

FIBRE-BASED COMPOSITES IN NEW ZEALAND: PAST DEVELOPMENTS AND FUTURE OPPORTUNITIES*

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(Received for publication 8 June 1992)

ABSTRACT

Composite wood products based on *Pinus radiata* D. Don fibre have been made in New Zealand since the 1940s when a wet-process fibreboard plant was established in Auckland. Medium-density fibreboard (MDF) production began in New Zealand in 1976 and the total capacity of the New Zealand MDF industry is now 465,000 m³ per annum or about 6% of worldwide capacity. In 1987 production began of a totally new type of board in which MDF surface layers are combined with a strandboard core in a steam-pressing operation.

Two areas of research in progress at the New Zealand Forest Research Institute (FRI) are aimed at adding value to composites such as MDF. Firstly, research on dimensional stabilisation of MDF focuses on in-line chemical treatments of fibre. Secondly, the vapour boron treatment developed jointly by FRI and Imperial College of the University of London has the potential to improve the fungal, insect, and fire resistance properties of fibre-based composites.

Keywords: composites; medium-density fibreboard; dimensional stabilisation; vapour boron treatment.

INTRODUCTION

The development of wood fibre-based composite products in New Zealand dates from the 1940s when a plant was built in Auckland to manufacture wet-process fibreboard from *Pinus radiata*. The plant has been significantly upgraded and automated over the years and is still producing both hardboard and softboard, largely for the New Zealand domestic market.

The first medium-density fibreboard (MDF) plant in the Southern Hemisphere was built near Christchurch, New Zealand, and came on stream in 1976. This plant was the first to use

* Paper originally presented at IUFRO All-Division 5 Forest Products Conference, 23–28 August 1992, Nancy France.

a single refiner and the first to inject adhesive on to the wood fibre in a blowline immediately after the refiner. The Canterbury Timber Products mill was also the site for development of the “kiwi” press cycle in which the through-board density of MDF was manipulated to the required profile by modifications to the rate of opening and closing of the press and the force imposed on the fibre mat during pressing. This development opened greater opportunities for producing boards with the desired surface and core densities.

A second New Zealand MDF plant was commissioned when Fletcher Wood Panels opened their panel manufacturing site at Taupo in 1985. MDF, particleboard (furniture and flooring grades), and Bisonboard, a thin particleboard made in a continuous process, are manufactured at this site. Installation of a second refiner has increased MDF production at Taupo to 160 000 m³/annum and, like other MDF operations in New Zealand, this plant runs at capacity. A major focus at the Taupo plant in the last few years has been implementation of the quality management principles of ISO Standard 9002 throughout the mill’s operations.

The Nelson Pine Industries MDF plant in New Zealand’s South Island was commissioned in 1986 and uses a Küsters continuous press to produce MDF exclusively from *P. radiata* in thicknesses down to 2.5 mm. The use of the continuous press makes the production of thin MDF an economically viable option. A second MDF line based on a Küsters continuous press started up in late 1991 and the Nelson operation now produces one of the largest volumes of MDF (215 000 m³/annum) on a single site anywhere in the world. Part ownership of Nelson Pine Industries by Sumitomo Forestry Ltd of Japan has assisted the introduction of the company’s products into the Japanese market.

The latest addition to the wood fibre-based composites scene in New Zealand has been a plant at Kaitaia in the far north of the country. This plant started up in 1987 using *P. radiata* from nearby plantation forests to produce Triboard, a three-layer product with MDF surface layers and a strandboard core. This product, combining the surface properties of MDF with a structural core material, is manufactured from separate mats of resinated wood strands and fibre laid up prior to pressing in a Siempelkamp steam-injection press (Moore 1990). The use of steam-injection, the first at any panel manufacturing plant worldwide, allows panels up to 100 mm thick to be produced. In practice, product thickness is usually in the 25–32 mm range. Triboard can be used as an alternative to traditional timber framing in construction and also finds application in furniture (e.g., bench tops), stair treads, and door stock. Since the acquisition of the plant by Juken Nissho Ltd in 1990, a significant percentage of Triboard production has gone to the Japanese market. The Kaitaia plant can also produce MDF; however, it was not designed to do this economically and MDF is not produced there at present.

The New Zealand MDF industry is one of the most dynamic and internationally competitive sectors of the country’s forest products industry. This position has been achieved by a reputation for quality in such factors as appearance, surface smoothness, and product consistency that has been maintained since the industry’s beginnings. The light colour of *P. radiata* MDF has appeal in a number of markets and the introduction of a wider product range, including thin boards, low-density boards (e.g., Nelson Pine Industries’ Super-Lite board with average density of 450 kg/m³), and boards that meet international standards for low formaldehyde emission (e.g., Fletcher Wood Panels’ Lakepine Plus), has maintained the position of New Zealand products in an increasingly competitive international market. With New Zealand’s production capacity now more than four times greater than

domestic demand, the industry wishes to maintain its main markets while also exploring new added-value product opportunities to compete on the international scene. In a sense, added-value products are already here, with MDF mouldings (with or without veneer overlays), thin boards, and low-density boards. However, market demands for MDF to meet certain national or international standards in respect to dimensional stability, durability, and fire resistance, for example, mean that MDF manufacturers in New Zealand and elsewhere are increasingly interested in improving the properties of their core product lines to further expand their product range.

This paper discusses two approaches to improving the properties of wood fibre-based composites currently under investigation at the New Zealand Forest Research Institute (FRI).

DIMENSIONAL STABILITY

Wood fibre-based composites, like the parent wood material, are affected by moisture. The changes that occur in composites are always greater than in solid wood and are linked to the absorption of water by the wood material and to the relief of compressive stresses induced in the wood elements during the hot-pressing operation. Exposure of fibre-based composites therefore leads to board thickness swelling of two types which are described as "reversible" and "irreversible", linked to water absorption by the wood substance and relief of compressive stresses respectively.

Hardboard is an established composite wood fibre product and over its life cycle has received the attention of researchers interested in reducing its dimensional movement when exposed directly to water or high humidity. Techniques for improving the dimensional stability of hardboard have been summarised (Meyers 1983) and include heat treatment of boards, use of specially formulated phenol-formaldehyde (PF) resins with or without thermoplastic resin additives, and gas-phase acetylation of boards. Alston (1988) showed that a change in the process conditions for hardboard was more effective in reducing product thickness swelling at high humidity than the addition of more PF resin to the board.

Many of the methods that may be suitable for improving the dimensional stability of hardboard are not directly transferable to MDF. The types of adhesive binder used and the medium used for transport of wood fibres are quite different. In addition, post-treatment of MDF boards with heat or chemicals to introduce dimensional stability may present difficulties because of adverse effects on the urea-formaldehyde (UF) or melamine-urea-formaldehyde (MUF) adhesives that are normally used.

Chemical modification techniques can potentially be applied either to the fibre or the board and examples include the use of acetic anhydride (Rowell *et al.* 1991) or formaldehyde (Minato *et al.* 1991). Chemical modification has the advantage that the root cause of dimensional instability is addressed by blocking water-absorbing hydroxyl groups in the wood structure. However, although this approach is technically attractive, companies must be prepared to introduce additional process steps and capital equipment. For this reason, manufacturers are also interested in technology that may provide some improvement in dimensional stability at lower initial cost. A current example of this interest is driven by needs in the Japanese market to improve the dimensional stability of *P. radiata* MDF to that

of MDF produced from hardwoods (e.g., Lauan). In response to this need, the Forest Research Institute has established a project to examine incremental improvement in MDF dimensional stability by in-line chemical treatment of wood fibre.

Experimental Approach

The treatments identified to improve the dimensional stability of wood fibre were applied to *P. radiata* fibre obtained from a commercial MDF plant. These treatments were:

(1) Heat:

Fibre mats were formed and heat was applied either by contact with the heated platens of a press or by the injection of steam on to a fibre sample held in a reaction vessel. The fibre samples were exposed to temperatures in the range 180°–240°C during dry heating and 160°–230°C during wet heating. Exposure times were set at 1 minute.

(2) Chemical and heat treatment

Fibre samples were treated with aqueous solutions of either chromium trioxide, aluminium sulphate, or a proprietary mixture of borax and boric acid. Solutions were applied to wood fibre by spray and concentrations were adjusted to give either 1% or 10% chemical addition to the fibre on an oven-dry basis

(3) Compression and heat treatment

Early trials showed that auto-adhesion occurred at pressures in the order of 10–18 MPa and this excluded further processing. Pressure was therefore limited to either 3.3 MPa or 6.4 MPa and applied for 15 or 60 seconds at temperatures in the 180°–240°C range.

The fibre furnish was adjusted to 17% moisture content prior to heating in all three experimental approaches. The effect of the treatments on fibre dimensional stability was assessed by packing wood fibre samples into a tubular mesh sock and exposing the material first to 65% relative humidity (rh) and then to 90% rh at 25°C. Changes in fibre weight with increasing humidity were recorded.

In addition, MDF boards (100 × 100 × 12 mm) were pressed from treated and untreated *P. radiata* fibre using 8.5% UF resin as the binder. Test samples from these boards were prepared and exposed to the same variations in relative humidity as the wood fibre. Weight increase after exposure to 90% rh and thickness increase after cycling from 65% to 90% rh and back to 65% rh were recorded. Internal bond strength of the board samples was also measured.

Results

Exposure of *P. radiata* fibre to heat without chemical addition darkened the colour of the fibre, particularly when steam heating was applied at 230°C. Chemical treatments followed by heating also produced colour changes. Chromium trioxide gave fibre a green colour which intensified at higher loadings. Aluminium sulphate-treated fibre was red-brown and, at the higher temperatures and 10% treatment level, the proportion of fines increased thereby reducing the fibre bulking characteristics. Borax/boric acid treatment produced a similar colour change but did not damage the fibre. Compression treatment resulted in the formation of hard lumps and at the higher temperatures these were not broken up in the subsequent blending step, giving boards a mottled appearance.

Treatments had a marked effect on water absorbency characteristics of the wood fibre (Fig. 1). Untreated fibre in the control treatment increased in weight on exposure to high humidity by an average of 8.3%. Within each treatment type there was an apparent increase in weight with temperature up to 240°C. A reduction in water absorbency after heat treatments at 240°C was consistently found under all treatment conditions. Treatment to a 10% loading with chromium trioxide solution also gave a consistent reduction in water absorbency.

An indication of the dimensional stability properties of boards made from treated fibres is shown in Fig. 2. Gaps in the diagram indicate where boards could not be successfully produced. The internal bond strength of all boards made from treated fibre was half or less of the 1300 kPa obtained in untreated controls. As with fibre water absorbency, the 240°C dry heat exposure gave a significant improvement in dimensional stability of board samples.

Discussion

Preliminary tests on wood fibre and board samples showed the effectiveness of pre-heating fibre to a temperature of 240°C. This approach to dimensional stabilisation provided results in parallel with those reported by others (Hsu *et al.* 1988; Shen 1990).

Compression of solid wood at high temperature is known to improve dimensional stability (Rowell & Konkol 1987). However, difficulties with auto-adhesion and fibre lumping appeared when compression and heat treatment were combined in our work.

Chromium trioxide, is known to react with wood to give improved water resistance (Williams & Feist 1985) and this was demonstrated by results from the fibre tests; however, this was sufficient to prevent satisfactory MDF boards from being made in our experiments. Aluminium sulphate is used in hardboard manufacture to create conditions for auto cross-linking of wood polymers, and borax has been shown to prevent oxidation of wood surfaces exposed to high temperatures (Chow 1975); however, tests on moisture absorption by fibre or board samples showed that these treatments provided no consistently significant improvement. As shown by internal bond tests, a key consideration must be the need to ensure that changes in the surface chemistry of wood fibre are compatible with the chosen adhesive system. Further work in this area of dimensional stabilisation will focus on wet-heat treatments with or without chemical additives that have the potential to be applied to wood fibre after the refining stage.

VAPOUR PHASE TREATMENT OF COMPOSITES

FRI and Imperial College of the University of London have jointly developed a very rapid dry method for boron treatment of wood products. The method, known as the vapour boron process, was developed as an alternative to dip-diffusion treatment of wood with boric acid/borax solutions to introduce insect and fungal resistance (Vinden 1990). The diffusion treatment has been used in New Zealand as part of standard practice to protect *P. radiata* framing material and *P. radiata* for other applications in protected situations since the 1950s (Carr 1959). The vapour boron process provides a much more rapid means of boron treatment, avoiding long diffusion holding periods with associated inventory costs, and opens prospects for very rapid conversion from the standing tree to treated timber in use.

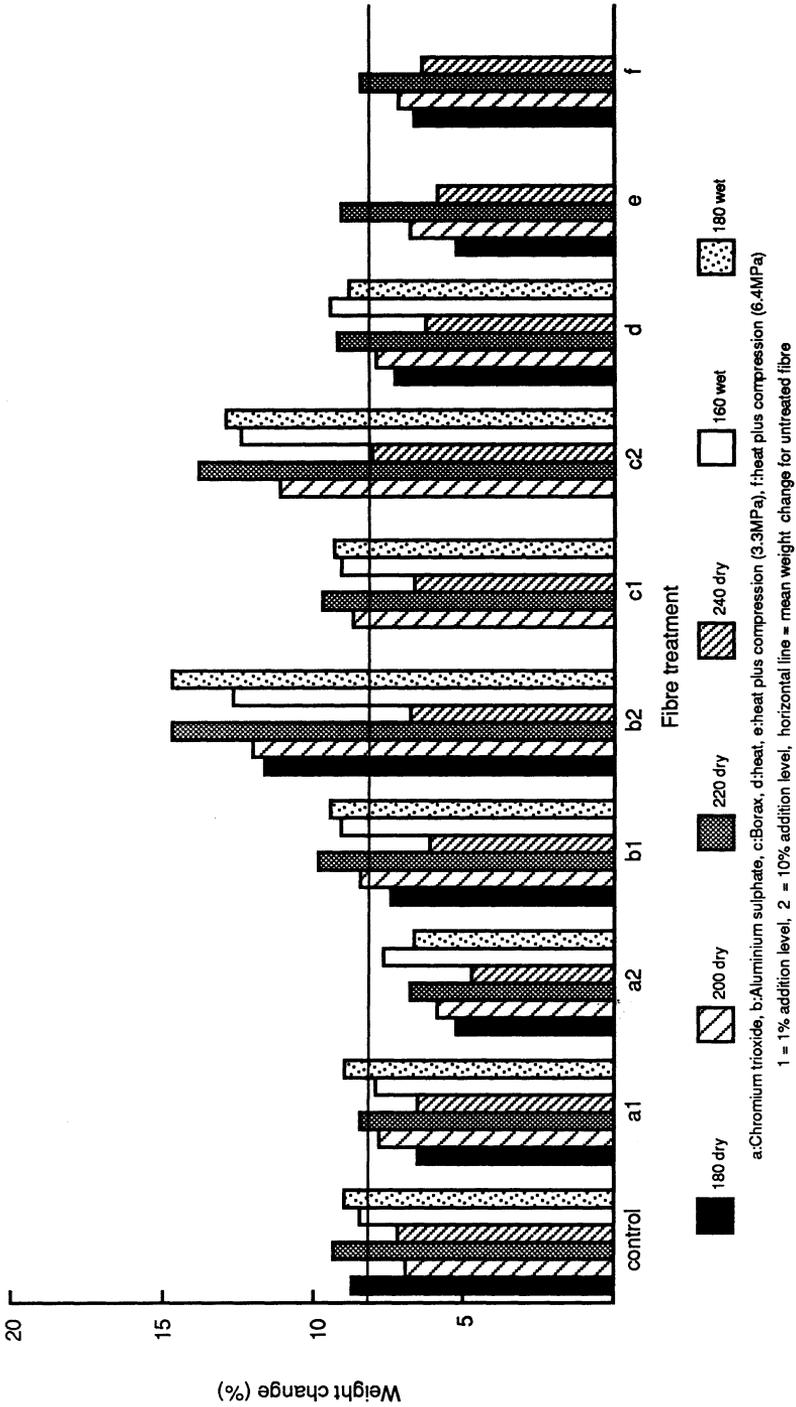


FIG. 1—Weight change (%) of treated and untreated *Pinus radiata* MDF fibre after conditioning from 65% to 90% relative humidity

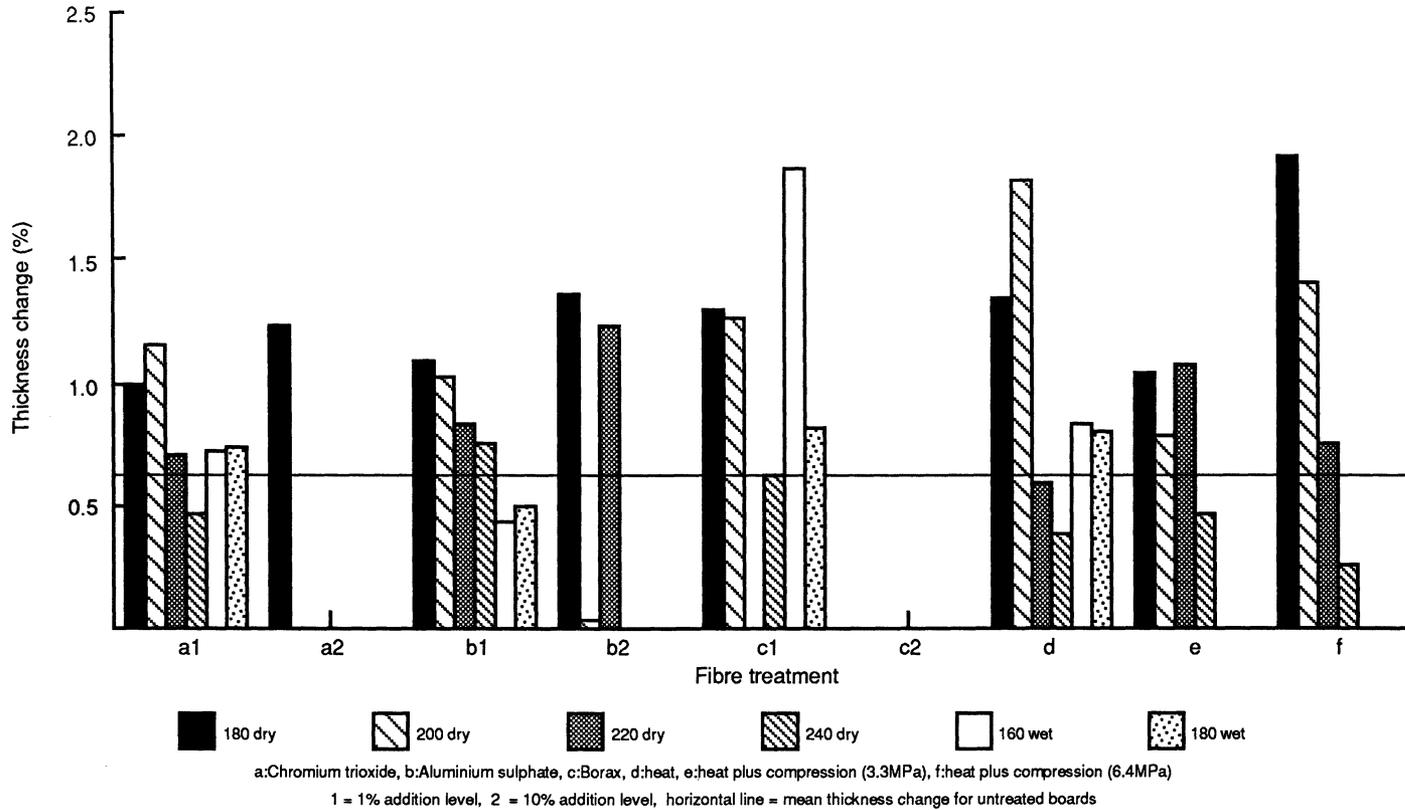
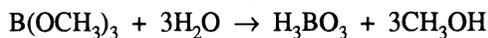


FIG. 2—Permanent thickness swelling of MDF boards made from treated and untreated *Pinus radiata* MDF fibre after exposure to a relative humidity cycle of 65% → 95% → 65%

Continued development of boron-based treatments for wood products is also stimulated by the need for more environmentally friendly methods of preservative treatment (e.g., alternatives to soil poisoning techniques to protect timber from termite attack).

One way to add value and expand markets for wood composites is to enhance their durability and to provide resistance to insect and fungal attack. Liquid-based preservative treatments for solid wood cannot be applied in the same way to such products as MDF because the dense outer layers (up to 1000 kg/m³) inhibit the passage of liquids and solvents may have adverse effects on adhesives and board additives. Aqueous treatments pose problems with board swelling and hydrolysis of the UF adhesives that have commonly been used. Incorporation of a preservative with the adhesive requires that the two be compatible and raises concerns with regard to disposal of contaminated residues from board sanding. These factors have led to an interest in vapour boron treatment of wood composites as an alternative preservative treatment process for these products (Bergervoet *et al.* 1992). Recent work has shown that vapour boron treatment is unlikely to have an adverse effect on mechanical properties of wood-based composites although impact strength may be reduced at high boron loadings (Hashim *et al.* 1992).

The vapour boron process has been described in some detail elsewhere (Burton *et al.* 1990; Turner *et al.* 1990) but the essential steps are as follows:



- The substrate is placed into a vessel where the pressure is reduced to about 10 kPa (abs).
- The appropriate quantity of trimethyl borate is dosed into the vessel and vapourised.
- The trimethyl borate diffuses rapidly into the wood where it reacts with the residual moisture in the wood to produce boric acid within a few seconds.
- The reaction by-products, methanol, and some moisture are removed and condensed.
- The system is brought back to atmospheric pressure and the treated product is removed.

The process can be completed in about 1 hour. For practical reasons the technique is limited to treatment levels below 3% BAE m/m (boric acid equivalent expressed on a mass/mass basis). However, it has been shown (Turner *et al.* 1990) that concentrations of boric acid at 0.7% BAE m/m will give complete protection from decay in wood composites. For higher treatment levels an alternative approach has been used whereby the composite product is held above a large pool of trimethyl borate at reduced pressure and the product picks up boric acid over a period of time.

Boric acid is also an active compound in fire retardant formulations. Investigations at FRI indicate that the loadings need to be in excess of 10% BAE m/m to achieve any degree of fire retardancy. To obtain such loadings necessitates long exposure times and this has resulted in swelling of the product. Some success has recently been obtained in treatment of softboard of density 300 kg/m³ to a level of 11% BAE m/m without swelling but this treatment technique has yet to be scaled up. A variety of other wood composite products have been treated at FRI using the vapour boron process to levels of between 0.5 and 3% BAE m/m. These products include *P. radiata* MDF, particleboard, and strandboard. The treatments have been carried out on products in volumes up to 0.25 m³. These products are easy to treat by the vapour boron process because they are produced at ideal moisture contents (between 5 and 7%) and are more permeable to vapour treatments than solid wood.

Discussion

The vapour boron process has the following significant processing advantages:

- Treatment is on final product independent of the manufacturing stage and can also be carried out on components.
- Treatment is very rapid.
- Treatment levels can be easily adjusted, allowing market requirements to be met on demand.
- The susceptible component in composites, the wood, is specifically treated.
- Boric acid loadings are uniform across the product.

The vapour boron process does have a role to play in the production of a range of value-added wood composites by adding durability and, potentially, fire retardancy to the base product. Interest in process applications is developing rapidly and is currently a major research focus in the Wood Technology Division of FRI.

CONCLUSION

The wood composite products industry in New Zealand has a significant history of innovation and an international reputation for quality products. The MDF industry in particular has achieved substantial product development and refinement with such innovations as thin boards, light boards, embossed boards, and mouldings. Future growth in the industry will require maintenance of existing offshore markets and continuation of the development of value-added products. Two important ways in which wood composite properties can be improved are dimensional stabilisation and durability enhancement to meet the needs of specific markets.

Research at FRI currently includes the evaluation of dimensional stabilisation treatments that might be incorporated in line at minimal cost. This research complements a longer term interest in chemical modification techniques and has, to date, included establishment of methodology and screening of some initial ideas involving chemical and heat treatment of fibre. The vapour boron process, developed jointly by FRI and Imperial College at the University of London, has been shown to be ideally suited to rapid preservative treatment of wood composites and, as well as adding durability, can potentially introduce fire retardancy into a range of wood composites.

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