Proceedings of Scientific Session 90, XXII IUFRO World Congress

Proceedings of Scientific Session 90
"Using composites as a tool for a sustainable forestry"
XXII IUFRO World Congress "Forests in the Balance"
Brisbane, Australia, August 12, 2005

Abstract

This report provides a summary of technical papers presented in Session #90 of the recent IUFRO XXII World Forestry Congress held in Brisbane, Queensland, Australia, August 8–13, 2005. Papers in this report include the oral presentations, poster presentations, and panel discussions exploring and providing technical information on the potential adaptability and applicability of using wood–composites technologies to create value-added commodities and new innovative bio-based composite products. These presentations reviewed how wood- and bio-fiber-composite technologies allow users to add considerable value to a diverse number of wood- and bio-fiber feedstocks, including small-diameter timber, fast plantation-grown timber, agricultural fiber and biofiber residues, exotic–invasive species, and timber removals of hazardous forest fuels. The presentations showed some possibilities for a distinct advantage for this type of economic development scenario: The application of this type of industrial composite processing technology allows the use of diverse species and an ever-changing quality level of wood and other natural biofiber feedstocks. A fundamental understanding of the relationship between materials, process, and composite performance properties may soon allow us to "control the process on-the-fly" to accept any number of input materials and still produce consistent value-added composite products. Once this fundamental understanding is developed, we will truly be able to use biocomposite technologies as a tool to help forest and land managers restore damaged ecosystems and promote sustainable forest management practices.

Keywords: sustainable forestry, composites, wood products, biocomposites

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Cover: Top left is Dr. Jeremy Warnes of SCION Research, Rotorua, New Zealand (photo by J. Winandy). Bottom right is (left to right) Professor Shigehiko Suzuki, University of Shizuoka, Japan; Dr. Jerrold Winandy, USDA-FS, Forest Products Laboratory, USA; Professor Salim Hiziroglu, Oklahoma State University, USA; Professor Marius Barbu, University of Transilvania, Romania; Professor Kelin Ye, Chinese Academy of Forestry, China (photo by R. Wellwood). Top center is the logo of the International Union of Forest Research Organizations (www.iufro.org). Bottom center is the logo of the XXII World Forestry Congress of IUFRO (www.IUFRO-2005.com). Tree plantation in the background is a high bio-yield, fast-growing Paulownia (Paulownia tomentosa) plantation in Queensland, Australia (photo by J. Winandy).

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Executive Summary

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This USDA Forest Service, General Technical Report presents a proceedings of a main technical session sponsored by IUFRO Division 5.05 Composites and held at the XXII IUFRO World Forestry Congress on August 8-13, 2005 in Brisbane, Australia. This technical session specifically addressed one of the WFC Primary Scientific Program Themes: Promoting development through Improvements to the Forest-Wood Products Chain.

The problem we wanted to address was too present new utilization-based options for forest/land/resource managers who are often tasked with improving forest health and restoring native indigenous eco-systems. In particular, these managers are usually initially faced with the dilemma of how to deal with undervalued or no-value forest resources such as growth-stunted timber, small-diameter timber, hazardous fuels (i.e., fire-prone timber and forest residues, or exotic-invasive bio-fiber species. Usually these forest or bio-fiber resources have little or no value because they exist far from markets and too far away from traditional solid-timber processing facilities. Thus, this biofiber resource seems to be just too expensive to remove because its economic value-added potential for traditional solid-timber bio-based products does not offset its inherent harvest, remediation, and/or eradication costs of the small-diameter timber or bio-fiber resource.

The objectives of this WFC Technical Session were to provide specific information to forest and land managers and governmental policy makers on how and why they should start to consider the potential(s) for using under-valued bio-fiber resources as a feedstock for engineered biocomposite products. They could also accrue significant potential for economic development and improvement of both eco-systems and quality of life for local peoples.

Five (5) oral presentations demonstrated on-going work in wood composites in five (5) different global regions explaining the availability and use of fibre resources beyond traditional sources.

1. **North American Perspective on Using Wood-Based Structural Composite Products as Forest Management Tool to Improve Forest Health and Sustainability and to Reduce Forest Fuels and Exotic/Invasive Species**
   Dr. Jerrold Winandy described the status of fibre availability in North America, especially fibre from exotic/invasive species and from burned stands. Dr. Salim Hiziroglu described a specific utilization issue – low quality Eastern Red Cedar particleboard with suitable properties.

2. **Using Cedar Plantation Materials for Wood-Based Composites in Japan**
   Dr. Shigehiko Suzuki described the use of Sugi-cedar plantation materials in a variety of wood products in Japan. Plantation Sugi is increasing rapidly and is now 57% of the growing stock in Japan. Large volumes are available on a sustained basis. Due to the small size and weak properties, a variety of research projects are underway to modify the properties to increase its usability.

3. **European Experience with Wood and Natural Fibre Composites**
   Dr. Marius Barbu summarized the production of composites in Europe and discussed the future with respect to supply and demand of wood products in the world. Wood supply will increasingly be a constraint, with competition with power generation. An increase in the utilization of recycled wood is needed.

4. **Wood Composite Made of Populus Plantation Material in China**
   Kelin Ye described the development in China of a significant volume of plantation poplar fibre. Rapidly rising demand for wood products, combined with a reduced supply of traditional wood sources due to environmental concerns has led to an increased reliance on plantation poplar as a fibre source in China. In the past fifteen (15) years, composites production in China has increased by a factor of 17x. Plantation poplar continued to be developed to meet this growing need.

5. **Advances for Utilization Whole Tree for Composites**
   Dr. Jeremy Warnes gave the New Zealand perspective on utilizing residues from Radiata Pine. Emphasis was put on research to develop two(2) new products that use residuals: barkboard (where bark is chemically modified to act as the binder) wood fibre-reinforced plastic composites, where wood is used for reinforcement.

Panel Discussion

Technological problems and resource issues when using wood composites as a tool for sustainable forestry. Panel members: Prof. Shigehiko Suzuki (Shizuoka Univ., Japan), Prof. Salim Hiziroglu (OSU, USA), Dr. Jerrold Winandy (FPL, USA), Prof. Kelin Ye (CAF, China), and Dr. J.Warnes (Scion, NZ); moderated by Dr. Marius Barbu (Univ. of Transylvania, Romania).

Overview of Panel Discussion:

The role of underutilized raw materials for high performance composites.

Sustainable forest management requires a harvesting and utilization tool to remove exotic-invasive species, growth-stunted small diameter timber, or fire-prone material. Converting non-desirable, hazardous, or low value raw materials into high-value, environmentally benign wood-based products will be best accomplished through conversion

technologies based on first processing the timber into fiber and then processing that fiber into a composites having designed-in performance. These fiber-based composites might be wood-based, wood-plastic, pulp-molded, or wood-inorganic composites. Each has a preferred use based on local conditions, user needs and raw materials. Fiber-based wood composite technologies offer the most options and greatest potential for consistently adapting hundreds of resource types and species options into a handful of high value-added products. We need to develop a fundamental material science-based understanding of how to best process low-value fiber into end-products having high-value, enhanced durability and known performance properties for a variety of species, fiber-type, fiber-size, fiber-orientation, adhesive, additives, binders, and temperature/pressure/time processing decisions.

Ten (10) poster presentations were also associated with this session. These 10 technical presentations were significant part of this program and were selected because they each were closely linked to the theme of this IUFRO XXII WFC session: *Using composites as a tool to promote sustainable forestry*. The titles and list of authors of each technical poster presentations is as follows:

- In-situ micro-dielectrical evaluation of the curing process of adhesives in plywood manufacturing. Ballerini A., A., Gacitúa E., W. (Universidad del Bío-Bío, Chile.

- Characterizing the rheological properties of wood-plastic composite formulations. Chastagner, M.W., Wolcott, M.P. (Washington State University, USA).

- Physical and mechanical properties of oriented strandboard made using kraft lignin phenol formaldehyede resin. Donmez, A., Kalaycioglu, H. (Karadeniz Technical University, Turkey), and Hiziroglu, S. (Oklahoma State University, USA).

- Study of wood plastic composites: a methodology for evaluation of interfacial adhesion. Gacitúa E., W., Oyarzún R., P., Ballerini A., A. (Universidad del Bío-Bío, Chile).

- Strength properties of engineered I-joists made from laminated veneer lumber, solid wood, oriented strand board, and plywood. Jamaludin, M.A., Nordin, K., Ahmad, M. (Universiti Teknologi Mara, Malaysia).

- Effect of particle orientation on properties of oriented particleboard made from Ethiopian highland bamboo (Yushania alpina). Seyoum, K., Paridah.Md., T., Wong, E.D., Rahim, S., Zaidon, A. (Universiti Putra Malaysia, Malaysia).

- Comparison of board properties made from different waste papers. Massijaya, M.Y. (IPB, Indonesia), Okuma, M. (University of Tokyo, Japan).

- An experiment on producing laminated waste newspaper boards. Massijaya, M.Y. (IPB, Indonesia), Okuma, M. (University of Tokyo, Japan).

- Strength properties of glued laminated bamboo strips for furniture. Nordin, K. (Universiti Teknologi MARA, Malaysia), Wahab, R. (Universiti Malaysia Sabah, Malaysia), Jamaludin, M.A. (Universiti Teknologi MARA, Malaysia).

- Fundamental properties of com-ply made of small diameter fast growing species and mersawa veneer. Massijaya, M.Y. (IPB, Indonesia), Nuryawan, A. (IPB, Indonesia), Nining, A. (IPB, Indonesia).

Acknowledgments

Contents

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Introduction

This USDA Forest Service, General Technical Report summarizes the topics presented at the recent IUFRO XXII World Forestry Congress held in Brisbane, Queensland Australia from August 8-13, 2005. The report records the topics covered in the IUFRO XXII WFC Technical Session #90 that included oral presentations, poster presentations and panel discussions exploring and providing technical information on the potential adaptability and applicability of using wood-composites technology to create value-added commodities and non-traditional products. Wood- and bio-fiber-composite technologies allow users to add considerable value-added to a diverse number of wood- and bio-fiber feed-stocks including small-diameter timber, fast plantation-grown timber, agricultural fiber and bio-fiber residues, exotic-invasive species and timber removals of hazardous forest-fuels. One distinct advantage of this type of economic development scenario is that application of this type of industrial composite processing technologies provides users with the ability to use many number of diverse species and an ever-changing quality level of wood and other natural biofiber feed-stocks. With the proper fundamental understanding of the relationship between materials, process, and composite performance properties we may soon be able to dial in the process to accept any number of input materials and still produce consistent value-added composite products. Once this fundamental understanding is developed, we will truly be able to use biocomposite technologies as a tool to help forest and land managers restoration of damaged eco-systems and then promote sustainable forest management practices.

Technical Session Overview

This IUFRO Division 5.05 Composites sponsored technical session included a short an overview of the how wood composite technology could add value to low- or no-value fiber resources and serve as a tool for economic development and enhanced quality of life issues for local residents. It then also include a series of five 20 minute technical presentations from a series of invited International experts in the field of engineered composites: their manufacture and use. The main technical session then concluded with a 20 minute Panel Discussion on the theme of "Using wood and biofiber composites as tools for sustainable forestry". In addition, a series of ten (10) session-focused poster presentations were also a critical second part of the Division 5.05 session. Each of the oral presentations and technical poster presentations is included in this proceedings as either a complete technical paper or, in just a few cases, as a brief *Executive Abstract*.

North American Perspective on Using Wood-Based Structural Composite Products as Forest Management Tools to Improve Forest Health and Sustainability and to Reduce Forest Fuels and Exotic–Invasive Species

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Abstract

Selective harvesting is now recognized as a critical tool in maintaining healthy and sustainable forests. Research is underway on developing value-added processes for manufacturing biocomposites from small-diameter timber, forest residue, and whole tree trimmings and from exotic and invasive species. In this way, "whole-site" forest management can be implemented to use all available residual biomass for optimum utilization, leaving minimal impact in the forest and reduced potential for future insect, disease, or forest fire. This research will also encourage rural development and reduce costs to government agencies for improved forest health, ecosystem management, and minimized fire mitigation.

Historically, after logging or thinning operations, much of the low-value timber is either left standing or felled and left on the ground, chipped, or burned because most North American mills are not equipped to handle this material. In many drier areas of the United States, forest residue does not decompose after it is felled. Also, remaining trees that are partially damaged or injured during logging soon become susceptible to attack by insects or disease. This build-up of dead or dying biomass can contribute to catastrophic wildfires. In other areas of North America, several exotic and invasive woody–shrubby bio-fiber resources are sparsely populated across large areas; these materials must be removed to promote forest health or reestablish native ecosystems, but the cost of doing so is immense. Some land managers are now working with utilization researchers to realize the value-added potential of utilizing the bio-fiber of these exotic–invasive species in high-value-added structural composite products.

This paper addresses specific examples of how structural biocomposite products can add value to valueless biomaterials, thereby assisting land managers in achieving land-use goals and offsetting the costs of eco-system remediation.

Keywords: Wood composites, invasive species, utilization, panel properties

Introduction

Past forest management policy looked only at providing maximum solid wood yield from a plot of land and did not consider the potential of the entire bio-fiber resource. To achieve maximum yield of larger trees, smaller trees were thinned to optimize growth of "higher quality" trees. This smaller diameter thinned material, which was generally chipped or left in the forest, usually had a higher percentage of bark and juvenile fiber and often cost too much to remove even as chips for uses such as paper. It was sometimes referred to as "bio-trash."

For sustainable forestry to succeed, methods are needed to utilize this undervalued and underutilized bio-trash material. We suggest that biocomposite utilization should become a primary tool of forest managers for achieving sustainable forest management. This paper highlights ongoing research in North America aimed at developing economical processing methods to use low-value biomaterials for a variety of value-added structural applications or as furniture or packaging. Our long-term goal is to be able to use almost any fibrous biomass material and economically process it into a value-added product with significant saleable performance criteria.

Many forest stands are densely populated and need to be thinned as part of good forest management. However, because these thinned materials are traditionally composed of

mixed species, are too small for structural lumber, contain too many defects, or are too costly to transport out of the forest, they are left to decompose naturally. In some cases, this represents a significant amount of material, and as we have learned in North America, after several years this residual bio-trash can present a significant fire hazard. Logging operations can also cause some damage to remaining trees after the best timber or thinnings have been harvested. This injured or damaged material often becomes susceptible to attack by forest insect or disease. This biomass build-up can contribute to catastrophic wildfires.

In other areas of North America, invasive and underutilized species such as eastern redcedar (Juniperus virginiana L.), salt cedar (Tamarisk spp.), one-seed juniper (Juniperus monosperma), and osage orange (Maclura pomifera) are adversely affecting natural ecosystems. Recent studies suggest that using these species as raw material in composite panel manufacture will provide a value-added economic incentive to convert a costly land management problem into marketable panel products. Several attempts have been made to manufacture single- and three-layer particleboard from whole-tree chipped furnish of eastern redcedar. Also, initial studies using such species in the form of value-added wood–plastic composites look promising. Therefore, the specific objectives of this paper are to review and to describe some recent research on utilizing these species in the form of value-added wood composite panels.

Eastern redcedar is one of the widely distributed invasive species in the southwestern United States. For example, acreage of eastern redcedar in Oklahoma exceeds seven million acres (Hiziroglu et al. 2002). Use of low-quality eastern redcedar as a raw material in lumber manufacturing is currently limited because of its low value and irregular growth pattern (Fig. 1). Eastern redcedar is a problem to farmers and ranchers who often lose crop and pasture land to the species (Adams 1978). The trees are generally considered a water-stealing and space-taking nuisance. Many wildlife species that need open range also are adversely affected by eastern redcedar. The greatest areas of expansion have been in southwestern Oklahoma, characterized by an arid climate and rocky soils, and northwestern Oklahoma, primarily open prairie land dissected by waterways. State biologists are concerned that encroaching redcedar trees may someday take over the tall grass prairies in northern Oklahoma (Bidwell et al. 2002).

Similar to eastern redcedar are salt cedar and one-seed juniper, which are largely distributed in New Mexico and Arizona. Their encroachment is also playing a significant environmental role. The U.S. Department of Agriculture (USDA), Forest Service; the U.S. Department of Interior, Bureau of Land Management; several State Foresters; and the International Boundary and Water Commission are interested in removing salt cedar from ecosystems because of its adverse effect on the environment (Winandy et al. 2005).

Osage orange is another underutilized species. Known as bodark, bowwood, or yellowwood, osage orange is native to Oklahoma, Arkansas, and Texas. Its sapwood is narrow and light yellow, but the heartwood is yellow to bright orange and becomes darker with exposure. Osage orange wood, with air-dry specific gravity of 0.85, has exceptional resistance against biological deterioration. It is considered as the one of the most durable woods in North America.

Currently the woody biomass from all these species is used mostly for firewood, fence posts, and novelty items, while the trees themselves continue to be planted for shelterbelts and windbreaks. There is no reported price for such low-quality invasive and underutilized species in the United States. This is in part because of their status as pests and the overwhelming availability of virtually free timber. Based on initial findings, use of these species as a fiber resource in panel manufacturing seems a promising alternative to solve their negative impact on the environment. This paper briefly summarizes some recent studies related to manufacture of value-added experimental panels from these species.

Research on Biocomposites
Eastern redcedar particleboard

Demand for particleboard by the furniture industry indicates a favorable market environment for products manufactured from the pleasantly aromatic eastern redcedar. According to the U.S. Census Bureau (1999), 108 establishments in the United States are capable of manufacturing various types of reconstituted wood products such as particleboard, oriented strandboard, and medium-density fiberboard.

Whole-tree particleboard manufacturing can use most of the redcedar tree, including bark, small limbs, and needles, and provides an alternative method to convert a potentially costly land management problem into a value-added product. Two recent studies involved using low-quality eastern redcedar as raw material for manufacturing experimental single- and three-layer particleboard and comparing mechanical and physical properties of such panels to those of particleboard made from other species (Hiziroglu et al. 2002, Hiziroglu and Holcomb 2004).

The whole-tree furnish was dried to 4% moisture content in a 1-m3-capacity dryer. Dried particles were classified into two size categories (fine and coarse) on a 20-mesh screen. Coarse particles were used for the core layer; fine particles were used for the face layers of three-layer panels. Based on ovendry particle weight, 6% (core) and 9% (face) urea formaldehyde resin were applied using an atomizing spray gun for the coarse and fine particles, respectively. A total of 40 panels 50.8 cm long, 55.8 cm wide, and 1.27 cm thick were made for the experiments. Static bending properties, thickness swelling, and internal bond strength of the samples were determined based on ASTM standards. Figure 2 illustrates a three-layer mat immediately prior to hot-pressing.

Table 1 shows the results of both mechanical and physical tests for panels manufactured from whole-tree chipped eastern redcedar. Properties were comparable to any commercial particleboards made from different species at a similar density level. Particle geometry plays an important role in determining final board properties, primarily bending strength. Based on the findings of this study, bending strength values of three-layer samples were lower than those of single-layer particleboard made from whole-tree chipped particles of the same species. Lower MOE and MOR values of the samples were related to fine material used in the face layers.

Wood-plastic composites from invasive species

The rapid growth of wood–plastic composites (WPCs) in the United States, especially in large-volume exterior products, provides an outlet for significant quantities of wood processing residues and also has the potential to use invasive species. These composites are becoming increasingly popular with consumers because of their inherent durability and low maintenance requirements. The greatest growth in WPCs has been in exterior building products such as decking and guardrails. Invasive species would be an excellent raw material to manufacture panels using both injection molded and extrusion methods.

Particles of salt cedar, one-seed juniper, and eastern redcedar were used to manufacture WPC samples (Winandy et al. 2005). Raw material was hammer-milled using 13- and 0.8-mm screens. The largest particles were removed by sifting the wood flour using a screen with 0.4 mm openings. The wood flours were dried for at least 4 h at 105ºC. Each wood flour batch was blended with an injection-molding grade of polypropylene (PP) in a 32-mm compounding extruder. For comparison, commercial pine wood flour was also compounded with PP. Each blend contained 40% wood flour by weight. The compounded blends were then dried, and test bars were molded using a reciprocating screw injection molder. Flexural, tensile, and impact tests were conducted based on ASTM standards (ASTM 2003a,b). Results of the mechanical tests are summarized in Table 2. Figure 3 illustrates profile extrusion of a salt cedar–HDPE (high-density polyethylene) composite. Laboratory and field evaluations are ongoing.

In another effort to address value-added uses for invasive juniper, Forest Products Laboratory (FPL) worked to develop technology to produce highly durable and dimensionally stable juniper–PP composite panels using melt-blending and compression-molding technology. These composite panels were made from 50% whole-tree juniper and 50% recycled PP. The PP was a post-industrial material that was a by-product from a company manufacturing small plastic balls. This waste PP was a granulated material, very similar to fine sand, resulting from a machining operation on the plastic

balls during their production process. This recycled waste PP was then used in producing our juniper–PP composite panels (Winandy et al. 2005).

Juniper–PP composite panels were made by first compounding juniper particles and PP together and then forming the mixture into a mat by pouring mixed juniper and PP particles into a forming box that was placed on a metal plate. The forming box was then removed and another metal plate was placed on top of the mat. The metal plates, with the mat between them, were then placed in a hot press at 188°C and hot-pressed for 15 min. The pressure was about 2 MPa. The heat caused the plastic to melt and the pressure densified the mat into a board. The boards were then cooled by running 15°C water through ports within the press-platens for 15 min, which allowed the plastic to harden before the press was opened.

Both eastern redcedar and salt cedar fiber may have potential in several composite products. Examples of composite materials that could be explored include particleboard, medium-density fiberboard, wood–plastic composites, or erosion mats.

In a third study, salt cedar chips were processed as a whole-tree furnish and used to manufacture WPC samples. Mostly 25- to 64-mm-diameter twigs, with bark and foliage still attached, were the raw material for the samples. The bark-on material was separated into two groups and the bark removed by hand on one group. Raw material of both groups was hammer-milled into particles able to pass through a 5- by 5-mm screen. Two groups were only salt cedar wood, and two groups were salt cedar wood and bark. In each of these, one group was 95% salt cedar and 5% phenolic resin and the other group was 50% salt cedar and 50% HDPE. Two series of three 405- by 405- by 6.4-mm-thick particleboard panels (six panels total) were manufactured, one using salt cedar woody chips alone and one using a mixture of woody and bark chips. Both types of particleboard panels used a phenol formaldehyde resin applied in a rotary blender at a 5% by weight application rate and were pressed at 180°C for 250 s. In all cases, the salt cedar particleboard and WPC seemed to process and perform similarly to panels made from more traditional wood furnishes, such as pine and maple.

3D fiberboard from hazardous fuels

Whole-tree particles from underutilized species and tree tops were also used to manufacture value-added three-dimensional (3D) engineered fiberboard (Hunt and Winandy 2002). In this research project, tree top residual material was first chipped (for ease of handling) with bark on, then fiberized, and finally refined using conventional refining techniques (Figs. 4 and 5).

First, flat panels were tested both nondestructively and destructively (Hunt and Supan 2005). Based on the

flat-panel tests and related previous design- and concept-related research (Danforth 1986, Gunderson 1986, Hunt and Vick 1999, Hunt 2004a), optimized designs for 3D panels have been developed using finite element analysis (Hunt 2004b). From these preliminary studies, two wet-formed processing methods were selected for additional work on processing fibers for use in making larger 3D-fiberboard panels for further testing and evaluation.

Conclusions

This paper describes some recent and ongoing work related to using various invasive and underutilized species to manufacture value-added experimental composite panels. The elimination or control of these problem species is a high priority for forest management in the United States. The development of value-added uses will defray the high costs currently associated with removing these species from arid rangeland-type ecosystems. After restoration with less water-demanding native flora, other benefits will include enhanced surface- and ground-water availability across arid western watersheds. Based on results of studies described in this paper, low-quality material from such species seems to have potential as whole-tree chipped particles for manufacturing composite panels. Further product development projects for adding value to bio-fiber obtained from these problem woody species are expected to follow as the commercial potential of additional new value-added products is shown in the laboratory.

In the case of wood-based plastic composites, manufacturing panels using flour from exotic and invasive species is apparently feasible. The next steps are to learn to use fiber instead of flour and to determine the unique characteristics of invasive species and how they affect processing and durability of wood–plastic composites. Problems with invasive species have prompted the involvement of several U.S. government agencies in programs aimed at eradication of invasive species and restoration with native flora. The U.S. Bureau of Reclamation, U.S. Bureau of Land Management, USDA Forest Service, and several interested State agencies are working together toward a total program for the investigation of uses and replacements for salt cedar and other exotic–invasive species.

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Table 1. Average values of single- and three-layer particleboard panels made form whole-tree chipped particle of eastern redcedar. [7,8].

Panel Type	MOE (MPa)	MOR (MPa)	IB (MPa)	2- h TS (%)	24-h TS (%)
Single-layer	2,273	13.74	1.02	20.0	22.0
Three-layer	1,752	12.84	1.08	15.3	16.8

Table 2. Summary of mechanical properties of injection-molded PP containing 40% of various wood flours. (Values in parentheses are standard deviations.)

Species	Modulus (GPa)		Strength (MPa)		Izod impact (J/m)	
	Tensile	Flexural	Tensile	Flexural	Notched	Unnotched
Salt cedar	4.66 (0.8)	4.28 (0.07)	26.3 (0.4)	50.8 (0.5)	15 (2)	48 (5)
Pine	4.53 (0.14)	3.75 (0.19)	29.0 (0.6)	54.4 (1.2)	22 (2)	68 (4)
Juniper	3.83 (0.07)	3.30 (0.08)	31.0 (0.6)	58.3 (0.9)	18 (2)	75 (9)
Red cedar	3.52 (0.15)	3.08 (0.26)	31.0 (0.1)	58.0 (0.2)	16 (2)	78 (9)

Figure 1. Low quality eastern redcedar tree.

Figure 2. Unpressed three-layer particleboard mat.
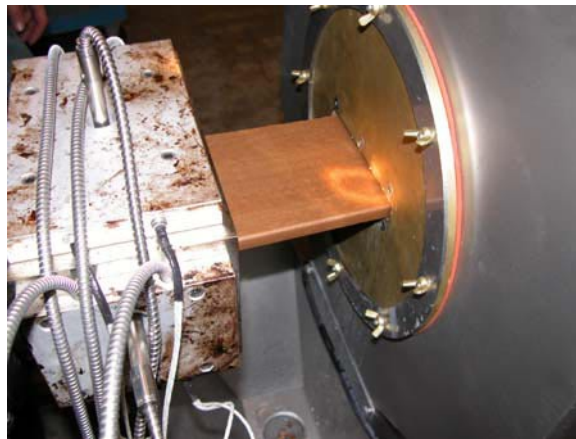
Figure 3. Profile extrusion of HDPE containing 50% salt cedar and additives. Composite melt exiting extruder die (left) and entering cooling tank (right).

Figure 4. Small-diameter lodgepole pine timber harvested from Wyoming and used for 3D engineered fiberboard.

Figure 5. Example of the three processing steps of chips, "tornado" fibers, and refined fiber used when producing 3D engineered fiberboard.

Using Cedar Plantation Materials for Wood-Based Composites in Japan

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Abstract

The standing timber volume in plantation forests in Japan is currently estimated at about 2.3 billion m^3 and it is increasing. Finding effective ways for utilizing these valuable wood resources is one of the most important issues in forest management and to the wood industry in Japan. *Cryptomeria japonica* (L.f.) D.Don (Sugi or Japanese cedar) is the primary plantation forest species planted in Japan. There are several examples of major timber construction using Sugi, such as domes and bridges. Three recent examples are the Ohdate-Dome with a diameter of 178m built in 1997 using Sugi glulam timber, the Miyazaki-Dome constructed in 2004 using Sugi glulam, and a large king-post truss bridge built in 2003 with 140m length. Laminated veneer lumber (LVL) and parallel strand lumber (PSL) are still other examples of engineered lumber products that use Sugi as a raw material. Recently another new technology, known as SST, was developed in Japan and is intended to encourage the utilization of low quality logs. In some respects, SST is similar to PSL in that it is composed of long strands, but the wood strands are made by tearing and splitting the small diameter logs. In the Japanese composite panel market, the production of domestic softwood plywood has been rapidly increasing, and the plywood industry has started to peel Sugi logs to produce thicker panels for structural use, especially for the floor systems in residential housing. In another attempt to promote forest sustainability, several under-utilized plantation species were shown to effectively reinforce Sugi plywood. This new type of plywood is environmentally friendly because it combines veneers from Sugi and other under-utilized plantation species to achieve superior mechanical properties over all-Sugi plywood. Also mat-formed panels can now be manufactured using Sugi as a raw material. While a part of sawmill residue is actually used for commercial particleboard and medium-density fiberboard (MDF) productions, oriented strandboard (OSB) made from Sugi is a product that achieves much higher mechanical properties than those of particleboard or MDF. Strandboard using conifers has been recently manufactured in a series of small-scale mills as a trial for commercial production. This work has shown that fast-grown plantation Sugi can provide high mechanical performance when used as the base strand-material in mat-formed structural OSB panel products.

Keywords: fast growing species, sugi, Japanese cedar, composites, timber product, wood-based panel

Sugi as a Potential Forest Resource in Japan

Overview of Wood Supply

The total wood supply in Japan is around 100 million m^3 every year and the self-sufficiency rate is decreasing this decade from 25 percent to 18 percent, even though forest area covers approximately 25.2 million hectares and total growing stock of forest is estimated to be about 4 billion m^3 (Forestry Agency 2004). Table 1 shows wood supply in 1991, 2001, and 2003. It can be found that the percentages from major suppliers, such as US & Canada and Malaysia & Indonesia are also decreasing. On the other hand, imports of softwood from Oceania countries, Russia, and Nordic countries are increasing.

Statistics of Sugi as Plantation Species

Figure 1 shows the forest growing stocks in Japan. As the results of intensively developed plantation of domestic conifers from late 1940s, the total stock increased remarkably, whereas the stock in natural forest remained in the same level. The stock in plantation forests increased from 0.56 billion m^3 in 1966 to 2.34 billion m^3 in 2002, while the stock in natural forest showed only a slight increase from 1.33 billion m^3 in 1966 to 1.70 billion m^3 in 2002 (Forestry Agency 2004). In 2002, natural forest stock consists of 1.23 billion for hardwood, and 0.45 billion for softwood species, in which stock of sugi in the natural forest is estimated to be about only 7 million m^3.

Figure 2 shows that the stock of sugi plantation forest has been increasing remarkably, whereas the plantation area of sugi and total area of the plantation forest leveled off at 1990 as shown in Fig. 3.

Species in plantation are shown in Fig. 4 with the percentages based on the total standing timber volume. It is seen that sugi (*Cryptomeria japonica* D. Don) is the largest in its volume and honoki, Japanese cypress (*Chamaecyparis obtusa* Endl.), is the second largest followed by larch (*Larix* spp), pine (*Pinus* spp), and others. The amount of sugi stock in plantation was 1.34 billion m^3 among the total plantation stock of 2.33 bilion m^3. Not only the total volume, but the stock of sugi per forest area is also large. The percentage of sugi plantation area of 4.5 million ha is about 44 % of the total man-made forest area, 10.3 million ha.

Figure 5 shows the distribution of age of sugi forests at every tenth year. Age-class in the figure is an index of the age after the plantation. Age-class 1 means one to five-year forest, and Age-class 2 is for six to 10-year age forest. It can be seen that the median of the distribution moved toward higher Age-class as year passed. The median in 2000 was at Age-class 8, which means that the age of sugi forest was from 36 to 40 and that those were planted between 1960 and 1965. This forest age distribution also suggests that sugi in Japan is now an appropriate condition to be utilized. However, there are some problems which make the utilization difficult. It can be true that high harvesting cost in forest management is one of the reasons for these problems.

Mechanical Properties of Sugi

As is being discussed, sugi is one of the fast growing species and the most familiar plantation species, however its wood quality would be lower than those of imported species, such as Douglas-fir from North America and white spruce from Nordic countries. To ascertain mechanical properties of sugi which has so many varieties, the test results were collected from approximately 60 published papers/reports, in which small clear specimens of sugi were used for the evaluation. Table 2 summarized the property test results. It shows that for MOR in bending for instance, information on 188 individual test groups were obtained. The lowest average value among 188 groups was 33.0 MPa and the largest value was 94.6 MPa. The mean value of 188 tested groups was 55.4 MPa, and the total number of the tested specimen was 6835 as shown in Table 2. Also the table shows that estimated mean values for compressive strength, MOE in bending, and density are 31.2 MPa, 5.98 GPa, and 0.386 g/cm^3, respectively.

Using the collected data, the relationship between density and MOR in bending was evaluated shown in Fig. 6 as an example of the mechanical properties of sugi. Each plot represented the average value of several number of the test specimens.

Timber Products

Statistics for GLP and LVL

Glue laminated products

Introducing some statistics, changes in glue laminated products (GLP) and LVL (laminated veneer lumber) are reviewed. GLP are classified into five categories here, i.e., imported Glulam for structural use, imported non-structural GLP, structural glue laminated timber (GLT) with medium or large cross section, and structural GLT with small cross-section used for traditional post and beam constructions, and GLP for non-structural use, as shown in Fig. 7. The GLP wood industry in Japan has been developing steadily for non-structural use in Japanese conventional wooden houses and for furniture. In 1986, Japanese Agricultural Standard (JAS) for structural GLT was established, and the

Building Code was revised in 1987. After these, large timber construction was allowed, and GLP supply increased remarkably (Hayashi 2000). Total GLP supply in Japan was about 300 thousand m^3 in 1985 and it increased up to 1.6 million m^3 in 2001. Among these GLP, the domestic production of structural GLT reached 1 million m^3 in 2003.

Figure 8 shows number of glue laminated timber (heavy timber) construction from the beginning of the GLP industry in early 1950s. It was found that more than 400 large-scale wooden buildings have been built every year, and that a drastic change occurred in the middle of 1980s. The first large wooden dome was built in 1991 at Izumo city using Douglas-fir Glulam, and "Ohdate-dome," the largest in Japan, was made of sugi GLT in 1997.

LVL (laminated veneer lumber)

LVL production had started in 1960s in Japan. At that time it was mainly used for furniture industry, and the Japanese Agricultural Standard (JAS) for non-structural LVL was established in 1980s. Demand for structural LVL has been increasing after the allowable stress was established in 1992. Statistics for LVL is classified into four groups (Fig. 9), i.e., domestic production using hardwood, domestic LVL from softwood, imported softwood LVL, and imported unknown LVL, and the record in 2001 was respectively 24,000, 27,000, 116,000, and 239,000 m^3. It would be difficult to grasp accurate values for each kind of LVL, because there is a certain amount of imported veneer-based timber products that are not classified precisely in the statistics.

Sugi Used in Large Timber Constructions

Sugi Usage in Miyazaki Prefecture

Activities and efforts to encourage the sugi utilization have been conducted through many research projects supported by the government or municipal governments. Miyazaki is one of the 47 prefectures, taken up here as an advanced case in sugi usage. Miyazaki locates in the southern region of Japan, and they produce about 1 million m^3 sugi every year. They started the Wood Utilization Research Center, which is one of the largest research institutes for wood science and technology, and they try to use sugi under a municipal government policy as material for public buildings. Solid sawn timber of sugi and LVL made from sugi were used for some community facilities, and also sugi GLT was used in large buildings like gymnasiums. The Miyazaki-Dome, shown in Fig. 10 (its local name is Konohana-Dome in Japanese) was built in 2004 using 1224 m^3 GLT on the basis of the research project in this institute for utilizing sugi grown in Miyazaki prefecture. Its dimensions are 102 m by 122 m in oval and 38 m in height. Not only buildings and dome, but also a bridge (Fig. 11) was made by sugi GLT there in 2003. It is a king-post truss type bridge with total length of 140 m. The span length of 48 m is the world's largest in this type of bridge made of wood. Sugi GLT was used both in its upper chord with a cross section of about 1 m square, and in lower

chord of 1 m by 1.8 m (Fig. 12) The volume of GLT used for this bridge was 1335 m^3, which corresponds to 4100 m^3 log volume and to ten thousands m^3 of standing trees. Not all of prefectures uses sugi like these. Miyazaki would be one of the advanced cases in Japan.

The Way to build a Large Dome Made of Sugi GLT

When discussing the recent technology for the sugi GLT, large-scale domes with a diameter of more than 100 m made of GLT would be symbolic. Three domes could be chosen as examples. Izumo-Dome with a diameter of 141 m and height of 49 m, which was the first large-scale dome made of wood, was built in 1991 using Douglas-fir Glulam imported from North America. Karamatsu-Dome was constructed in 1993 using domestic larch GLT in Nagano prefecture. Its diameter was 130 m and the height was 31 m. Ohdate-Dome in Akita prefecture was built in 1997, as the largest wooden dome in Japan, 178 m in diameter and 52 m in height. A feature of this dome is not only the size, but also that sugi GLT was used.

It could be summarized that the technology for heavy timber construction was imported from North America with Glulam itself, and it was distributed to many places using different species. Started from Douglas-fir Glulam, domestic larch was used, because its density and mechanical properties were close to those of Douglas-fir. Technology for Douglas-fir from North America was able to be translated into larch GLT construction (Iimura 1994). After that our technology has ever reached sugi, which has lower density and lower strength compared with the former two species. Miyazaki-Dome in 2004 (Fig. 10) is the newest one made of sugi GLT. It has more advanced structure for sugi utilization than rather than in Ohdate-Dome in 1997. And we need to think about what the future direction is. It could be said that technology for fast grown species or for low-density wood would be necessary.

SST

SST is a newly developed timber product in FFPRI (Forest and Forest Products Research Institute) for Japan to utilize fast growing species or small diameter logs, like sugi thinnings. The term SST was the abbreviation for "Small logs, Short logs and Twigs, producing Superior Strength Timber" (Miyatake et al. 1997). The strands for SST are produced by splitting small logs or waste wood from sawmills using two types of roll press-slitters as shown in Fig. 13, while the strands for PSL are produced by clipping peeled veneers. The first slitter splits small diameter logs into thin plates, and the second slitter with pairs of disc cutters splits the wood plates into strands used as element of SST. Experimental test results showed that slabs of sugi from sawmill would be suitable for producing high performance SST (Fig. 14), and that MOR and MOE were 75.6MPa and 10.1GPa, respectively, for sugi SST with density of 0.67 g/cm^3.

Panel Products

Statistics for wood-based panels

Figure 15 shows the wood-based panel supply in Japan. Total supply in 2003 was about 11 million m^3, which consisted of about 8 million m^3 for plywood and 3 million m^3 for mat-formed panel products, such as fiberboard and particleboard. It is clearly found that the domestic plywood production of 8 million m^3 at around 1980 started to decrease into less than 3 million m^3 in 2003. This is the most prominent and important change in the history of the wood-based panel industry. This deduction of 5 million m^3 during two decades was a huge amount not only for the panel industry, but also for construction sectors. It is being replaced by imported plywood mainly from South East Asia, and also by imported mat-formed panels.

Total supply of mat-formed panels has been increasing, as shown in Fig. 16 because of increasing amount of the imported panels. Almost all imported fiberboard is MDF (medium-density fiberboard), and the imported particleboard in this case was mainly OSB (oriented strandboard) from North America and Europe. There is no OSB mill in Japan at present. At the beginning of 1990s, OSB or MDF was thought to be a big concern for wood based panel industry as for a next generation to plywood. While many OSB mills were installed in North America, Japanese wood industry chose MDF rather than OSB. Even when production condition is changing, as is found in Fig. 15, we need 11 or 12 million m^3 wood-based panels per year for construction, housing and furniture.

Plywood Production

Figure 17 shows the change of log supply for plywood production in Japan. The rate of domestic resource use was very low before 2000. It was around 3% based on the log volume; however, in these years it is increasing up to 10% in 2004. In 2004, 47% of the log was imported from Russia, mainly larch, and 28% was from South East Asian countries. Other log suppliers were New Zealand and Chilie.

While the total domestic production decreased from around 5 million m^3 in 1994 to 3 million in 2004 as shown in Fig. 18, the domestic production of softwood plywood has been increasing. Ratio of softwood plywood to the total production was 20 % in 1994 and it increased to 71% in 2004. Statistics in 2004 shows that using 5.39 million m^3 logs in volume (Fig. 17) , which consisted of 4.84 million m^3 imported and 0.55 million m^3 domestic harvested, plywood of 3.15 million m^3 was manufactured, where softwood and hardwood plywood production was 2.23 million m^3 and 0.92 million m^3, respectively. There are no official statistics for the plywood made from sugi. Figures of sugi data were included in these domestic log supply and domestic softwood production.

Another statistic indicated that domestic supply of sugi logs for plywood production was approximately 0.56 million m³ in 2004. Roughly assuming that the process yield ratio was to be 50% in this case, 0.28 million m³ sugi veneer was thought to be produced. Some discrepancies in the figures on sugi usage for plywood could be the definition of 'softwood plywood' and differences of origin of the statistics. It can be estimated that about 10% of plywood manufactured in Japan in 2004 was made of sugi.

Upon the reflection of the excessive dependence on tropical hardwood resources in 20th century, the plywood industry in Japan started to use softwood as a raw material. Larch from Russia is being a main species used for softwood plywood as alternative for the tropical wood. However, a large amount of Siberian larch utilization was thought to be unfavorable. After the trend from tropical wood to softwood from Russia, sugi would become a candidate as a raw material from plantation forests.

Thicker plywood with thickness of from 28 mm to 32 mm was mainly produced using sugi for structural purpose, for floor, wall, and roof sheathing.

Mat-Formed Panel Products

There are no statistics on how much amount of sugi was used exactly for mat-formed panel products, such as particleboard or fiberboard. Total wood chip used for particle- and fiber-board was about 885 thousand m³ in 2004, and the amount of fresh chip in this figure was 268 thousand m³. The fresh chip from softwood was estimated to be 38 thousand m³, and it was about 4.3% of the total amount (JFPMA 2004). While the ratio of chip from recycled wood is increasing for particleboard production, some MDF mills intend to utilize sugi chip as raw material because of environmental awareness of consumer.

Research work conducted in Shizuoka University

Plywood Project in Shizuoka

Research for utilizing sugi (Fig. 19) as a raw material for plywood production, which was conducted in Shizuoka University, is introduced. Results of previous research revealed that strength properties of sugi were not enough for plywood in structural grade. As one of the candidates for reinforcing the sugi plywood weakness, *Eucalyptus grandis* (Fig. 20), which is a plantation species and has strength properties comparable to Shorea species for traditional plywood production, was chosen. Some people believed that the plywood industry destroyed the tropical rain forest. To confront this and to think about environmental awareness, *Eucalyptus grandis* was chosen because it is imported from plantation forest, while larch from Siberia was primary species as a candidate in early discussion.

Sugi veneers were classified into three groups, for face, for back, and for core plies. After being glued and assembled, they were hot-pressed. A plywood company in Shizuoka joined in the project so that commercial scale production tests were conducted. Physical and mechanical properties were determined and the vibrating test for full size panels was conducted to obtain elastic constants. A part of the result is shown in Table 3. It is obvious that if we use grandis veneer for the face ply, higher mechanical properties can be obtained. However, many people in Japan love sugi appearance rather than that of grandis. In such case, sugi veneer of high grade was used for the face ply, even though the bending properties would decrease.

There is sufficient scientific evidence to show that wood is more environmentally correct than other materials based on fossil fuel; however, this is not yet common view. Using plantation species, such as sugi and *Eucalyptus grandis*, is one of the ways that the plywood industry in Japan can be recognized as environmentally friendly.

Strandboard Using Sugi and Recycled wood

Much research for wood recycling are now ongoing, such as composites made from recycled wood and plastics. One attempt, fabricating mat-formed panel products, which has been researched in our university, is introduced in Fig. 21. We call this type of three-layer wood based panel J-OSB however, face strands were not oriented in this stage. Recycled wood particles, which are hammer-milled or ring-flaked in some cases, are used as furnish for core layer (Suzuki 1995). Strand made from sugi small diameter logs can be used for the face layers. This type of panel may be classified into waferboard or strandboard if it has random oriented face layers (Suzuki et al. 2002).

The motive of the development for this type of panel was as follows. Demolition wood generated every year, which has to be recycled, is roughly estimated to be about 10 million m³. Mat-formed panel product is a material that can utilize the recycled wood effectively. The total supply of mat-formed panel products in Japan, which includes the domestic production and imported products, is about 3 million m³ as shown in Fig. 16. Even though we assume that the all of this amount is provided from "the demolition wood", it is only about one thirds of the annual generation. This is the reason we tried to develop a structural grade panel using sugi and recycled wood, because the plywood consumption is about 8 million m³ as shown in Fig. 15.

A merit for full size board fabrication test was that the board of 1800 mm by 900 mm could be supplied to the performance evaluation as it was. The method specified for plywood's elasticity and the vibration method were adopted as evaluating methods here. Fig. 22 shows a view of mat forming by hand. Size of the forming box was 2000 mm by 1000 mm to obtain the full-scale board. After the forming, the mat was conveyed (Fig. 23) and was hot-pressed into a

board. The boards consolidated were stacked (Fig. 24) and was trimmed down to the size of 1800 mm by 900 mm for Japanese panel module.

The results are shown in Table 4. The board made with only sugi strand, board type 1, had elastic modulus of about 5 GPa, and the value of about 4 GPa was obtained for the board with SR 39%. Although there were some discrepancies between Ex and Ey which were obtained both by the static test and the vibration methods, comparison between the elastic constants with various SRs could be made. The test result showed that the full size three-layer panel with 39% shelling ratio (face layer ratio) was proved to have elastic modulus in bending more than 4 GPa, which was specified for the structural plywood Class 2. Mechanical properties depended on SR as same as the results obtained by the researches conducted in the laboratory. It is well known that face strand orientation will provide higher mechanical properties than that of random orientation (Suzuki et al 2000). Orientation of the face layer would be done in the future work.

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Table 1. Wood supply in Japan (%)

Year	1991	2001	2003
US & Canada	38.6	30.4	20.2
Malaysia & Indonesia	15	12.2	12.4
Australia & NZ	8.8	12.4	13.7
Russia	4.4	6.5	8.4
Chilie	3.7	3.7	4.5
Europe	-	2.5	6.3
China	-	2.4	3.5
Others	4.5	11.0	11.9
Domestic	25	18.9	19.1

Table 2. Summary of property test results of sugi clear specimens collected from published reports (Suzuki 1991).

Property	Mean	Min.	Max.	Number of groups tested	Total number of specimens
MOR in bending (MPa)	55.4	33.0	94.6	188	6835
Compressive strength (MPa)	31.2	11.5	51.5	141	4438
Shear strength (MPa)	7.74	5.10	13.5	69	2631
MOE in bending (GPa)	5.98	1.86	9.60	189	6150
MOE in compression (GPa)	6.66	3.04	9.80	33	307
Density (g/cm^3)	0.386	0.290	0.533	209	-
Annual ring width (mm)	3.7	0.4	7.6	105	-
Age (year)	35	10	570	201	-

Table 3. Properties of sugi-plywood reinforced by Eucalyptus grandis veneer.

Type	Thickness (mm)	Ply	Veneer Face	Core	Density (g/cm3)	E (GPa)	G (GPa)
A	28	11	Sugi	Grandis	0.530	3.85	0.49
B	28	11	Grandis	Sugi	0.498	6.13	0.48
C	28	11	Sugi	Sugi	0.431	3.59	0.49
D	9	3	Sugi-A	Sugi	0.437	6.73	0.49
E	9	3	Sugi-B	Sugi	0.431	5.37	0.44

E: modulus of elasticity in bending, G: shear modulus.

Sugi-A, Sugi-B: selected veneer from high quality sugi logs.

Table 4. Elastic properties of the boards obtained by full-size board test.

Board type	Resin	SR (%)		Density (g/cm3)	Static bending Ex (GPa)	Ey (GPa)	Vibration test Ex (GPa)	Ey (GPa)	Gd (GPa)
1	PF	100	Mean	0.679	5.41	4.67	4.49	4.88	1.51
			cov (%)		2.6	9.2	6.0		
2	PF	54	Mean	0.623	4.55	3.79	4.04	5.09	1.40
			cov (%)		2.9	3.7	2.5		
3	PF	39	Mean	0.630	4.33	3.60	3.68	3.99	1.22
			cov (%)		2.1	3.5	3.3	2.7	5.4	4.9
4	PF	33	Mean	0.596	4.05	3.27	3.17	3.83	1.24
			cov (%)		1.8	2.3	3.8		
5	PF	0	Mean	0.624	3.00	2.47	2.19	2.87	0.90
			cov (%)		2.2	8.7	7.9		
6	MDI	100	Mean	0.687	5.59	5.14	4.80	5.73	1.32
			cov (%)						
7	MDI	54	Mean	0.621	4.30	3.89	3.69	4.24	1.09
			cov (%)		2.1	5.6	3.6		

SR (shelling ratio): weight ratio of the face layers to the total weight.
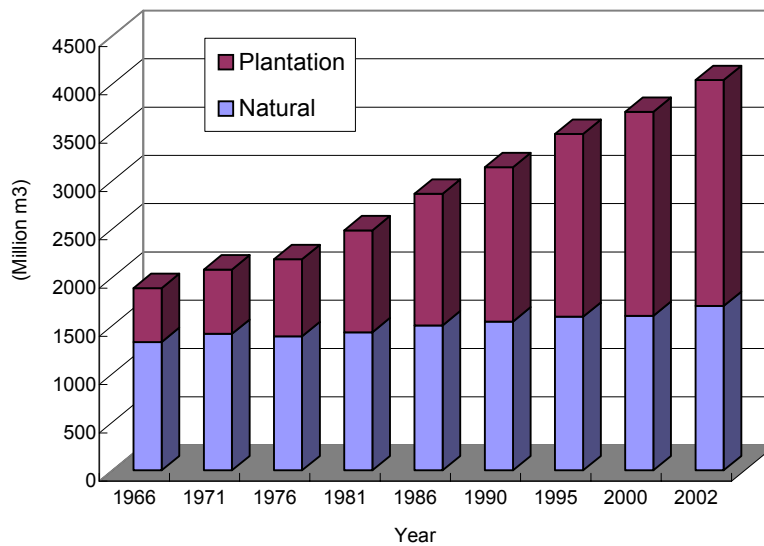

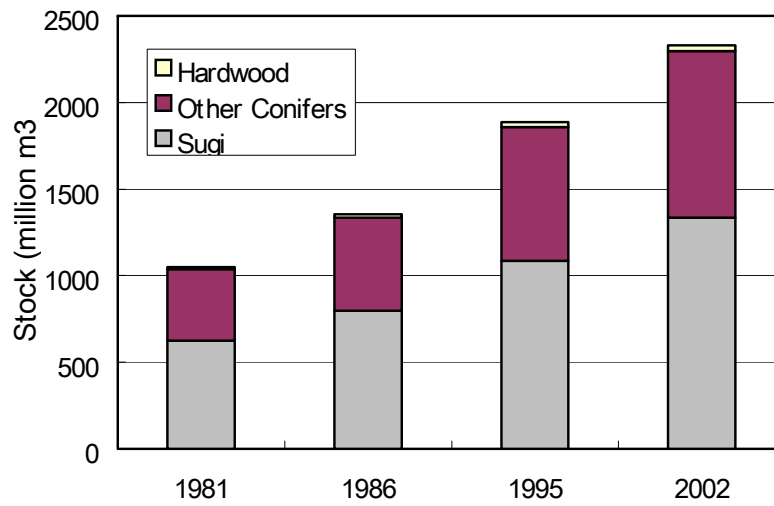Fig. 1. Change of growing stock of forest in Japan.

Fig. 2. Change of stock of sugi.
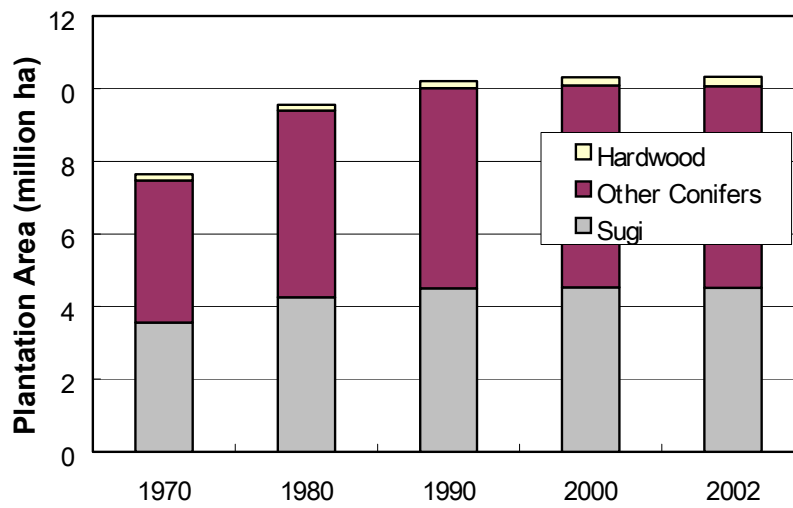
Fig. 3. Change of plantation area for sugi.
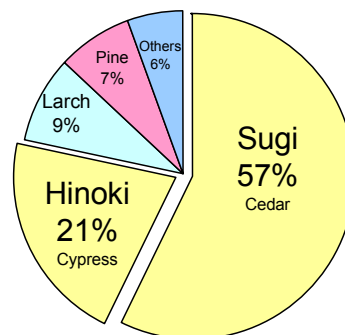
Fig. 4. Percentage of standing tree
volume for each species.

16
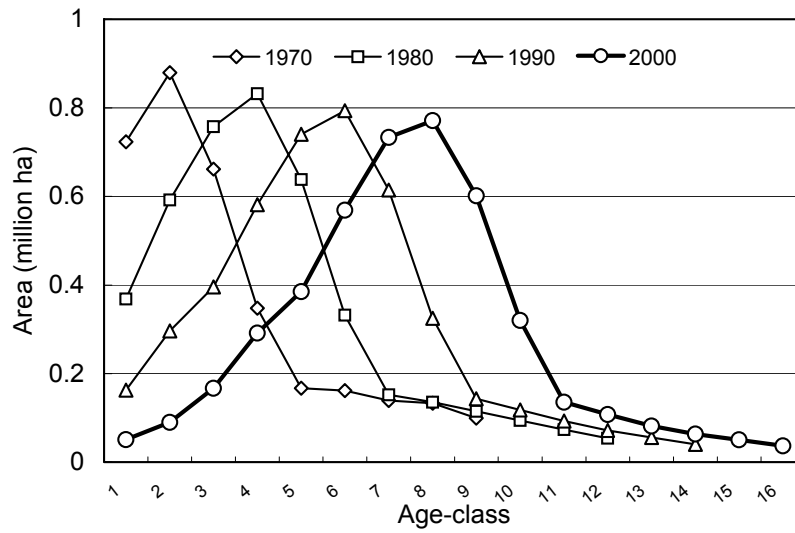
Fig. 5. Change of age-class distribution for sugi plantation.
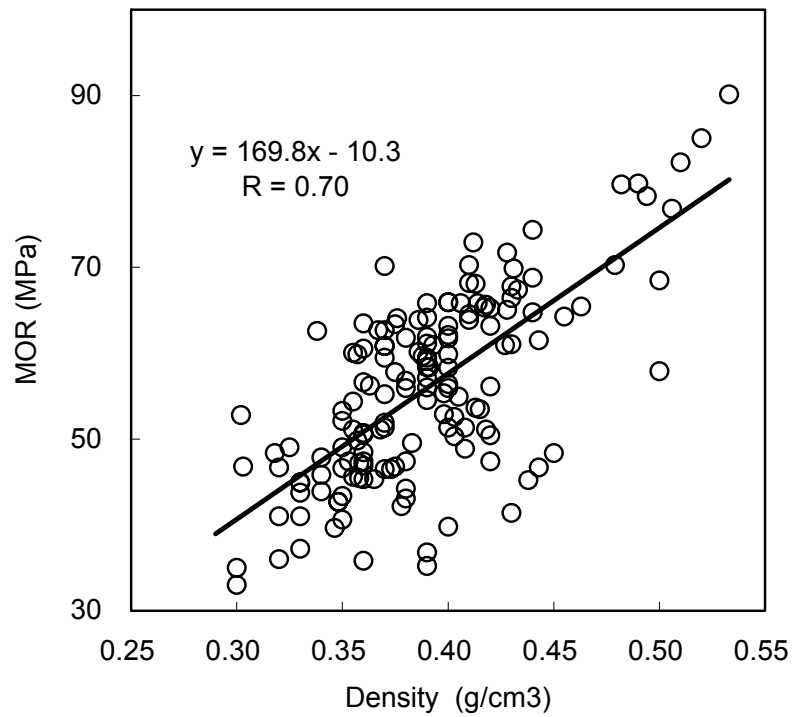
Fig. 6. The relation between density and MOR of sugi data collected from published reports.
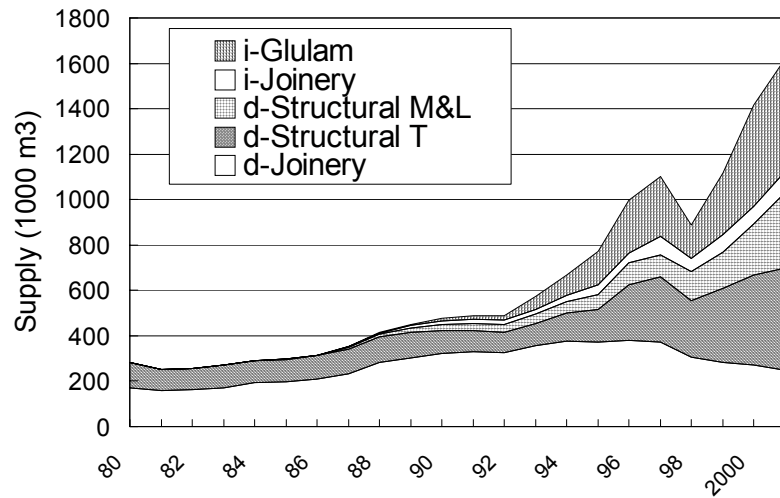
Fig. 7. Glue laminated products supply in Japan. i: imported, d: domestic. Structural M&L: structural glue laminated timber with medium or large cross section, Structural T: structural with small cross-section.
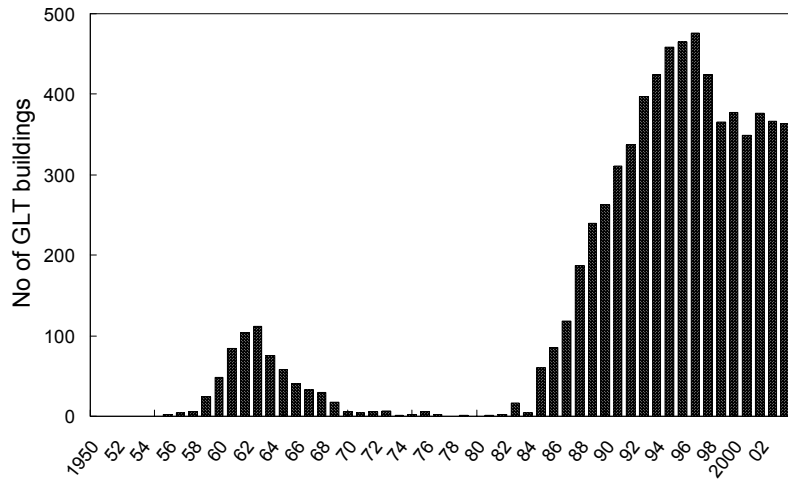
Fig. 8. Number of glue laminated timber construction.
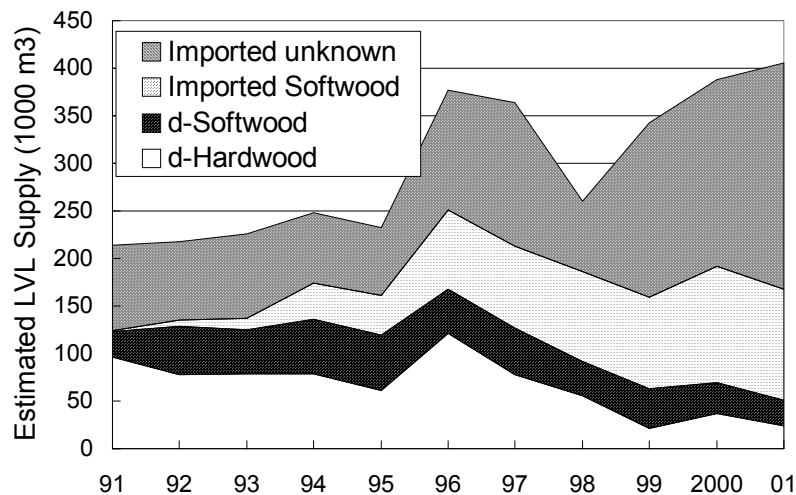
Fig. 9. Estimated LVL supply in Japan.

Fig. 10. Miyazaki-Dome built in 2004. Photo by S. Suzuki just after "the jack-down."
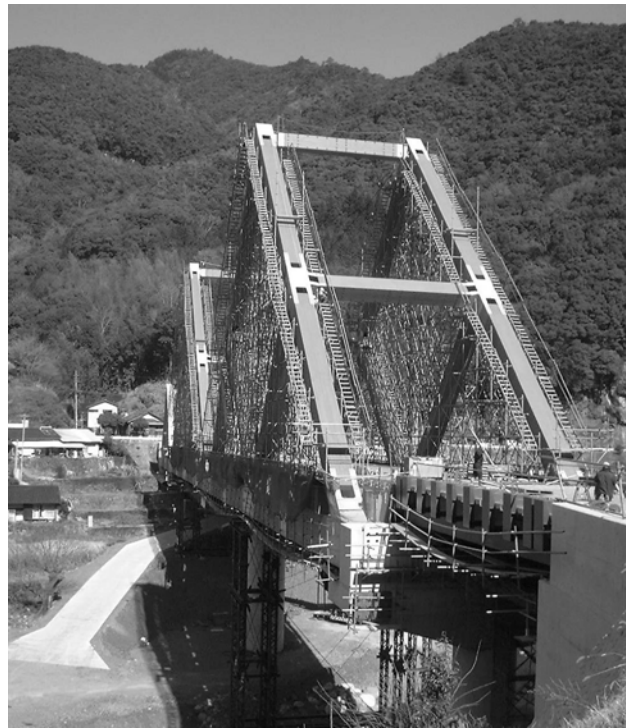
Fig. 11. A king-post truss bridge constructed in Nishimera, Miyazaki (Photo by S. Suzuki).
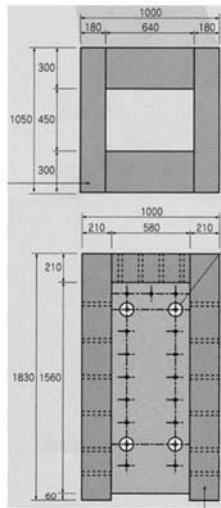
Fig.12. The diagram for the cross section of upper chord (top) and lower chord (bottom) using sugi GLT.

Splitting roughly

Type I

Splitting finely

Type II
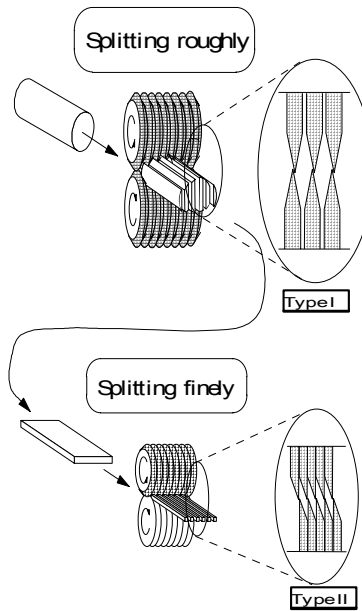
Fig. 13. Schematic diagram of a roll-press splitter for processing long strand for the composite timber "SST" (Miyatake et al. 1997).

Fig. 14. Sample of SST made from sugi strands.
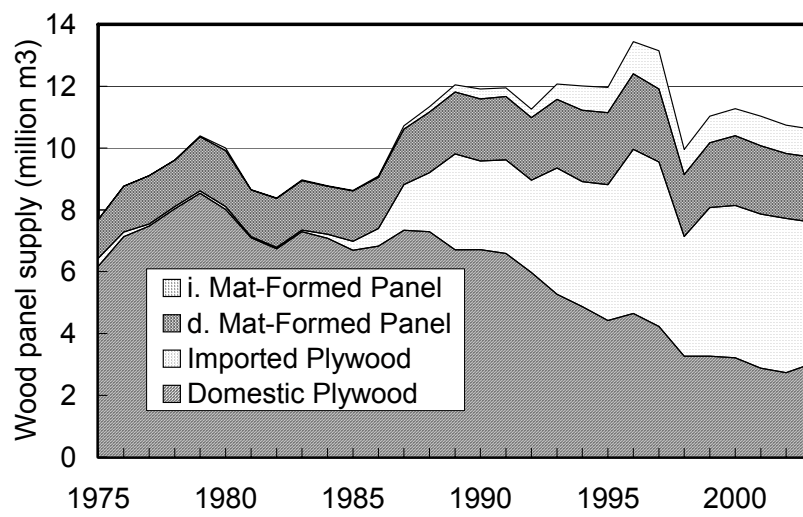
Fig. 15. Wood panel supply. Mat-formed panel: Fiberboard plus particleboard, Wood panel: Plywood, fiberboard, and particleboard.
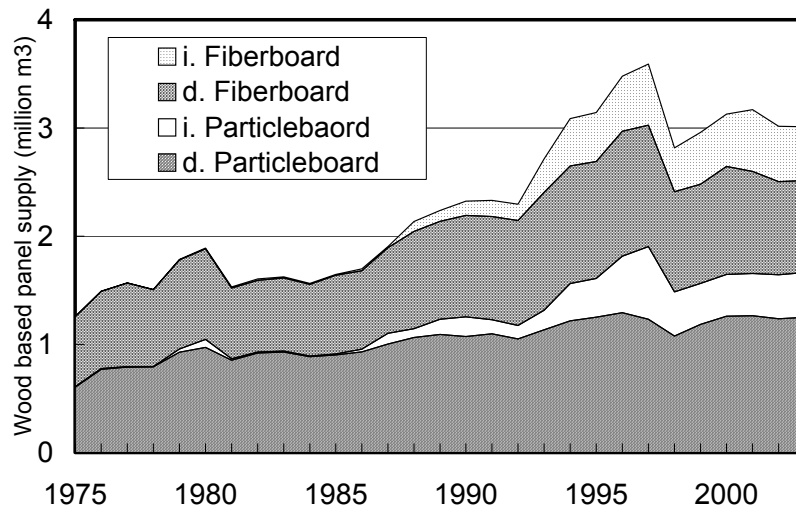
Fig. 16. Mat-formed panel supply in Japan. Mat-formed panel: Fiberboard plus particleboard, Wood panel: Plywood, fiberboard, and particleboard.
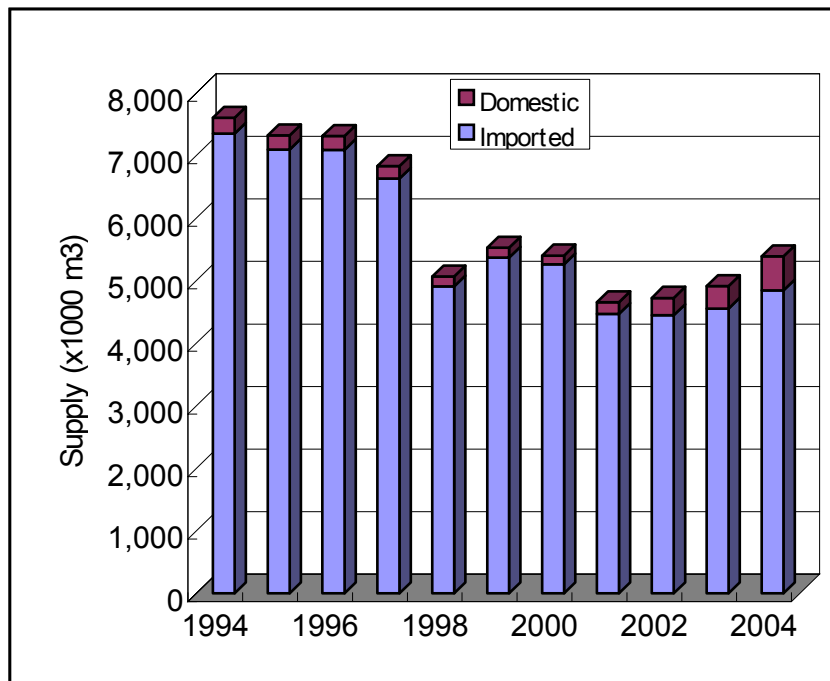
Fig. 17. Log supply for domestic plywood production.
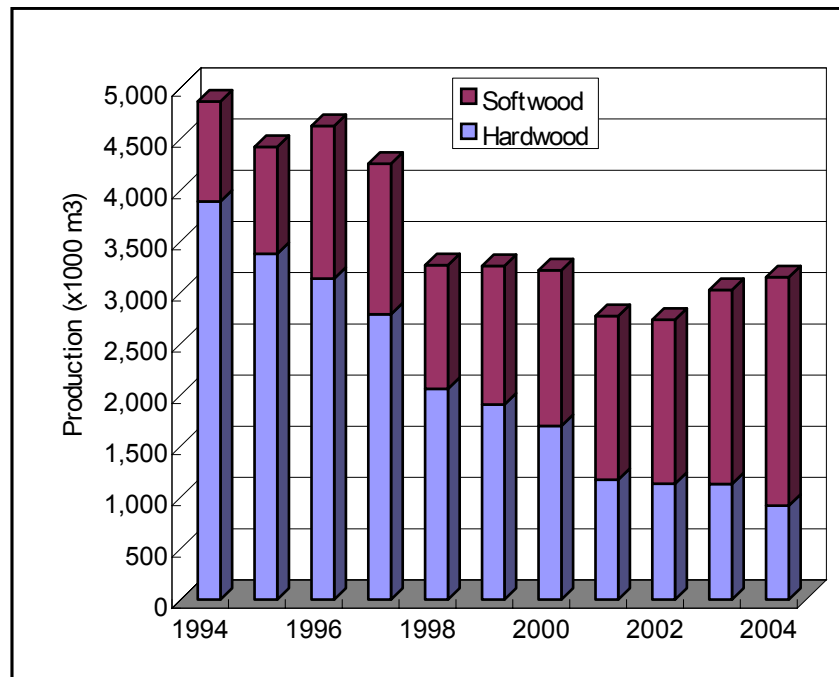
Fig. 18. Domestic plywood production.

Fig. 19. Sugi logs used for plywood project in Shizuoka.

Fig. 20. *Eucalyptus grandis* logs imported from South Africa.
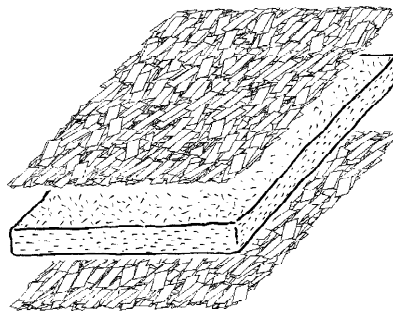
Fig. 21. Schematic diagram of three-layer mat-formed panel called J-OSB consisting of sugi strand for the face layers and recycled wood particle for the core layer.

Fig. 22. A view of mat forming for the size of 2000 mm by 1000 mm.

Fig. 23. Three-layer mat formed.

Fig. 24. The boards after pressing were stacked.

European Experiences with Wood and Natural Fibre Composites

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Abstract

The world social and economic situation at the beginning of the new millennium has a direct influence upon the forest economy, both in Europe and in overseas regions. The forecasts for the next decades point out new centers of economic development, that will concentrate capital and change today's political and economic balance. The unprecedented demographic growth in Asia and the aging of the European population will result in the occurrence of controversial scenarios for the economic evolution of different regions. China and Russia seem to become the world leaders in the production of wood semi-finished products and furniture. Countries with tradition in wood working and furniture manufacture will be subjected to a harsh competition, in terms of raw materials and manufacturing costs. The expansion of the European Community from 15 to 25 members open up new prospects, but also bring about completely new aspects, for which no previous experience or adequate regulations are available. Outstanding productivities may be obtained by means of the new wood working technologies, with low raw material and power consumption. Wood products with pre-designed performances can be used for original applications in high-tech fields. New environmental regulations significantly increase restrictions on process and product emissions (VOC and formaldehyde), and on organic solvent and hazardous substances used for finishing of wood products. Besides panel and beam products, new types of composites based on wood and other natural fibres have entered the European market in recent years, and can be expected to gain further importance. The launch of Wood Plastic Composites (WPC) production in Europe has been associated with the introduction of new technologies not known for wood based products so far. Products based on agro-fibres have become important for automotive applications and for insulating materials.

Key words: European forest economy, wood-based products, wood working industry.

Speculations upon future are credible only when based on actual examinations, this being rather difficult to carry out in the case of the European and world forestry, due to the complex connections in this field. The complexity is especially related to the local and structural conditions of vegetation, which differ according to the organizational and administrative system of each country.

World social and economic situation

Population distribution and its welfare still contrast strongly from a country to another. In 2004, world population was of nearly 6.4 billion, mainly concentrated in the Far East, as follows: 24% in China (1.3 billion), 22% in India (1.1 billion) and Pakistan, 14% on the African continent and 10% in South-Eastern Asia (Fig.1).

The population growth forecast for the following decades favours the Asian and African continents. While the population of the two American continents will grow by 30% in the north and up to 40% in the south, the European population will dramatically diminish from 730 million (Russia, inclusively) in 2004 to only 650 million inhabitants. In the next 40 years, the African population will increase twofold (1.9 billion), and India, with 1.6 billion will surpass China (1.4 billion). In addition, the populations of the today's advanced countries will significantly decrease; for example in CIS (-20%), Japan (-15%), Italy (-13%), Germany (-5%), the population will grow old, the group below 15 years of age will diminish by 30%, and the one over 60 years of age will increase twice as much as at present. In accordance with the present moderate forecasts, the world population will reach 9 billion inhabitants in the year 2050 [UNO].

The world gross product (WGP) was of about USD 35,000 billion in 2004 (Fig. 2). North America and Central and Western Europe, with only 15% of the world population, contribute more than 60% to the WGP. Also contrasting is that Africa and the Indian Peninsula contribute with only 4% to the WGP, although possessing considerable natural riches and having 35% of the world population [IMF]. The industrial production, under recession for more than a decade especially in the developed countries, decreased during the last 5 years in countries like Japan, USA, Germany, and increased by more than 20% in India and Russia or by more than 70% in China (Fig. 2) [OECD].

Forestry worldwide

About 30% of the earth land is covered by forests, which means 3.9 billion ha, out of which 57% are in the countries

under development, while the rest of 43% belongs to the industrialized countries. In terms of the forest types imposed by the geo-climatic areas, 48% of the planet's forested land is tropical, 22% temperate, and 30% northern. 12 to 15 million ha of rain forests are destroyed every year within the southern hemisphere, particularly in the countries under development (Tab.1). 3.3 billion m³ are yearly harvested all over the world, out of which 55% is used to produce heat and electrical energy, and 45% for wood products and by-products (Fig. 3). 500 species are harvested worldwide, most of them originating in the tropical and sub-tropical regions, and manufactured in the area of origin only under the form of semi-finished products. In Europe, only 20 to 30 species are harvested, after attaining an average age of 60 years.

A new type of forest plantation appeared in the last decades and extended in many countries all over the world, especially in the southern hemisphere. Huge areas, uncultivated or taken over from the agricultural field, were planted with hybrids of species like poplar (Italy), eucalyptus (Spain, Brazil etc.) and pine (France, New Zealand, Chile etc.), which come to maturity in 15–25 years and reach diameters of 20–30 cm and heights up to 20 m. These plantations represent the raw material sources for the cellulose and paper industry and the boards and building materials industry [FAO, DGfH].

The rapid changes in Europe, determined by the political and economic reforms in the central and eastern countries, as well as by the increasing pressure upon the present ecological legislations regarding the environment protection (air and water, especially) are permanently generating new scenarios that cannot be faster assimilated either politically or economically.

Europe holds a wood total volume of 25 bill.m³ distributed over an area of 149 million ha of harvestable forest. The European Community initially held forested area of 50 million ha and harvested an annual volume of wood of 164 million m³/year; starting with 1995. When other countries like Austria, Finland, and Sweden, with high potential (46 million ha and 100 million m³/year), tradition, and reputation in the field joined it, the EC had to rapidly re-examine its forest policy. The expansion of the European Community from 15 to 25 states during the year 2004 brought about substantial changes in terms of the wood stock extent (117 million ha), structure, and property (Fig. 4) [FAO, Schwarzbauer].

With the expansion of the European Community to 25 members (EC25), the wood annual growth of 500 million m³ in the EC15 (15 members) increases by 35%, and the import–export balance favourably changes, becoming an excess one. The annual volume of logs harvested within EC15 exceeded 300 million m³/year in the year 2000, an additional amount of 65 million m³/year being added from the 10 new members, and more than 20 million m³/year

from the future members, i.e., Romania and Bulgaria. The natural annual growth of this geographical region (EC25+2) attains the approximate value of 650 million m³/year [FAO, Giesen, Schwarzbauer].

Forest property structure is very diverse, determining different conditions of development and administration at a national and especially regional level. In the Scandinavian countries, more than 90% of forests are private property, while in central Europe it varies between 60–80%, and in the southern and eastern parts of the continent only 10–50% of forests are held privately, depending on to what extent the reform regarding forest retrocession has been applied. Under these circumstances, the private forests in Europe are possessed by 12 million owners. Therefore, the average area statistically allotted per owner is less than 200 ha of forest, in most of cases adjacent to the farming lands, and managed in a family system [FAO, Giesen].

In the new and future states members of EC, the wood conversion degree differs a lot from an area to another. The log consumption per inhabitant in EC25 was 0.75 m³ in 2000 as compared to 0.55 m³ in Romania and Bulgaria. The timber consumption in EC25 in the same year was of 0.20 m³ per inhabitant as compared to the group of the 10 new members, with 0.15 m³ per inhabitant if considered separately, or the future members with 0.05 m³ (Tab. 3). Much more dramatic and eloquent would be a comparison regarding the cardboard and paper consumption. In the same year, EC15 had 190 kg per inhabitant, while the group of the 10 new members had 65 kg and the future members 35 kg [FAO].

It would also be interesting to examine the evolution of Russia and of the CIS member states. Compared to Europe, with forested area of almost 180 million ha, CIS held in the year 2000 forests covering an area of 880 million ha, with an annual growth of approximately 1,000 million m³, out of which 40% is in Europe. Starting with 1990, the volume of the harvested logs suddenly decreased from 385 million m³/year to less than 100 million m³/year at present; in spite of that, even in the industrialized countries a deforestation policy is carried on, instead of a rational harvesting. The main enemy of the CIS forests still remains fires, which destroy up to 6 million ha each year. The hot discussions caused by the privatization of forestry have not led yet to any result; the compromise solution was the forests being taken into custody for a 99-year period, also by the foreign investors. As in Eastern Europe, in Russia, the political changes from 1989 and 1990, respectively, directly affected the wood working industry as well. A conclusive example might be the dramatic reduction of the timber production, from 90 million m³ in 1970, to 20 million m³/year in the year 2003. Under these conditions, the export of logs increased from 14 million m³/year in 1980 to 40 million m³/year in 2004 (40% of the total production), especially towards the neighbouring countries like Finland (15 million m³) and China (15 million m³). After China, the most important acquisitions of

wood working equipment and technology are being made by foreign investors in Russia. The short-term forecasts present Russia as the greatest exporter of semi-finished products for the furniture and wood constructions industry. The furniture in the CIS market is manufactured 50% by domestic production. Russia will be the biggest importer of boards, although the number of the new plants started up or under construction in the latest 5 years is large [Bemmann, FAO, Siempelkamp].

As against its surface and population, China has rather low wood resources; however, because of the booming economic growth in the last decade, it became the main machinery and equipment importer in the wood working industry. The short- and medium-term forecasts hold China as the world future manufacturer and exporter of furniture. Special efforts are being made to create new forest plantations in order to assure the wooden raw materials. However, the volume of the wood imports from Russia, South-East Asia, New Zealand, and Africa grew more that 5 times in the last 5 years, attaining 25.5 million m³ logs/year. More than half of the China's import of logs comes from Russia, to which other 5.5 million m³ of timber are added. Therefore, Europe and America will gradually lose their supremacy both in furniture production and especially in the manufacturing of certain types of boards, i.e., MDF. The annual increase of furniture production in China by 15% will lead in the year 2015 to a total amount of 30–40 billion. China will specialize in office and kitchen furniture, due to the rapid changes in society and living conditions. In Germany, for example, the furniture imports from China increased in a single year by 33%.

Logs and timber production

In the central European countries, the prices of the wooden raw material have continuously grown for several decades. For example, in the Alps region, in case of the resinous logs for timber, the price per m³ has increased since 1970 nearly 3 times. This phenomenon resulted in an increase of the resinous timber price from 50 USD/m³ in 1970 to more than 155 USD/m³ in the year 2000. The fluctuations in prices for the wooden raw material and various assortments were obviously influenced by blowdowns, which were almost periodic between 1990 and 2000 in Bavaria ("Lothar" 1992: 5 million m³) or in 1995 in Romania (2 million m³) and in 2005 in Sweden (70 million m³). In the year 2002, the import price worldwide for resinous logs was of 61 USD/m³ and of deciduous trees 66 USD/m³, as compared to 48 and 49 USD/m³, respectively, within EC15. In case of the resinous timber, the worldwide price was 167 USD/m³, while within EC it was 172 USD/m³ [FAO].

It is also interesting to compare the volumes of the yearly harvested logs per inhabitant (Tab. 4). Against the world average of 0.6 m³ per inhabitant, in Europe 30% more wood is harvested, the record belonging to Russia (1.2 m³), Austria (1.8 m³), USA (2.2 m³), and Sweden (5.5 m³). The use of

wood for domestic consumption in some European countries is low, for various reasons: 40% in the 10 new members of EC, 50% in Austria, 55% in Germany, 60% in EC15, 80% in Scandinavia. Theoretically, this will allow in the future eliminating to a great extent the import of logs. In the year 2002, 1,009 million m³ resinous logs and 562 million m³ deciduous logs were harvested worldwide. 288 million m³ of timber were cut in the world from 659 million m³ resinous logs. 208 million m³ of resinous logs were harvested in EC15 in the same year and 61 million m³ of deciduous logs, respectively. About 73 million m³/year of timber were cut in EC15 from 120 million m³ of resinous logs (Fig. 5). Although the firewood volume grew worldwide at the value of 1.8 billion m³/year, the consumption per inhabitant decreased to 0.29 m³, as a result of the population growth especially in the countries under development, being much higher than in Europe, i.e. 0,08 m³ (31 million m³) [FAO].

Due to the increasing mechanization and automation in the wood working industry that took place in the last decades, especially in case of the timber plants, the number of low capacity facilities (<10.000 m³/logs and year) has been dramatically decreasing. As compared to the year 1970 when 70% of the timber volume in the Central Europe was processed within small plants, in the year 2000 it represented only 25%. The number of small plants decreased between 1970 and 1990 in EC15 by 75% as compared to the central and Eastern Europe countries, where this phenomenon occurred after 1990, but with the same intensity.

Thanks to new timber working technologies that cut logs into cants and into timber on multi-blades circular saws, speeds over 300 m/min and capacities over 1 million m³ logs/year and line could be attained; therefore, productivity has increased in the last decades from 210 m³ to 1,050 m³ timber/employee (Tab. 5) [FAO].

The European timber producers will be constrained to reduce the transportation expenses, to use wood and processing wastes in a superior manner, and to take organizational actions destined for making the manufacturing process more flexible. An interesting example is that of briquetting of wet or dry chips resulted from the wood primary processing, as well as that of the bark conversion in order to efficiently produce heat energy, electric power, and compost.

Wood based composites [after Botting, Fruehwald, Giesen, Huebert, Siempelkamp].

The last 10 years have been some of the most active and fascinating in the history of the wood-based panel industry, certainly in terms of technology and growth of the industry globally (Fig. 6). A summary of the European wood-based panel production in 2003, supplemented by numbers for timber and pulp/paper production, is given in Figure 7.

The continuous press is one obvious example of a major change in the technology employed. It really started with the first continuous particleboard press made by Bartrev

in England in 1955. However, the Bartrev press was not successful, due to technological constrains. Bartrev was followed by Küsters in 1977, Siempelkamp's ContiRoll in 1985, and Dieffenbacher's CPS in 1990 Germany.

Notable is the Mende-type continuous press made by Bison, Germany. This calender type press has limitations, particularly in terms of the thickness of board it can press. It is however, still popular for thin board production. In the mid-90s the major developments of the continuous press concept, mainly in the production controls with real time visualizing PC controls increase flexibility of the process and allow to pre-design the thickness and density profiles of the panels. Today's continuous presses have flexible infeed sections and, in some cases, cooling zones, to enable ever-faster production speeds to 90 m/min. The daily production capacity of such a modern line varies depending of the panel type from 800 m³ for MDF to 1400 m³ for particleboard. Further sophisticated on-the-line quality control and measurement systems make possible automatic adjustment of the press during production, instead of off-line lab samples testing before corrections can be made. Fire protection and environmental protection have been other major areas of development.

After more than half a century development of equipment, technology, production process, and products quality, Europe lost its dynamic development in the panel production. Today, Europe has the highest number of continuous lines for MDF, PB, and OSB (Tab. 6).

Western European companies such as Kronospan, Egger, and Sonae have increasingly gone for so-called Mega-Sites, producing two or three panel types on one site with obvious advantages in logistics (Fig. 8). That philosophy is now being transferred to mega-sites in eastern Europe, notably Russia and the Far East.

The mid-1990s was boom time in South East Asia, with PB and MDF mills being built at an almost alarming rate. The continuous press was transforming the Asian panel industry into a profitable one. The investment did not just come from established panel manufacturers but also from all angles because of the returns on investment available at that time. Part of the success behind the new MDF lines in South East Asia was the fact that Takeuchi, Japan, realised that MDF could be produced out of rubberwood. Today the main concern is whether there will be enough rubberwood to feed all the MDF mills and furniture factories which have grown up around it, as rubberwood plantations are replaced with the more commercially viable oil palm plantations.

At the last count, about three dozens of new European-made continuous press lines for PB and MDF had been ordered by Chinese companies since 2000. More than 100 lines were built only for MDF including of course the new Chinese-made multi-opening lines.

China is increasingly an export country for furniture. A number of European and US furniture producers have relocated their manufacturing facilities to China. The furniture produced in China is mainly for export back to the US or to Europe so the MDF or PB used in its manufacture has to be up to international standards. That, and an increasingly sophisticated domestic market, explains the rapid increase in the number of new modern lines in China. So now China has a world-class industry growing fast and threatening to produce an extra 4 million m³ of MDF very soon. It is unlikely the domestic market will consume all that material. There is an interesting parallel with European thinking concerning over-production of wood-based panels.

There are, surprisingly, few continuous press lines in North America despite the US and Canadian tradition. While more than 80% of the European wood-based panel production is manufactured on continuous presses, this holds for approximately 25% of the North-American production. Lots of big Washington Iron Works multi-daylight presses but few Siempelkamp, Dieffenbacher, or Metso continuous presses for PB or MDF are there in use. The USA has around three out of 46 particleboard lines with continuous presses and Canada has about four out of twenty. North America does have several continuous OSB lines and in fact the US has the biggest continuous press in the world at Huber's with a capacity of 1,600 m³/day.

The most recent of these surveys – and the most difficult to compile – is particleboard. That's because commercial production can be traced back to the 1940s. The development lines for particleboard are pretty flat. This does not necessarily indicate no new mills in Europe's case, but rather a balance between new investments and line closures.

The capacity changes to OSB can be easily noticed. North America has witnessed a spectacular surge in the price of OSB throughout 2004 and this suggests they have got the capacity about right. The European industry, after years of gross over-supply, has shown marked improvement in 2004, partly due to increased exports to North America, but also to a growth in demand, especially in eastern Europe, where more capacity is rumoured to be planned.

With all the concentration of the industry focused on MDF, particleboard, and OSB, it is perhaps easy to forget the oldest-established panel product, plywood. Today, some of the best state-of-the-art plywood production lines are produced by Raute, Finland, and Cremona, Italy. The traditional birch and poplar, and more recently spruce and pine plywoods and LVL are made. Logs are automatically loaded and centered on the lathe, which runs at speeds of up to 300m/min for 1 inch thick veneer. Grading is fully automated, at least for core veneers. Even veneer patching can be automated, for example using a combination with a grading visual defect analyser. It has a patching cycle of 0.6 seconds, or 15,000 patches per head per eight-hour shift.

PB and MDF are mainly produced from lower grade fresh wood or, particularly in the case of particleboard, from residues. In Italy and Spain some PB producers with a total production capacity of some millions m³/year produce all the PB from 100% waste or recycled or urban wood, which is collected in a fleet of trucks distributed around the major cities of these regions. Mills using recycled wood also operate in China, Japan, South Korea, and Singapore.

In terms of protecting the environment from the panel production process, regulation has increased dramatically during the last 10 years, with ever more stringent control of dust, gaseous emissions, water quality, and noise. That can only be applauded but it does mean considerably increased costs for panel makers, with no commensurate advantage on the income side of the balance sheet. It is also a cost which competitors in China and some other countries are not required to bear.

Producing only raw board surely cannot be a long-term option for the panel makers. In an often over-supplied market, they have to find ways to increase their margins. Many mills have short cycle presses to laminate their PB or MDF panels but this is probably not going to be enough. Mills in South East Asia quite commonly have downstream processing right through to furniture manufacture. Many of the larger producers of panels also make laminate flooring. But here again, over-capacity is killing the market.

The last few years have been tough in Europe and there is currently little sign of a strong recovery in the markets for panel products. What is sure is that the technology will continue to develop thus helping the panel makers to meet the future demands of the market.

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*** Start noch heuer. Holzkurier 17/2005, pg. 5-6
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Abbreviations

CIS = Comunitaty of Independente States (Russia etc.)
DGfH = Deutsche Gesellschaft für Holzforschung
EPF = European Panel Federation
FAO = Food and Agriculture Organization
OECD = Organisation for Economic Cooperation and Development
UNECE = United Nations Economic Comission for Europe

Table 1: Evolution of forested lands worldwide (1990-2000) [FAO]

Forest type	1990 [1.000 ha]	2000 [1.000 ha]	Ratio [%]	Surface [ha/inhab]
Tropical	1.967,2	1.854,6	48	0,7
Temperate	819,3	839,9	22	0,3
Boreal	1.152,2	1.153,9	30	5,9
Total	**3.947,7**	**3.846,4**	**100**	**0,7**

Table 2: Worldwide forested land (2000) [FAO]

Country/Region	Forest surface [mil.ha]	Forest share [%]	Surface [ha/inhab.]
Scandinavia	58,3	55	2,45
EC15	113,57	36	0,3
Europe	**175,83**	**31**	**0,3**
CIS	855,74	40	3,01
North America	461,39	25	1,52
World	**3442**	**27**	**0,64**

Table 3: Wood and wooden products consumption in Europe (1998) [FAO]

Area	Logs volume [mil.m³]		Processing logs [mil.m³]		Timber total [mil.m³]		Wood based panles [mil.m³]		Pulp [mil.t]		Paper and cardboard [mil.t]	
	Prod.	Cons.	Prod.	Cons.	Prod.	Cons.	Prod.	Cons.	Prod.	Cons.	Prod.	Cons.
G 1 [a]	64,4	52,6	54,3	44,6	15,2	9,1	6,5	5,3	2,1	2,0	4,0	4,5
G 2 [b]	20,2	19,0	15,6	14,8	3,7	1,1	0,9	1,0	0,7	0,6	1,0	1,2
CE15	253,7	282,0	225,0	253,2	72,7	80,5	39,8	43,1	33,9	40,7	77,4	69,6
CE25	338,3	353,6	294,6	312,6	91,6	90,7	47,2	49,4	36,6	43,3	82,4	75,3

a) Estonia, Latvia, Lithuania, Poland, Slovenia, Czech Rep, Hungary; b) Bulgaria, Romania, Slovakia

Table 4: Wood and logs production (2002) [FAO]

Country/Region	Harvest		Ratio	
	Total [mil.m³]	Ratio [m³/inhab.]	Softwood [%]	Process logs [%]
Scandinavia	130,6	5,5	88	91
CE15	264,4	0,7	76	89
Est Europe [1]	87,4	0,7	56	82
Europe [2]	**395,2**	**0,8**	**71**	**87**
Russia	174,2	1,2	60	72
North America	678,2	2,2	67	89
World	**3384,4**	**0,6**	**36**	**47**

[1] - incl. Croatia, Slovenia, no CIS; [2] - incl. Baltic state, nu Russia

Table 5: The first 10 timber producers in Europe (2005) [after Holzkurier]

Industrial Group	Origin country	No. of lines	Production [mil.m³]
Stora Enso	Finland	24	7,4
Finnforest	Finland	30	4,2
Klausner*	Germany	4	3,1
UPM-Kymmene	Finland	10	2,4
Setra Group	Sweden	14	2,3
Binder Holz*	Austria	2	2,2
Klenk Holz	Germany	4	1,6
SCA Timber	Sweden	7	1,5
Mayr-Melnhof*	Austria	2	1,4
Södra Wood	Sweden	10	1,4
Total Top 10			

* - one line in erection by the end of 2005

Table 6: European wood-based panel users (2004) [after EPF]

Panel type	Furniture	Building	Flooring	Others
Plywood	20	50	10	20
OSB	5	75	5	15
MDF	55	8	33	7
PB	57	23	5	15
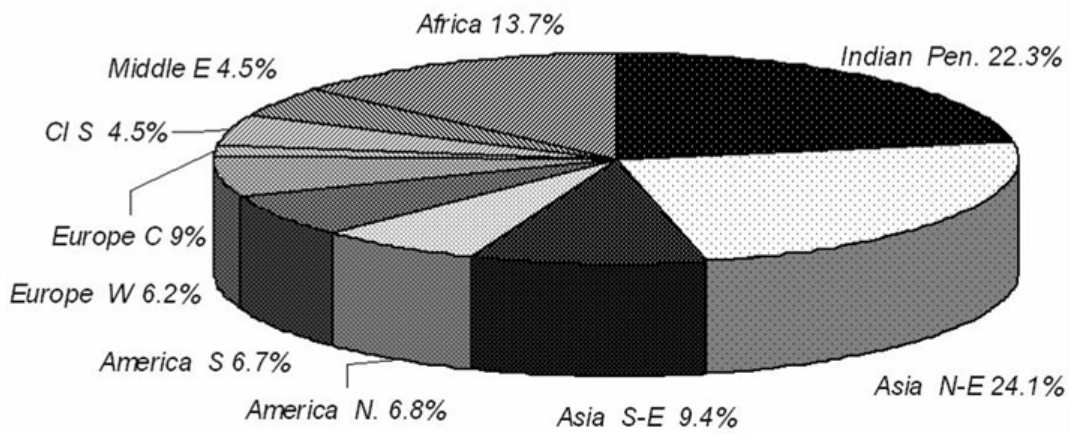
Figure 1: World population distribution in 2004 (6.4 bill. inhabitants) [Bonarius]
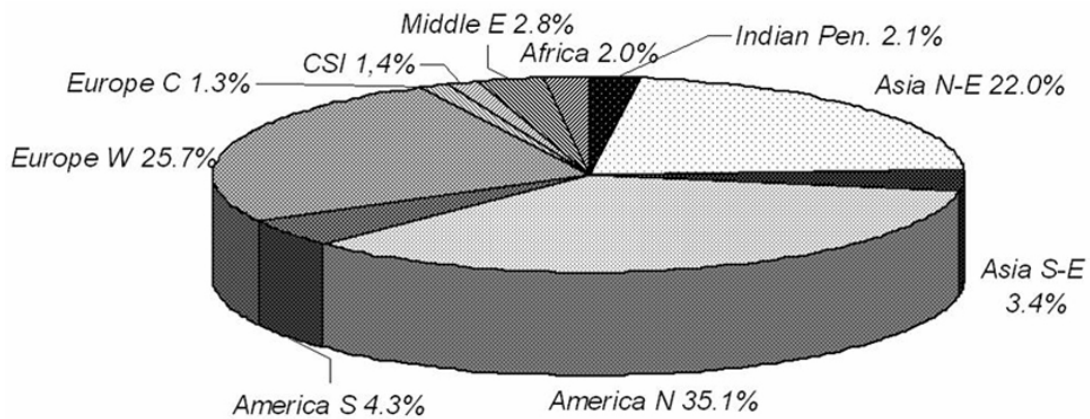
Figure 2: World gross product in 2004 (USD 35,000 bill.) [IMF/OECD]
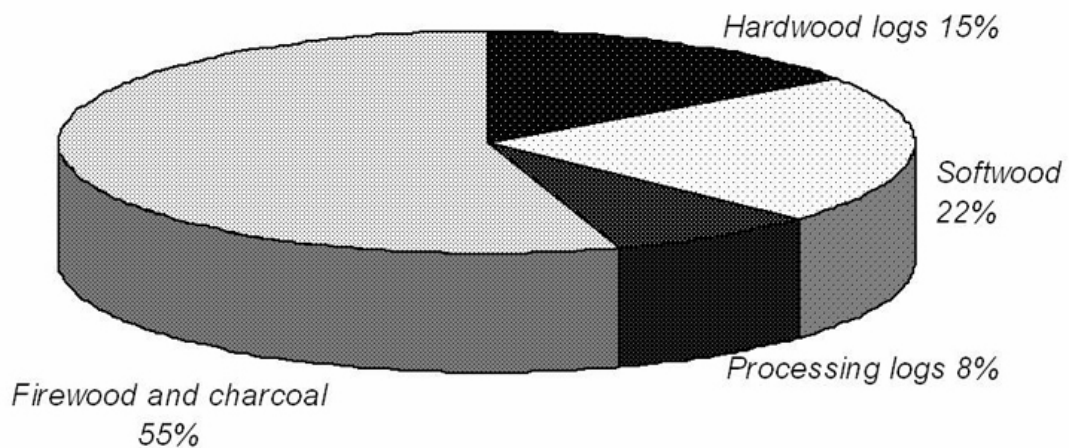
Figure 3: Production of logs worldwide [FAO]
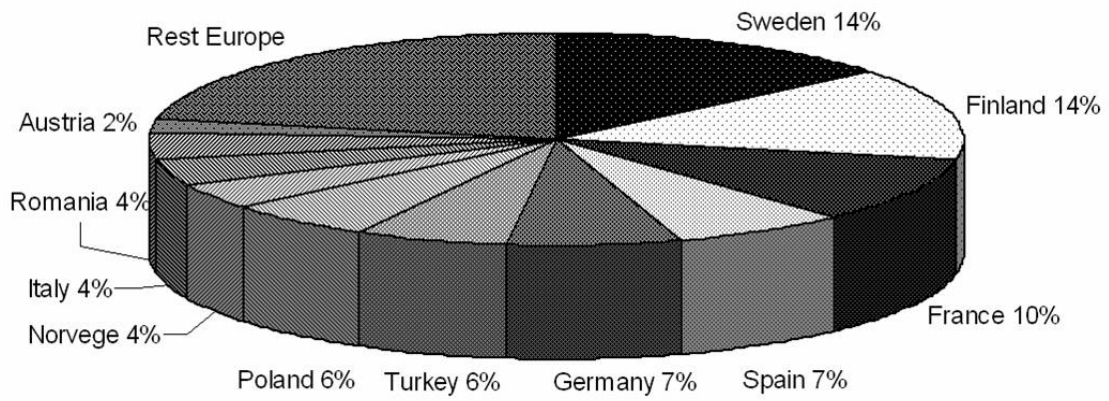
Figure 4: Forested lands in Europe (excepting CIS) [FAO]
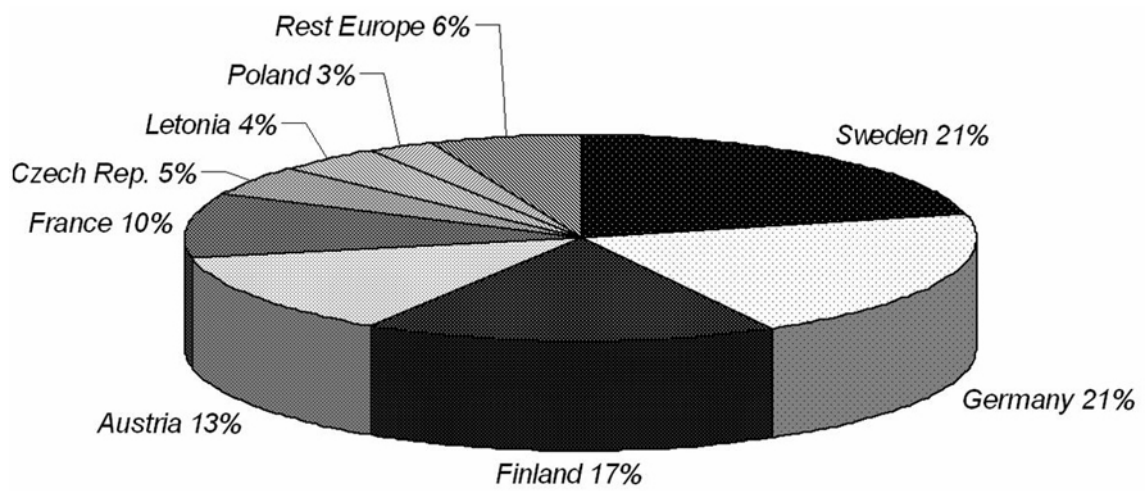
Figure 5: Resinous timber producers in Europe (2002) [FAO]
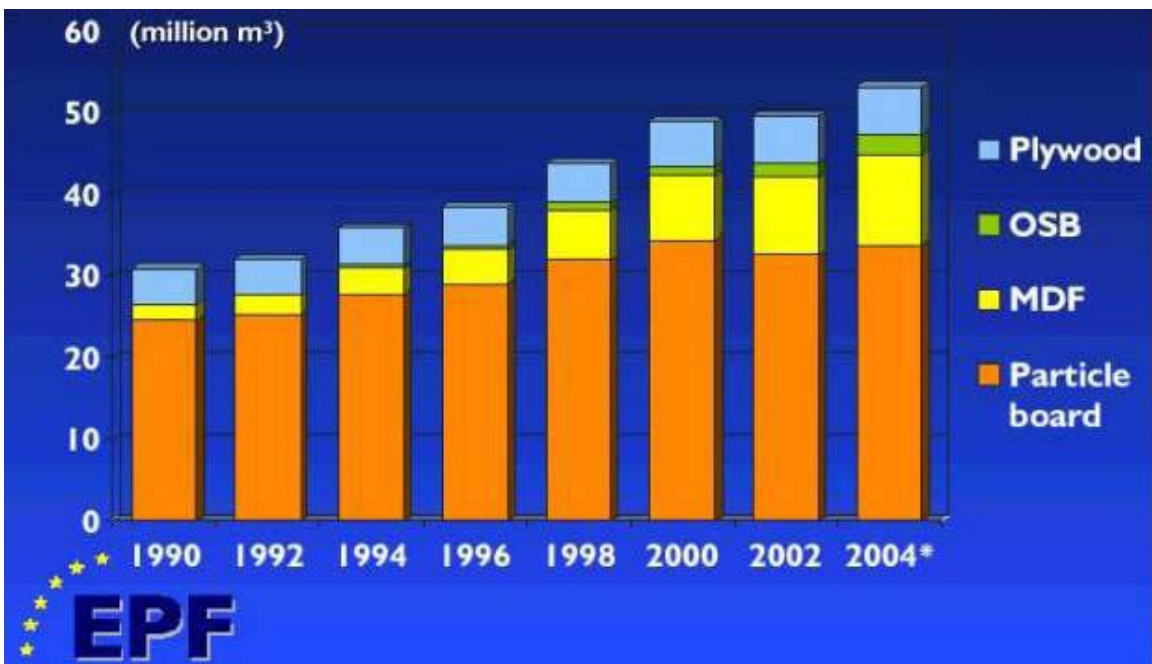
Figure 6: Consumption of wood-based panels in Europe in 2003 [EPF]
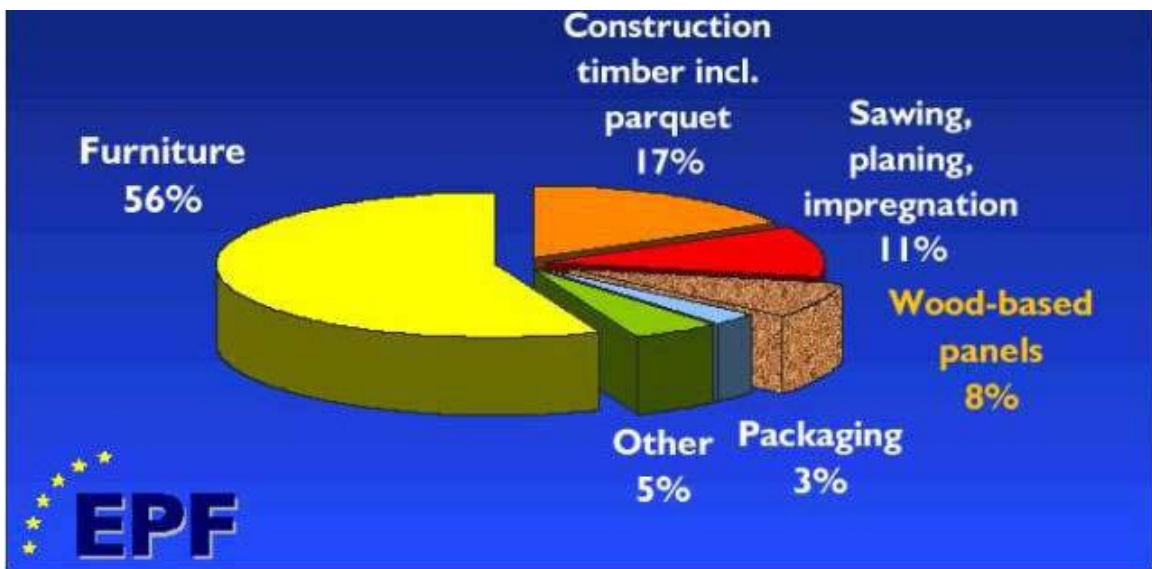
Figure 7: Wood-based panels in Europe 2003 (Total: 55.7 mill. m³) [EPF]
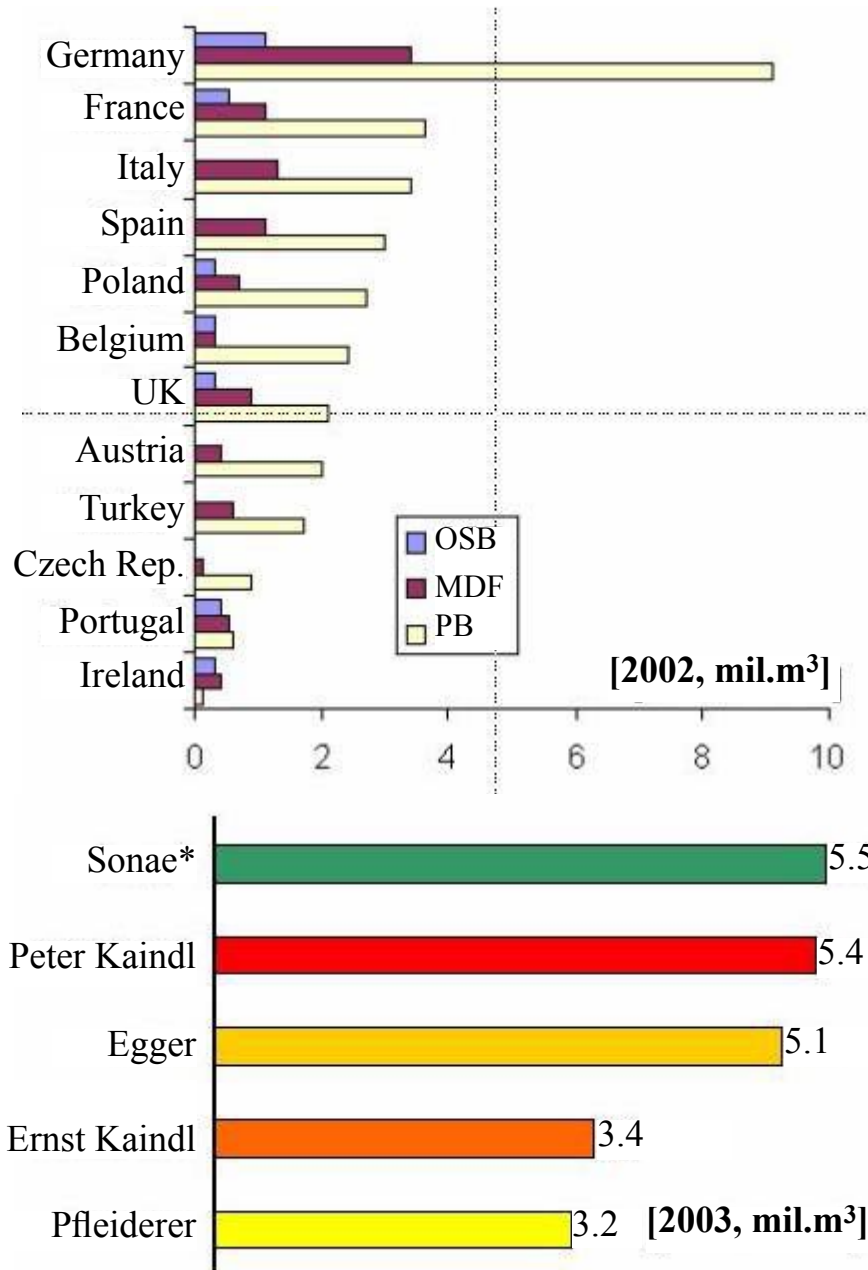
Figure 8: Production capacities in Europe [after EPF 2003 and Huebner]

Wood Composite Made of *Populus* Plantation Material in China

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Abstract

Populus is one of the major forest plantation species in China with more than 6 million hm^2 of plantation forests. Wood composites made of plantation material play a very important role in balancing supply and demand of timber in China. This paper summarizes physical and mechanical properties, and chemical composition of this material. The key characteristics of wood composites made of *Populus* are: low density, light color, high and unevenly distributed moisture content, easy to deform, and high stress wood proportion. *Populus* plantation material is widely used to manufacture plywood, block board, particleboard, MDF, and reconstituted fancy veneer in China. And research and development of *Populus* plantation material in China is also introduced. This paper also suggests focusing on future Chinese market segmentation, particularly that: fast growing *Populus* species with high quality be further genetically improved, more intensive management be practiced in plantations (such as wider spacing, pruning, irrigation, fertilizing, and beetle prevention, aiming at large diameter, fewer and smaller knots, and low taper for veneer manufacturing), more technology improvements be made (veneer peeling and softening, drying and gluing technology to make better use of the material), new products be developed to meet new construction and decoration demand (OSB, LVL, and reconstituted fancy veneer), and the Chinese government develop policies that favour plantation forestry.

Keywords: Poplar; Plantation forests; Composite; Processing; Utilization; Policy

Introduction

The economic development of China has continued to increase and is expected to go on in the future. GDP in China was 13,651.5 billion RBM in 2004, increased by 9.5% over the last year (State Statistics Bureau. 2005). Between 1978-2004, the annual average increment of GDP in China is 9.5% and is planned to further increase at 7-8% annually in the coming 15 years. Rapid economic development and growth in investment and consumption have spurred wood consumption and therefore created a great wood demand in China.

In the meantime, China is facing serious environmental problems such as soil erosion, desertification, shortage of water resources, and decrease of biological species.

The impact of natural forests on ecological environment is greatly concerned by more and more people in the society. In 1998, the Chinese government initiated Natural Forest Conservation Program (NFCP) which applied to 18 provinces and autonomous regions, covering the up-stream regions of major river systems like the Yellow River and Yangtze River. With the implementation of NFCP, timber harvest from China's natural forests was reduced greatly. During the first period (1998-2000), timber harvest quota was cut down from 26.7 million m^3 in 1997 to 14.34 million m^3 in 2000. During the second period of NFCP (2001-2010), another 3.64 million m^3 of timber harvest quota will be further cut off. It is obvious that this policy will accelerate the contradiction between demand and supply of the timber in China.

China recently released the results of the sixth national forest resources inventory (1998~2003) (State Forestry Administration, 2005). The report shows that the forest area is 175 million hectare with 18.21% of forest coverage and 12.456 billion cubic metres of forest growing stock, among which the plantation forests area and growing stock of plantation is 53 million hectares and 1.505 billion cubic metres, respectively. Since the 1960's plantation forest has expanded rapidly in China. Plantation forests are supposed to play a very important role in supplementing the diminishing supply of timber from natural forests. It is hoped that wood resources in China will transfer from natural forests to plantation forest and timber stock volume, quality and species will be more flexible to meet market needs in 15 years (Zhang S.G. et al. 2002).

Considering the facts mentioned above, the only way for China to solve the contradiction between wood supply and demand is to expand plantation forests and better utilize plantation timber. Therefore, the State Forestry Administration in China has launched the Fast-growing Commercial Plantation Program, aiming to produce more timber for local markets. It is apparent that with the implementation of this program, plantation timber will become more and more important in meeting the national economy needs for wood materials.

To meet market demand and utilize wood resources more efficiently, wood composite industry in China developed very fast in the past to increase market supply of wood materials under lower log production. The log and wood composites production in China during 1991-2004 (Table 1) showed that the log production per year was

steadily decreased by 21% but the production wood composite increased by 1740% in the past 14 years. It should be mentioned that plywood face veneer is mainly depending on imports and core materials are mainly made of wood from *Populus* plantation material.

In order to fill the gap between demand and supply of wood products, China spends billions of US$ to increase imports of wood and wood products. In 2004, log imports have been recorded at 26.244 million cubic metres valued at US$ 2.797 billion, sawnwood imports at 6.004 million cubic metres valued at US$ 1.381 billion, plywood imports at 780,000 cubic metres valued at US$ 377.4476 million, veneer imports at 1.16 million cubic metres valued at US$ 109.655 million, fiberboard imports at 812,000 cubic metres valued at US$ 272.349 million. On the other hand, in 2004, plywood exports grew strongly. China exported 4.291 million cubic metres of plywood valued at US$ 1.245 billion, a year on year increase of 110.2% in volume and 151.1% in value (China Timber Logistics Association. 2005).

Current Situation

Populus is one of the major forest plantation species in China and first introduced from United States and Europe in the 1940's. Since the 1960's, fast-growing *Populus* species and clones have been selected and bred and fast-growing *Populus* plantations have been developed from garden greening to windbreaks establishment to agro-forestry and to large industrial plantations in China in large scale with more than 6 million hm^2 of *Populus* plantation forests mostly in middle and low reaches of the valleys of Yellow River and Yangtze River . China has made great progress in breeding, silviculture, wood processing and utilization so far. For example, Jiangsu province, which is located in the low reach of Yangtze River, started to develop *Populus* industry in 1991 and has developed an industrial chain from breeding to end products. Now there are 400,000 ha. of *Populus* plantation forests in Jiangsu province but log production from *Populus* plantation forest reaches 5.6 million m^3 and the annual production of the industry reaches 36 billion RBM. It is analyzed that the key factor of *Populus* plantation forests industry development is that it suits the needs of market economy and re-structuring of agriculture. *Populus* plantation forests grow very fast with DBH annual growth of 2-4 cm, needing only10 years for large diameter log production.

Populus plantation forests grow very fast. Normally, the *Populus* plantation forests could reach 9-15 m^3 /ha/year with 6-10 years of rotation(Chinese Society of Forestry and China Poplar Committee. 1990). *Populus* plantation material produces much higher proportion of juvenile wood than that of natural forest because of its fast growth and shorter rotation period. Therefore, significant difference of wood property characteristics exists between the timber

from plantation and natural forest, such as low basic density (0.35g/cm^3), soft, light colour, high and unevenly distributed moisture, large longitudinal variation of main chemical composition (Qin T.F. et al. 2004), much stress wood, easy to deform and peel, and so on. If incorrect forest management practice is implemented, *Populus* plantation material may bring a lot of defects, such as bad trunk shape, more knots, black heart core, and more holes, resulting in low quality and low price of the material (Bao F.C. and Jiang Z.H. 1998). *Populus* plantation material used to be utilized for making low valued and low performance products, such as packaging, rural housing building materials, match and instinct chopsticks due to the poor quality of the material(Chinese Society of Forestry and China Poplar Committee. 1990).

With better forest management practice implemented, wood processing technology improved and timber market needs increased, application of *Populus* plantation materials has been much expanded. Now the material is widely used to make plywood, blockboard, MDF, particleboard and laminated lumber production (Wang Jinlin. et al. 1999) and it is possible to make new composite products, such as surface densified lumber, LVL and reconstituted fancy veneer. *Populus* plantation materials have become the main raw materials for wood composite industries in valleys of Yellow River and Yangtze River. It should be mentioned that there are thousands of different scale plywood factories which use logs of *Populus* plantation forests to make veneer, plywood, blockboard and laminated lumber as core veneer and core strips combined with tropical hardwood veneer as surface. Small diameter logs, head logs, branches and processing residues are used to make particleboard and MDF.

Products made of *Populus* plantation materials are further overlaid with either high value hardwood sliced veneer or impregnated paper to make decorative plywood and paper overlaid floorings. The challenge faced by the industry is to further decrease free formaldehyde emissions from the products.

Due to the characteristics of *Populus* plantation materials, it is necessary to improve the performance including low surface hardness, low strength and poor dimensional stability through development of modification technology. One way is to impregnate organic polymers into the timber and harden the composite at high temperature to improve the dimensional stability and durability. Another way is to impregnate water soluble low molecular PF or isocyanate resins into the timber and harden the composite at high temperature and pressure to increase surface density resulting in high MOE, MOR, surface hardness, anti-wearing and dimensional stability (Liu Junliang and Wang Yuqiu.2004).

Since veneers with light colour are easily peeled from logs of *Populus* plantation material, the *Populus* veneers are

used to make reconstituted fancy veneer with beautiful grains and patterns though bleaching, dying, assembling, flitch forming, conditioning and slicing procedures (Zhou Yu. et al. 2005). Simulation technology is applied so that the colour, grain and patterns could be designed and manufactured according to market needs. Reconstituted fancy veneer made of *Populus* plantation material is widely used in decorative plywood manufacturing, interior decoration and furniture manufacturing to substitute for valuable veneer made of hardwood from natural forests.

Research and development on utilizing *Populus* plantation material has caused high attention in China. Wood/plastic composite by extrusion technology and wood liquefaction technology are developed to further explore application opportunities of the material (Qin Tefu. 2002). The wood powders from *Populus* plantation material were made and screened by mill machine and meshes and then oven-dried until certain moister content was reached. The wood powders were compounded with polymers by injecting into a mould. Polymers, wood powder and additives (stabilizers) were pre-blended in a high speed mixer and then compounded into a twin-screw extruder and the extruded strands were cooled in a water bath. The wood/plastic composite through extrusion technology could be made with shaped end products without any processing residues produced and could be used widely in outdoor use applications without free formaldehyde emissions and excellent durability.

Populus wood meal was phenolated in the presence of sulfuric acid as a catalyst (Li Gaiyun. Et al. 2002). The weight ratio of *Populus* plantation material to phenol was enhanced to 0.7. The reacted liquefaction products were used directly to prepare phenolic adhesives without further residue removal. The adhesives with different molar ratios of formaldehyde to phenol (F/P) were prepared. The results showed that the phenolated wood-based phenolic adhesives had high bond property and durability with extremely low formaldehydes emissions.

Recommendations and Suggestions

The industry of *Populus* plantation material plays a very important role in forestry development. Better plantation forest management, processing technology and favorite policies should be further improved (Ye K.L. et.al. 2003). First, fast growing *Populus* species should be further genetically improved aiming at market needs, high quality and high growth. Secondly, more intensive management should be practiced such as wider spacing (5 X 5 meters), pruning, thinning if planting density implemented, irrigation, fertilizing and beetle prevention, aiming at large diameter log production with fewer and smaller knots and low taper for veneer and plywood manufacturing. Thirdly, more technology improvements should be made, including veneer peeling and softening, drying and

gluing, to make better use of materials. Fourthly, new products should be developed to meet new construction and decoration demand such as OSB, LVL, wood/plastic composite and reconstituted fancy veneer. Finally, the Chinese government should adjust and revise plantation forest policies to encourage and stimulate investment into plantation forests to promote agricultural restructuring, develop rural economy, provide more job opportunities, improve ecological environment and meet market need for the materials so that the industry and forest farmers could gain economic benefit and the government could gain social and ecological benefit.

Conclusion

The economy development in China has been increasing and is expected to continue in the future, which creates a dramatic market demand for wood and wood products. On the other hand, the forest resource in China is very limited and the implementing of National Native Forest Protection Program has strong impact on wood supply. Even though China has large *Populus* plantation forests, characteristics of *Populus* plantation material are quite different from other wood species and the wood of natural *Populus* forests. Thanks to better forest management practice implemented, wood processing technology improved and timber market needs increased, application of *Populus* plantation material has been much expanded and the material is widely used in manufacturing various kinds of composites in China. China is now carrying out intensive research and development of *Populus* plantation material, aiming at improving the performance of the composite by modification technology, extrusion technology and liquefaction technology. Furthermore, recommendations and suggestions for better plantation forest management, processing technology and favorite policies to develop *Populus* plantation forests were also made.

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Table 1: Wood Composite Production in China (Unit: 1,000 M3)

Year	Logs	Wood Composite	Plywood	Fiberboard	Particleboard
1991	58073	2960	1054	1174	614
1992	61736	4289	1565	1445	1159
1993	63922	5798	2125	1810	1571
1994	66151	6647	2606	1930	1682
1995	67669	16846	7593	2164	4351
1996	67103	12033	4903	2055	3383
1997	63948	16485	7585	2759	3604
1998	59662	10563	4465	2195	2663
1999	52368	15030	7276	3906	2401
2000	47240	20017	9925	5144	2868
2001	45520	21108	9041	5701	3445
2002	47588	29302	11350	7674	3690
2003	44360	45534	21024	11283	5474
2004	45558	54465	20990	15600	6430

Advances in Utilizing Whole Trees for Composites

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Abstract

Cost reduction and maximisation of timber yield from the forest has been an area of continued focus to ensure commercial viability of wood based materials. Composite materials offer an opportunity to increase the effective yield from the forest by using every part of the tree in an added value form. A number of projects undertaken at Scion, New Zealand, have focused on developing new composite materials based on radiata pine, utilising chip material and also waste bark in order to maximise recoverable value from the forest.

This paper outlines work undertaken to reinforce Wood Plastic Composites using wood fibres such as MDF and kraft. Petrochemical plastics such as polypropylene have been reinforced in addition to bio-plastics, such as polylactic acid, allowing the production of compostable and biodegradable materials.

Use of tannin from pine bark as a binder in wood composites has been well reported. A method of utilising the binding properties of pine bark tannin in composites is described in this paper where the tannins are mobilised without requiring extraction from the bark. Cost effective and durable composites result.

Keywords: Composite, bark, tannin, fibre, MDF, wood, plastic

Introduction

Over the last decade, in New Zealand, the return from plantation forests has been decreasing to the point that land is currently being converted from plantation forest to other uses such as pasture for grazing (MAF, 2004). This trend reflects the increasing pressure internationally to obtain maximum value from a plantation forest and to minimize fibre waste in order to be commercially viable. Approaches of intensive pruning have been used to maximize value of timber cut from a log, and in other instances pruning has been avoided to reduce compounding costs over the life of a forest. However, in all approaches advancing the utilization of the timber resource is required to ensure that all value is captured and costs associated with waste disposal are minimized. Two main forms of residue considered in the current research are waste fibre, such as saw kerf and chips from log processing, and bark.

When dealing with biological resources, variability of material can be a significant challenge to manage. With residues, the issue of variability is compounded further. In New Zealand the plantation estates are primarily radiata pine (Fig. 1) and many mills will only process radiata. This gives an advantage over some countries where a range of species will be processed in a single mill. The variability is less of an issue for low value applications, such as for an energy source, but when targeting more functional uses, such as discrete fibre or chemical components, variability becomes much more significant.

Wood Waste

Wood fibre residues currently find some value for use in composites, such as MDF and particleboard, and for pulp and paper and energy plants. However, some still ends up in landfill. Wood plastic composites (WPCs) have successfully utilized significant quantities of waste fibre in North America by filling plastics with wood flour. This reduces the cost of a plastic based material while improving some properties such as modulus. Wood flour in this application is primarily acting as a filler. However, wood fibre of high aspect ratio has potential to improve properties further by giving some reinforcing value (Stark and Rowlands, 2003). A range of fibre types has been evaluated for WPCs, including waste newsprint, MDF, Kraft, and agrifibres. (Spear, Hill and Tomkinson, 2002). For the New Zealand situation, MDF fibre is a thermomechanical pulp that is produced in a number of locations and is the most cost effective method of separating individual fibres from wood chips. Although the high aspect ratio fibres give some reinforcing, challenges are faced in feeding such fibres into plastics processing equipment due to clumping and poor flow properties. Winski (2001) gives an overview of fibre feeders to overcome some of these difficulties for producing WPCs.

Scion has developed a proprietary method of converting MDF fibres into pellets (Anderson et al. 2005) that can be readily fed into a plastics extruder without special crammers or equipment for feeding the longer fibres. Through this route, residual wood fibre can be utilized for its reinforcing value in WPCs. For these reasons, the reinforcing potential of MDF fibres have been explored in a number of studies at Scion. Although not using the MDF pelletising method, this currently reported study compares MDF fibre with three

fibre types to ascertain the reinforcing potential of MDF fibre over wood flour and relativity with other organic fibres.

Bark Waste

Bark is a residue stream that is high volume and very low value. The volume of bark on a tree varies with age but would average to approximately 10% over a 27 year old radiata pine in New Zealand. Based on the current fell, this would equate to approximately 2 million cubic metres per annum (MAF, 2004). Depending on time of the year and harvesting techniques, approximately half will remain in the forest and the other half taken off the tree at the primary processing plant. The 1 million cubic meters from the processing plant is currently used for energy, and horticultural applications, and the remainder taken for landfill.

Bark is a rich source of polyphenolics and these have previously been extracted for a variety of purposes (Table 1). Of these, the bonding of composite wood panels remains a viable use and may become more attractive as petrochemical prices increase. Tannin based adhesives are characterized by their bark brown colour and form a durable bond that is on par with their petrochemical phenolic equivalents.

The commercially available tannins tend to be from a wattle or quebraco source and chemical reactivity is dominated by the resorcinolic tannin moieties (Fig 2.) (Pizzi 1983). Radiata pine bark is different in that it is chemically characterized by the more reactive phloroglucinolic tannins. Although both types of tannin can be cross-linked with aldehydes to form durable bonds, it is only the resorcinolic tannin that is used commercially, as the radiata tannins can pose challenges due to various factors including their reactivity (Pizzi 1979). The current research explores the potential for utlising radiata pine bark tannin in composites where the tannin is not extracted prior to use. Rather, it is mobilized in-situ. The concept is to add ground bark to wood particles and mobilize the tannins, with the assistance of an additive mixture, during a hot pressing stage and the tannins will cross-link while the insoluble bark material acts as an inert filler. In such a situation the reactivity of the pine bark tannin could be an advantage rather than a disadvantage when conventional tannin solutions and glue mixes need to be stable.

The idea to use ground bark as a substitute for more expensive ingredients is very appealing and thus is not entirely new (Hall, Leonhard and Nicholls 1960). A few years ago Forintek, a Canadian research organisation, started to develop an OSB board based on "hogfuel," containing 70-95% bark with the remainder being primarily wood. The wood source was Douglas-fir, Hemlock, and Western White spruce (Troughton, Chan and Love 1998, 2000). However, because of a lack of reproducibility, poor appearance and a significantly inferior quality, there has been no commercial success so far with 'bark boards.'

A key difference between the approach taken by Scion and earlier work is that our approach does not need special press technology to allow the steam to escape (such as a perforated PTFE membrane on an interwoven stainless steel wire mesh). The Scion approach described in this paper is thus suitable for standard presses used in existing particleboard manufacturing plants (drop-in-technology), which is a major advantage.

Methodology

Wood Plastic Composites

Materials

The MDF fibre used was produced at the Ensis PAPRO pilot plant refiner from *Pinus Radiata* toplog using processing conditions to mimic commercial MDF fibre. The fibre was air dried to approximately 10-15% moisture content before storage in plastic bags. The bleached Kraft fibre used was from a commercial source, supplied as lap pulp sheet. Hemp fibre was a commercial source of Chinese origin, supplied as a continuous yarn. The wood flour used was ground *Pinus Radiata,* 99% passing through a 1 mm screen.

The polypropylene resin used was Hyundai Séetec grade M1600 supplied as pellets. The maleic anhydride modified polypropylene (MAPP) pellets used was Epolene G3015 obtained from Eastman Chemical Company. The biopolymers used were Monsanto's Biopol 400G and Cargill Dow's polylactic acid PLA 3001D, supplied as pellets. Zinc stearate powder was AR grade obtained from BDH.

Sample Production

The composites were produced by compounding in a twin screw extruder and subsequently injection moulding samples. An OMC 19/30 twin screw co-rotating extruder (19mm screw, L:D 30) was used for compounding with a screw speed of 150-200 rpm and a temperature range of 160-210°C for the petrochemical plastics. Biopol used a temperature range of 140-170°C and PLA a range of 170-190°C. The natural fibres/fillers and plastic pellets were fed in two separate streams. The plastic was fed first, followed by the natural fibre/filler partway along the extruder barrel. MDF fibre was manually fed in loose form into the extruder. The bleached Kraft lap pulp sheet was cut into pieces approximately 5 mm square for feeding into the extruder. The hemp yarn was chopped into 10 mm lengths. All of the natural fibres and fillers were dried at 60°C for 48 hours before compounding. The mixture was extruded through a die, which formed a 3 mm-diameter strand. To minimise moisture uptake, the extruded strand was air-cooled and ground using a Wiley mill through a 4 mm mesh.

The compounded materials were re-dried at 60°C for 24-72 hours before injection moulding, with the exception of PLA, which was re-dried at 80°C for 24 hours. The dry polypropylene based pellets were injection moulded using a Boy 15S injection moulder (28 mm screw, 20:1 L:D), using

a screw speed of 100-200 rpm, and a temperature range of 200-230°C. The dry bioplastic based pellets used a lower temperature range of 160-200°C.

Testing

Samples were conditioned at 23°C and 50% RH for at least 1 week before measurement and testing. Tensile properties were evaluated according to ASTM method D638 - 96 (Type I). An Instron model 5567 test machine was used for testing, equipped with a 10 kN load cell and 25 mm extensometer. The initial separation between grips was 100 mm, with a testing speed of 5 mm/min. Flexural properties were evaluated according to ASTM method D790 - 96a, except that the loading nose and supports had radii of 7.5 mm. An Instron model 5567 test machine was used for testing, equipped with a 10 kN load cell. A span of 50 mm and speed of 1.3 mm/min was used for flexural tests. Impact properties were evaluated according to ASTM method D256 - 93a (Test Method B - Charpy). A CEAST 6545/000 test instrument with supports 95.3 mm apart was used for testing, using a 0.5 J hammer.

Bark Panel

Radiata pine bark from butt logs was dried and ground to <125 um before blending with wood particles, sourced from a local particleboard mill, in an orbital action bench top mixer. To this was added a propriety solvent mixture and blended in. A ratio of 50% bark to 44% wood particles and 6% solvent mix was used. Once thoroughly blended, the particles were formed into a mattress and pressed at 220°C for 370 seconds to produce 9 mm thick panels.

Panels were tested for density, internal bond (IB), thickness swell after a 24 hour cold soak, modulus of rupture (MOR), modulus of elasticity and V313 according to the Australian/New Zealand standard AS/NZS 4266:2001. Samples of different composite panels were also submerged in boiling water for 2 hours to obtain a comparative visual indication of performance.

Results and Discussion

Wood Plastic Composites

Polypropylene Matrix

Tensile modulus results are shown in Table 2 and Figure 3. Tensile test specimens containing Kraft fibre could not be moulded without the addition of zinc stearate, as the mould cavity could not be completely filled. This may have some influence on mechanical properties. The filled samples had a higher tensile modulus than the unfilled polypropylene. The differences in tensile modulus for the uncompatibilised wood based fibre composites (MDF, Kraft, and wood flour) were minor, but the tensile modulus of the hemp fibre composites was higher than the MDF or Kraft fibre composites. This would imply the hemp fibres have higher modulus compared to the wood based fibres.

The addition of Epolene to the filled composites led to an increase in the tensile modulus, with the difference being larger with wood flour and MDF than for the hemp and Kraft fibre composites.

The addition of natural fibre reduced the maximum tensile stress (Table 2, Figure 4) of the uncoupled polypropylene composites in all cases. There was little difference in the tensile strength of the different fibre composites when no additives were used. The addition of Epolene increased the maximum tensile stress of all the fibre composites. The SEM micrographs of the Epolene coupled fibres (Figure 5) clearly show resin coated fibres, to the point of making it difficult to distinguish fibres in some cases. This is in sharp contrast to the uncoupled fibres (Figure 6), where the fibre surface can be clearly seen with no adhering resin.

The tensile stress of the hemp/Epolene composite was raised back to the level of unfilled polypropylene, while the maximum tensile stress of the Kraft, MDF, and wood flour composites was greater than the unfilled polypropylene. The effect of Epolene was greatest for the Kraft and MDF samples. However, the hemp fibres appear to be damaged, as there are a number of short (<50um) and torn fibres in both the uncoupled and coupled samples (Figure 7).

The addition of the natural fibres decreased the impact strength of all the samples compared to unfilled polypropylene (Table 2, Figure 8). Of these, the Kraft fibres had the highest impact strength followed by the MDF samples. The wood flour and hemp samples had the lowest impact strength. This is most likely due to a fibre length effect.

Bioplastic Matrix

The flow properties of the filled bioplastics were different to filled polypropylene and the tensile mold did not always fill properly. However, the bending mold produced well-filled samples, resulting in only bending tests being undertaken. All the samples tested in bending had no coupling agents added.

Both Biopol and PLA were stiffer and appeared to be stronger than polypropylene composites in flexure (Table 3, Figures 9 and 10). The pure polypropylene sample wasn't tested to failure, as the ASTM method limit was 5% strain, which polypropylene reached before failing. The polypropylene stress value is for 5% strain. The addition of 40% MDF fibre resulted in approximately two-fold in stiffness for the biopolymers, whereas a four-fold increase in stiffness was observed with polypropylene.

Both the Biopol and PLA composites were stronger than the polypropylene composite, with PLA being the strongest by almost a factor of 2. The MDF fibre had little effect on the strength of the biopolymers, with Biopol being slightly stronger and PLA slightly weaker. This may possibly due to coupling agents not being used. Although initial results indicate that the biopolymer composites have good mechanical

properties in comparision to polypropylene composites, further properties, such as impact, need to be tested and methods of optimising the coupling investigated.

Bark Panel

One outstanding feature of the composite bark panels is the moisture resistance, which becomes obvious in harsh conditions, e.g., a boil test. This is without wax addition and can be visually seen in Figure 11.

For a more quantitative description, a few key performance criteria are compared in Table 4 to those of a commercial General Purpose (GP) particleboard. In addition, minimum requirements for different classes of particleboard are given according to the Australian/New Zealand standard AS/NZS 1859.1.

The internal bond strength (IB) of the bark panel is similar to the commercial particleboard sampled and a factor of 2 above the Standard requirement (AS/NZS 1859.1). The higher density of the bark panel will be positively influencing these IB results. The Modulus of Rupture (MOR) is also improved through the higher density and is comparable with standard commercial board.

The performance of the bark panel is very close to the minimum requirements of a High Performance (HP) panel and it is thought that some further optimization of processing parameters should make meeting HP criteria feasible.

The utlisation of bark as a binder and filler in a particleboard type panel would be a 'drop in technology' in that little or no modification to a standard panel line would be required to switch to bark panel production.

Conclusion

Although wood and bark residues are underutilized, research has shown that there are new applications for these residues that offer an opportunity to increase the effective yield from the forest by using every part of the tree in an added value form. Waste wood chips can be refined through a thermomechanical pulping process, such as MDF, and the resulting fibres have the potential to improve mechanical properties of thermoplastic matrices of both petrochemical and biological origin. The introduction of high aspect ratio wood fibres into plastics can improve both the modulus and strength of the composite.

Waste bark contains reactive tannin units that can be utilized for their cross-linking and bonding potential in composites without extracting the tannin from the bark in a separate process. The bulk of the bark becomes a filler in the composite and the tannins are mobilized in-situ using a special solvent and the heat of the pressing operation to give a cost effective, moisture resistant wood based material.

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Acknowledgements

Table 1. Uses of Bark Tannins

Adhesives	Metal corrosion inhibitor
Preserving leather	Paint additive
Concrete flow modifier	Neutraceuticals - antioxidants
Roading (Bitumen) additive	Drilling mud additive

Table 2. Mechanical Properties of Polypropylene – Natural Fibre Composites

Sample	Tensile Modulus (GPa)	95% CI	Tensile Stress at Max Load (MPa)	95% CI	Charpy Impact J/m	95% CI
PP	1.39	0.05	25.16	0.11	102.6	4.6
PP+E	1.18	0.08	23.23	0.25	105.3	8.1
Wood Flour	3.14	0.07	21.11	0.57	40.3	1.1
Wood Flour + E	4.43	0.58	29.56	0.55	43.7	1.2
MDF	2.77	0.29	20.85	0.55	58.2	1.2
MDF + E	4.05	0.85	45.82	0.85	44.7	0.4
Kraft	3.15	0.33	19.72	0.91	68.3	4.7
Kraft + E	3.52	0.27	43.47	2.24	59.3	1.2
Hemp	4.45	0.82	20.36	0.22	40.7	2.5
Hemp + E	5.32	1.68	26.22	0.87	26.2	2.5

PP = Polypropylene
E = Epolene coupling agent (MAPP)
CI = confidence interval
All samples 40% natural fibre by weight.

Table 3. Flexural Properties of Bioplastic – Natural Fibre Composites

Sample	Modulus (GPa)	95% CI	Stress at Max Load (MPa)	95% CI
BP + MDF	5.79	0.15	55.09	0.89
BP	2.52	0.06	50.49	0.26
PLA + MDF	7.72	0.06	108.18	2.56
PLA	3.82	0.02	116.64	0.78
PP + MDF	4.04	0.11	40.60	0.60
PP	1.05	0.03	33.81	0.68

PP = Polypropylene
BP = Biopol
CI = confidence interval
All samples 40% MDF fibre by weight

Table 4. Composite Panel Properties

		Density (Kg/m³)	24h TS (%)	IB (KPa)	MOR (MPa)	MOE (GPa)	V313 IB (KPa)	TS (%)
Bark board		800	10	0.8	11	1.5	0.3	<9
Bark board		925	7	1.0	17	4.7	0.51	3.1
Particleboard (GP)		620	12	0.73	12	3.0	0.3	19
Particleboard Requirements accord. To AS/NZS 1859.1	GP	-	25	0.35	13		-	-
	MR	-	18	0.35	13		0.25	17
	HP	-	12	0.45	18	2.7	0.4	10

TS = Thickness Swell, IB = Internal Bond Strength, MOR = Modulus of Rupture, MOE = Modulus of Elasticity. V313 is a cyclic test where test pieces are exposed to three cycles, each comprising immersion in water, freezing and drying at elevated temperatures.
GP = General Purpose, MR = Moisture Resistant, HP = High Performance

Plantation forest area by species

84.9% Radiata pine
1,622ha

Total area:
1.814 million ha
(000ha)

3.0% All exotic harwoods
54ha

1.9% Other exotic softwoods
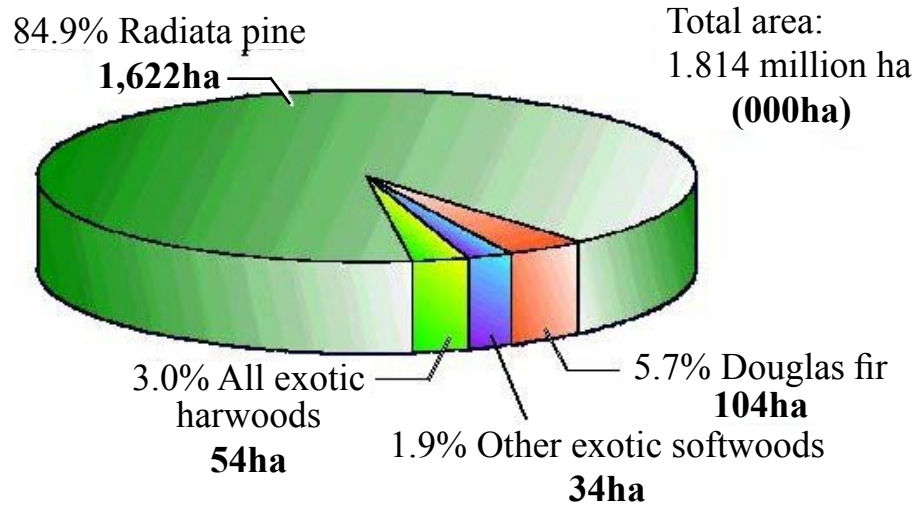**34ha**

5.7% Douglas fir
104ha
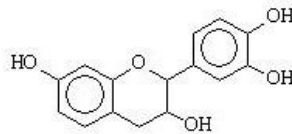
Figure 1. New Zealand Plantation Forest by Species
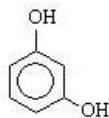
Tannin chemistry

Petrochemical

phenol

Tannins equivalents

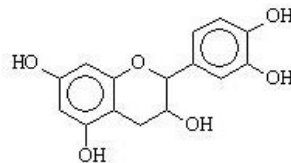resorcinolic tannin
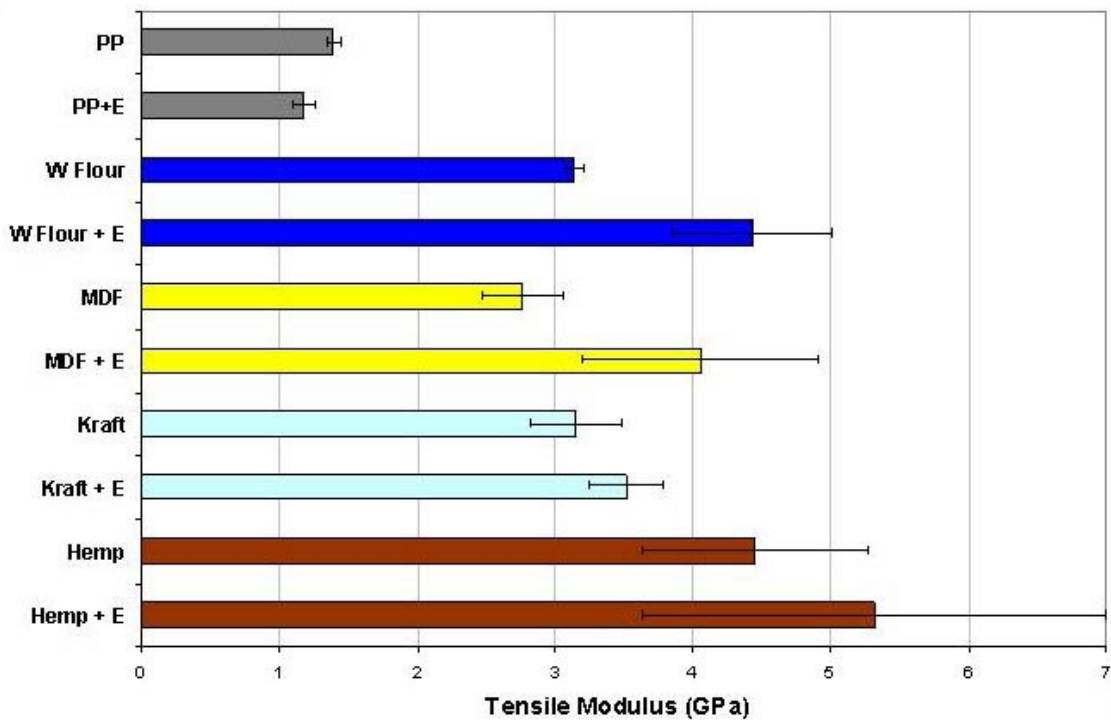
Derived from:

acacia/quebracho

resorcinol

phloroglucinolic tannin

pine bark

Figure 2. Tannin Chemistry

E = coupled with Epolene

Figure 3. Tensile Modulus of Polypropylene – Natural Fibre Composites
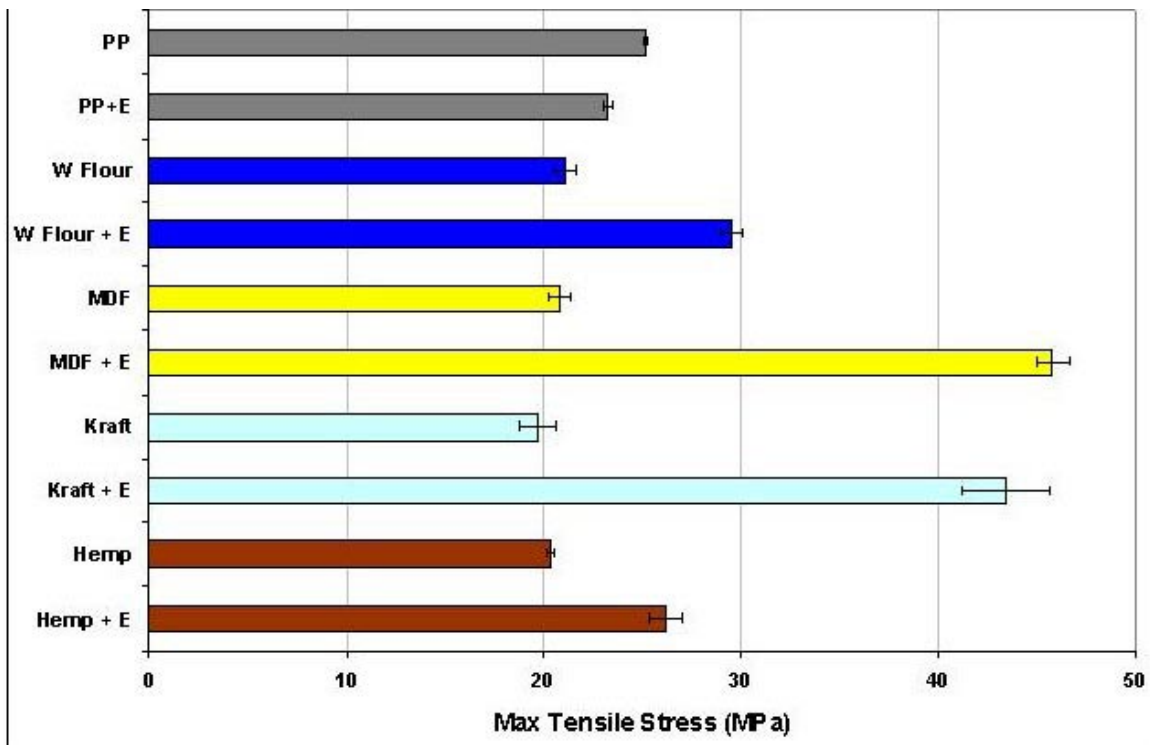
E = Coupled with Epolene

Figure 4. Tensile Strength of Polypropylene – Natural Fibre Composites

Figure 5. MDF Fibres in Polypropylene Matrix with Epolene Coupling Agent

Figure 6. MDF Fibres in Polypropylene Matrix with no Coupling Agent

Figure 7. Broken Hemp Fibres In Polypropylene Matrix with no Coupling Agent

E = Coupled with Epolene (MAPP)

Figure 8. Charpy Impact Strength

Figure 9. Flexural Modulus of Bioplastic Composites

Figure 10. Flexural Stress Of Bioplastic Composites

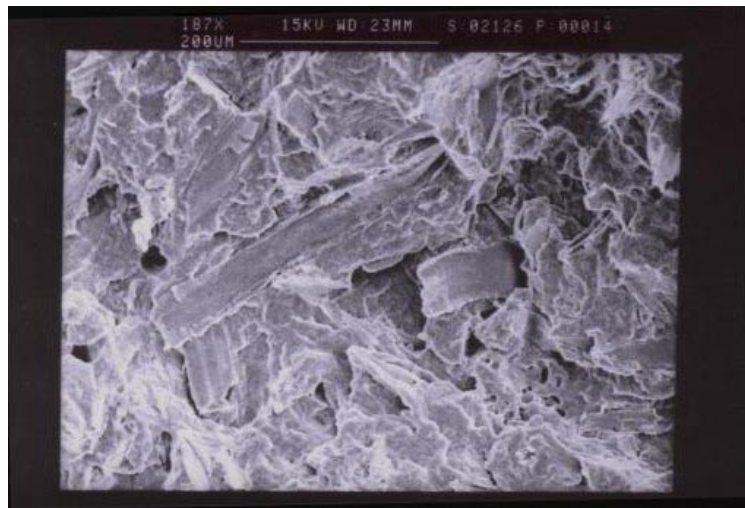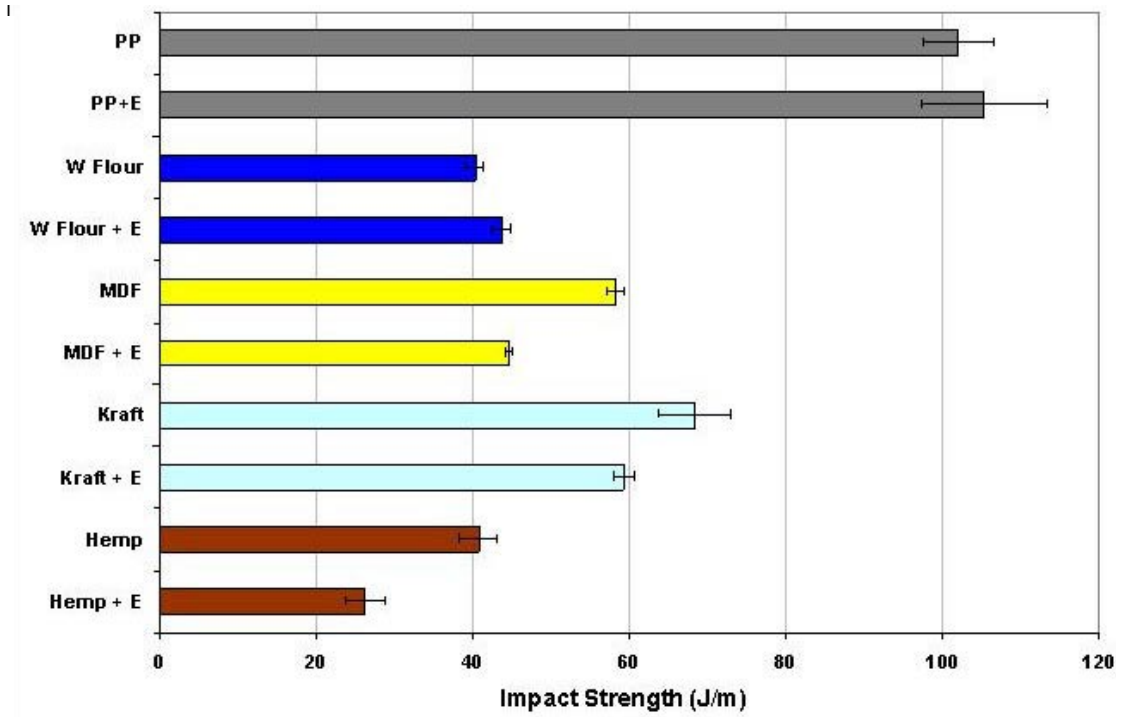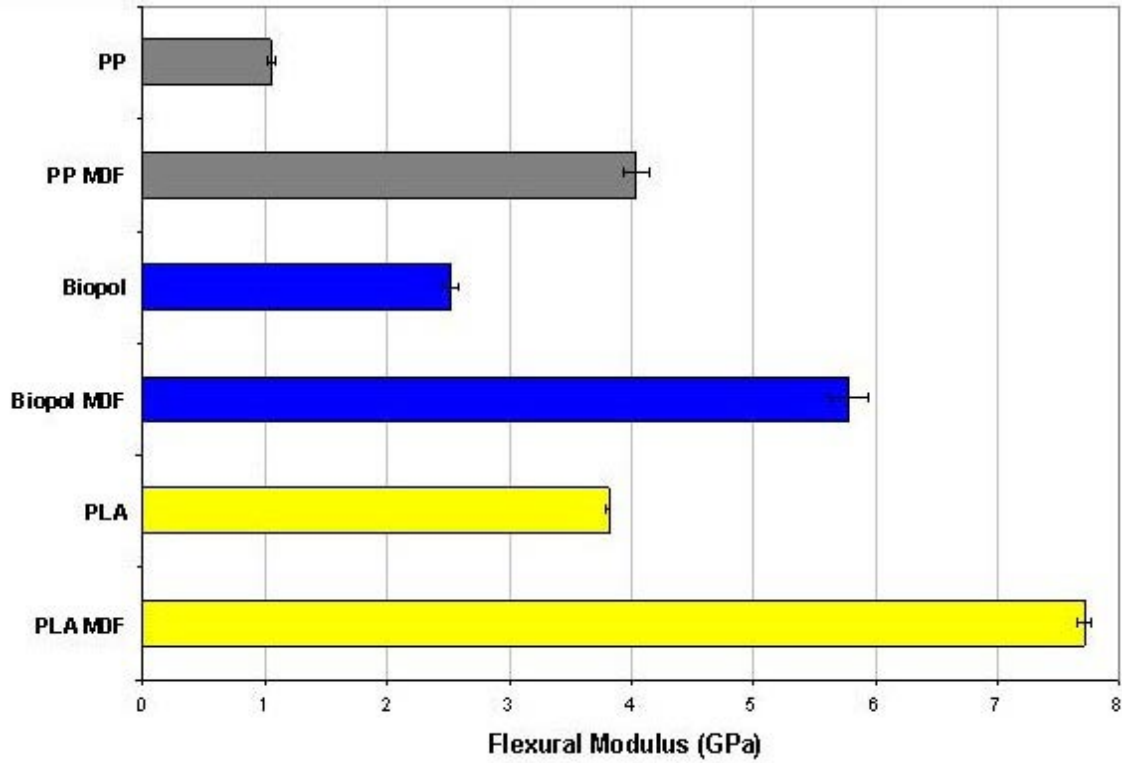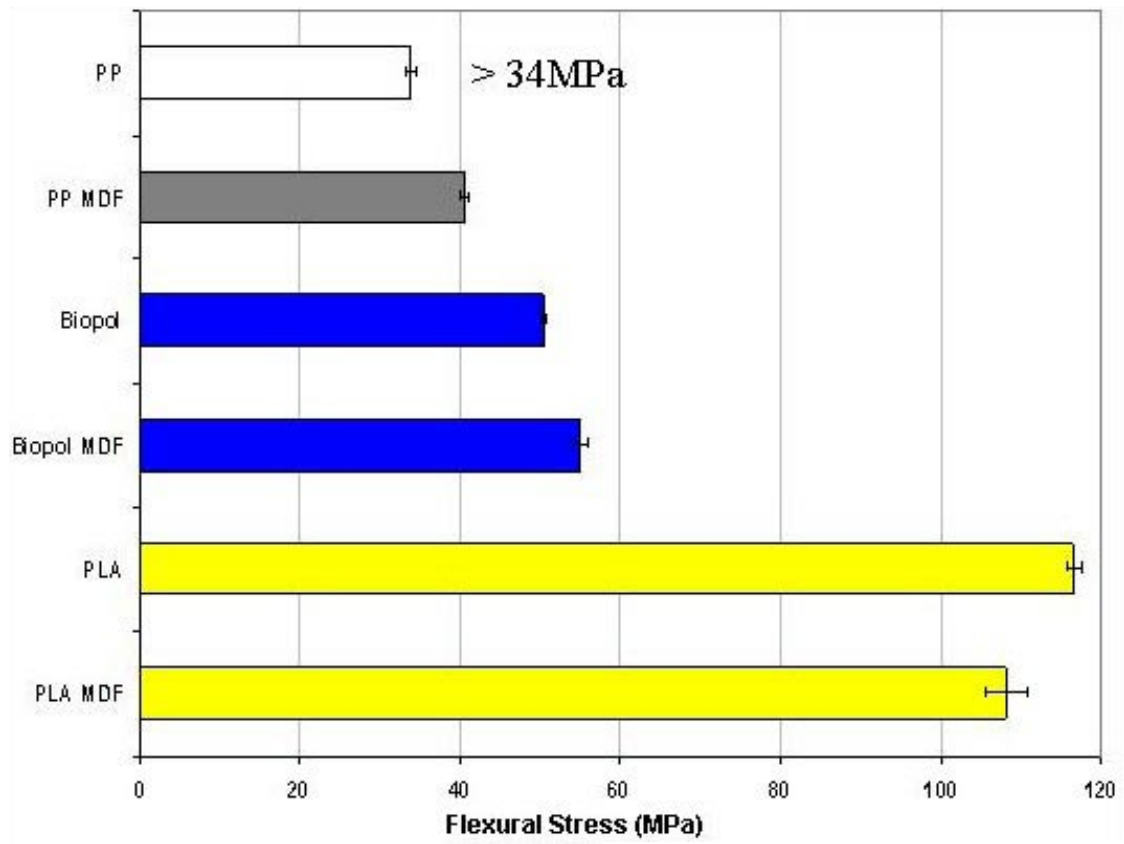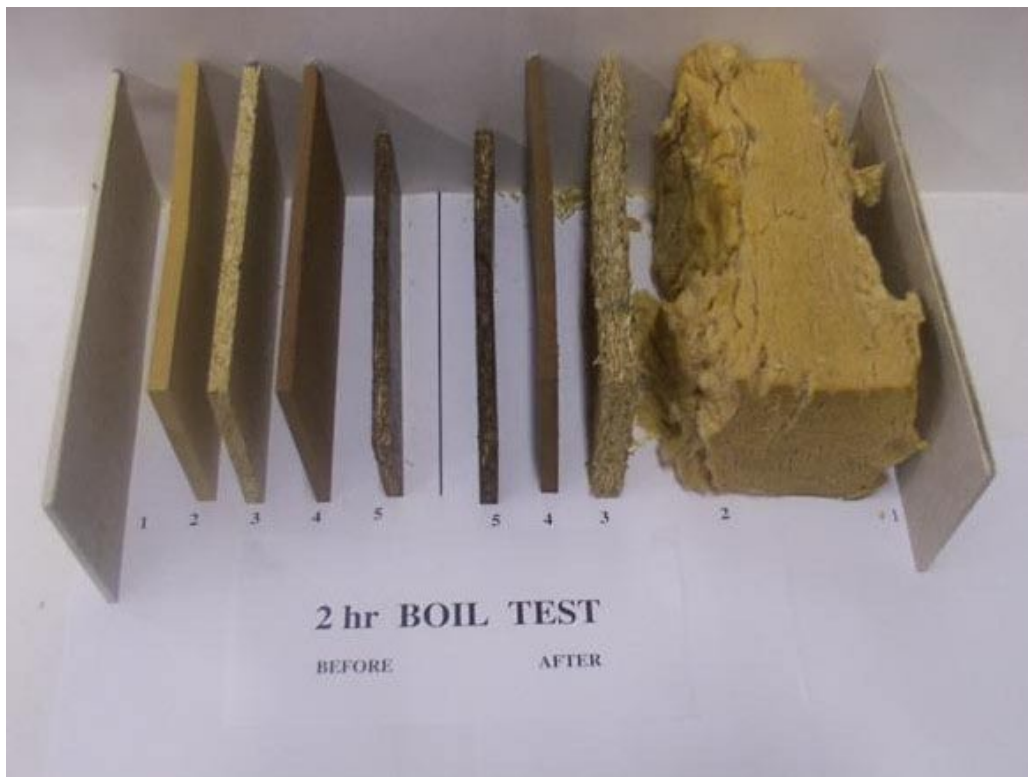Figure 11. Composite Panels After a 2 Hour Boil

In-situ Microdielectrical Evaluation of the Curing Process of the Adhesive in Plywood Manufacturing

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Executive Summary

A key stage of the plywood manufacturing process is the pressing of the board, where consolidation occurs and where designs of the physical and mechanical properties are made. At this stage not only the wood but the adhesive system plays a major role, especially in the way in which it changes from the aqueous state to a high resistance solid matrix.

In this research it was determined with micro-dielectric spectroscopy technique and thermal analysis, at laboratory and at industrial scale, the way in which operational variables associated to wood (moisture content, density), adhesive and hot pressing (pressure, temperature, time) affect the curing mechanism of the adhesive and the mechanical resistance of the matrix formed.

Curing diagrams of the adhesive system during hot pressing and a manual of the methodology required to monitor the adhesive curing at industrial scale were made. The methodology of this research allows reducing the amount of adhesive to make plywood about 10 to 15 percent. In addition, it was possible to reduce the total pressing time about 11 and 20 percent, at laboratory scale and plant scale, respectively. It was possible to reduce the time to adjust the optimal condition to produce plywood with optimal properties.

Characterizing the Rheological Properties of Wood-Plastic Composite Formulations

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Abstract

In the last decade, wood-plastic composites (WPC) have emerged as a viable replacement to many traditional timber products used in the residential construction industry. While most WPC research deals with mechanical properties of these products, little research has gone into understanding the flow mechanisms of WPC as they are produced from the extruder. However, the flow of the molten wood-plastic blending during processing is critical to the formation of the end product. This behavior is characterized by the rheological properties of the material. As the production of WPC has increased, the need to better understand the rheological behavior of the melt has become an important concern, since changes in the rheological properties can alter the overall product shape and the mechanical properties of the composite. In this work, the rheological properties of high-density polyethylene (HDPE)/maple (*Acer* spp.) and HDPE/pine (*Pinus* spp.) composites were studied with a specially designed slit die. Melt viscosity was found to increase with filler content and decrease with shear rate. Depending on the formulation, the measured melt viscosity was up to 62.1% lower than similar formulations examined using standard capillary techniques. In addition, the technique produced excellent reproducibility within the individual formulations.

Keywords: wood plastic composites, polyethylene, rheology, formulation

Introduction

Over the past couple of decades, the market for wood plastic composites (WPC) has continued to grow, with 700 million lbs. of WPCs being manufactured in 2001 (Mapleston, 2001). These materials are comprised of an organic filler with a polymer matrix. As WPC have become more accepted, their expansion into a wider variety of applications has occurred. The most explosive growth has occurred in the residential building market as composite deck boards, siding and window moldings are being used as replacements to traditional timber products.

While these composites can be manufactured with a variety of thermoplastic resins, the use of high-density polyethylene resin (HDPE) as the polymer matrix has continued to dominate commercial products (Clemons, 2002). In HDPE-based WPC, a 50% wood filler amount is commonly used (Li, 2005). These materials tend to be defined by good mechanical properties and low material cost, due in part to the high percentage of wood filler (Kowalska, 2001). The wood filler adds to the tensile strength and provides rigidity to the polymer matrix, while improving processing, machining properties, and material costs.

Due to the importance of understanding the melt flow characteristics of these composites when designing an extruder die, a rheological slit die will be used to quantify the important flow properties. The shear stress, shear viscosity, first normal stress difference and exit pressure can all be calculated. However, only the viscosity of the melts for a variety of HDPE/wood composite blends will be analyzed. These rheological values obtained using the slit die will be compared to published values obtained from capillary die rheometery.

Literature Review

While most of the rheological work being conducted within the WPC community is done using a capillary die rheometer, the use of a slit die rheometer to test the rheological properties of these materials allows for some of the disadvantages of the capillary die to be overcome. The technique of using a slit die to measure rheological properties of unfilled polymer melts has been around since the 1970's, when Han (1971, 1974) conducted significant amounts of slit die research. When examining the viscosity flow curves for the melts from both the slit die and the capillary die, it was found that the results correlated very well with each other. Therefore, the use of either rheometer should yield similar results.

Many of the equations used in slit die analysis are based on the work of Han (1971, 1974), Eswaran et al. (1963) and Wales et al. (1965). The theoretical concepts and equations

behind the slit and capillary die are the same; with the main difference being that capillary is circular, while the slit is rectangular.

For accurate results using a slit die, a minimum of three pressure transducers are required along the slit length. Knowing the pressure gradient along the longitudinal length axis ($-\partial p / \partial x$), the viscosity of the melt can be calculated. The equations for the slit die are more complicated than the capillary die and a full derivation of these equations can be found in a paper by Han (1974). A brief synopsis will be given here of the pertinent equations, with the determination of shear stress at the die wall (τ_w):

$$\tau_w = \left(\frac{\partial p}{\partial x} \right) \frac{h}{2} \tag{1}$$

where h is given as the slit height. The apparent shear rate ($\dot{\gamma}_a$) is defined by:

$$\dot{\gamma}_a = \frac{6Q}{wh^2} \tag{2}$$

where w is the width of the slit die, and Q is the volumetric flow rate. The theoretical equation for true shear rate ($\dot{\gamma}$) as developed by Han, including the Rabinowitsch correction, is expressed as:

$$\dot{\gamma} = \left(\frac{2}{3} + \frac{1}{3} \frac{d \log \dot{\gamma}_a}{d \log \tau_w} \right) \dot{\gamma}_a \tag{3}$$

where n is the Rabinowitsch correction factor. The viscosity (η) of the melt can then be calculated by:

$$\eta = \frac{\tau_w}{\dot{\gamma}} \tag{4}$$

It is important to note that in equation (3) the derivative, $d \log \dot{\gamma}_a / d \log \tau_w$, cannot be calculated without a change in the apparent shear rate. Therefore, at least two different shear rates must be tested for each formulation (Laun, 1983).

Materials

The rheological experiments were performed using HDPE (Equistar LB-0100-00) with between 30 and 70 wt% wood flour. The wood flour filler was commercially obtained (American Wood Fibers) as either maple (*Acer spp.*) or pine (*Pinus spp.*) in the mesh sizes ranging from 40 to 100. Prior to extrusion, the wood flour moisture content was reduced from 8.0% (as received) to < 3.0%, in an open-ended extruder (Cincinnati Milicron TC 86) set at 325 deg F and a screw speed of 25 rpm. The HDPE powder was used as received. All formulations were dry blended in 4ft. drum tumbler for 10 minutes prior to extrusion to assure a proper dispersion of the components. A full listing of the materials and formulations used in this research is found in Table 1 and 2, respectively.

Results

A variety of formulations using 40-mesh maple in HDPE-wood melts were examined and are shown in Figure 1. A Carreau-Yasuda (1996) curve fit was applied to all of the data in this experiment and all of the figures show only this curve fit for clarity. As to be expected, when the percentage of wood filler in the melt increased, the viscosity of the melt also increased. This can be attributed to the increase in slip resistance between the additional wood particles that are contained within the melt. This result is in agreement with results found for both HDPE-wood systems (Li, 2005) and other highly filled plastics (Vlachopoulos, 2003; Han, 1974b). However, the melt viscosities of the HDPE-wood composites tested on the slit die were up to 62.1% lower (using the 30% maple formulation) than the viscosities of the identical formulations tested on a capillary rheometer. This change is easily seen Figure 2 and is due to the differences in the processing conditions and die size between the two rheometers. This difference does not indicate that the viscosity readings obtained using this slit die are incorrect, since the rheological flow properties have a great dependence on morphology and flow of the melt. It is important to note that in the preparation of the samples for the capillary die results by Li (2005), the samples go through an extra compounding step not found in the slit die tests. Therefore, the shear flow of the two samples is different, thus leading to a difference in the morphology of the melts (Han et al., 1995).

Besides a change in viscosity due to different wood filler percentages, a weak dependence on the mesh size of the wood filler was also found. Figure 3 shows that for a 40% maple filler level, as the mesh size of the maple increased, the overall melt viscosity decreased very slightly. This phenomenon is due to the smaller filler particle size allowing for slippage of nearby particles as the melt is sheared. Similar results are also found in Li's (2005) capillary die work. Note must be taken though, as Li's work was done with a 60% filler level while this work was done with a 40% filler level. However, this change in viscosity due to different particle sizes has a much less pronounced effect on the viscosity than changes in the wood filler percentage.

All of the research presented so far has used maple wood flour as a filler; however, the use of pine wood flour is also of great interest to the WPC community. Li (2004) reported on differences in viscosity between pine and maple wood flours in HDPE/wood composites. This research will provide the basis for the second half of this analysis. The results obtained by the slit die method indicate that both maple and pine exhibit different viscosities when the wood filler percentage changes. Both wood species follow the same trend, since the 60% filler level produces a higher viscosity than the 40% filler level.

When a comparison is made to the work of Li (2004), it appears that the slit die results are in general agreement with those of the capillary in the case of the maple-based composite. While the results may not directly line up with the results of the capillary, they do have the same general trend. However, the results of the pine based composites are in disagreement. Li's work indicated that there was no change in the melt viscosity of the 40 mesh pine based WPC, when the filler percentage changed from 40% to 60% as can be seen in Figure 4. When identical formulations were run on the slit die, there was a difference in the melt viscosity of the pine based composite. It is believed that the work of Li is incorrect, since further results obtained with the slit die produce results to substantiate these findings. When both 60 mesh pine, and 40 and 60 mesh maple based composites were run on the slit die, using the same 40% and 60% wood filler levels, similar results to the 40 mesh pine results were achieved. All of the results indicated that when there is an increase in the wood filler percentage in the formulation, the shear viscosity of the melt will rise as well.

When a comparison of the melt viscosity for different filler percentages of 60 mesh pine is examined, the same trend as for the 40-mesh pine is observed. Both mesh sizes show an increase in viscosity as the filler percentage is increased. This result is seen in Figure 5 where the 40% and 60% HDPE filled composite flow curves are plotted. Therefore, this change in viscosity would indicate that the slit die results are correct since agreement at two different formulations is achieved.

A comparison of different mesh sizes and percentages was also made in relation to HDPE/maple composites. Very similar trends developed for both the 40 and 60 mesh size particles. As seen in Figure 5, the results are very similar to those obtained in the pine based composites. As the percentage of wood filler increased so did the viscosity of the melt. This has been previously demonstrated for the 40 mesh size but it is also seen here for the 60 mesh particle size. In a direct comparison of the pine and maple based composites, the pine based WPC produces a slightly lower melt viscosity as compared to the maple based WPC.

Conclusions

While little research has been published in relation to the rheology of WPC materials, the importance of understanding the melt flow properties is very important. In examining the results obtained in this research, distinct changes were noticed in the shear viscosity of the melts when the formulation was run on a slit die versus a capillary rheometer. For most of the melts, the slit die produced results that were considerably lower than the capillary rheometer. However, the higher the wood content in the blend, the closer the results of the two rheometers were to one another. It is believed that this difference is due to the morphological differences in the melt from the different processing conditions

of the two rheometers. The second noticeable result is that unlike previous capillary rheometry research, the slit die results showed that changes in wood filler percentage in pine based composites do affect the shear viscosity of the melt. This is different from as previous work, which indicated that similar viscosities where obtained for two dissimilar pine based WPC formulations.

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Table 1: Raw Materials

Materials	Supplier	Grade	Description
HDPE	Equistar	LB-0100-00	MFI = 0.1 g/10 min MW=91.6 kg/mol
Pine	American Wood Fiber	4020	40 Mesh
Maple	American Wood Fiber	04010 to 14010	40 ~ 140 Mesh; Acer *spp*.

Table 2: Material formulations filled with HDPE

Formulation	Wood Type (Mesh Size)	Wood (%)	Plastic (%)
1	Pine (40)	40	60
2	Pine (40)	60	40
3	Pine (60)	40	60
4	Pine (60)	60	40
5	Maple (40)	30	70
6	Maple (40)	40	60
7	Maple (40)	50	50
8	Maple (40)	60	40
9	Maple (40)	70	30
10	Maple (60)	40	60
11	Maple (60)	60	40
12	Maple (80)	40	60
13	Maple (100)	40	60
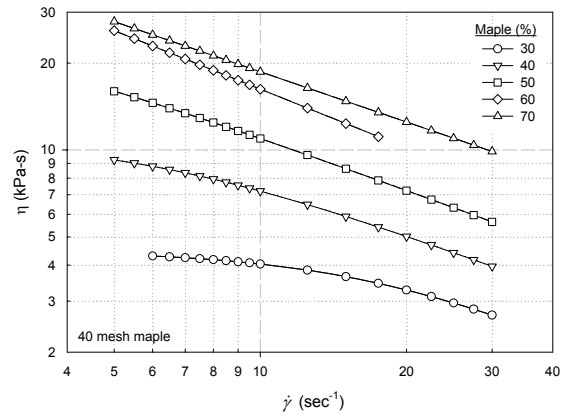
Figure 1: Shear viscosity flow curves for HDPE/maple composites with a variable amount of wood filler.
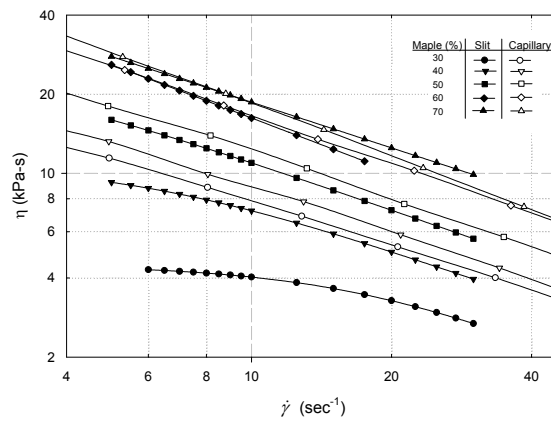
Figure 2: Shear flow curve results for HDPE/maple composites using slit and capillary die rheometry.
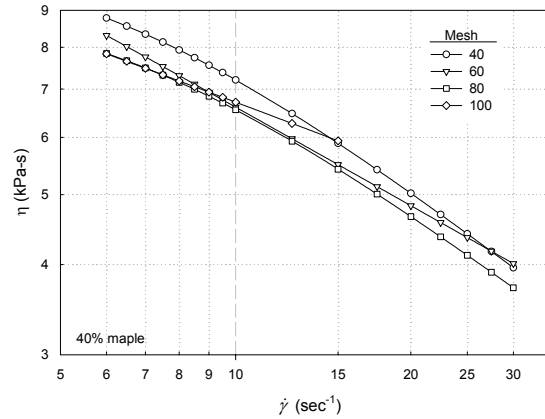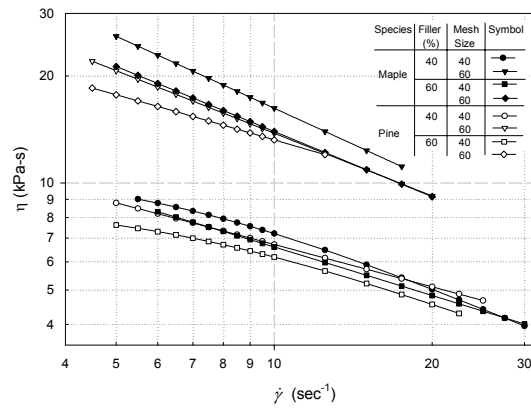

Figure 3: Changes in viscosity due to different particle size within maple based composites.
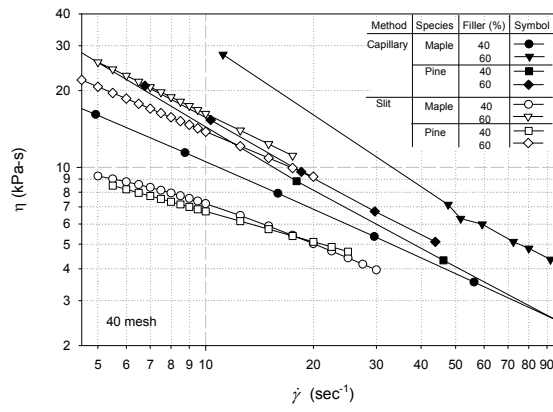
Figure 4: Comparison of capillary and slit die rheometry results.

Figure 5: Comparison of viscosity results for HDPE/wood composite blends

Physical and Mechanical Properties of Oriented Strandboard made using Kraft Lignin Phenol Formaldehyde Resin

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Executive Summary

Kraft lignin phenol formaldehyde (KLPF) resin has certain advantages as a binder in oriented strandboard (OSB) manufacture over the other commercially used exterior resins. Since kraft lignin is used as substitute for almost 50 percent of phenol in a typical resin, KLPF is not only more environmentally friendly but also less expensive as compared to other binders. The purpose of study is to evaluate the potential of this resin to produce experimental OSB panels. Therefore, a total of six panels with dimensions of 56 cm by 56 cm by 1.5 cm and with an average target density of 0.60 g/cm^3 from aspen (*populus Americana*) were manufactured under the laboratory conditions. Bending properties including modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength, screw holding strength in both face and surface of the panels, water absorption, thickness swelling, and density profiles of the samples were determined. MOE values of control samples made using phenol formaldehyde and KLPF resins were found as 2,332 N/mm^2 and 2,338 N/mm^2, respectively. Corresponding average values for MOR were 21.66 N/mm^2 and 19.18 N/mm^2. Based on the initial findings of the study it was determined that both mechanical and physical properties of the samples were not adversely influenced by modified resin. Test results of the panels revealed that all properties met the minimum requirements specified in related standards and are comparable to those commercially produced OSB panels. KLPF showed good potential for the manufacture of OSB panels.

Study of WPC: A Methodology of Evaluation of Interfacial Adhesion

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Executive Summary

Wood plastic composites (WPC) have a complex morphology that influences their behavior. It is important to shed light on the interaction among wood and thermoplastic polymers because they have a significant effect on the physical and mechanical properties of the compounds.

The objective of this study was to manufacture WPC and to develop a methodology of evaluation of the interfacial adhesion, by means of thermomechanical analysis. Radiata pine wood flour was blended with Polyethylene and polypropylene. Maleic anhydride polypropylene (MAPP) was used as a coupling agent. Mixtures in three proportions, 40-60, 50-50 and 60-40 of wood and plastic were made in a thermal mixer. Brabender and their thermomechanical properties were evaluated with Dynamic Mechanical Analysis (DMA).

It was found that the size of wood flour does not have an important influence on the mechanical properties of the compound. Best thermomechanical properties in the final compound were obtained by using the highest amount of wood in the mixture. In addition, the coupling agent is very important in the interfacial adhesion of the compounds improving its final properties. The behavior of the WPC during creep was determined using the Burger model obtaining significant information about the strain at time and applied load.

Strength Properties of Engineered I-Joists Made From Laminated Veneer Lumber (LVL), Solid Wood, Oriented Strand Board (OSB), and Plywood

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Abstract

The study was an evaluation on the strength of engineered I-Joists made from compositions of different materials. The materials were made from wood of lesser- used forest and plantation species. The successful utilisation of these materials would increase the commercial values of lesser-used natural wood resource. It will also contribute towards reducing the burden imposed on the commercial wood resource from natural forest. The materials for the I-Joists in this study were Laminated Veneer Lumber (LVL), Oriented Strand Board (OSB), plywood and solid wood (Light Red Meranti). The LVL was from lesser-used meranti species (*Shorea spp*.), whereas the OSB was from rubberwood (*Hevea brasiliensis*). Solid wood joist from light red meranti was used as a control. The static bending test (ASTM D198-84 and D143-52) was performed to determine the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) for each I-Joist. Solid wood joist exhibited the highest MOE and MOR compared to the engineered I-Joists. Among engineered I-Joists, composition of LVL flange and OSB web exhibited the highest MOE and MOR. However, all the engineered I-Joists have achieved the standard required by the Malaysian Standard (MS 544:1978) for floor joists.

Introduction

Wood I-joists can be used for longer spans than conventional lumber, and because they are manufactured at a low moisture content, greatly reduce performance problems such as nail pops and squeaky floors that sometimes occur with conventional lumber. Wood I-joist can be cut to desired lengths either on the job site or by order from the manufacturer. Engineered wood I-joists (ASTM 1993) with OSB webs provide a high quality support system that minimizes deflection and eliminates floor squeaking. Since OSB is engineered to perform, it is adaptable to specific industrial application.

This project aimed to determine the strength properties of different I-joists that were made from OSB, plywood, solid wood and LVL. This was to determine whether OSB is a better alternative to replace plywood as web in I-joists. Results obtained will also be helpful in improving the manufacturing of I-joists using OSB and plantation species as web material. As plywood is slowly losing its preference in the open market, it will be of advantage if the manufacturers are able to diversify into other products such as OSB, LVL, and I-joists.

Materials and Methods

Materials and Preparation of Engineered I-Joist

Each I-joist was made up of two flanges and one web fabricated using Phenol Resorcinol Formaldehyde (PRF) glue as indicated in Figure 2. OSB, LVL, plywood, and solid wood were used to make the engineered I-joist. Flanges size were 50 mm x 19 mm x 1500 mm and web size were 12 mm x 32 mm x 1500 mm.

The types of LVL and solid wood used in making the flange for this study was of Light Red Meranti species of approximately the same density and within the same strength group. The other web material was structural plywood. The procedure for preparing the samples in this study is shown in Figure 1. All the samples were separated into five major groups and identified as:

1. Group OSBLVL (composed of OSB web and LVL flanges)

2. Group OSBSOL (composed of OSB web and Solid wood flanges)

3. Group PLYLVL (composed of Plywood web and LVL flanges)

4. Group PLYSOL (composed of Plywood web and Solid wood flanges)

5. Group SOLID (Solid joist)

Collective significant differences of the independent variables to the observed strength (MOE and MOR) were tested using the ANOVA. The independent variables were joist type (solid joist and I-joist), flange type (LVL and solid wood), and web type (OSB and plywood). MOE and MOR,

as the dependent variables, were calculated and Duncan's Multiple Range Test was used to compare among the different groups (Table 1) to determine if there were any significant differences between these different groups.

Results and Discussion

In comparing the Modulus of Elasticity (MOE), solid wood joists exhibited the greatest value among the samples. Their MOEs were almost 50% higher than OSBLVL. There were no significant differences between groups OSBSOL, PLYLVL, and PLYSOL. The MOE of these three groups were 74 % less than the solid wood joists and about 48% less than the OSBLVL.

In comparing Modulus of Rupture (MOR), solid joists exhibited the greatest value among the samples. Their maximum bending strength was almost 77% higher than OSBLVL. There were no significant differences between OSBSOL, PLYLVL and PLYSOL. The MOR of these three groups was only 85% less than the solid wood joists, and around 40% less than the OSBLVL.

I-joists used in this study showed MOE that was 50% lower and MOR that was 76% lower than a solid wood joist. The force-deflection curves as shown in Figure 3 were almost linear; therefore, very little stored energy was lost in the joists due to nonlinear stress-strain behaviour. This indicated that the high in-plane shear modulus of OSB or plywood would enable it to be used as a shear web in a composite joist.

Among the engineered I-joists, composition of LVL flanges and OSB web exhibited the highest MOR and MOE. LVL was better then solid wood as flange. OSB was equivalent to plywood as web. It can be concluded that OSB performed as well as plywood and will be a great potential substitute to plywood application in I-joists.

I-joists with LVL flanges exhibited higher MOR and MOE values than I-joists with solid wood flanges for both OSB and plywood webbed I-joists. The higher values were due to LVL being an engineered product where the density and properties were higher than solid wood of the same species. Moreover, LVL made of selected veneer contained the least number of defects. This is an advantage over solid wood.

In this study, the solid Meranti flanges did not possess serious defects such as loose knots, checks, and wood decay. Strength-to-weight ratio was considered a very critical factor to maximize the strength properties. The higher the density, the higher will be the strength. LVL had a higher density; therefore, it will have higher strength.

Failure Modes

Almost all the failures were initiated in the vicinity of the web and flange joint under tension. The diagonal failure in the OSB web surfaces were probably due to a shearing action once the failure was initiated. The crack appeared to

propagate through the individual particleboard segments as though they were a single material, showing that the particle–to–particle glue bond created an essentially unit structure. In plywood web, failure was probably influenced by the grain direction of plywood that was perpendicular to the direction of applied force. Failure characteristics are as described in Table 3.

The high quality of this new engineered I-joist, especially the composition of OSB web and LVL flange, could be selected as flooring material. All types of I-joists tested qualified as floor joist according to the Code of Practice for the Structural Use of Timber, MS 544: 1978. All the I-joists qualified to be used as flooring materials for *medium traffic* and *light traffic* condition as specified in that standard. The average density of the samples was approximately 580 kg/m^3. The average bending stress in groups PLYLVL, OSBSOL, and PLYSOL were in the range of 9.8 to 11.0 MPa, which were sufficient for floor joists of *light traffic* condition, whereas group OSBLVL had achieved bending stress of 17.9 MPa, which was suitable for floor joists of *medium traffic* condition.

Conclusion

Solid joists exhibited higher MOR and MOE compared to engineered I-joists. LVL was better then solid wood as flange, whereas OSB was equivalent to plywood as web. Therefore, composition of OSB and LVL possess the potential as favourable materials in engineered I-joists manufacturing.

Failure was sudden with little or no prior warning. The mode of failure was difficult to determine but appeared to start in the tensile region near the flange-web interface. This was followed by failure propagation in the flange then web.

Bending strength of composite I-joists was considerably affected by the quality of the flange and web. The influence of flange was greater compared to web. This was evident by the propagation of the failure which started from the flange.

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Table 1. Duncan's Multiple Range Test for Variable: MOE

DUNCAN GROUPS	MEAN MOE (kg/cm^2)	GROUPS
A	61332.6	SOLID
B	30778.0	OSBLVL
C	20304.7	PLYLVL
C	14927.5	OSBSOL
C	14091.1	PLYSOL

Note: Means with the same letter are not significantly different.

Table 2. Duncan's Multiple Range Test for Variable: MOR

DUNCAN GROUPS	MEAN MOR (kg/cm^2)	GROUPS
A	774.3	SOLID
B	178.9	OSBLVL
C	109.8	PLYLVL
C	106.0	PLYSOL
C	98.2	OSBSOL

Note: Means with the same letter are not significantly different.

Table 3. Failure Modes

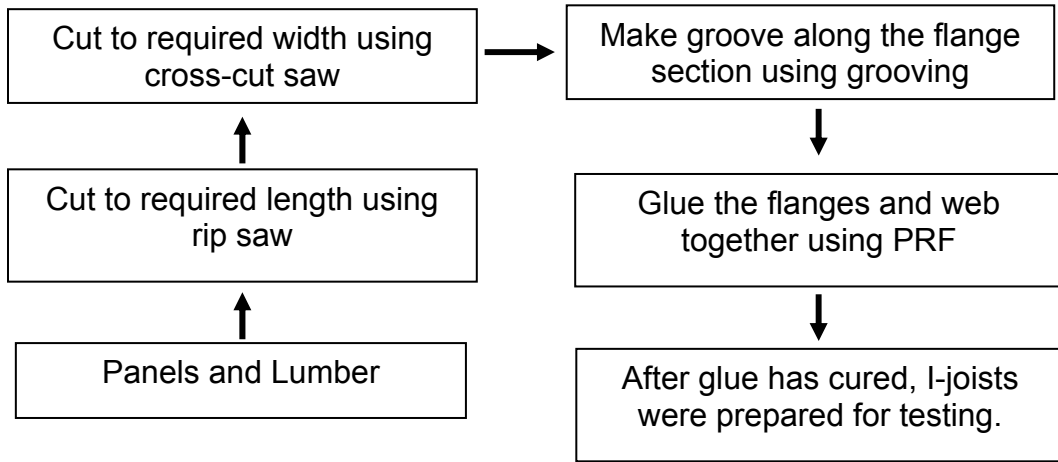| Materials	Failure
OSB	Diagonal failure
Plywood	Brash tension
Solid Wood	Splintering tension Simple tension
LVL	Splintering tension

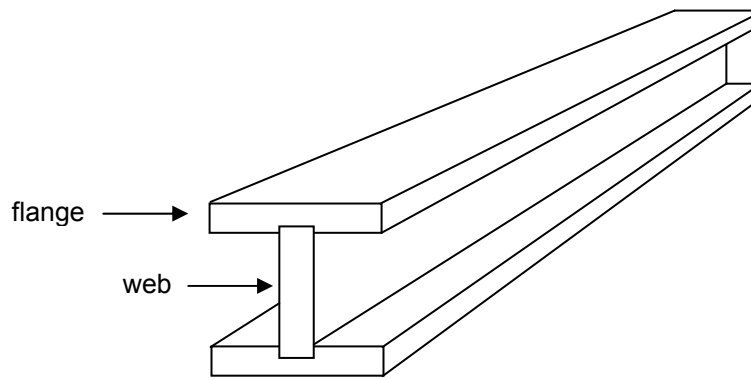**Figure 1.** Procedure for preparing the test samples

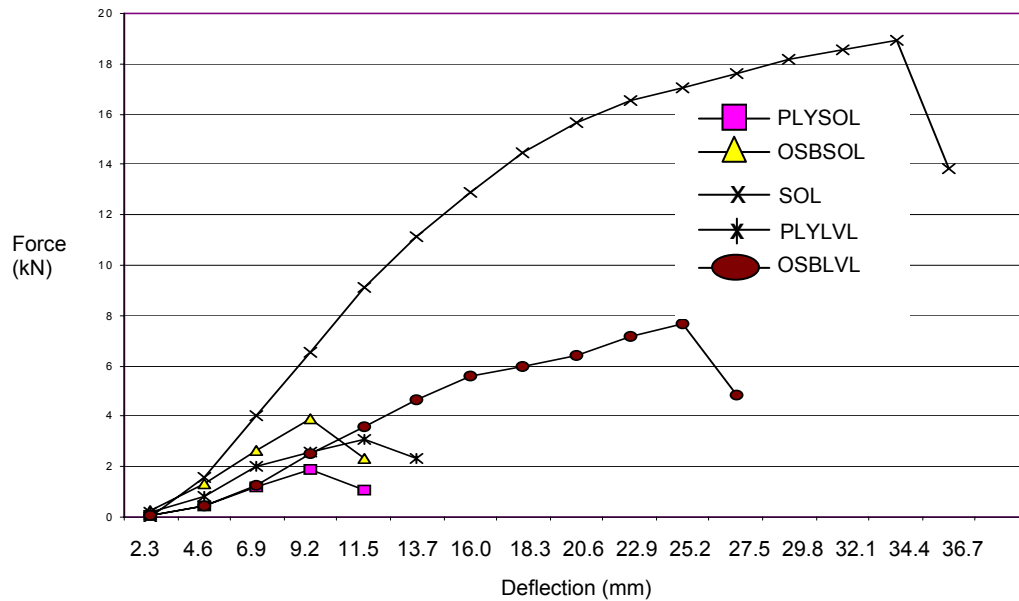**Figure 2.** Flange with square–edged web

Figure 3. Force deflection curve

Effects of Particle Size and Orientation on Properties of Particleboard Made From Ethiopian Highland Bamboo (*Yushania Alpina*)

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Abstract

This study was conducted to evaluate the effects of particle size and orientation on the properties of particleboards made from Ethiopian highland bamboo (*Yushania alpina*). Oriented and control boards of 750 kg/m^3 were fabricated from three-year old bamboo using two particle sizes of 1-2 and >2 mm mesh sizes. Urea formaldehyde resin was used as a binder. Properties of the boards were evaluated based on the ISO Standards for Wood-based Panel Products (2003). The oriented particleboards had 15% and 37% higher modulus of rupture and modulus of elasticity, respectively, compared to the controls. The internal bond (IB) strength of the boards was more affected by particle size than particle alignment. Boards made from small particles recorded 35% higher IB than those made from coarse particles. Screw withdrawal resistance was significantly affected by both particle size and alignment. Boards made from coarse particles boards had 9% and 12% higher edge and surface screw withdrawal resistance, respectively, than those made from small particles. About 8% superior edge and surface screw withdrawal resistance was obtained in randomly oriented boards than parallel-oriented boards. Particle alignment did not show significant effect on the thickness swelling (TS) and water absorption (WA) of oriented boards, whereas particle sizes had significant effects on both tests. Boards made from small particles had 12% and 20% lower TS and WA, respectively, than those made from coarse particles.

Key words: Bamboo (*Yushania alpina*) particleboard, particle size, orientation, mechanical and physical properties.

Introduction

Bamboo is a tropical or warm temperate member of the grass family belonging to the sub-family of *Bambusoideae* in the family *Gramineae*. It grows in temperate, subtropical and tropical areas of all continents except Europe (Liese 1985). There are more than 1250 species in 75 genera in the world (Tewari 1993,Yang and Xue 2000). Bamboo is a multipurpose plant with high economic and environmental values that plays an important role in fulfilling many human needs. Traditionally, bamboo has been widely used for the construction of walls, ceilings, handicrafts, scaffolding, furniture, and countless other products. (Wong 1995, Lee and Liu 2003). Recently, the use of bamboo has expanded into manufacturing various commercial structural composite panels such as oriented strand board (OSB) particleboard, fibreboard, and laminated bamboo composite (Lee et al. 1996, Naresworo and Naoto 2000, Jamaludin et al. 2001, Lee and Liu 2003). Interest in utilizing bamboo for composite boards manufacturing is increasing worldwide because of its fast growing nature, high strength, light weight, and suitable fibre characteristics. Bamboo can be harvested in 3-5 years while most softwood species used for composite board manufacturing require 10-20 years (Chen et al. 2000).

Ethiopia has two indigenous bamboo species: the highland bamboo (*Yushania alpina)* and the monotypic genus lowland bamboo (*Oxytenanthera abyssinica).* These species of bamboo are widespread in the country and both cover approximately 1 million ha of the total vegetation area (Kassahun 2000). On the other hand, the country's natural forests are declining at an alarming rate, estimated at 150,000 to 200,000 hectares per year (EARO 2000). Despite the decline, the country is still highly dependent on wood as a raw material for building construction, wood–based panel industries, and furniture. The abundant resources of bamboo used in the country can be used as an alternative raw material for wood–based panel industries. However, information on the industrial use of bamboo, especially with respect to manufacturing composite boards is lacking.

In recent years, the use of oriented particleboards made by aligning the particles in a desirable direction has become a common trend in various structural applications. The mechanical and electrostatic method of orientation recently used in manufacturing of particle-based structural composite can increase the use of low-quality raw material to produce high-quality engineered composite boards. Due to these achievements, particle-based structural composites like flakeboard, wafer board, and oriented strand board (OSB) have continued to have more wide use for various applications compared to the traditional composite panels like plywood and glued–laminated boards.

The development of an electrostatic orientation method has increased the use of short elements of low quality materials in the production of composite boards with equivalent or higher strength. Results of many studies have shown that when an electrostatic method of orientation is applied, orientation can be achieved with particles regardless of dimension (Kawai 1996). The mechanical and physical properties of particleboard are affected by many processing variables. The alignment of particles is considered to be the most effective factor (Geimer 1976). Considerable amount of work has been reported on this subject. For instance, bending strength of highly oriented particleboard was found to be two times higher than that of random particleboard (Geimer 1976, Suzuki and Sekino 1982, Kawai et al. 1990, MCNatt et al. 1992, Shupe et al. 2001). However, most of these results are obtained from softwoods because of the properties of softwoods and the desire to efficiently utilize them for oriented particleboard. Limited research has been reported on the use of hardwoods for manufacturing acceptable flakeboard products. For example, the stiffness strength of highly oriented particleboards made from hardwood species (Aspen and Red maple) was found to be only 18% and 3%, respectively, higher than that of random boards (Kuklewski et al. (1985). Published reports on the effect of bamboo particle alignment, especially small particles, on properties of oriented particleboard are lacking. Therefore, the objective of this study was to evaluate the effects of different levels of particle alignments and particle sizes on mechanical properties and dimensional stability of oriented Bamboo particleboards.

Materials and methods

Raw material

Three-year old Ethiopian highland bamboo (*Yushania alpina*) harvested from major bamboo growing areas in Ethiopia was used as the raw material for particleboard manufacture in this study. After drying to 12% moisture content (MC), bamboo culms were cut into 2.5 cm lengths by using a circular saw. The nodes were removed, and the cut samples were further split into four parts manually. Urea formaldehyde resin was used as a binder, with ammonium chloride as hardener. A wax emulsion was also added to impart water repellency to the boards.

Board Manufacture and Evaluation

The split bamboo chips were flaked by using a Pullman ring flaker. The particles were then screened on a circular vibrating screener. Small particles of 1-2 mm and coarse particles >2 mm mesh sizes were chosen, for board fabrication. The accepted particles were then dried to 5% MC in an oven set at 60ºC.

Three-layered oriented particleboards of 750 kg/m³ target density were fabricated from small and coarse particle sizes. All the oriented boards were prepared with equal proportions of face and core particles. The face and core layers were oriented perpendicular to each other. Prior to board

manufacturing, the particles were dried to 5% MC. Ten percent of urea formaldehyde resin (based on the oven dry weight of the particles), 3% of ammonium chloride solution (based on the resin solid content), and 1% of liquid wax emulsion (based on the oven-dry weight of the particles) were used as binder, hardener, and water repellency. A square aluminium frame of 400 mm by 400 mm was used for board forming. The frame has slots spaced at 10 mm apart divided by thin aluminium plates. The forming box was placed underneath the aluminium frame and the furnish was passed between the slots manually. The distance between the aluminium slot and the mat was maintained at 25-40 mm to ensure proper orientation of the particles. The mats were prepressed at 3.5 MPa pressure for about three minutes, followed by hot pressing to a thickness of 15 mm at a target density of 750 kg/m³. The press closing time was 1 minute, and the mat was hot pressed for 6 minutes at 170±2ºC with a maximum pressure of 4.0 MPa. Distance bars were used to control the final thickness of the board.

The particle orientation angles were measured at ten points on the surface of each board, using a method developed by Geimer (1976) to determine the degree of particle alignments along the longitudinal axis of the board. Percent particle alignment, a measure for the level of particle orientation, was determined by: *Percent particle alignment = [(45-A)/45]100,* Where A (in degrees) is the average of the absolute values of the flake angles measured relative to a line parallel to the longitudinal axis of the panel. An alignment of 0% indicates a random particle alignment, whereas 100% corresponds to perfect alignment.

The properties of the three-layered oriented and control boards were evaluated in accordance with the Standards of International Standard Organization (ISO) Standards for Wood-based Panel Products (2003). The modulus of elasticity (MOE) and modulus of rupture (MOR) were determined by applying a load at a loading speed of 15 mm/min at the centre of a 370 by 50 by 15 mm test piece over a span of 320 mm (Anonymous 2003, ISO/DIS 16978). The static bending test specimens were prepared for bending along 0º (parallel), 45º, and 90º (perpendicular) by rotating the oriented board during cutting. The internal bond (IB) strength was determined by using 50 x 50 x 15 mm sample at a loading speed of 2.5 mm/min (Anonymous 2003, ISO/DIS 16984). The screw withdrawal resistance was determined by using 50 x 75 x 15 mm specimens in according with the British standard wood-based panels determination of wood screw retaining force BS EN 5669-1:1989 (Anonymous 1989). Test specimens of 50 x 50 x 50 mm were used to determine the thickness swelling (TS) and water absorption (WA) after 24 hours of soaking in cold water (Anonymous 2003, ISO/DIS 16983).

The data were analysed with statistical analysis software (SAS) using analysis of variance (ANOVA) procedure, and the least significant difference (LSD) was used for mean comparisons.

Result and Discussion

Oriented and control particleboards were made from small (1-2 mm) and coarse (>2 mm) particle sizes of three-year-old bamboo culms. The orientation of particles was controlled with respect to the longitudinal axis of the boards. Parallel-aligned boards with face particles aligned parallel to the board length and core-cross aligned were prepared from each particle size. Then identical random-oriented boards were produced from each particle size for comparison purposes. All boards were prepared with equal proportions of face and core ratios. For evaluating the effects of particle alignment at perpendicular direction (90º) and at inclination of 45º, the specimens were ripped from parallel-oriented boards at predetermined angles (45º and 90º). The mechanical properties and dimensional stability of oriented particleboards were then compared with those of randomly arranged boards, which were fabricated with the same parameters with exception of flake orientation.

Mechanical Properties (MOR and MOE)

Effects of particle orientation and particle size were analyzed and the result showed that both significantly influence MOR and MOE of bamboo particleboards. As shown in Figures 1a and b, particle size had different effects on MOR and MOE. The MOR of parallel-aligned boards made from coarse particles afforded an increase of only 6% more boards made from small particle. On the other hand, the MOR of boards made at 45º and 90º particle orientation particle size showed a marked difference on the strength where coarse particles consistently produced significantly higher strength boards (8% and 19%, respectively).

The MOR of randomly arranged boards made from both particle sizes reduced compared to parallel-oriented boards, where even though boards made from coarse particles are stronger, the differences are not great (7%). One important observation in boards that contained coarse particles; they are much more varied and have higher standard deviation than those of small particles. Similar to MOR, but to a greater extent, the MOE values from boards using coarse particles had increased significantly (22%). The effects of particle size on board stiffness for orientation at 45º and random are slightly improved 10% and 12%, respectively, compared with board strength. Using coarse particles also improve the stiffness at 90º cross aligned boards (observed 8%). As indicated in the results, high strength and stiffness performances were observed in all boards made from coarse particle sizes.

The effect of particle alignment, particle size, and their interaction had highly significant (p 0.01) effect on MOE, while the effect on MOR was significant at $p < 0.05$. This implies that particle alignment and size had more influence on stiffness of bamboo particleboards than strength. The interaction of particle alignment and size on MOR and MOE suggests that changes in stiffness and strength properties resulting from particle alignment was dependent on particle size. As indicated in the results, high strength and stiffness performances were observed in all boards made from coarse particle sizes. This implies that the size of coarse particles could facilitate the alignment of particles more than the size of length of small particle sizes.

Study on strandboard showed that increasing strand length to certain levels increases the MOR and MOE. A wood particle should be sufficiently long to allow adequate overlap for transfer of applied stress from one particle to the next (Brumbaugh 1960, Canaddo et al. 1988, Barnes 2001). Comparisons of the MOR between oriented and random boards show that parallel-aligned boards to the longitudinal axis from both particle sizes had significantly higher strength (about15%) than random boards (Figure 1a). Further comparisons of the MOE between oriented and random boards showed that stiffness of parallelly aligned boards to the longitudinal axis of the boards was highly improved (28% and 37%, respectively, for small and coarse particles) than those of random boards (Figure 1b). On the other hand, random boards from both particle sizes had higher strength and stiffness values than cross aligned boards at 45º and 90º. Therefore, it is clear that stiffness and strength properties of bamboo particleboards can be significantly increased by aligning the particles to the longitudinal axis of the board.

Study on oriented boards proved that particle alignment to the longitudinal axis of the boards greatly influences the strength and stiffness properties of the boards. Indeed, research dealing with the effects of orientation have shown it to be of prime importance. Giemer (1976), MCNatt et al. (1992), and Bares (2001) reported that by orienting the grain of the particles in the direction of the load, the stiffness of particleboards was highly improved. In general, it is also possible to conclude that particle size had less effect on strength and stiffness properties of oriented boards. The dominant parameter controlling the strength and stiffness properties of oriented board in this experiment is particle alignment.

Comparison of parallel-oriented *Y.alpina* particleboards with the longitudinal axis boards with oriented particleboards made from hardwood species showed that *Y.alpina* oriented boards had 8% and 13%, respectively, higher MOR and MOE values than Maple (Acer *rubrum* L.). Oriented boards and almost an equal MOR and MOE with Aspen (*Populous grandidentata* Michx) oriented boards reported by Kuklewski et al. (1985). The micro fibril angle of bamboo fibres that was not measured in this study might be the cause for additional increase in board strength containing particle oriented parallel to the longitudinal axis of the board. As reported by Jain et. al (1992), bamboo has a maximum strength along the fibre and a minimum strength across the fibre.

The results of this study were similar to earlier findings of oriented boards made from bamboo. Lee et al. (1996) reported on oriented strand boards made from moso bamboo (*Phyllostachys pubescence*). The results of their study

showed that the MOR and MOE values of oriented boards at 2.5 and 3.5% phenol-formaldehyde (PF) resin content were greater by 19 and 38%, respectively, than random boards.

The results of this study is also in agreement with the finding of Meyers (2001) who examined the effects of particle geometry and particle orientation separately in adequately controlled orientation conditions and reported that particle geometry has less effect on strength of composite boards than orientation. Meyers' study further indicated that panel elastic properties were influenced by strand orientation and density, thus the need for long strands is only to attain adequate orientation.

Regression equation gave in Figure 2 can be used to predict the stiffness of oriented boards aligned from 0º to 90º. High r^2 values ($R^2=0.99$) indicated the strong relationship of particle alignment and stiffness of oriented boards. The MOE of oriented boards was drastically decreased with increases of particle alignment.

Internal Bond Strength and Screw Withdrawal Resistance

Regardless of the orientation, the internal bond (IB) strength of the particleboards was dependent on the particle size rather than particle alignment. Boards made from small particles had significantly higher IB strength (35%) than those made from coarse particles, as shown in Table 1.

The higher IB strength in particleboard made from small particles could be attributed to the better ability of these particles to act as gap filling elements during board pressing. In addition, small particles are more flexible and compressible under hot press compared to coarse particles. This increased the inter-particle contact area, and improved the efficiency of adhesive, hence increasing the IB strength (Brumbaugh 1960). Similar results were also reported on production of bamboo particleboard and strand boards in earlier studies (Lee et al. 1996, Jamaludin 2001, Nareswaro and Naoto 2000).

Particle size and alignment had significant effects on surface and edge screw withdrawal strengths (Table 1). Edge and face screw withdrawal resistances of coarse particle boards were higher by 9.3% and 12%, respectively, than those made from small particles. The higher screw withdraw resistance is probably affected by the thickness of the particles. Boards made from thick coarse particles might have better screw holding capacity than thin particles. Boards with random oriented particle had 8% higher screw withdrawal resistances compared with those with parallel orientation. This could be due to the higher internal bond strength of the former, which might have increased its screw holding ability.

Thickness Swelling and Water Absorption

Particle alignment did not show significant effect on thickness swelling (TS) and water absorption (WA) of oriented

boards after 24 hours of water soaking, whereas particle sizes had significant effects on both tests. Boards made with small particles had 12% lower TS values compared to boards made of coarse particles. This could be related to the compression behavior of small particles. Under hot pressing, small particles could be compressed easily and fit together very closely, thereby reducing void spaces between them. This created intimate inter-particle contact and reduced the penetration of water into the board. A higher IB was also reported to reduce TS (Lee et al. 1996, Jamaludin 2001). On the other hand, boards made with small particles had 20% lower WA values compared to coarse particles boards. This could be associated with high springback behaviors of coarse particles. Springback could be increased with increasing particle sizes. Due to this condition, boards made from coarse particle might absorb more amounts of water than boards made from small particles.

Conclusion

Particle size and alignment were found to have significant effects on the properties of oriented bamboo particleboard made from Y. *alpina*. Boards with parallel particle alignment had 15% higher MOR than controls, corresponding to 28-27% increase in MOE in the case of small and coarse particles. The IB of the boards was more affected by the particle size rather than alignment. Boards made from small particles recorded 35% higher IB strength than those made from coarse particles. The screw withdrawal resistance of oriented boards was significantly affected by particle alignment and particle size. Edge and face screw withdrawal resistance of coarse particles boards were higher by 9% and 12%, respectively, compared to small particles boards. Random-oriented boards were showed about 8% superior face and edge screw withdrawal resistance than oriented boards. Particle sizes had significant effect on TS and WA of the boards after 24 hours of water soaking. Due to reduced porosity, boards made from small particles absorbed less water, hence resulted in 12% lower TS than those made from coarse particles. It is possible to conclude that Ethiopian high land bamboo (Y. *alpina)* has good potential to be used for particleboard production, as irrespective of particle size and alignment. All particleboards produced in this experiment exhibited properties which surpassed the minimum requirements for high performance particleboards stipulated in the ISO standards.

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Table 1. Mean comparisons of internal bond, screw withdrawal, thickness swelling, and water absorption properties of Y. *alpina* particleboard

Properties	Particle size		Board type	
	Small	Coarse	Parallel alignment	Random
IB[1] (MPa)	1.0a	0.648b	-	-
SWS[2] ( )	773b	878a	793b	858a
SWE[3] (KN)	753b	831a	759b	824a
TS[4] (%)	6.9b	7.8a	-	-
WA[5] (%)	30b	37a	-	-

Notes: Means with the same letter are not significantly different at P<0.05.
 Each value is the average of 9 specimens
   [1] internal bond, [2] screw withdrawal surface, [3] screw withdrawal edge, [4] thickness swelling, [5] water absorption
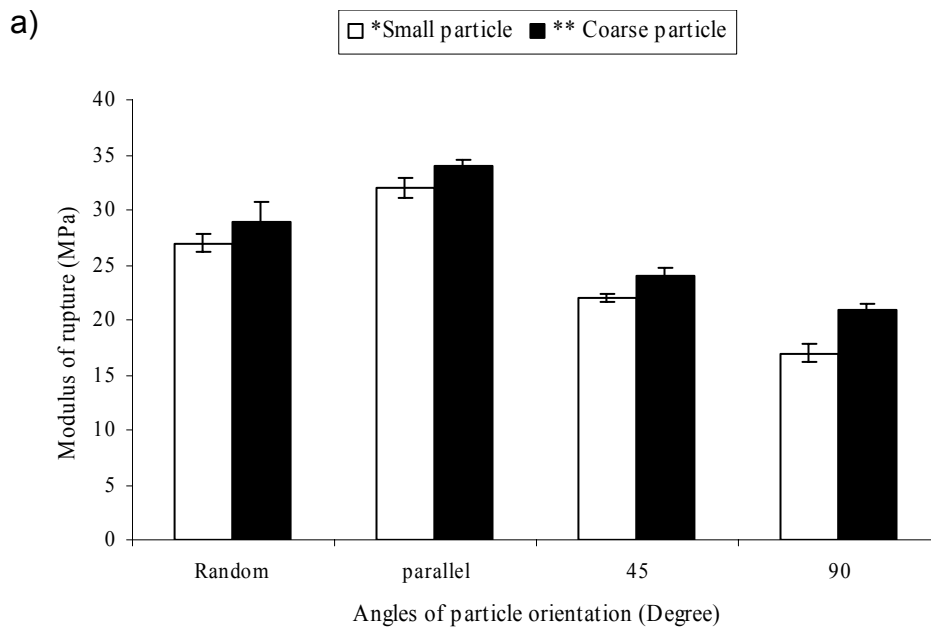
a)

Note: Each value is the average of 9 specimens; bars indicate standard deviation of these values
Legend (particle size: * small, **coarse)

b)
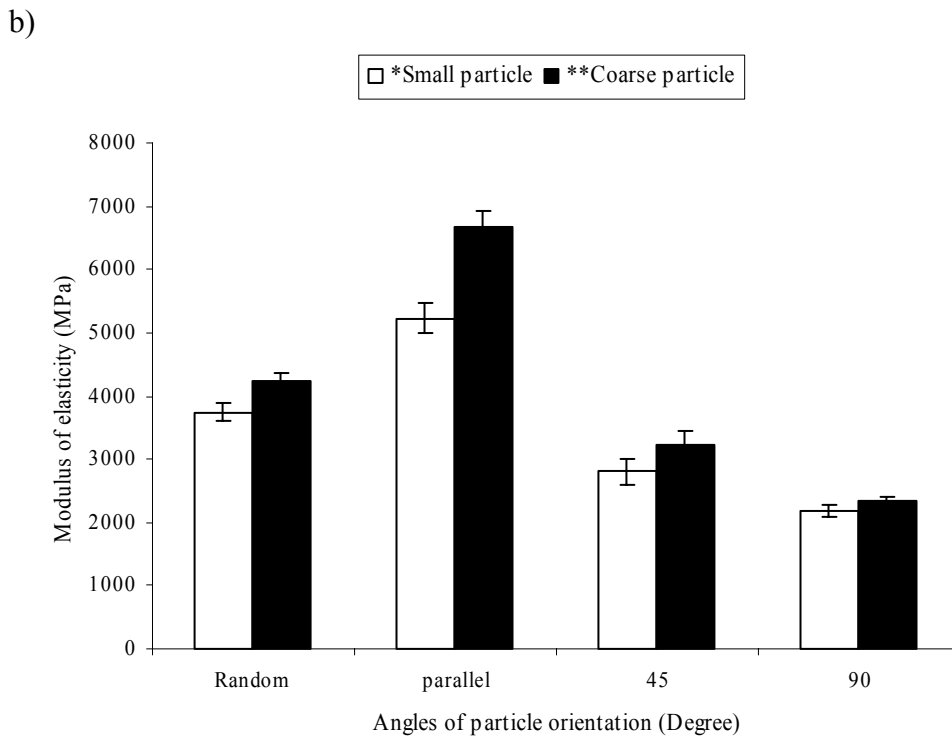
Note: Each value is the average of 9 specimens, bars indicate standard deviation of these values
Legend (particle size: * small, **coarse)

Figure 1. Effects of particle size and alignment on moduli of rupture (a) and elasticity (b) of Y. *alpina* particleboard
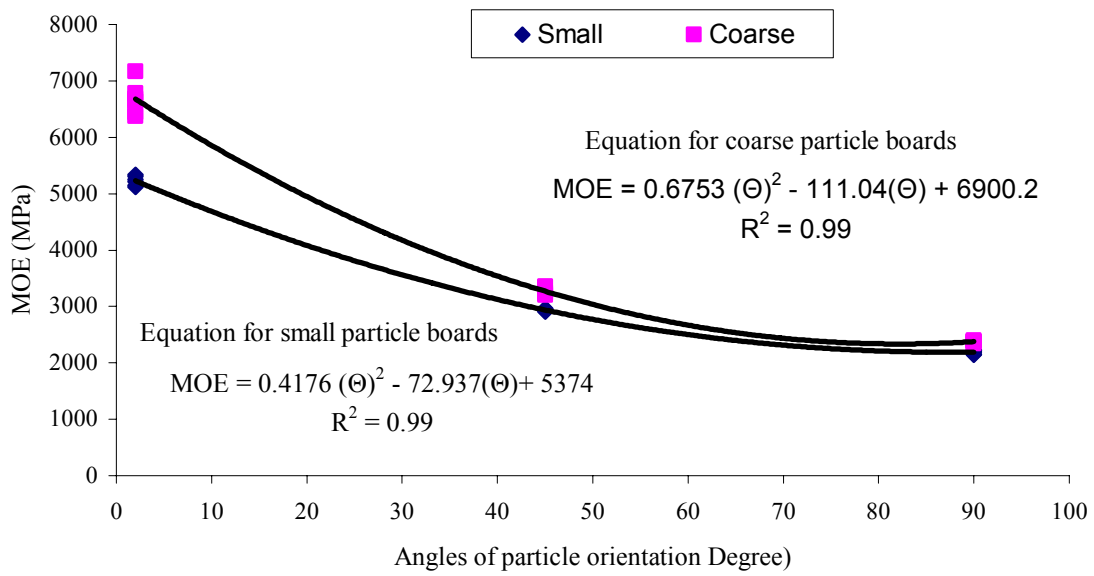
Legend (particle size: * small, **coarse)

Figure 2. Relationship between MOE and particle alignment

Comparisons of Boards Properties Made From Different Waste Papers

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Abstract

This research was conducted to compare the fundamental properties of boards composed of different types of waste paper: office paper, advertisement paper, and newspaper. The results obtained are as follows: 1) boards made from office waste papers at all resin types had the best performance in MOE, MOR, and IB properties. 2) considering the bonding material, the order of the best fundamental properties of waste paper boards were isocyanate, phenol formaldehyde, and urea formaldehyde, and 3) compared to the JIS A 5908 standard, only urea formaldehyde and phenol formaldehyde bonded boards failed to meet the minimum requirement for 8-type particleboard, while the others type boards met 13-type or 18-type board requirements.

Keywords: Waste paper, Modulus of Elasticity, Modulus of Rupture, Internal Bond.

Introduction

Waste paper lately increased sharply in volume and kinds. Some of the waste paper can be easily recycled, but others could cause a negative environmental impact if recycling to paper. This is because of colors, ink, clay, and other additives in the waste papers. Office waste paper and waste newspaper could be recycling to the paper again with some difficulties especially in copy paper. However advertisement papers are very difficult to be recycled due to the very high contents of clay, colors, and other additive. From this view point, it is interesting if we can recycle these kinds of paper to boards without any negative environmental impact, or at least the produced boards can be used with a minimum negative environmental impact (Massijaya and Okuma, 1996 a, 1996 b, 1996 c; Massijaya, 1997).

This research was conducted in order to compare the fundamental properties of waste newspaper boards with another waste paper board types. The waste papers used in this research were office waste paper, advertisement waste paper and waste newspaper. Waste office papers were collected in the Faculty of Agriculture the University of Tokyo, while the advertisement waste papers were collected in the newspaper agent with the newspaper. Advertisement papers are always sent to the consumer by putting them inside the newspaper.

Experiment

In this research, waste paper boards were produced purely using three kinds of waste papers, namely: waste newspaper, office waste paper, and advertisement waste paper. The target waste paper board density was 0.90 g/cm^3. The board size was 40 cm in length, 30 cm in width, and 6 mm in thickness.

All of the waste paper particles were produced by a cross cut shredder, RICUT 3103 FL. The average dimensions and density of the waste papers particles can be seen in Table 1.

Three types of liquid resins were used in this research; UF (PB-270) formulated by Tohoku Dic Co. Ltd., PF (PB-1310) and IC (PB-1605) formulated by Oshika Sinko Co. Ltd. The resin solid content of UF, PF and IC was 64.3%, 46.6%, and 97.8 % respectively. Each resin type was applied at 8 % resin level based on dry weight of the particle.

All of the waste paper particles were dried in an oven at 105±2ºC for 48 hours. The moisture content of the particles after drying was next to 0%. Mat moisture content was adjusted to 20% by diluting the resin with a certain volume of distilled water.

The waste paper particles were blended with resin by means of a blender and spray gun. After the blending process, the particles were hand formed into a mat. Both top and bottom surfaces of the particle mat were covered by a glass fiber reinforced Teflon sheet to prevent the mat from sticking to the cauls. The hand formed particle mats were pressed at 140ºC for UF, 170ºC for PF and 160ºC for IC bonded boards. A three step pressing schedule was used for the waste newspaper boards to avoid blistering. In the first step, the mat was pressed under a pressure of 35 kg/cm^2, and in the second and third steps the mat was pressed at 25 kg/cm^2 and 20 kg/cm^2, respectively. During board pressing, steel bar stops were used to meet the board target thickness. Each step down lasted for three minutes for a total pressing time of 9 minutes.

After hot pressing, the board samples were conditioned in a conditioning room at 24ºC with a relative humidity of 65% for a minimum of two weeks. The boards were tested according to JIS A 5908 for particleboard with six replications for each condition.

Results and Discussion

Board Appearance

The color of the boards, which were bonded with UF, PF, and IC resin, were quite different. UF-bonded boards are the natural color of the waste paper. PF resin tends to change the raw material color to brown, while IC resin tends to change the produced boards to yellowish white. The difference of the boards' color was understandable because these color tendencies are the same as the resin type color.

The resin spots can be seen very clearly in office waste paper boards, especially in PF-bonded boards. The brown color distribution is not uniform along the boards, while in IC and UF-bonded boards, it is not so clear. This related to the contrast color of the brown to the white paper compared to IC (yellowish white) and UF (colorless) resins. However, the color distribution in advertisement particleboards is uniform. Uniformity of the resin distribution was related to the blending properties of the waste papers when mixed with resin. There is no tendency of advertisement waste paper to clump in a clustered mass when it was mixed with any resin type. This may be due to the density of the advertisement paper (1.16 g/cm^3), which is higher than that of office waste paper (0.75 g/cm^3) and waste newspaper (0.58 g/cm^3). Moreover, the surface of the advertisement paper is glossy due to the coating or other special treatments in the paper production.

Mechanical Properties

Figs. 1 and 2 show the comparisons of MOR and MOE in dry conditions of waste paper boards at different resin types, respectively. In Fig. 1 it is clear that among the resin types, IC-bonded boards perform highest MOR compared to the other types, the weakest was UF-bonded boards at any kinds of waste papers. MOR properties of office waste paper bonded by IC were 2 and 2.5 times stronger compared with the PF and UF-bonded boards, respectively. The office waste papers were stronger than other waste papers, because office waste papers are produced from high quality pulp that is stronger than waste newspaper and advertisement waste paper pulps.

Compared to the JIS A 5908, IC-bonded boards meet 18-type particleboards for all of the waste paper types, PF-bonded boards meet 18-type for waste newspaper and office waste paper, while advertisement paper meets 13-type. In the case of UF-bonded boards, waste newspaper meets 13-type and office waste paper meets 18-type. Advertisement waste paper only meets 8-type. Previous research results also shows that resin type performed remarkable influence to the mechanical properties of composite boards (Brochmann *et al*., 1994; Maloney, 1997; Massijaya, 2003; Erniwati and Massijaya, 2005, Subiyanto *et al*., 1988; 1989).

These results were understandable since the compression ratio of the advertisement paper was the lowest. Also, the resin penetration was more difficult in advertisement paper compared with the other waste paper types. This is because the special treatment (coating) was applied to the surface of advertisement paper.

MOE properties of the produced boards perform the same trend with MOE, except the PF-bonded boards. All the IC-bonded boards meet the 18-type particleboard set forth by JIS A 5908, office waste paper and newspaper of PF-bonded boards meet the 18-type. However, advertisement boards only meets 13-type. Concerning the UF-bonded boards, only office waste papers meet 18-type particleboards, and the others meet 8-type.

Fig. 3 describes comparisons of internal bond properties of waste paper boards at different resin types. In Fig. 3, it is clear that IC-bonded boards yielded the best internal bond properties compared to PF and UF-bonded boards. PF-bonded boards were in the second place and the worse was UF-bonded boards. This figure also shows that the average internal bond of office waste papers was superior to that of waste newspaper and advertisement waste paper. The second place was advertisement waste paper at PF and UF-bonded boards, while in IC-bonded boards, waste newspaper yielded better internal bonds compared with those of advertisement papers.

Compared to the JIS standard, only UF-bonded boards and waste newspaper PF-bonded boards failed to meet the minimum requirement for 8-type particleboards. The other type boards meet 13-type boards or 18-type boards.

Dimensional Stability

Figs. 4 and 5 show comparisons of water absorptions and thickness swellings of waste paper boards at different resin types after 24 hours of water immersions. In these figures, it is clear that all of the board samples failed to meet the maximum value (12%) set forth by JIS A-5908 for particleboards. Among the waste paper, advertisement waste paper yielded better properties compared with the waste newspaper and office waste papers. This may be caused by the coating effect of the advertisement waste paper.

Figs. 4 and 5 also describe the effect of resin types on the dimensional stability of waste paper boards. In 24 hours of water immersions, all of the samples absorbed so much water. During this process, the waste paper particles swell. This produced tension forces to the cured resin as a binder for waste paper particles. If the tension forces were larger than the cured resin forces, the residual stress during hot press were released and the thickness of the boards will be increased.

In the case of UF resin, the UF bonds were deteriorated during water immersion due to the hydrolysis of its aminomethylenic bond. Therefore UF-bonded boards performed relatively lower dimensional stability compared with the PF and IC-bonded boards (Pizzi, 1994). Previous

research results also show that resin type showed a remarkable influence to the dimensional stability of the composite boards (Brochmann *et al.*, 1994; Maloney, 1997; Massijaya, 2003; Erniwati and Massijaya, 2005, Subiyanto *et al.*, 1988; 1989).

Conclusions

1. The order of the best fundamental properties of waste newspaper boards were IC-bonded boards, PF-bonded boards, and UF-bonded boards, respectively.
2. In comparison among the waste papers, boards made from office waste papers yielded better performance in MOR, MOE, and IB properties compared with other waste paper types at any resin type.
3. IC-bonded boards had the highest internal bond properties compared to PF and UF-bonded boards. PF-bonded boards were in the second place, and the UF-bonded boards were the lowest. The average internal bond of office waste papers was superior compared with the other waste paper types. The second place was advertisement waste paper at PF and UF-bonded boards, while in IC-bonded boards, waste newspaper performs better internal bonds compared with advertisement papers.
4. Comparison to the JIS standard, only UF-bonded boards and waste newspaper PF-bonded boards failed to meet the minimum requirement for 8-type particleboards. The other type boards meet 13-type boards or 18-type boards.
5. All of the board samples failed to meet the maximum thickness swelling (12%) set forth by JIS A-5908 for particleboards. Among the waste papers, advertisement waste paper performed better properties in dimensional stability compared with the other waste paper types.

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Subiyanto, B., S. Kawai, M. Tanahashi, H. Sasaki. 1988. Curing Conditions of Particleboard Adhesive II. Curing of Adhesive Under High Steam Pressures or Temperature. Mokuzai Gakkaishi. Vol. 35. No. 5. page 419–423.

Table 1. The average dimensions and physical properties of waste paper particles.

No.	Properties	Waste newspaper	Office waste paper	Advertisement waste paper
1.	Dimensions :			
	a. Thickness (mm)	0.08	0.09	0.70
	b. Width (mm)	2.90	2.62	2.61
	c. Length (mm)	53.20	30.32	29.57
2.	Density g/cm^3	0.58	0.75	1.16

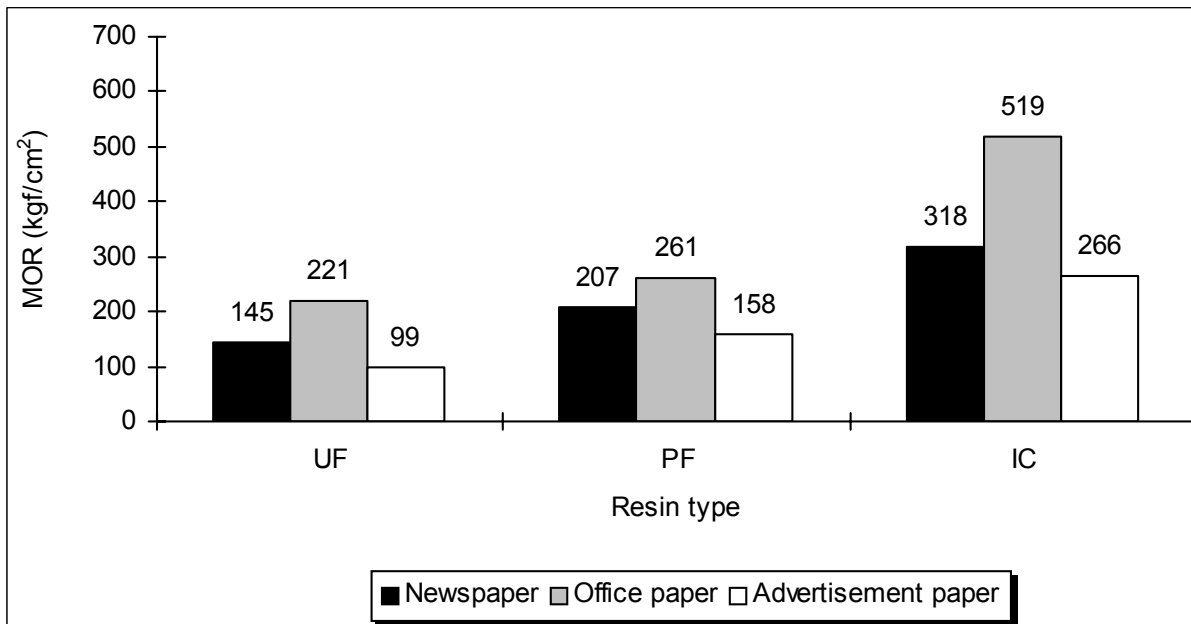Note: The dimensions data were averaged from 30 samples. The densities data were averaged from 10 samples.

Figure 1. Comparisons of MOR under dry conditions of waste paper boards at different resin types
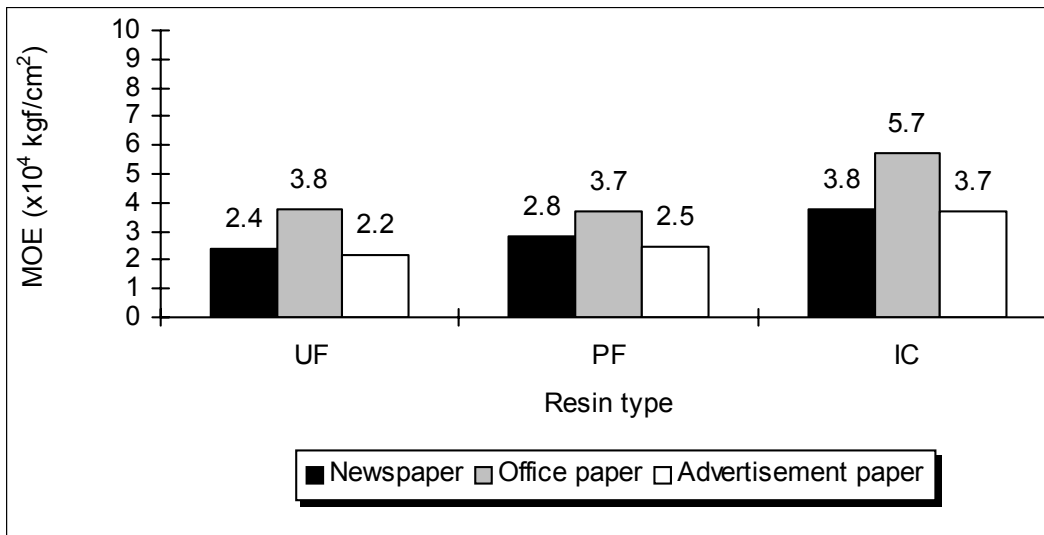
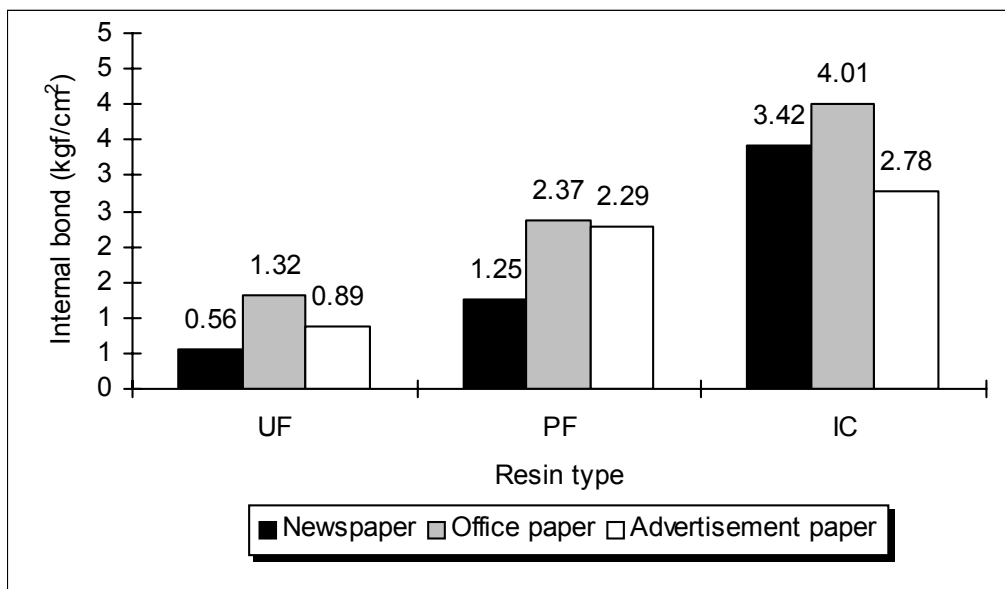Figure 2. Comparisons of MOE under dry conditions of waste paper boards at different resin types.

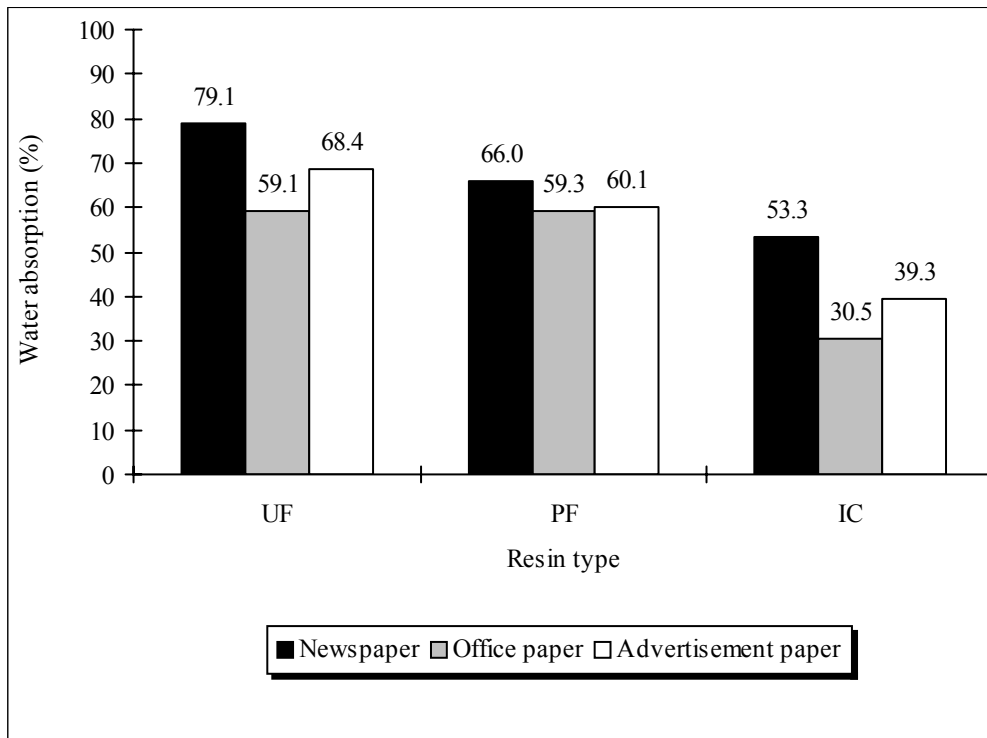Figure 3. Comparisons of internal bonds of waste paper boards at different resin types.

Figure 4. Comparisons of water absorptions of waste paper boards at different resin types after 24 hours of water immersions.
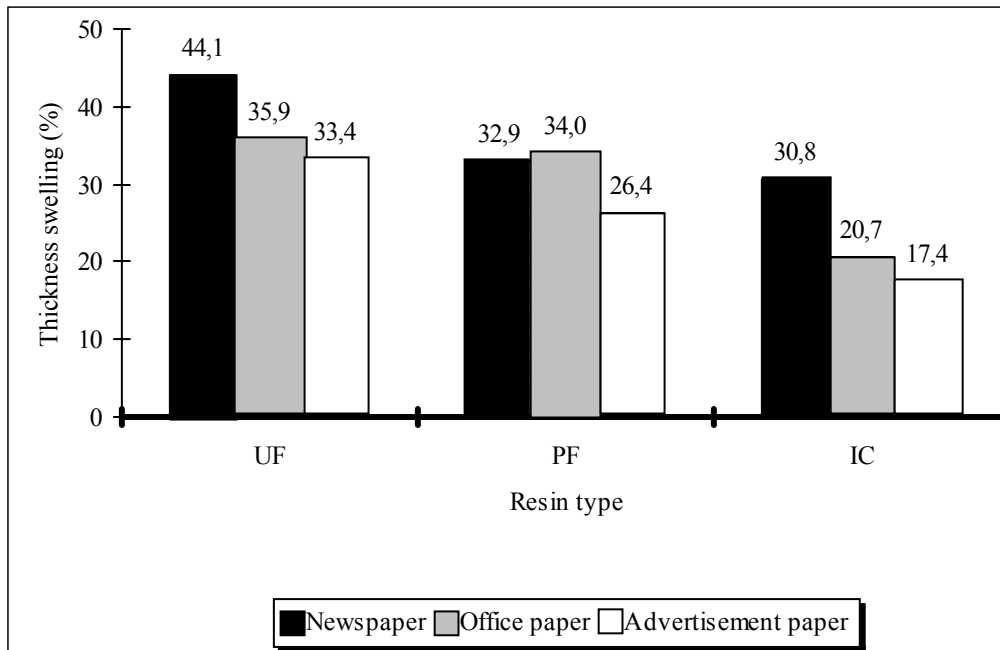

Figure 5. Comparisons of thickness swellings of waste paper boards at different resin types after 24 hours of water immersions.

An Experiment On Producing Laminated Waste Newspaper Boards

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Abstract

In order to improve the appearance of waste newspaper boards, several boards bonded by urea formaldehyde, phenol formaldehyde, isocyanate, and laminated with thick white paper were produced. In general, boards bonded by isocyanate had better properties compared with those of phenol formaldehyde or urea formaldehyde. Lamination with thick white paper significantly improved the modulus of elasticity and modulus of rupture of waste newspaper boards regardless of resin type. Isocyanate bonded boards and phenol formaldehyde bonded boards meet JIS A 5908 for 18-type particleboards, while urea formaldehyde bonded boards met 18-type for laminated and 13-type for non-laminated waste newspaper boards. There were no differences between laminated and non-laminated urea formaldehyde and phenol formaldehyde bonded boards in wet modulus of rupture. Lamination by thick white paper tends to decrease the modulus of rupture and modulus of elasticity strength retention regardless of resin type.

Keywords: Waste Newspaper, Waste Newspaper Board, MOR, MOE, Internal Bond.

Introduction

In the previous experiments, the waste newspaper boards were produced without lamination in the surfaces of the waste newspaper boards at various production conditions (Massijaya and Okuma, 1996a, 1996b, 1997, 1998). So as the consequence, the waste newspaper can be seen very clearly on the surface of the waste newspaper boards. This may be very interesting for somebody, but could be unappealling to the other people.

The lignin still remains in the waste newspaper, and lignin and certain carbohydrates yellow with age, particularly when exposed to the ultraviolet light of the sunlight. This was a potential problem to the newspaper boards, especially for UF-bonded boards.

In order to improve the appearance, physical and mechanical properties of the waste newspaper boards, several boards laminated by thick white paper were produced. Thick white paper was selected because it was made of pulp, the same raw material with waste newspaper, so it will not make any problem in adhesion with UF, PF, and IC. Moreover, the strength of this material is isotropic.

Experiment

The waste newspaper particles were produced using a cross cut paper RICUT 30FL. The rectangular particles were dried in an oven until the particles were oven dried.

The laminated waste newspaper board target density was 0.90 g/cm^3. The board size was 40 cm in length, 30 cm in width, and 6 mm in thickness. Lamination process was done by just simply spreading a little bit of resin to the surface of the lamination paper by spray gun while mixing the waste newspaper with the resin.

Resin sprayed lamination paper was then put on the surface layer of the mat forming process, so the lamination process was done in one step. The thickness of the white paper was 0.71 mm and the density was 0.76 g/cm^3.

There were three types of liquid resins used in this research; UF (PB-280) produced by Tohoku Dic Co. Ltd. and PF (PB-1310) and IC (PB-1605) produced by Oshika Sinko Co. Ltd. The resin solid contents of UF, PF and IC were 64.3%, 46.6%, and 97.8 % respectively. Each resin was applied to the board production at 8% level based on the oven dry weight of the particles.

After the blending process, the particles were hand formed into a mat. Both top and bottom surfaces of the particle mat were layered by white thick paper and covered with glass fiber-reinforced Teflon sheets to prevent the mat from sticking to the cauls. The hand formed particle mats were pressed at 140°C for UF, 170°C for PF, and 160°C for IC bonded boards. A three step pressing schedule was used for the laminated waste newspaper boards to avoid blistering. In the first step, the mat was pressed under a pressure of 35 kg/cm^2, and in the second and third steps the mat was pressed at 25 kg/cm^2 and 20 kg/cm^2, respectively. During board pressing, steel bar stops were used to meet the board target thickness. Each step down lasted for three minutes for a total pressing time of 9 minutes.

After hot pressing, the board samples were conditioned in a conditioning room at 24°C with a relative humidity of 65% for a minimum of two weeks. The boards were

tested according to JIS A 5908 for particleboards with six replications for each condition.

Results and Discussion

Mechanical Properties

Figs. 1 and 2 show the effect of lamination to the MOR and MOE, respectively. In these figures, it is clear that the bending properties (MOR and MOE) improved when the waste newspaper boards were laminated by thick white paper. It means that thick white paper can handle the maximum compression and tension stresses on the surfaces area better than waste newspaper. This can be understandable because the thick white paper was formed by a wet process that allows more inter-fiber contact compared to the waste newspaper boards. As the results, the MOR properties of the waste newspaper boards were remarkably improved. This improvement is the same as other research results concerning utilization of veneer, cement sack waste paper, and bamboo for face and back layers (Sudijono and Subyakto, 2002; Massijaya, 2003; Suhasman *et al.*, 2005; Massijaya *et al.*; 2005; Erniwati and Massijaya, 2005). The improvement of UF, PF, and IC-bonded boards were 29.66%, 10.14%, and 11.94%, respectively. These results were large enough for MOR improvement, especially for UF-bonded boards because it can improve the quality of UF-bonded boards from 13-type boards to 18-type boards according to JIS A 5908. Improvement of MOE properties of the waste newspaper boards were larger than MOR. Improvement of MOE properties of the waste newspaper particleboards for UF, PF, and IC-bonded boards was 86.96 %, 67.86%, and 44.74 %, respectively.

Compared to JIS A 5908 for particleboards, all of PF and IC-bonded boards (laminated and control) fulfill the minimum requirement of 18-type particleboards, meanwhile for UF-bonded boards, only laminated waste newspaper boards meet the 18-type, the control one meet 13-type particleboards.

Fig. 3 shows the effect of lamination on the internal bonds at different resin types. In this figure, the difference of internal bond strength of UF and PF-bonded boards was not clear. However lamination with thick white paper decreased the internal bond of the IC-bonded boards. This happened because the internal bond of the waste newspaper boards was stronger than those of thick white paper. This can be seen in the broken area of the internal bond samples. All of the samples were broken in the thick white paper area. Changing of the thick white paper to the stronger one could improve the internal bond properties of the laminated waste newspaper board.

Compared to the JIS A 5908 standard, only IC-bonded boards meet the minimum requirement. The control boards (non-laminated) meet the 18-type particleboards, while the laminated boards meet 13-type.

Dimensional Stability

Figs. 4 and 5 show the effect of lamination on the water absorption and thickness swelling at different resin types after 24 hours of water immersions, respectively. In Fig. 5 it is clear that all of the board samples failed to meet the maximum value (12%) set forth by JIS A-5908 for particleboards. Among the produced boards, IC-bonded boards performed with better properties compared with those of UF and PF-bonded boards, and UF-bonded boards were the worse in dimensional stability compared with those of others. This phenomenon was understandable because the UF resin is not resistant to water and moisture, due to the hydrolysis of its aminomethylenic bond (Pizzi, 1994).

According to Figs. 4 and 5, the dimensional stability of IC-bonded boards was not remarkably different between laminated and non-laminated waste newspaper boards. However it was remarkably different in PF and UF-bonded boards. Especially the water absorption of UF-bonded boards, lamination with thick white paper increased the water absorption of UF-bonded boards up to 106.6 %. This may be related to the properties of thick white paper, which tends to absorb so much water, because thick white paper relays only to the hydrogen bond. In IC and PF-bonded boards, the water absorption was not as large as those in UF-bonded boards. This is because PF and IC resins penetrate into the thick white paper and keep it from absorbing so much water. PF and IC resins were resistant to the water and moisture. For UF-bonded boards, even though UF resin penetrates into the thick white paper, it was destroyed when the boards were immersed in water for 24 hours.

Conclusions

1. In general, IC-bonded boards had better properties compared with PF and UF-bonded boards. And PF-bonded boards had better properties compared with the UF-bonded boards.
2. Lamination with thick white paper significantly improved MOR and MOE properties of waste newspaper at any resin type. IC and PF-bonded boards meet the minimum requirement set forth by JIS A 5908 for 18-type particleboards, while UF-bonded boards meet 18-type for laminated and 13-type for non laminated waste newspaper boards (controls).
3. Lamination by thick white paper improves the internal bond of UF-bonded boards. Lamination, however, decreased the internal bond of PF and IC-bonded boards. Among the board samples, only non-laminated IC-bonded boards meet the minimum requirement set forth by JIS A 5908 for 18-type particleboards while the laminated IC-bonded boards meet the 13-type. UF and PF bonded board failed to meet minimum requirement set forth by JIS A 5908 for 8-type.
4. All of the samples failed to meet the maximum thickness swelling set forth by JIS A 5908 for particleboards

(12%). Lamination by thick white paper decreased the dimensional stability of the PF and UF-bonded boards. However, there was not any significant effect on the IC-bonded boards.

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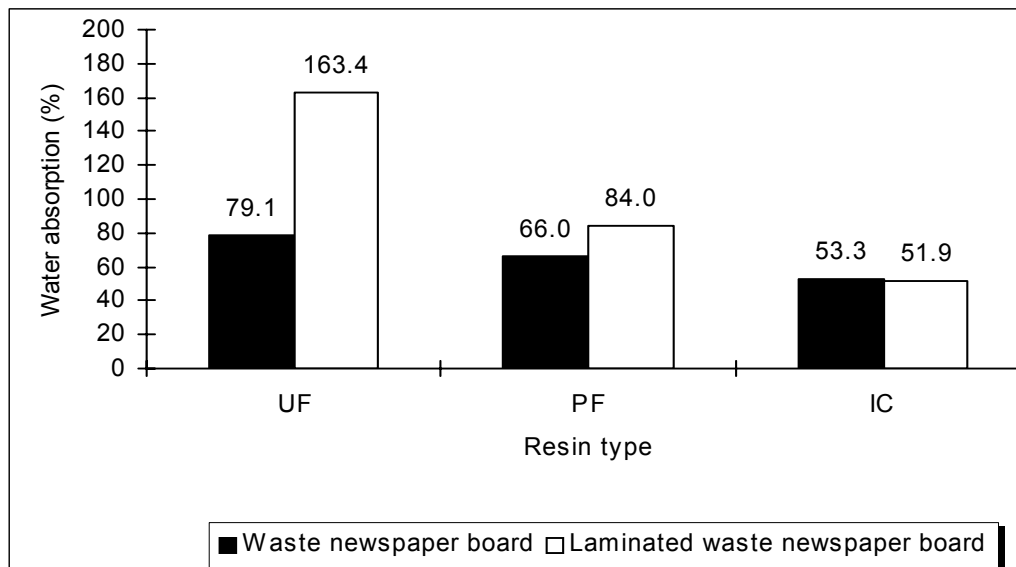

Figure 1. Effect of lamination to the modulus of rupture (MOR) in dry condition at different resin types.
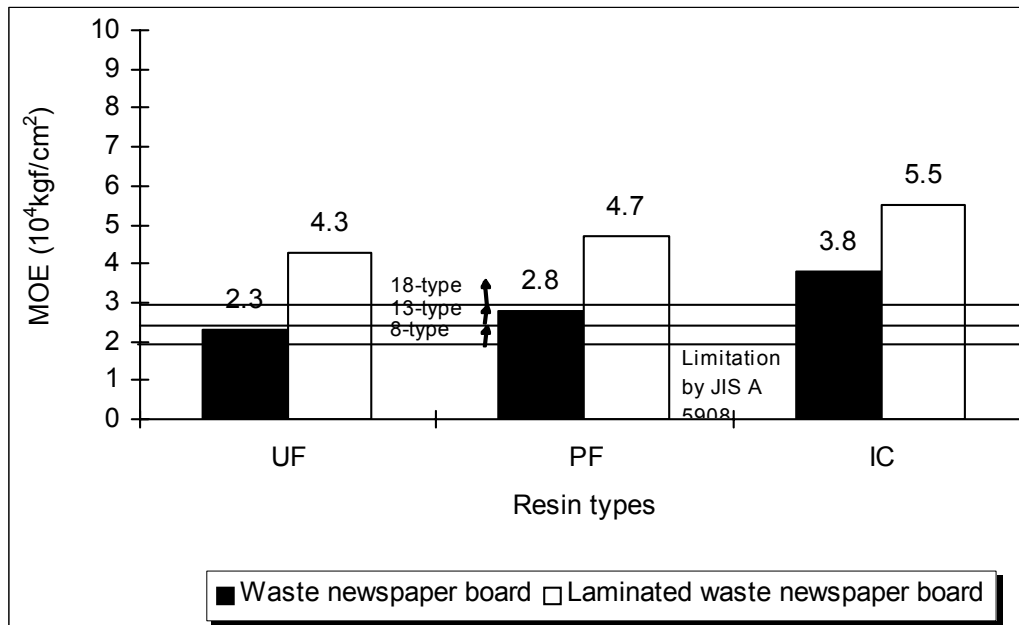
Figure 2. Effect of lamination to the modulus of elasticity (MOE) in dry condition at different resin types.
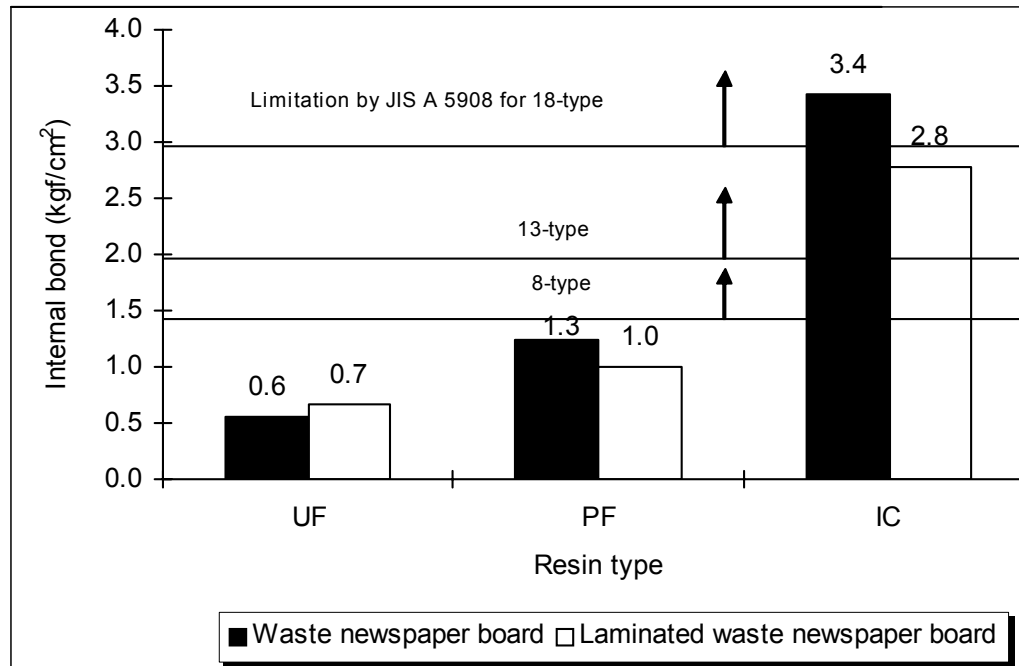

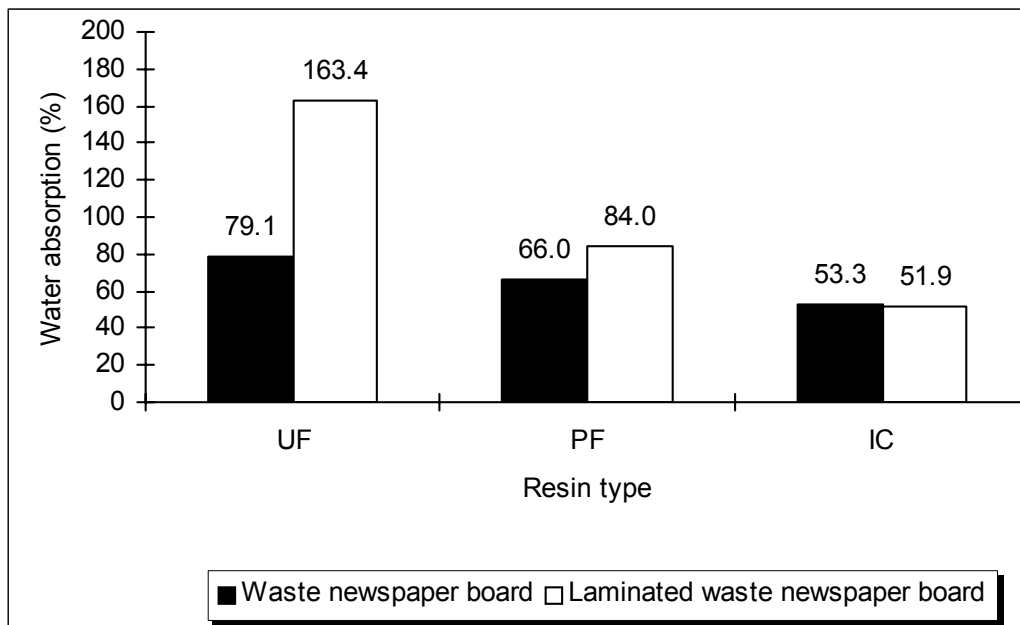Figure 3. Effect of lamination to the internal bonds at different resin types.

Figure 4. Effect of lamination to the water absorption at different resin types after 24 hours of water immersions.
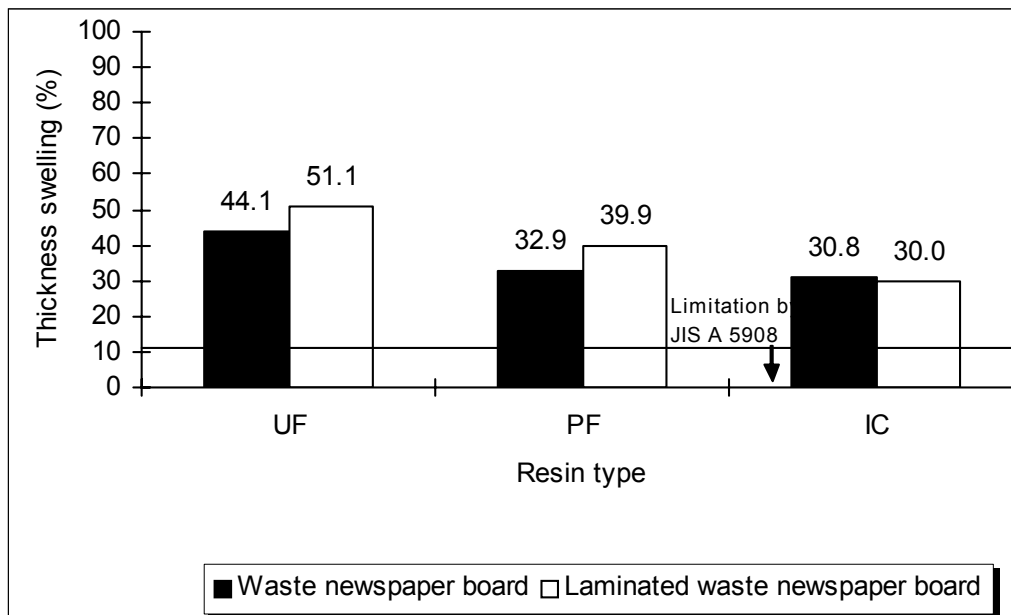

Figure 5. Effect of lamination to the thickness swelling at different resin types after 24 hours of water immersions.

Strength Properties of Glued Laminated Bamboo (Gigantochloa scortechinnii) Strips for Furniture

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Executive Summary

Utilization of bamboo as an alternative material to timber has markedly gain interest nowadays not only among researchers and timber users in the world, but in Malaysia as well. Nevertheless, bamboo-utilizing industries in Malaysia generally comprise of small mills producing products such as chopsticks, poultry cages, vegetable baskets, and skewers where usage of low technology with labor intensive is prominent. Bamboo utilization for furniture making, conversely, is restricted to solid round bamboo of limited design and with simple construction procedures due to lack of fundamental knowledge and information. In order to make bamboo more versatile and a value-added material for furniture and other products, its utilization in the form similar to lumber needs to be promoted. For this reason, the bending and compression strength of glued laminated bamboo strips at different age (2 and 4 years old) were assessed and compared with those of Malaysian oak (formerly known as rubberwood), timber species that are commonly used for furniture manufacturing in Malaysia. The glue bond strength properties in terms of block shear and delamination tests were also investigated.

Utilization of bamboo strips in laminated form is seen to have great potential to supplement timber, hence reducing dependency on some timber species for furniture in the future.

Abstract

This paper discusses the results from a study that has been undertaken to determine the strength properties of glued laminated bamboo strips at different age (2 and 4 years old) and to compare the results with those of Malaysian oak (formerly known as rubberwood), a timber species that is commonly used for furniture manufacturing in Malaysia. Utilization of bamboo strips in laminated form is seen to have great potential to supplement timber, hence reducing dependency on some timber species for furniture in the future. The principal tests performed were bending strength, compression strength, and block shear test. With the exception of bending strength, all other results showed significant differences existed between laminates made from 2- and 4-year-old bamboo strips. In addition, laminates made from the two different age groups of 'semantan' bamboo also produced higher bending and compression strength than solid Malaysian Oak timber, apart from its poor performance in shear strength.

Keywords: laminated, bamboo, strips, bending, compression, block shear test, Malaysian Oak

Introduction

Utilization of bamboo as an alternative material to timber has markedly gain interest nowadays not only among researchers and timber users in the world, but in Malaysia as well. Nevertheless, bamboo-utilizing industries in Malaysia generally comprise of small mills producing product such as chopsticks, poultry cages, vegetable baskets, and skewers where usage of low technology with labor intensive is prominent. Bamboo utilization for furniture making, conversely, is restricted to solid round bamboo of limited design and with simple construction procedures due to lack of fundamental knowledge and information. In order to make bamboo more versatile and value-added material for furniture and other products, its utilization in the form similar to lumber needs to be promoted. Utilization of bamboo strips in laminated form is seen to have great potential to supplement timber, hence reducing dependency on some timber species for furniture in the future. For this reason, the bending and compression strength of glued laminated bamboo strips at different ages (2 and 4 years old) were assessed and compared with those of Malaysian oak (formerly known as rubberwood), a timber species that is commonly used for furniture manufacturing in Malaysia. The glue bond strength properties in terms of block shear test were also being investigated.

Materials And Methods

Bamboo samples of approximately 2 and 4 years old were used in this study. The 'semantan' bamboos (*Gigantochloa scortechinii*), which were obtained from Chebar Forest Reserve in Nami, Kedah were cut into 4 meter lengths from

just above the ground level. The diameter of the bamboo culms was relatively uniform with an average size of 7 cm.

The bamboo was cut and split into strips of rough sizes prior to soaking into a large container containing the mixture of water and 5% concentration of boron preservative substance. After the bamboo strips have been soaked for about one day, they were later dried using a closed-force air-dry system for 2 weeks to obtain strips with moisture content between 10-12%. Dried bamboo strips were later cut and planed using conventional cross-cut saw and planer machine into strips of uniform thickness, width, and length of approximately 5mm X 20mm X 1250 mm.

Subsequently, strips of uniform sizes were glued with polyvinyl acetate (PVAc) adhesive using standard procedures for glue spreading (250 g/m^2 spread rate) and clamping (15 kgf/cm^2 pressure) before the assemblies were finally removed from the clamp. Two different sets of 3-ply glued laminated bamboo strips were made, each consisting of bamboo strips from different age group (2 and 4 years old). Prior to further processing of samples for testing, the glued laminated bamboo assemblies were allowed to condition for at least one week to ensure proper curing of the glue.

The strength properties of the 2- and 4-year-old glued laminated bamboo strips were determined in terms of its bending and compression strength, while the glue bond strength were determined through the block shear test (BST). All tests were conducted in accordance with standard procedure as stipulated in the Japanese Agricultural Standard JAS: SIS-7 (Anonymous, 1987).

Results And Discussion

The results of bending and compression tests for the glued laminated bamboo made from 2- and 4-year-old bamboo strips are presented in Table 1. The mean bending strength for both assemblies of different age group were by some means having proximate values of 78 MPa. Analysis of variance (ANOVA) test showed that the bending strength of glued laminated bamboo made from 2- and 4-year-old bamboo strips were not significantly different. The value was certainly higher compared to the bending strength of solid Malaysian Oak of 66 MPa. Bamboo has been reported having superior mechanical properties to most materials including wood (McDonough 2000).

In contrast, the compression strength parallel to the grain of laminated bamboo made from 2-year-old bamboo strips exhibited higher value than the one made from 4 years old bamboo strips with a value of 212.9 MPa and 184.1 MPa respectively. Analysis of variance test conducted shows that significant difference existed between laminated bamboos made from the two different age groups in terms of its compression strength. The 2-year-old bamboo, which apparently contains vessels of a larger size than the 4-year-old bamboo (Anonymous, 2000), possibly would allow a larger

amount of glue to fill the vessel that consequently acts as strengthening agent. In comparison to Malaysian Oak, the compression strength of laminated bamboo made from both the 2- and 4-year-old bamboo strips produced exceptionally higher values than solid Malaysian Oak.

In terms of glue bond strength, laminated bamboo made from 2-year-old bamboo strips exhibited better results than the one made from 4-year-old bamboo strips (Table 2). The maximum failing load and shear strength values were significantly different when tested by means of analysis of variance test between laminates made from bamboo of different age group. The explanation for such outcomes may possibly be the same as mentioned previously for compression strength. However, when comparing the results of glue bond shear strength of laminates made from 2- and 4-year-old bamboo strips with solid Malaysian Oak, the results of this study fall short tremendously. The shear strength values of 0.839 MPa and 0.687 MPa, respectively, for laminates made from 2- and 4-year-old bamboo strips unsurpassed the values of 10.98 MPa for solid Malaysian Oak laminates. In this light, it is recommended that a lot more research efforts should be embarked on to improve the glue bond properties of laminated bamboo in order to substantiate its used for furniture in the near future.

Conclusions

The strength properties of glued-laminated bamboo strips made from 2- and 4-year-old 'semantan' bamboos (*Gigantochloa scortechinii*) in most cases exhibited higher values than solid Malaysian Oak. This indicates that utilization of bamboo strips in laminated form have great potential to supplement timber for furniture in the future. Nevertheless, the poor performance of the glue bond shear strength might be a setback for the development of furniture products from glued-laminated bamboo strips. As such, efforts towards improving the glue bond properties of bamboo strips using novel technologies should be given more consideration in order to tailor bamboo into a more versatile and value-added material.

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Acknowledgements

Table 1: Mean bending and compression strengths of 2- and 4-year-old glued-laminated bamboo strips.

Material	No. of samples	Bending strength[2] (*MPa*)	Compression strength // to the grain[2] (*Mpa)*
2-years old glued-laminated bamboo strips	20	78.52 [a]	212.9 [a]
4-years old glued-laminated bamboo strips	20	78.56 [a]	184.1 [b]
Solid Malaysian Oak[1]	na	66.0	32.3

Note: [1]Source: Lee *et al.* (1979)
[2]Means followed by the same letter vertically are not significantly different
na - not applicable

Table 2: Mean maximum failing load and glue bond shear strength of 2- and 4-year-old glued-laminated bamboo strips.

Material	No. of samples	Maximum failing load [2] (*kgf*)	Glue bond shear strength [2] (*MPa*)
2-years old glued-laminated bamboo strips	20	225.14 [a]	0.839 [a]
4-years old glued-laminated bamboo strips	20	208.84 [b]	0.687 [b]
Malaysian Oak laminates [1] (24 years old)	na	na	10.98

Note: [1]Source: Kamarulzaman & Tan (1994)
[2]Means followed by the same letter vertically are not significantly different
na - not applicable

Fundamental Properties of Com-Ply Made of Small Diameter Fast Growing Species and Mersawa Veneer

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Abstract

Wood utilization efficiency is very low in Indonesia, and it is predictable that in the future, the wood industry cannot rely on high quality and large diameter wood. As consequence, increasing wood utilization efficiency and development of new products like com-ply is not a choice but a necessity.

This research was conducted as a response for the above condition. In the first step, we investigated the effect of veneer thickness on the quality of com-ply. The small diameter (less than 15 cm) fast growing species (sengon, acacia, eucalyptus) was used as core and mersawa veneer was used as face/back layers and bonded by phenol formaldehyde (PF) resin at 10% based on the particle and veneer oven dry weight.

The results obtained are as follows: (1) Dimensional stability of comply made of acacia is better compared with the others. (2) Increasing veneer thickness improved internal bond (IB) significantly of the produced com-ply. All the samples meet the minimum requirement for JIS A 5908. (3) Utilization of thicker veneer significantly improved MOR in length direction but significantly decreased MOR in widthness direction. (4) MOR strength retention in length direction was higher compared to those of width direction.

Keywords: com-ply, fast growing species, Modulus of rupture, Modulus of elasticity.

Introduction

Wood utilization efficiency is very low in Indonesia. Small diameter fast growing species are usually used as a fuel or chips for pulp and paper raw material because they can not be used as joint lumber raw material or converted to lumber due to the limitation of their diameter and fundamental properties (high portion of juvenile wood).

In the future sawn timber and plywood producers can no longer rely on the high quality and large diameter wood for their raw material. They have to apply new innovation technology and more diversification in their products, using low quality and small diameter wood from plantation forests to minimize raw material shortage. So, wood demand can be fulfilled without destroying the natural forest. Based on the above conditions, one well-known alternative is production of com-ply. Com-ply is a very good alternative because it can use low quality of wood, small diameter logs, and even wood waste in the core layer and thin veneer in the face and back layers. In this case, the utilization of high quality wood will be minimized, while the appearance of the com-ply is the same as plywood.

The main purpose of this research is to determine the effect of veneer thickness to the quality of com-ply. We hope that this research will contribute to the knowledge of production of com-ply made of fast growing species.

Materials and Method

In this research, the com-ply boards are determined as board made of veneer on face and back layers and particle on core layer. The target of the board thickness was 1.0 cm and the density was 0.75 g/cm^3. Totally, there were 90 board samples.

Rotary/lathe was used to peel mersawa logs for veneer production. The veneer thicknesses were set up to 0.5 mm, 1.0 mm, and 1.5 mm. The core layer was made of sengon (*Paraserianthes falcataria* L. Nielsen), acacia (*Acacia mangium* Willd), and eucalyptus (*Eucalyptus* sp.). The particle type was wafer. The adhesive resin used was phenol formaldehyde (PF) formulated by PT. Pamolite Adhesive Industry.

The board production procedure is described below:

a. Face and back layers preparation: the produced veneer was classified based on the veneer thickness (0.5 mm, 1.0 mm, and 1.5 mm). After the classification process, the veneer was dried in an electric oven to about 5% of moisture content.

b. Core layer preparation: the small diameter fast growing species was debarked before being converted to wafer particles. The obtained particle was dried in an electric oven to about 5% of moisture content. After drying the process, the particle was separated from the dust and other contaminant by a particle screener.

c. Blending process: the amount of particle needed for one board was weighed after drying and screening. The particle was put into a rotary blender and mixed with PF resin by means of a spray gun. The resin solid level of PF resin was 10% based on the particle and veneer oven dry weight.

d. Mat forming and hot pressing: after the blending process, the particle was hand-formed into a mat. Veneer sheets were used to cover the top and bottom surfaces of the particle mat. The hand-formed mats were hot-pressed at 170ºC. The pressure was 60 kgf/cm^2. During board pressing, steel bar stops were used to control the board thickness. Total pressing time was 10 minutes.

e. Conditioning; after hot pressing, the board samples were conditioned for 3 weeks in an ordinary room, so the temperature and the relative humidity were the same as the actual environmental condition.

After the conditioning process, the boards were cut into specimens and tested for mechanical strength and dimensional properties according to JIS A 5908 for particleboard with ten replications for each condition. The strength testing includes dry internal bond (IB) and static bending test (dry and accelerated-aging modulus of rupture and modulus of elasticity). The accelerated aging MOR and MOE are expressed in percent strength retention after single retention (2 hours of boiling and 1 hour of water immersion at room temperature). Percent of strength retention was determined by comparing wet MOR of one sample to dry MOR of other sample. The calculation of % MOR strength retention using the following formula:

% MOR strength retention: $\dfrac{WetMOR}{DryMOR} x100\%$

% MOE strength retention calculation is the same as the % MOR strength retention calculation. The size of the samples for the bending test (MOR and MOE) was 25 cm x 5 cm with a span length of 15 cm. The bending test used centre loading by Baldwin Universal Testing Machine. Water absorption and thickness swelling were 15 cm x 15 cm and the internal bond strength sample size was 5 cm x 5 cm (JIS, 1994).

Results and Discussion

Dimensional Stability

Figs. 1 and 2 show the relationships between veneer thickness and water absorption and thickness swelling after 24 hour water immersions at room temperature, respectively. These figures show that increasing veneer thickness did not influence remarkably dimensional stability of com-ply made of acacia. However, veneer thickness did influence dimensional stability of com-ply made of eucalyptus and sengon. Com-ply made of acacia performed better dimensional stability compared to those of eucalyptus and sengon.

This phenomenon may be related to the combination effect of wood density and the board production process.

Previous researches showed the same tendency where composite boards made from lower density (sengon) displayed poor dimensional stability compared with the higher density. Medium density fiberboard made from acacia displayed better dimensional stability compared to the MDF made of sengon, which has density lower compared with the acacia (Massijaya, 1992).

There is no prerequisite for water absorption, according to JIS A 5908. This was done as additional information. According to JIS A 5908, the thickness swelling of com-ply made of acacia fulfils the standard. However com-ply made of acacia and eucalyptus failed to fulfil the standard.

Mechanical Properties

Figure 3 show the relationship between veneer thickness and internal bond. The internal bond properties remarkably improved with the increasing of veneer thickness for com-ply made of eucalyptus. However, for com-ply made of acacia and sengon improvement was relatively low. The relationships between these parameters were linear. Comply made of eucalyptus performed better internal bond compared with those of sengon and acacia. Compared to the JIS A 5908 Standard, all of the com-ply fulfilled the minimum requirement for 18 type.

According to the observation to the internal bond broken samples, it was found that all of the broken area was in the particle (core) area. It means that the weakest part in the board was in the particle (core) area (Massijaya, 1997; Massijaya and Okuma, 1997, 1998). In the hot pressing process, the conventional hot pressed was used. The adhesive was curing from the surfaces (top and bottom) to the centre of the boards; in this case, there is a possibility that the adhesive curing is not perfect in the centre of the board area compared with the both surfaces area. If the adhesive in the centre area was perfectly cured, there is a possibility the resin in the both surfaces may over cure, which will lead to low quality board properties.

Figs. 4 and 5 show the relationships between veneer thickness and dry Modulus of Rupture (MOR) in length and width. These figures show that increasing veneer thickness tends to improve dry MOR in length direction. However, it decreases the dry MOR in width. This is because the increasing veneer thickness increasing the portion of the stronger portion (longitudinal direction) of the com-ply element, while on the contrary happens in widthness direction as a consequences of fiber direction in the face and back layers.

Figs 6 and 7 show the relationships between veneer thickness and MOR strength retention in length and width. MOR strength retention is an indicator to show the effect of boil treatment to the MOR of the boards. MOR strength

retention in length direction was higher compared with the MOR strength retention in widthness direction. In general, the results of MOR strength retention in length and widthness directions were relatively high.

Conclusions

1. Dimensional stability of com-ply made of acacia is better compared with the others.
2. Increasing veneer thickness improved internal bond (IB) significantly of the produced com-ply. All of the samples meet the minimum requirement for JIS A 5908. The highest IB resulted from eucalyptus and the weakest resulted from sengon.
3. Utilization of thicker veneer improved significantly MOR in length direction. However, MOR decreased significantly in width.
4. The range of MOR strength retention in length direction for eucalyptus, acacia, sengon were 57 – 89%, 74 – 81% and 67 – 77%, respectively.
5. The range of MOR strength retention in widthness direction for eucalyptus, acacia, and sengon were 50 – 58%, 55 – 67% and 44 – 62, respectively.

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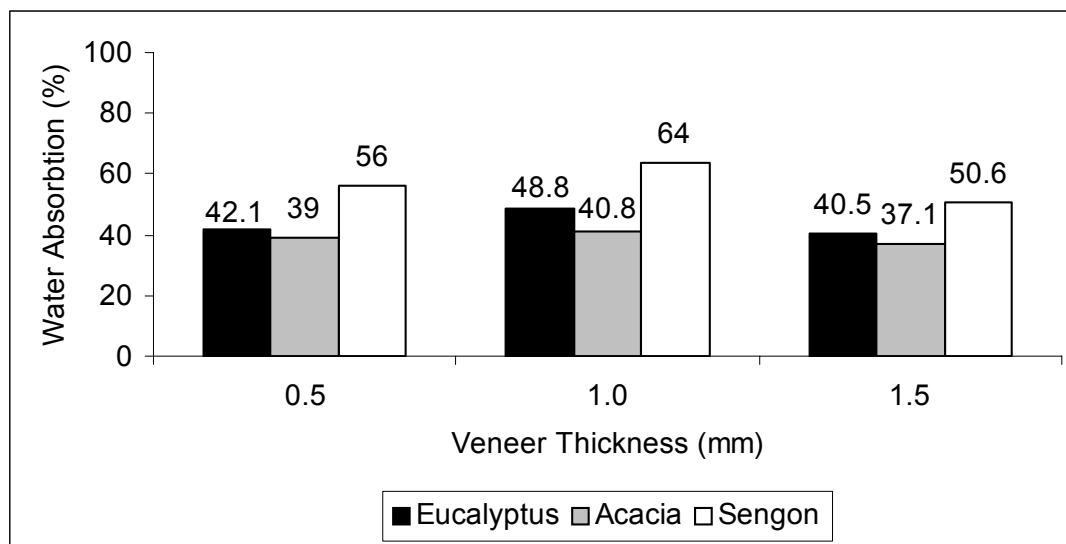

Figure 1. Water absorption of com-ply made of small diameter fast growing species
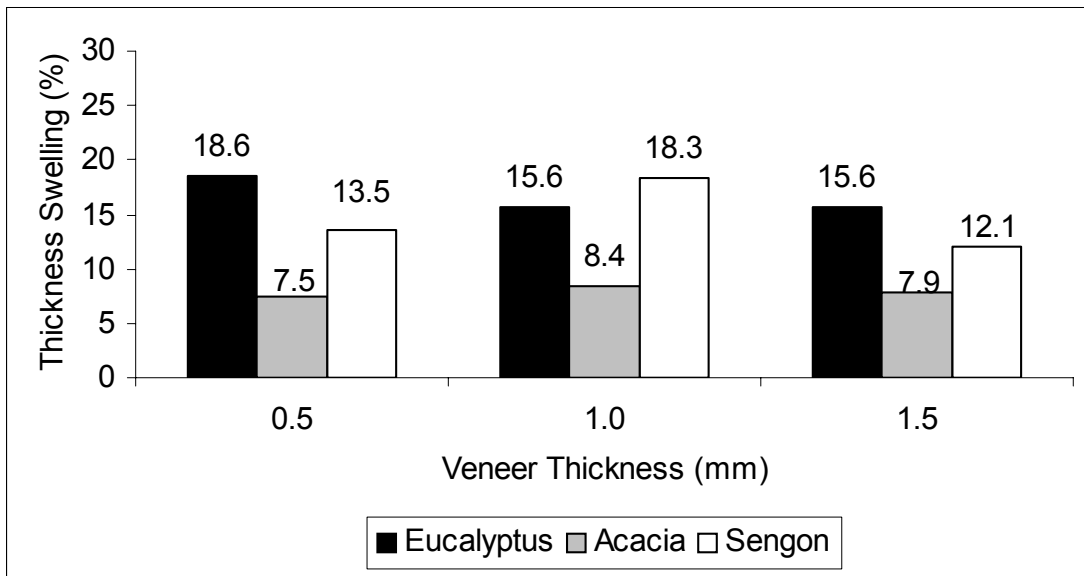
Figure 2. Thickness swelling of com-ply made of small diameter fast growing species
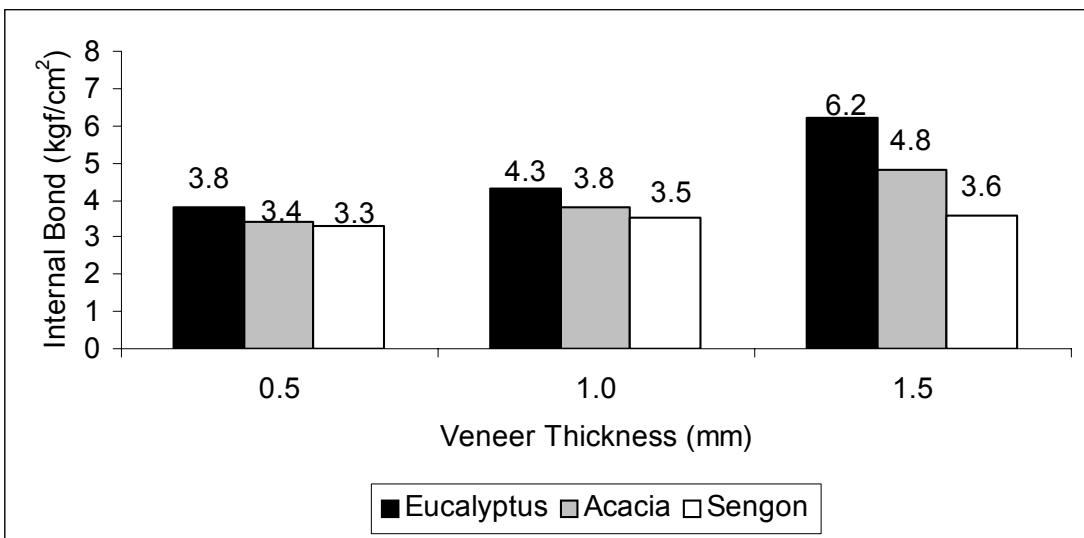

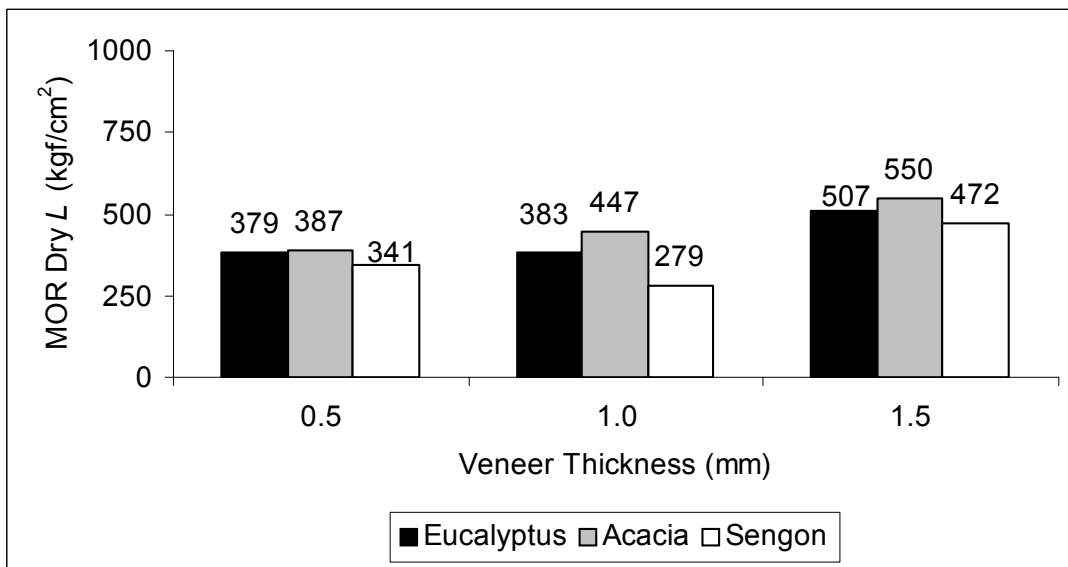Figure 3. Internal bond of com-ply made of small diameter fast growing species

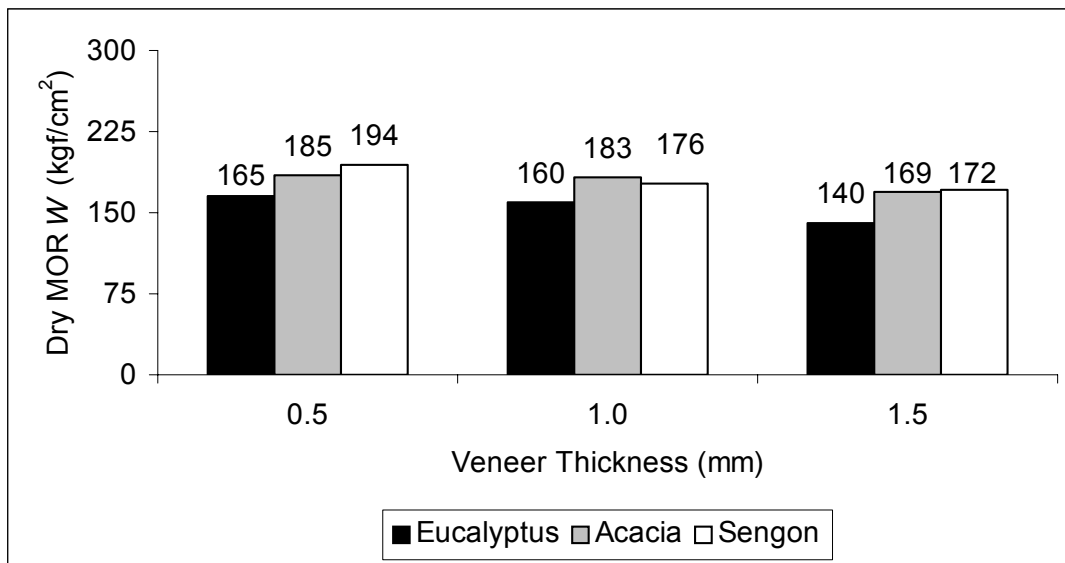Figure 4. Dry MOR in length direction of com-ply made of small diameter fast growing species

Figure 5. Dry MOR in widthness direction of com-ply made of small diameter fast growing species
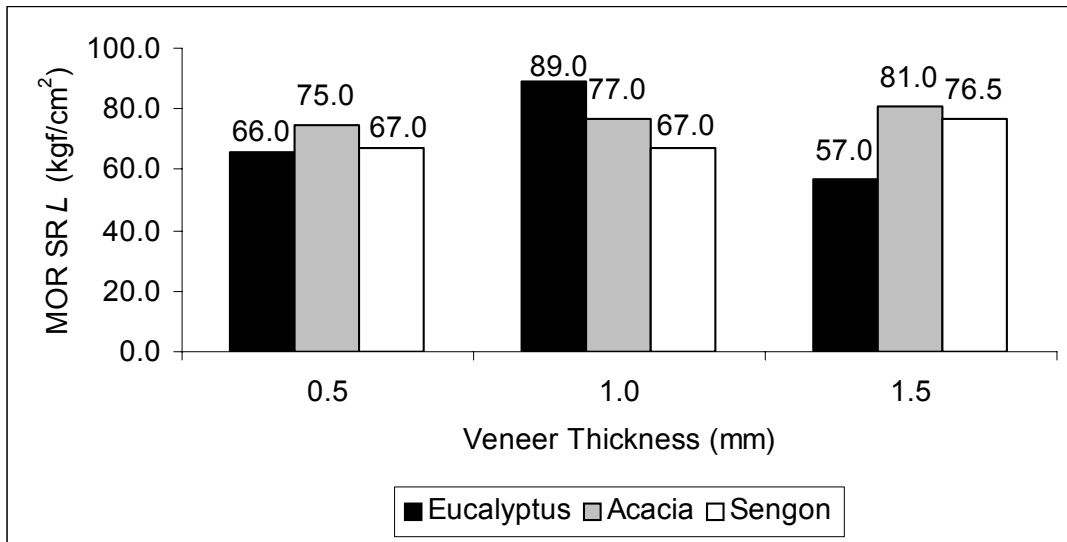
Figure 6. MOR strength retention in length direction of com-ply made of small diameter fast growing species
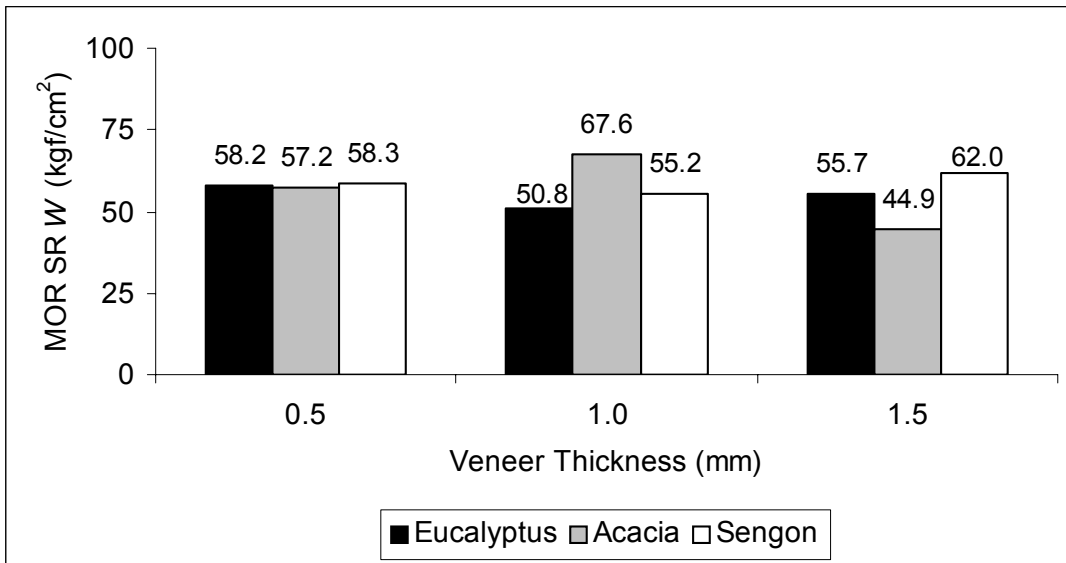

Figure 7. MOR strength retention in widthness direction of com-ply made of small diameter fast growing species