WOOD POLYMER COMPOSITES (WPC)
IMPROVING WOOD'S NATURAL VIRTUES BY POLYMER IMPREGNATION

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Summary

Wood polymer composites (WPC) are made by impregnating polymerizable chemical formulations into wood using full cell or diffusion processes similar to preservative treating and then polymerizing the liquid formulations within the wood. WPC has better resistance to moisture and higher mechanical properties than the wood from which it is made. Formulations and methods of making WPC developed in the last 4 years are starting to be commercialized, and may have potential for use in applications in which previously only wood treated with toxic preservatives has been suitable. With this in mind, some of the new WPC materials were tested using a soil block test and the results are reported in this paper.

1. Introduction

Wood's natural virtues are its renewability, recyclability, excellent working properties such as machinability and fastenability, and its good mechanical properties-to-density ratio. For some uses, however, wood must have enhanced properties. Making wood into a wood polymer composite (WPC) increases mechanical properties, machinability and dimensional stability (Schneider 1994). It also has the potential to protect wood from biodeterioration without using toxic chemicals. Thus it may be possible to, at the same time, make wood stronger and resistant to decay.

WPC development information: About 25 years of plastic impregnated wood development in the Wood Science Laboratories at the University of New Brunswick in Eastern Canada by Dr. Marc Schneider culminated in 1992 with several superior formulations (Schneider 1995) which have been improved upon since then. The ownership of these developments were joint between Dr. Schneider and the University, and the University licensed its share to Dr. Schneider giving him control for commercial development. Dr. Schneider's company Woodtech Incorporated is acting as licensor for the technology. The licensee for manufacturing in Atlantic Canada is Colonial Manufacturing Ltd. of Fredericton, New Brunswick.

Impregnated woods are hard (about 50% harder than hard maple), dense (about the density of water) and finishable by sanding and buffing. Impregnation is complete, so any exposed surfaces will have the same properties. They are resistant to water. The material can be made in several colours and with several different combinations of properties. Since natural wood is variable, the treated product made from them reflects that variability; however impregnated woods have lower variability than untreated wood. The grain and figure of the parent wood remains evident, and may be enhanced by the treatment. Thus, within each type of treatment, customizing by choice of species, grain orientation and figure is possible. To date, the material has been used to make military pace sticks, knife handles, kitchen cutting boards, kitchenware, flooring, bridge heavy construction blocking and a prototype bathroom sink. Typical properties are given in Table 1. Formulations available, and some of their properties, include:

Cell wall type is dark brown to black. It is very dimensionally stable, including in hot water and should be highly resistant to decay. It stands up well in dishwashers and when exposed to outdoor weathering. Resistance to acid and alkali is high. It is the darkest, most dimensionally stable but most brittle of the series. It is produced using chemicals from renewable resources.

Combination type is light brown to natural wood colour. Its properties are intermediate between cell wall and cell lumen types. A recent development is a dark reddish-brown formulation containing lignin from spent pulping liquor.

Coloured cell lumen type have properties equivalent to cell lumen type, but are coloured. Other colours are being developed, and custom colours are possible.

Cell lumen type has the colour of wood varnished with a clear varnish. Like the other WPC material, properties are uniform throughout, unlike coated wood. Movement of moisture in this material is very slow, therefore changes in the moisture environment over days and weeks have little effect on it. In a continuously wet environment, it will ultimately swell similarly to untreated wood. It is the toughest, most elastic and strongest of the series. Toughness, elastic moduli and strength are greater than untreated wood.

<u>Machining and finishing:</u> Machining properties are nearer those of hard plastics than wood. Woodworking tools and machinery can be used to shape WPC, but reduced workpiece feed speeds or higher cutterhead rotational speeds may be required to accommodate the high density. Abrasive machining can work well with this material. Metalworking machines such as lathes and milling machines perform well on WPC.

Knife cutting can produce an attractive surface. Sanding produces a matte surface, with the coarseness of the grit determining the roughness of the matte. Very fine grit (such as 600) produces a matte with a sheen. Buffing after sanding, using a fine compound, produces a glossy surface. Machining and sanding properties for particular production processes can be modified somewhat by customizing the treatment.

<u>Service and maintenance:</u> The surface hardness of these woods give them better resistance to marring and wear than untreated wood. Should uneven wear or marring occur, it can be repaired by sanding and buffing since the plastic is throughout the wood. Slight colour

changes occur upon prolonged exposure to ultraviolet, largely a result of yellowing of the wood substance. Weathering resistance is good compared to untreated wood, but surface bleaching will occur under severe or prolonged conditions. Such surfaces, however, can be rejuvenated in appearance and colour by light oiling with drying or non-drying oils, either undiluted or solvent-diluted for easier application. Linseed and tung oils are examples of drying oils. Mineral oil and salad oil are examples of nondrying oils.

Species: Standard woods from which WPC is made are maple and birch. Ironwood (hophornbeam), ash, red oak, cherry, figured maple, poplar, alder and laminated wood also treats well. Low permeability species (such as spruce) can be treated to limited depths from the surface similarly to the manner in which they receive preservatives.

Production methods: The most common method we use to make WPC is a full-cell process for impregnation with monomer and then curing in a separate oven. Impregnation pressures and times are the same as needed for similar-type material in preservative pressure treating. We also produce "shell-loaded" material using refractory species and the full-cell process, higher-viscosity formulations with a full-cell process and lower-viscosity formulations using a diffusion process. Curing of all chemical formulations takes place below the boiling point of water. Some formulations and uses requires baking at higher temperature to strip ureacted monomer which would give objectional odours during service. The main differences from preservative treating are the chemical formulations used and the requirement for curing schedules. The chemical formulations use readily-available, standard commercial chemicals.

Some current uses: A licensee in Fredericton, New Brunswick has produced blocking and wedges used in the construction of the bridge between New Brunswick and Prince Edward Island, pacestick blanks for the Canadian military, material used in partially decayed and decay-susceptible areas during the restoration of an historic building and blanks used for custom knifemaking and turning. A licensee in Europe is doing trial treating contracts of knife handles, flagpoles, park benches, flooring, window and door frames and tool handles. There is a trial floor labelled with the names of Schneider and two Norwegian colleagues named Placht in the domestic flight tunnel of Oslo's Fornebu airport. Interest in the material is high in Europe where some countries have banned the use of toxic preservatives and others are expected to follow. Road sign supports and guard rails and posts are two products that have been mentioned as having immediate potential interest in Sweden. There is also interest in treating formulations containing lignin because of its environmentally friendly flavour. We have developed a formulation using organosol lignin from the Alcell$^{(R)}$ (Repap) process which might help with this.

Decay resistance: The types of polymers used to make WPC are decay-resistant. Because of this, and because of the manner in which the polymers relate to the wood, it is expected that WPC will resist decay. The cell lumen type leaves the cell walls unaltered, so fungi should still be able to attack them. However, the polymer in the lumens should provide a mechanical block to fungal hyphal movement, thereby reducing the rate at which decay occurs.

Cell wall type treatments alter the cell wall, making it less hygroscopic and perhaps blocking sites accessible to fungal degradation. Thus cell wall WPC should have a lowered susceptibility to decay. This has been demonstrated in work with phenol-formaldehyde and furfuryl alcohol WPC (Takahashi 1996).
Recently, we did preliminary screening of several of our licensed WPC formulations for fungal decay resistance. A conventional, methyl methacrylate-based, cell lumen WPC and untreated wood were used as controls. The results are reported in this paper.

2. Methodology

Red maple (*Acer rubrum* L.) lumber was impregnated with monomer formulation, cured, cut into samples and tested in a soil block test (ASTM D2017-81). Several replicates of each formulation were made for each of the 3 fungi used (*Trementes versicolor* L. ex Fr., *Poria placenta* (Fr.) Cke. and *Gleophyllum trabeum* Pers. ex Fr.). After 8 weeks of exposure, one sample was removed from each treatment/fungus combination and weighed. The remaining samples were weighed after 34 weeks of exposure. Since having polymer present complicates weight loss calculations, the following procedure was used for those measurements. The ovendry density of the ovendry wood was measured. Samples for treatment were ovendried, weighed, treated, weighed again and the percent polymer loading calculated. The ovendry weights of soil block samples cut from the impregnated samples were obtained and then the decay tests were done. After exposure to fungi, samples were ovendried and weighed. This allowed calculation of weight loss based upon composite and upon wood substance to be calculated.

3. Results and Discussion

Two of the 3 fungi proved inactive (there was virtually no weight loss even with untreated samples). A parallel study using the same fungi gave the same results. There was slow loss of unreacted monomer from the samples, causing weight loss. The samples from the inactive fungi allowed this to be quantified and the results were used to adjust the weight loss for the active *T. versicolor* fungus.

The cell wall, lignin and combination (combo) formulations had no weight loss after 34 weeks of exposure while the cell lumen treatment had 13%. The outside cells of the cell lumen treatment samples were degraded, leaving casts of polymer. Deeper in the sample, the wood appeared intact. This suggested attack was progressing slowly from the outside in. The untreated samples lost 93% of their weight over 34 weeks. The results are shown in Figure 1.

Weight loss appeared to occur at a faster rate early in the experiment. In the cell lumen samples at 8 weeks, about half of the weight loss measured at 34 weeks had occurred. For the untreated samples, 85% had occurred. This is shown in Figure 2.

4. Conclusions

WPC properties and production methods are outlined. One property which has not been tested is decay resistance. The screening experiment reported substantiates the ideas that cell lumen WPC will decay slowly and cell lumen WPC will be resistant to decay. It demonstrates that the formulations tested have, in addition to their other desirable properties, potential to resist fungal decay.

5. Literature

Schneider, M.H. 1994. Wood polymer composites. Society of Wood Science and Technology State-of-the-Art Review Paper. Wood and Fiber Science 26(1), pp. 142-151.

Schneider, M.H. 1995. New cell wall and cell lumen wood polymer composites. Wood Sci. & Technol. 29:121-127.

Takahashi, M. 1996. Biological properties of chemically modified wood. in Chemical modification of lignocellulosic materials, D. Hon, ed., Marcel Dekker Inc., NY, NY.

Table 1. Some typical properties of WPC made under Woodtech Incorporated licenses.

Type	1	2	3	4	5	6	Colour
Untreated maple	0.6	70	13	0	1	66 8 17	Bright tan, low saturation
Cell wall	1.0	85	3.5	72	0.6	25 3 3	Very dark brown
Combination	1.0	85	7.5	30	0.7	32 12 10	Dark red-brown
Cell lumen*	1.0	85	13	0	1.8	54 13 10	Bright tan, medium saturation

1 = density, g/cc
2 = Shore D hardness
3 = 24-hr boiling water swell
4 = % antiswell efficiency
5 = relative toughness, 1.0 = 3.3 x 10^2kJ
6 = $L^*a^*b^*$ colour coordinates
* Except for colour, properties of coloured material are the same as for Clear