WOOD-BASED PANEL PRODUCTS

REPORT ON 1994 STUDY TOUR TO NORTH AMERICA

SIEW K. HO

1995 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

1. Fellowships - each year applications are invited from eligible candidates to submit a study programme in an area considered to be of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

4. Study Tours - industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

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REPORT ON STUDY TOUR TO NORTH AMERICA NOVEMBER, 1994

by

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Siew Ho gained her Masters degree in Engineering at the University of Canterbury in 1989. She was a Chemical Engineer for the Sherwin Williams International-Titanium Dioxide Plant for a year prior to joining the New Zealand Forest Research Institute in 1991. She was a Wood Scientist at the Institute's Wood-Based Composite Panel Group for two years before embarking on a Doctorate degree at the School of Forestry, University of Melbourne. The topic of her research thesis is "Chemical Modification of Wood Panels" where dimensional stabilisation of wood panels is the key area of study.

Siew Ho has currently been awarded a 1995 Gottstein Fellowship from the Joseph Gottstein Memorial Trust Fund. This has enabled her to conduct a study tour to forest product laboratories in various universities, research organisations and also wood panel production plants in both Vancouver and the north-west part of America.

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Acknowledgments

I wish to offer my sincere thank to the ***trustees*** *of* ***Joseph William Gottstein Memorial Trust Fund*** *for providing a fellowship to study research and trends in wood-based composite manufacture in North America. The main aim was to attend the Pacific Rim Bio-Based Composites Symposium. This was followed by a study tour to various composite panels production sites, universities and other research organisations in both the British Columbia and the North West regions of USA.*

I would also like to express my gratitude to Mr Alberto Cimmino, Professor Peter Vinden and Dr Peter Kho for their valuable advice in undertaking my research work. This research was presented as a Poster at the Pacific Rim Bio-Based Composites Symposium.

Synopsis

The visit to North America consisted of four days participation at the Pacific Rim Bio-Based Composites Symposium, Vancouver, British Columbia, followed by five days study tour to various wood-based panel production sites, research organisations as well as universities.

This report highlights the latest developments in wood-based/lignocellulosic reconstituted panel products. Issues discussed include the growing global interest in structural wood-based products, specialty products, market niches, current research in manufacturing technologies, the performance of wood adhesives, and the utilisation of wood/agriculture residues. Recent projects undertaken by various research organisations and universities are also discussed.

<u>Key points raised in the Pacific Rim Bio-Based Composites Symposium</u>

* **Changes in global timber supply**

Decreasing availability of old growth forest has resulted in a greater proportion of lower quality juvenile wood and, an increasing number of species to be utilised. This has created an impetus for developing:

i) new products based on the physical and chemical modification of wood fibres.
ii) high performance engineered wood-based composite products.

* **Market expansion of structural wood-based composite products**

Structural wood-based composite panels are gaining popularity for substituting steel in buildings in North America.

* **Recycling of wood waste**

Stringent legislation from the Environment Protection Agency (EPA) in North America has resulted in the promotion of wood waste recycling. New industries have been built on the utilisation of these secondary raw materials. Currently, most of these waste products are used for fibreboard manufacture.

* **Chemical modification**

- Panel product characteristics such as strength, durability, dimensional and colour stability can be achieved by chemical modification of the wood fibre cell-wall by either using a bulking, or a cross-linking agent. Cross-linking is currently the preferred process due to the high board anti-swelling efficiency achieved with low chemical uptake.

- Acetylation of wood, a cell-wall bulking process has shown to improve the wood weatherability. However, it is not immune to photoreactions. These reactions cause the deacetylation and cleavage of β-0-4 linkage in lignin and result in the re-generation of phenoxy radicals, which are the major culprit of discolouration.

- Strong emphasis was placed on:
  i) the incorporation of chemical modifying agents during panel manufacture.
  ii) selective modification of wood fibre cell-wall structure followed by binderless thermoplasticisation during panel consolidation.

- Surface chemical modification of wood fibres was reported to improve the compatibility of fibres and thermoplastic resins.

* **The use of preservative chemicals/fire retardants**

Zinc borate powder has been incorporated as a biocide into an aspen flake board during board making. The board is resistance to termite (Coptotermes formosanus). The low solubility of zinc borate in water makes it leach resistant. It is also an effective fire retardant.

* **Wood panel manufacturing**

- Non-conventional technique like steam-injection pressing offers new opportunities for innovative manufacturing of specialty products. For example, vapour phase chemical injection of the preformed wood fibre mat provides a system for rapidly modifying the fibre component during the pressing operation.

- Microwave and radio frequency pressing provide alternative technologies for producing thick and high density panels where heat transfer poses a problem with conventional pressing.

* **Future directions in wood panel research**

- Fundamental studies of the interaction of physical phenomena (unsteady-state heat and moisture transfer) with rheological changes (densification and stress relaxation) and also the adhesion of chemicals during wood panel consolidation.

- Wood fibre orientation in two or three dimensions within simple or complex shapes. Preliminary experimentation suggests that fibres may be aligned using a magnetic field.

- The adoption of computer models (based on simulations of conventional pressing operation) into non-conventional pressing technologies.

Recommendations

a) In Australia, the adoption of new high performance panel products and innovative panel manufacturing technologies by forest industries is beginning to take place. The slow start arises from:

i) a lack of communication between universities, research organisations and the wood-product industries.
ii) a shortage of niche markets within Australia.

Communication between universities, various research parties and the wood product industries can be achieved through the establishment of firm linkages. This requires universites and research organisations to interact with industry and determine industry requirements. It also requires the participation of industry and further investment in research and development by both industry and government.

b) The Hardwood Fibre and Paper Science Program, funded by the Australian Government's Cooperative Research Centre (CRC) provides full support to the pulp and paper industries. Fundamental understanding of fibre properties gained from this program offers unlimited benefits to the relevant industries. However, there is still no involvement of wood-based composite panel industries in the similar programs.

In view of the fact that government departments are responsible for promoting Science and Technology in Australia, future involvement of wood product industries in programs funded by various government organisations such as the Australian Government's Cooperative Research Centre and the Australian Research Council is to be encouraged. Likewise, the industry/government initiative in establishing the Forest and Wood Products Research and Development Corporation must continue to be nurtured.

c) The main trust in wood composite research in overseas involves chemical modification of wood and other lignocellulosic fibres to enhance product properties and performance. Such activity is at a relatively low level in Australia.

There needs to be greater focus on research into the chemical modification of wood and wood fibres to maintain Australian independence and leadership in composite products manufacture.

d) In North America, wood-based structural products are seen to replace the conventional construction materials such as steel and concrete. These products have not yet gained a foot-hold in the Australian markets. Multi-storey timber frame buildings are common in Canada and USA, but in Australia, these buildings have yet to be accepted.

The lack of wood-based engineered products in Australia evolves around the following issues:

i) The culture in Australia is centred on steel structural components. This arises from too few engineers with adequate background in timber engineering. In particular, there is a lack of training of timber engineering in civil engineering and architectural courses.

ii) There is also a lack of qualitative and quantitative market information in identifying market opportunities for new products.

The Australian culture toward steel and concrete can only be changed through public awareness of the high performance attribute of wood-based structural products. To accomplish this, a stronger emphasis on timber engineering training need to be placed in both the civil engineering and the architectural courses.

The acceptance of new products in the Australian market requires analysis of the consumer needs (market pull), coupled with the identification of new technologies -production push.

e) Increases in wood production will lead to a greater volume of wood residues-bark, sawdust, chips and shavings. Further research is needed to maximise potential returns from these residues.

To maximise potential returns from the forest residues, recognition of their potential usage is essential. In addition, the short rotation hardwood species in Australia may provide a new source of raw materials for composite panels manufacture.

f) Panel product quality can be assured and standardised by having accurate statistical quality control (SQC) of board properties (internal-bond, board thickness and density) along the production line. Although there is an awareness and trend towards automated SQC, very few of the panel production plants in North America are ISO 9000 registered. Similarly, in Australia, movement of panel industries in this direction is still slow.

The implementation of automated statistical quality control (SQC) systems along the production line should be encouraged.

g) The combination of wood fibers with agro- and other recycled- fibres to form reconstituted products is still new to the wood composites sector in Australia.

Agriculture residues (barley stalks, sugar cane waste, rice husks and bamboo) and recycled cotton fibres from the garment industry could be combined with wood fibres for low cost panels production.

h) The long fibre strands that are used as raw materials for scrimber and parallam manufacture appear to provide composite products of superior mechanical properties not matched by other wood-based particle and fibre products.

The use of long fibre strands in a network combination with other fibres matrix both synthetic- and agro-fibres has potential for research in the manufacture of new structural wood-based composite products.

1. PACIFIC RIM BIO-BASED COMPOSITES SYMPOSIUM

Introduction

According to Suezone Chow, chairman of British Columbia Science Council, the forest industries in Canada are going through a transition period. Transition means "opportunity". Decreasing availability of old growth forest has resulted a greater proportion of lower quality juvenile wood. This coupled with an increasing number of tree species to be utilised have contributed to the changes in global timber supply. The variability in timber supply is occurring at a time when codes and standards are becoming more international as well as more rigorous, and are based on design and performance criteria. Thus, the predictability and uniformity of materials is becoming more important in the development, design and marketing of new products.

The changing global timber supply creates an impetus for two distinct avenues of growth for wood-based product development. These include the development of:

i) new products based on technologies, such as physical and chemical modification of wood fibres, to impact a variety of very specific product attributes for particular end uses.

ii) high performance engineered wood based composite products.

The need to identify opportunities for new markets governs the performance driven process. Performance-based products must be developed to meet their application.

The ability to produce uniform, and continuous properties from low quality pulp logs coupled with maximisation of wood residue to minimise disposal problems have added to the demand for engineered wood-based reconstituted panel products. These products include Parallel Strand Lumber (PSL), Laminated Veneer Lumber (LVL), Glulam, Timberstrand (LSL), Oriented Strandboard (OSB) and plywood. Other wood-based composite panels such as particleboards, and in particular, medium-density fibreboards (MDF), have also gained an increasing interest in Europe and the Asia/Oceania region. North America is expected to increase its output capacity in these products in the near future. As existing products are adopted rapidly throughout the world, it becomes imperative to constantly innovate and adopt new technologies to further enhance product attributes.

A broad spectrum of topics was covered in the meeting. These were as follows:

i) Processing strategies and product characterisation.
ii) Property enhancement through wood modification.
iii) Hybrid composites : Inorganic-wood combinations.
iv) Adhesives for wood composites.
v) Utilisation of recycled fibre in composite products.

Symposium Highlights

1.1 Processing strategies and product characterisation

1.1.1 Engineering composites from oriented natural fibres: A strategy

New types of moulded engineering components incorporating spatially oriented and modified lignocellulosic fibres were proposed by Humphrey, (Oregon State University, 1994). The outcome envisaged includes an array of products which may partially replace pressed steel, aluminium alloys and some polymers in a diverse range of engineering applications. To achieve property control within the products, Humphrey (1994) proposed the manipulation of a combination of spatial distribution of fibre type, fibre orientation and also of the localised conditions to which pre-formed fibre networks are exposed during the consolidation process. It is well known that the structures of conventional wood-based composites (mainly panel products) are highly influenced by mechanisms that occur within them during the hot pressing operation. These mechanisms include:

i) unsteady-state heat and moisture transfer.
ii) rheology (densification and stress relaxation).
iii) adhesion.

Models which simulate material behaviour during the hot-pressing processing of wood panels were summarised by Humphrey (1994), and their possible adaptation to aid in the development of new composites was considered. During hot-pressing, the rheological changes affect the changes in board density profile. This directly influences properties of the furnish material such as permeability to water vapour and thermal conductivity. For this reason, numerical methods of simulation had been used to account for these interactions. The resultant algorithms are now being used as tools to aid in optimising the production of conventional composites, and also for the development of new machines/pressing technologies for panel production.

Strategies now under detailed development include the stages listed below:

i) **Wood fibre separation and selection**
This could be from naturally occurring populations (for instance, from the whole tree), or by species-dependent ranges in properties. Natural and man-made fibre may ultimately be combined. Very rapid and accurate fibre sorting techniques would be required.

ii) **Fibre modification prior to re-constitution**
This encompasses a diversity of chemical and mechanical treatments which could impart desirable properties to the fibres prior to further modification during the re-constituted phase to follow.

iii) **Fibre orientation**
Creation of some type of preform which consists of fibres spatially oriented in two or three dimensions within simple or complex shapes.

For example, the application of very small quantities of a ferromagnetic element renders the fibres amendable to subsequent orientation in a magnetic field.

iv) **Fibre consolidation**
Consolidation of the preform to create a component with controlled shape and internal structure. This includes consolidation of preform in a sealed pressing system to affect the thermodynamic and chemical environment in such a way as to trigger a desirable range of reactions. In other words, concentrations of reactive vapours could be transfluxed through the porous matrix of fibres. This could stimulate reactions which affect localised densification, adhesion, dimensional stabilisation and the like. Zoned injection and removal offers the potential for spatially controlled reactions and thence final structure.

1.1.2 Wood panel density profile measurements during the pressing operation

Vertical density profile of pressed wood panels is commonly determined by a densitometer. The typical analysis approach has been to manufacture panels under different conditions and then evaluate the density profile after manufacture, relating conditions of manufacture to development of the vertical density profile. In a recent attempt by Winistorfer and Moschler (The University of Tennessee, 1994), instrumentation to measure the density profile development through horizontal plane during the pressing operation has been developed. This device translates three radioactive sources and detection elements in concert with the closing press, at constant proportional positions of 25, 50 and 75% of the mat thickness.

1.1.3 Radio frequency pressing

Various presses manufactured to accommodate the latest pressing techniques were reported. For instance, conventional hot presses have been converted into radio-frequency (RF) presses for commercial production of LVL. The pressing operation using RF as the main heating source was found to reduce the pressing time of LVL manufacture by a factor of 2.5 compared to the conventional hot-pressing operation (Klemarewski, Durand-Raute Industries, 1994). In other words, the RF heating system increases panel production substantially without the addition of press openings. In addition, the RF pressing system eliminates the cold pre-pressing stage which is required for conventional pressing.

1.1.4 Steam-injection pressing: LVL manufacture

A great advancement has been achieved by the Wood Research Institute, Kyoto University in steam-injection pressing technology for the manufacturing of wood-based composite panels. Recent attempts featuring LVL manufacture using a pilot continuous steam-injection press were conducted. The steam was injected from both sides of the horizontal plane. A few considerations were made to enhance the penetration of steam into glue layers. These included the insertion of:

i) rough fibre mesh sheets into glue layers to maintain spaces between veneers.

ii) corrugated veneers for every other layer.

The mesh reinforced the laminates after pressing. Isocyanate and resorcinol resins were used and the injected steam temperature was 160°C (Sasaki, Kawai, Umemura, Eusebio and Kuroki, 1994).

1.1.5 Rapid curing of cement-bonded particleboards

Another recent attempt using steam-injection pressing technology was to speed up cement hardening in the production of cement-bonded particleboards (CBP) (Sasaki, Kyoto University, 1994). The normal pressing cycle for CBP is at least 10 hours due to the slow hardening of cement, whereas with the steam-injection process, the cement hardening time is shorten to three minutes press cycle time. In this process, sodium hydrogen carbonate ($NaHCO_3$) is added to an ordinary portland cement prior to mixing them with wood particles and water. The injection of steam into this mixture results in the emission of carbon dioxide, and thus the formation of calcium carbonate. However, the hydration of cement clinker is to be accelerated to improve board mechanical properties.

1.1.6 The use of preservative chemicals/fire retardants

The composite matrix allows possible incorporation of preservative additives during board manufacture. This eliminates the pre-treatment stage prior to board manufacture and thus decreases total production costs. In addition, a constant loading of preservative throughout the panel thickness can be achieved. The preservative-containing composite can then be machined without loss of biological resistance. It is also possible to manufacture preservative-containing wood composites from wood species that are normally too impermeable to allow effective conventional pressure treatment. Extensive work with zinc borate as a preservative has been carried out in Michigan Technological University (Laks and Manning, 1994). Zinc borate is sparingly soluble in water at room temperature (<0.28%) and could be considered "leach resistant". Because of its low solubility, it is impractical to pressure treat solid wood with an insoluble borate salt such as this. However, it is relatively simple to incorporate powdered chemical into the wood composite during blending process. The aspen-based waferboard incorporated with zinc borate was found to have a superior termite resistance compared to the board consists of disodium octaborate tetrahydride. The reason for this is zinc borate has higher intrinsic activity and leach resistance. Work is on the way to evaluate this compound as a preservative for composites to be used in ground-contact applications. Zinc borate is also widely used as a fire retardant for plastics.

1.2 Property enhancement through wood modification

1.2.1 Technical issues and market prospects

The technical issues and market prospects for chemically modified wood composites were reviewed. Chemical modification of wood has been widely studied, and in parallel with the long term research in this area at a number of universities and research laboratories, there has been considerable commercial interest; however, adoption of the technology especially the acetylation process for high-value niche wood products has so far been slow to take place. From both scientific research and industry perspectives, chemically modified wood products represent a unique, distinct field of study and development whereas, from a customer or market perspective, they are but another competing means of achieving an end user's product performance objectives. The degree of modification, the preferred species of wood, the type of backing for rigidity, and the plant size amongst other factors would all be designed based on two market concepts:

i) adding value to the customer, that is improving the product performance/price ratio.
ii) incorporating target group/end users' considerations into research and development for both the process and product.

Examples of markets for chemically modified wood composites could include water-resistant MDF for exterior siding in residential construction, fire resistant panelling for interior wall panels, enhanced wood/polymer composites for light weight automobile panels, and surface modified wood flooring with improved water resistance and dimensional stability.

1.2.2 Acetylation

Some of the recent research in the field of chemical modification applied to wood composites were acetylation of particleboard, flakeboard, and MDF. These boards are bonded with various adhesives such as melamine-urea-formaldehyde, phenolic and isocyanate adhesives. Acetylated composite product such as flakeboard has been reported to have better resistance to dry wood and subterranean termites, and fungal attack (Hadi, Darma, Febrianto and Herliyana, 1994). However, the acetylated wood was found reactive towards light (Hon, Clemson University, 1994). The wood changed its colour and lost surface reflectance when irradiated with the ultraviolet light. This was explained to be attributed to the progression of photo induced reactions. These reactions caused the deacetylation and cleavage of β-o-4 linkage in lignin. The result is the re-generation of phenoxy radicals, which are the major culprit of discolouration.

1.2.3 Cross-linking with formaldehyde

The vapour formaldehyde (formalisation) process, based on wood cell wall cross-linking, is another common form of chemical modification. Formalisation of MDF made from hardwood and softwood was claimed to have increased the specific Young's modulus. The attack by a white rot fungus was also reduced. However, vapour formaldehyde is toxic to human beings, therefore other non-formaldehyde cross-linking agents such as glyoxal, glutaraldehyde and dimethylol dihydroxy ethylenurea (DMDHEU) were investigated (Yusuf, Imamura, Takahashi and Minato, 1994). These dialdehydes and ethylene urea are known to cross-link with cellulosic materials. The order of effectiveness exhibited by these reagents in suppressing the attack by decay fungi and termites ranked from glutaraldehyde, DMDHEU followed by glyoxal. Glutaraldehyde and DMDHEU modifications gave 40-50% ASE (antiswelling efficiency) at 5-10% weight gain, but could not yield 70% ASE at 25% weight gain. Glyoxal treatment gave the lowest ASE among all the treatments. The conclusion drawn from this is that these non-formaldehyde cross-linking reagents cannot yield high ASE with low weight gain as recognised in formalisation. To achieve high ASE, bulking process may be required instead of cross-linking.

1.2.4 Chemical modification of non-wood fibres

The possibility of MDF manufactured from chemically modified non-wood fibres has also been investigated. For instance, the use of acetylated bagasse fibre was investigated by Rowell and Keany (1991, cited in Plackett, 1994). The latest feature of chemical modification involves the modification of cellulose, lignin, and the hemicellulose. This is to recrystallise the cellulose, and also to thermoplasticise the lignin and hemicellulose matrix in order to mould the entire lignocellulosic resource into films or thermoplastic composites. According to Rowell, O'dell and Rials (1994), past research has shown that the glass transition temperature of agro-based fibre composites (made up of rigid cellulose polymer in a thermoplastic matrix of lignin and hemicellulose) can be lowered from 170°C to 135°C by reacting fibres with succinic anhydride in refluxing xylene. Rowell et al (1994) stated that, if non-recrystallising reaction conditions are used, it is possible to chemical modify the lignin and hemicellulose but not the cellulose. This selective reactivity has been shown to occur if uncatalysed anhydrides are reacted with wood fibres. The reaction of succinic anhydride with kenaf fibre to give high weight gains by esterification of cell-wall polymers (either by solution or solid state chemistry) is currently being studied at the Forest Products Laboratory, Madison. Initial results indicated that it is possible to thermoplasticise the fibre matrix, and forms a composite bonded together by thermoplastic flow. The first glass transition temperature was found to decrease from 170°C to about 130°C.

1.2.5 Surface chemical modification

The consolidation of wood fibre/thermoplastic composites presents a number of problems. The most notable shortcoming is the lack of adhesion between the two components. The mechanical performance in current recycled wood fibre/thermoplastic composites is far from satisfactory because of the low interfacial shear strength between wood fibres and thermoplastic matrices. Chemical modification of wood fibres, however, can improve the incompatibility between wood fibres and thermoplastic matrices. In the study conducted by Gardner, Liu, Wolcott and Rials (1994), the mechanism of adhesion between the chemically modified wood fibres with styrene-maleic anhydride and polystyrene matrix composites was determined using the dynamic contact angle (DCA) measurements and the microbond tests. Both of the test results showed that chemical treatment of wood fibres with styrene-maleic anhydride copolymers improved the interfacial adhesion between the wood fibre and polystyrene matrix system. This improvement in interfacial shear strength was believed to be attributed to the reduced acid/base interaction between modified fibres and the polystyrene matrix, to the better wetting and spreading of the polystyrene matrix on the chemically modified wood fibre surface, and to the formation of the interdiffusion and entanglement between the fibre/matrix interface (Gardner et al, 1994).

1.3 Hybrid composites : Inorganic-wood combinations

The hybridisation of wood and inorganic fibres offers opportunities for the expansion of composite products and properties. This approach requires flexible bonding systems capable of strongly adhering wood substrates and various nonwood materials into coherent composites. It has been recognised that there are benefits from combining natural fibres such as wood with synthetic polymers to produce hybrid composites. For example, wood fibres can provide a light weight, damage-tolerant, inexpensive, and widely available reinforcing element for polyolefins. Similarly, small amounts of thermoplastic can be added to traditional wood fibre composites to aid in moulding and pressing. This type of product can not only potentially enhance the use of wood in traditional markets, but also allow wood to compete directly with synthetic plastics.

Some inorganic construction products of which combining wood particles or fibres with portland cement or gypsum are emerging in North America. These include siding, shakes, shingles and tiles, fencing, cladding, tile backer boards, sub flooring, building blocks and others. These composites use not only wood fibres and particles, they can also utilise such waste by-products as pulp mill sludge, newspapers, magazines and other solid wastes. Inorganic-bonded composites offer unique advantages over conventional building materials. This is mainly due to the fact that these materials are water resistant and very durable in the rigours of the outdoor applications. Almost all are either fireproof or highly fire-resistant.

Fibre-cement board has had a strong acceptance in North America for such products as tile backer board and as a masonry exterior substrate. In Australia and Asia, wood-cement particleboards and fibre-cement boards have been very successful as siding and roofing products. In Japan, surface technologies have been developed to produce a deep embossed brick and block finish along with wood grains. The Australian developments have concentrated on Cape Cod shingle finish whereas in the U.S., acceptance of this composite has been slow, primarily due to the domination of the market by wood manufacturers and the high cost of this material compared with resin-bonded wood products (Moslemi, University of Idaho, 1994).

There are a number of technologies either developed or in the process of refining. These include combinations of wood particles or fibres with mineral matrices. The Ecocern process, developed in Finland, is based on the use of alkali-activated, ground granulated blast furnace slag as the binder-matrix. The process, due to its rapid setting characteristics, is capable of utilising any type of wood species. It has been suggested that currently available but unprofitable conventional particleboard plants can be retrofitted to produce this material. The properties of Ecocern boards are similar to that of cement-bonded particleboards. The boards are hot-pressed.

1.4 Adhesive for wood composites: MDI and PF resins consolidated fibre composites

The properties of diphenyl methane diisocyanate (MDI) and phenol formaldehyde (PF) resins consolidated wood fibre composites were examined. These properties were then used to evaluate the competitiveness of the MDI-consolidated wood fibre composites with certain metals, performance thermoplastic and thermosetting resins. The results indicated that the MDI resin consolidated wood fibre composites substantially out-performed the PF resin consolidated wood fibre composites in particular, tensile strength and elasticity, flexural strength, internal bond strength, water resistance, thickness swell, and accelerated aging treatment induced weight retention. The elasticity, specific tensile and flexural strength of MDI-consolidated wood fibre composites were found comparable to (mostly the glass fibre reinforced resin and metals), and better than mostly unfilled or un-reinforced thermoplastic and thermosetting resins (Sun and Hawke, Michigan Technological University, 1994).

Polymeric diphenyl methane diisocyanate (pMDI), another type of isocyanate adhesive is gaining increased popularity in North America especially in the OSB mills. The Rubinate binders, based on pMDI, is developed by ICI Polyurethanes. The chemistry, penetration and morphology of the isocyanate/wood interphase were studied using solid state nuclear magnetic resonance (NMR) data, and also data from thermal analysis as well as the fluorescence microscopy. This study contrasted the Rubinate binder and phenol formaldehyde (PF) binder systems. The results from fluorescence microscopy showed a much deeper penetration of Rubinate; 1-1.5mm compared to 100-300mm as achieved by PF binder. Based on the data, the Rubinate binder appeared to provide a larger interphase region within the wood sample. This large interphase region is believed to have resulted from "apparent plasticisation" of the lignin prior to curing, as indicated by the solid state NMR measurements. This apparent plasticisation can facilitate both the activated and convective diffusion mechanisms of binder penetration into the wood (Marcinko, Newman and Phanopoulos, 1994).

1.5 Utilisation of recycled fibres in composite products

1.5.1 Recycled fibreboard

In North America, several million tons of solid wood waste ends up as landfill annually. The rapid filling of disposal sites near cities and urban areas has resulted in the escalation of dumping fees. For this reason, legislation is being adopted to promote recycling. There are two distinct waste wood streams being collected. These are:

i) industrial, commercial and institutional waste wood.
ii) municipal waste.

Most of these wood wastes (construction waste lumber, wood pallets and crates, demolition wood such as joists, rafters, trusses and wood floor boards) are comminuted for the manufacture of composites, in particular fibreboards.

For fibre preparation, it is essential to remove the contaminants such as metals and preservative chemicals from the wood wastes. This is achievable with screening processes. The fine wood fractions that passed through a screen with 3.175mm openings was found to have the highest heavy metals content (Hsu, 1994). Most of the chemical contaminants stay on wood surfaces and these surfaces can easily be broken down by any milling action. The acceptable fractions of wood materials are those passing through a 19mm screen and retained by a 3.175mm screen. It was also found that washing of wood chips with water did not reduce the heavy metal problem but amplified it.

1.5.2 Biobased, biodegradable geotextiles

Commercially available geotextiles contain a high percentage of biobased materials that are held together by some portion of synthetic materials (polypropylene nets or polyester scrim sheets) which sandwich the biobased component. It is the research goal of USDA Forest Service, Wisconsin to manufacture a 100% biobased, biodegradable geotextiles. According to English (1994), from a worldwide geotextile market of approximately 700×10^6 m^2, a small but growing percentage of 2% is biobased. The fibres used in the biobased geotextiles include coir, jute, kenaf, flax, sisal, hemp, cotton and wood fibres. These geotextiles are any textile-like material, either woven, nonwoven, or extruded. They are mainly used for short-term (6 month to 10 year) applications where biodegradability is a positive attribute. The main applications are:

i) as a mulch to increase plant growth and survival.
ii) as a control for soil erosion.
iii) as an industrial and agricultural filters for oil and an absorbent for chemical spill.

Other recycled materials selected for biobased geotextiles manufacture are:

* Old corrugated containers which are shredded into 0.8cm wide strips and subsequently hammermilled using a 9.5cm screen.
* Construction waste woods from construction sites. These are hammermilled and reduced to fibre bundles by refining.
* Recycled jute fibres obtained from old woven spice bags.
* Recycled cotton fibre from garment industry.
* Automotive carpet trim waste, a blend of polyester and polypropylene.

2. STUDY TOUR

2.1 Forintek Canada Corporation
Vancouver, B.C.

A brief tour to Forintek Canada Corp. was organised by the conference committee. Most of the timber and panel industries in British Columbia are the member of Forintek. Members provide fund in terms of levy to Forintek, in return they are entitled patented technology from Forintek without royalty payment. The industries contribute to 2.8 million out of 15 million budget of Forintek. Major funding to Forintek are from both the federal and the provincial governments. The main areas of research in composite wood products are:

i) preservation and wood protection.
ii) veneer peeling and drying.
iii) finger-jointing of various panel products (OSB, LVL, MDF, plywood and particleboard).

A new patent using a boron compound in liquid phase as a wood preservative has been developed. Wood panels treated with this compound was reported to have protection against attacked by certain termite. At the same time, a new lathe technology for veneer peeling, a new resin spraying technique (electrostatic technique) and a new test method on structural finger-joint are also investigated. Effort is also being channelled into reducing the pressing time of certain panel product manufacture using the steam-injection pressing technology.

2.2 MacMillan Bloedel Limited
MB Research, Burnaby, B.C.

MacMillan Bloedel Limited is the largest integrated forest product company in British Columbia, serves a global market with principal customers located in Europe, North America and Japan. It holds a 50% partnership with Trus-Joist in America to form Trus-Joist MacMillan Limited. The research and development centre of MacMillan Bloedel Limited are divided into several divisions- Wood Harvesting, Building Materials, Pulp and Paper, Engineering, Material and Corrosion, and Packaging. The company manufactures and distributes a multitude of wood based products:

* Lumber: structural and decorative
* Engineered wood: Panel board and parallel strand lumber
* Chemical pulp: bleached and unbleached
* High yield pulp: groundwood and thermomechanical
* Groundwood printing papers: standard newsprint and specialty
* Containerboard: corrugating medium and linerboard
* Packaging: corrugated containers

The main structural engineered panel products marketed by Trus-Joist MacMillan Limited include parallam, PSL, LSL and LVL. The conventional I-Beam, an engineered product manufactured from microllam (glulam) is rapidly replaced by a combination of LVL/PSL/LSL with other panel products such as OSB, MDF and particleboard. Parallam has by far the highest allowable stresses in tension and compression of any engineered timber product in the world. It makes an ideal beam and purlin. The manufacturing process is discussed in section 2.3 (a visit to Trus-Joist MacMillan Limited-Parallam plant). Timberstrand LSL, on the other hand, is a new panel product developed from PSL. It consists of longer strands than that of OSB and the strands are better oriented. It shares the same strand cutting method and pressing technology (steam-injection pressing) as the OSB manufacture process. An isocyanate resin is applied and the pressing temperature is between 120-130^{o}C.

Timberstrand is a cheaper product to be manufactured compared to parallam, but it's stiffness is less than the parallam. However, the company believes that the stiffness can easily be increased to compete with parallam. Current market values for timberstrand and parallam are $10 and $18 per cubic feet respectively. The main applications of timberstrand are window components such as side jambs, mullions and sills. In doors, the material is used as stile cores that typically would be veneered. In ceilings, timberstrand forms the structural component in long length rafters. In floors, it is used as the rim joist in Trus-Joist MacMillan's patented system "Silent Floor". This is important in 3-4 storey construction.

Future directions of MacMillan Bloedel Research involve the investigation of means to improve parallam manufacturing technology. This includes removing knots on veneer strands to increase its strength, and also the design of new veneer strand alignment systems. Good alignment of the strands will provide better strength to the product. The current dipping technique used where the strands are dipped into a phenolic resin bath was found to introduce too much moisture into the product. Improvements to this method are on the way.

2.3 Trus-Joist MacMillan Limited
Annacis Island, B.C.

The Trus-Joist MacMillan Ltd's parallam production plant employs 25 staff members. The Douglas fir veneers used for parallam manufacture are bought from local saw mills. These veneers are dried from 35% moisture content (MC) to approximately 2-4% prior to the cutting operation into long strands. The strands are then dipped into a mixture of phenol formaldehyde and wax emulsion. This dipping method is believed to provide uniform coating to the veneers, and it results in an increase of veneer MC to between 10-11%. The phenolic resin coated strands are aligned and formed into a stack of fix density prior to the pressing operation which, forms the most interesting feature in the whole production line. Non-conventional microwave pressing technology is used. The press is continuous and consists of an enclosed chamber with a length of 10 feet. During the pressing operation, parallam is irradiated with microwave from four magnetrons located on each side of the closed chamber. The speed of this continuous press line is 3 min/feet, the microwave frequency used is 915MHz and, the total energy required to provide heating to the veneer strands is 360Kw. Electrical elements are incorporated into the top and the lower press platens. This is to maintain the platens at a set temperature whereas the microwave provides the essential heating to the strands. In order to ensure maximum microwave heating efficiency, the density of the formed veneer stack requires accurate control. The width of parallam is limited to 20 inches due to the limitation of microwave length. The final product dimensions are 11 inches deep, 20 inches wide and cut off at 66 or 48 feet lengths.

2.4 Canadian Forest Products Ltd. New Westminster, B.C.

Canadian Forest Products Ltd. (Canfor)'s 1993 lumber production totalled 1.49 billion cubic board feet, ranks as one of the largest lumber producers in the world. Canfor operates lumber remanufacturing, finger-joint, edge-gluing and laminating facilities to improve profit margins on lumber that would otherwise yield lower returns. To diversify the range of wood fibre products, the plant in New Westminster produces baled and refined dry fibres from wood residues and chips. These fibres are refined utilising the hardboard mill's refining capacity where the fibres are dried and compressed into highly compacted bales for easy handling and shipping. These fibres are used as raw materials for hardboard production, cement board products and also in the manufacture of moulded products for the automotive industry. The baled wood fibres are sold into Pacific Rim and European markets. The refined dry fibres, on the other hand are used to produce three products for the hydro-seeding business. These products, which are sold under the names of Ecofibre, Ecotac and Ecoblend, when mixed with grass seeds, fertilisers and water, can be sprayed on the ground as a fast and an economical way of returning a disturbed surface area to a natural state. The latest product, "Take Home Turf" is a lightweight carpet which consists of the refined wood fibre and the premium grass seed. It can be installed quickly by virtually anyone, and it grows into lawn in six to eight weeks.

For composite products, the wood-based composite mats are pressed into three dimensional shapes to make a range of products including interior car panels, furniture components and building materials. These pressed wood fibre mats have a hard, smooth finish which can be covered with cloth, paint, veneer or other materials. The mats can also be engineered to meet special performance requirements of different products, such as high strength-to-weight ratio, and fire or water resistance. For example, the Canfor's automotive Woodmat product is pressed into various products such as car interior door panels, package trays and headliners, while its non-automotive Woodmat is sold to an industrial manufacturer for the production of specialty moulded doorskins. The making of Woodmat involves the use of a needle-punch woven technology where the mat is formed from a combination of hemlock and polyester fibres. The addition of an adhesive to bind the fibres together is necessary. This technology has recently been patented. Although the Woodmat technology is successful, but product pick-up has been slow to develope.

2.5 Weyerhaeuser Technology Center
Tacoma, Washington 98477

Current research focus in the areas of wood-based composite materials include the enhancement of :

i) wood panel preservation properties.
ii) dimensional stability insitu with wood panel manufacturing process.

There is a strong move to find an alternative for the replacement of toxic preservatives such as copper-chromium arsenate (CCA) and PCP although these chemicals are permitted for use by the EPA. There is a high hope for boron as an environmental friendly preservative, but leachability of boron is still a problem. Recent work on boron treatment concentrates only on its application as a fire retardant in particleboard.

In the area of chemical modification, an economic analysis on acetylation of wood was conducted and it was found to be uneconomic. The process is envisaged as too expensive for commodity products where a large demand is required. However, acetylation is believed to have a future for specialty (high performance) products.

In adhesive research, isocyanate is gaining interest. The fast curing, low temperature requirement for curing, and also moisture resistant property of isocyanate makes it popular in the OSB production. For example, an OSB sheeting product proprietary to Weyerhaeuser is made by conventional hot-pressing using a combination of adhesives where the surfaces are bonded with PF resin, and the core is isocyanate bonded. The amount of PF resin loading on the surfaces are less than 3.5% and the isocyanate loading at the core is approximate 3%. Other product such as Timberstrand, is another wood-based composite panel using steam-injection pressing technology, and an isocyanate binder.

Another product marketed by Weyerhaeuser using the steam-injection pressing technology is UF-bonded particleboard. It is used as a door core with veneer faces. Since the invention of steam-injection pressing technology by Michael J. Taylor in 1985, no further work has apparently been pursued in this area by the inventor. Attributes that drive the steam-injection pressing technology are the abilities to produce:

i) thick boards (where heat transfer poses a problem with conventional pressing).
ii) wide range of products, and also high density products or products with high density surfaces.

However, the steam-injection pressing technology has a few drawbacks. For example, due to the complication of manufacturing a continuous press line to cater for a continuous process, a batch process is preferred. This limits the plant production capacity. In addition, the press configuration is also restricted to a single-daylight instead of multi-daylight. Therefore, the steam-injection pressing process tends to use a fast curing adhesive to compensate for the limitations on production capacity.

Extensive research on continuous steam-injection pressing technology is being conducted by Kyoto University and also CSR of Australia.

2.6 Washington State University Wood Materials and Engineering Laboratory, Pullman.

The research currently undertaken by the Wood Materials and Engineering Laboratory of Washington State University (WSU) include performance testing of solid wood and wood panels in particular, wood panel physical and mechanical properties. New testing procedures such as non-destructive testing and new methods of building construction are the main focus of research. The latest research breakthrough has been the green finger jointing of solid wood. Commercial scale trials are currently in progress.

The wood composite area on the other hand, is concentrating on developing new structural engineered products as well as investigating the potential utilisation of wheat residue in wood hybrid composite products. In addition, a joint effort with Trus-Joist MacMillan Limited, WSU is looking into the possible combination of structural products (LVL, PSL, LSL and solid wood) and wood-based panels (OSB, MDF and particleboard) to form I-Beams of high performance. The making of LVL from juvenile veneer using 6% of isocyanate adhesive has been attempted and quality LVL was produced. Current work involves the performance improvement of MUF-bonded LVL for wet application. The laboratory has a 4'x4' manual control radio frequency hot press, capable of providing heat up to a temperature of 425^{o}F.

Other areas of interest, involve the use of hemp fibres bonded with isocyanate resin for wood panel manufacture. Research on OSB manufactured from a fast growing 6 year old cotton wood (currently being used for pulp and paper manufacture) is also being undertaken.

2.7 Oregon State University Department of Forest Products, Corvallis.

Key research projects in the wood-based composite area are:

- i) bonding reactivity of adhesives.
- ii) modelling to optimise design and manufacture of wood composites.
- iii) rheological studies of wood composites for process and product property improvement.

Computer models to simulate conventional hot-pressing have been very successful in predicting the interaction of wood moisture (MC) and temperature (T) during panel manufacturing process. These models are extended to simulate vapour phase pressing to further predict interactions between wood materials, modifying chemicals and adhesives. A new method of determining density profiles in the vertical plane of a composite mat (an OSB mat) during pressing has been patented. Other new invention includes the use of an electrostatic method to effectively align small particles (<5mm in length) in one plane. This has resulted in strength improvement of wood panels.

In the field of wood preservation, work has been carried out by John Simonsen to improve the permeability of CCA preservative into Douglas fir species. The method used is sonification. Other treatment method such as vapour copper treatment using a copper alkoxy compound as the wood preservative is also being investigated. The author does not have further details for the above treatments, however, the appropriate contact persons are attached in Appendix A.1.

3. CONCLUSIONS

* Changes in global timber supply has created a big demand for structural wood-based composite products in North America.

* Globally, the adoption of new composite products and the manufacturing technologies by forest industry is still slow to take place.

* In North America, the utilisation of recycled fibres from wood waste products for fibreboard production is gaining popularity.

* Current research directions undertaken in chemical modification of wood, wood fibres and other lignocellulosic fibres include:

  i) selective modification of fibre cell-wall structure followed by binderless thermoplasticisation.
  ii) the incorporation of modifying agents insitu with panel manufacturing.

* Future directions in wood panel research:

  i) Fundamental studies on the interaction of physical phenomena with rheological changes and the adhesion of chemicals during panel manufacturing. This provides the background for the innovation of non-conventional pressing technologies.

  ii) Manipulation of the wood fibre orientation in two or three dimensions within a simple or a complex shape. This will lead to new products as well as enhancing attributes of the existing products.

  iii) Adoption of computer models into non-conventional pressing technology to assist the understanding of interactions between process variables.

4. REFERENCE

All the references are cited from: Proceedings of SECOND Pacific Rim Bio-based Composites Symposium. November 6-9th, 1994.

APPENDIX

A.1 Contacts

Forintek Canada Corporation, Vancouver.
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A.2 Travel Itinerary

Week 1

November 6-9
Pacific Rim Bio-Based Composites Symposium,
Forintek Canada Corporation, B.C. (conference tour).

November 10
MacMillan Bloedel Limited,
MB Research, B.C.

Trus-Joist MacMillan Limited,
Parallam, B.C.

Canadian Forest Products Ltd.,
B.C.

Week 2

November 14
Weyerhaeuser Technology Center
Tacoma, Washington State.

November 15
Wood Materials and Engineering Laboratory
Washington State University,
Pullman, Washington State.

November 16-17
Department of Forest Products
Oregon State University,
Corvallis, Oregon.