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THE POTENTIAL OF BIOLOGICAL TREATMENT TO IMPROVE DURABILITY OF COMPOSITES

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Summary

Durability of composite panels is becoming an increasing concern for home owners. In North America, composite panels are normally made of less-durable wood species and are susceptible to attacks of mold and decay when exposed to wet conditions. Using a low environmental impact technology to improve the durability of composite products could have advantages over using chemical protection products in the marketplace. In recent years, a series of research projects were conducted in FPInnovations–Forintek Division for exploring various biological technologies and treatments to protect composite panels from biodegradation, and to improve the durability of panels for better resistance to mold and decay. These projects concerned1) investigating bark antifungal properties and use of bark for durable panel manufacturing; 2) developing manufacturing technology for using naturally resistant wood species to increase the durability of panels against mold and decay; 3) protecting strand board against mold and decay by post-treatment of panels with natural extracts from durable wood species; 4) developing a biological treatment to protect logs from biodegradation and increase panel mold resistance; 5) developing a treatment process of wood strands with fungal antagonists to increase the durability of panels against biodegradation; and 6) examining antifungal properties of extracts from fungal antagonists and their potential use as panel protectants. Significant technical breakthroughs have been made in these studies, and these have been summarized in this paper.

1. Introduction

Composite panels, such as oriented strand board (OSB), are the main wall framing material in residential construction. This market represents approximately 30% of the total 21 billion sq. ft. of panels consumed annually in North America. Most composite panels are normally made of less-durable wood species such as aspen, and are susceptible to mold and decay under wet conditions. Panels used in house construction can get wet from a variety of water sources. Moisture problems lead to mold problems, which have potential economic and health consequences (May, 1991; Dales et al., 1991; Uzunovic et al., 2003). In recent years, many residential houses have been built with energy-efficient wood-frame, and with poor design and construction hence they are prone to moisture accumulation. To ensure durability and avoid moisture problems in wood-frame houses, the most important consideration is the use of design features and construction tools and practices, which will not only keep wood as dry as possible, but also make it easy to dry if it gets wet. However it may also be advisable to provide building materials with an increased tolerance to short term wetting and drying. Using fungal-resistant panels to limit fungal attack is one of such options (Morris et al., 1999a).

Increasing panel durability and producing fungal-resistant panels have been the subject of extensive research for many years (Schmidt et al., 1983; Morris, 1995; Morrell, 2002; Smith and Wu, 2005). The most comprehensive studies have been focused on chemical additives or treatments (Morris 1995; Smith and Wu, 2005). Some naturally durable wood species, such as white cedar, have also been used for making composite panels resistant against decay and termites (Haataja and Laks, 1995). However, limited research was conducted on using a biological treatment to improve panel durability (Mai et al., 2004).

Biotechnology is one of the world's fastest-growing technologies. Under FPInnovations–Forintek Division’s Protection Program, this technology has shown tremendous potential in wood and panel protection. Forintek has carried out several projects related to this area and three patents have been received. The progress made by Forintek in developing and applying the biotechnology for protecting wood has been recognized internationally. Since 2000, the research has been extended to using biotechnology to improve mold, stain and decay resistance of composite panels and has showed potential for making major technology breakthroughs in durable panel manufacturing. Many of these promising results have been published in recent issues of scientific journals. The purpose of this paper is to summarize these results and provides some references for future research on potential biological methods for protecting composite panels from mold and decay.

2. Improving Panel Durability by Using Natural Durable Wood Species

2.1 Use of Bark

Utilization of bark has been a major concern facing the wood industry for a long time, but until now, only a small portion of bark has been used for the production of high-value products and most of the bark is used as fuel and land fill (Harkin and Rowe, 1971; Troughton, 1995). Efficient bark utilization can make valuable products out of wood production waste and boost economic development. One method of bark utilization is making various types of composite panels, such as bark board, particleboard and fiberboard. Such possibilities have been studied for a long time (Anderson and Helge, 1959; Branion, 1961; Sullivan, 1970; Morris et al., 1999b). In general, bark contains a high content of extractives, resins and waxes. The boards made of bark or a portion of bark may need little or no binders, and may be resistant to attack from molds and decay fungi.

However, bark of various wood species contains different chemical compositions and elements, and bark from some wood species may be more fungal resistant than others. To address this issue, a study was conducted to evaluate antifungal properties of bark from 6 wood species: aspen, red maple, yellow birch, balsam fir, white spruce and white cedar (Yang et al., 2004). Five fungi: *Aureobasidium pullulans*, *Aspergillus niger*, *Penicillium* sp., *Gloeophyllum trabeum* and *Irpex* *lacteus*, representing molds, wood staining and decay fungi, were used in the test. Based on the colony growth rates of these fungi on bark-extracts-agar media, white spruce bark was the best for inhibiting the growth of these fungi, followed by red maple bark. White cedar and balsam fir bark provided some inhibition to some of fungi tested. Bark of aspen and yellow birch possessed little or no inhibition of fungal growth.

2.2. Use of Wood Strands from Durable Wood Species

It is known that some natural durable wood species, such as eastern white cedar, have been used for making medium density fibreboard (Behr, 1972), particleboard (Behr and Wittrup, 1969) and flakeboard (Haataja and Laks, 1995) to against decay and termites. However, this wood species contains a high volume of volatile organic compounds (Wang and Wan, 2004) in its heartwood, and it is difficult to manufacture well-bonded strand board panels due to blow problem during hot pressing. A long pressing time will lower productivity and is not acceptable for the panel industry. Extending the pressing time will cause the surfaces of boards to be carbonized and reduce panel strength. Thus to produce mold or decay resistant strand panels with eastern white cedar for industry application, specific manufacturing methods and technology should be pursued.

To solve this problem, a series of homogenous and three-layer panels were made with wood strands of white cedar and aspen under hot pressing conditions similar to those used in orientated strand board panel industry (Wan et al., 2007). For manufacturing three-layer strand board, aspen strands were placed in the core layer (50%) and white cedar strands were placed in two face layers (each layer contained 25% white cedar strands). Homogeneous panels were made of the mixture of steam-treated white cedar strands (30%) and aspen strands (70%).

The mold and decay resistance and the physical and mechanical properties of the panels were tested. The results showed that the panels made with mixture of white cedar and aspen strands were mold and decay resistant, while the physical and mechanical properties of these panels were similar to those of pure aspen control panels. Mixing steam-treated white cedar strands and aspen strands homogeneously was a way to overcome blows and delamination created by white cedar volatile extracts, with improved panel durability.

In another study, a series of three-layer strand panels were manufactured using strands of white/black spruce and aspen. White/black spruce strands were used in the face layers (25% each layer) and aspen strands in the core layer (50%) (Yang et al., 2006). The results showed that three-layer panels made with various proportions of sapwood and heartwood strands of white spruce or black spruce in their surface layers and aspen strands in the core layer were mold resistant, moderately resistant to white-rot fungi, but not resistant to brown-rot fungi. The physical and mechanical properties of these panels were similar or inferior to pure aspen strand panels.

2.3 Use of Extracts from Durable Wood Species

It is well known that the durability of durable wood species, such as cedars, is due to the presence of extractives in heartwood. Purification, identification and utilization of these extractive chemicals as antifungal agents have been a focus of much research effort (Nault, 1987; DeBell et al., 1999). In a parallel study of manufacturing durable strand panels with eastern white cedar, using heartwood extracts of this wood species to increase aspen strand panel durability was explored (Wan et al., 2007). The heartwood of white cedar was extracted with hot water, and the extracts were freeze-dried into powder. The cedar extracts were added to aspen strand boards in 3 ways: a) panels (24 x 24 x 7/16 inches) made of strands sprayed with 0.4% white cedar extract solution at a dosage of 250 ml per kg of strands (at an oven-dry basis) during blending; b) panels made of strands sprayed with 2% white cedar extract solution at a dosage of 50 ml per board after forming; and c) panels made of untreated strands sprayed on surfaces with 2% white cedar extract solution at a dosage of 50 ml per board after pressing. The durability tests on these panels showed that panels made of aspen strands sprayed with white cedar extracts before or after forming slightly reduced mold infection, but not brown-rot or white-rot.

A further study showed that the mold growth was much reduced on aspen panels dip-treated with the extracts of white cedar heartwood at concentrations higher than 5%. No mold growth was detected on panels dip-treated with the extracts at concentrations higher than 5% and then brushed with a finishing coating. The decay test showed that dip-treated aspen panels with cedar extracts alone was not effective, but brushing a coating on the top of treated panels significantly increase their durability against brown-rot and white-rot (Yang et al., 2005).

3. Improving Panel Durability by fungal treatment

3.1 Treatment of Logs with Fungal Antagonists

Decay in logs before flaking for panel manufacturing can cause wood fiber losses, and strand-based panels made of decayed wood have lower mechanical properties than those made of normal wood. The panels made of moldy and stained wood strands are also darker than those made of uninfected strands. Therefore, the protection of logs in storage from biodegradation is necessary for panel manufacturing.

Among various approaches for outdoor storage in mill yards, biological protection of wood from degradation is one of the most attractive methods (Freitag et al., 1991). *Gliocladium roseum* is one of these biological control fungi and has been successfully tested against sapstain on softwood logs and lumber (Yang and Gignac, 2003). In a recent study, aspen logs for panel manufacturing were treated with spores of *G. roseum* and stored for 4 months in summer (Wang et al., 2006). The results showed that the fungal infection in aspen logs was significantly reduced by the treatment.

In a further study (Yang et al., 2007a), logs of aspen, red maple and yellow birch were either debarked or not debarked, and treated with spores of *G. roseum*. Logs were piled in different treatment groups and stored in a yard for 5 months and one year before evaluation. The results showed that all untreated logs, with or without bark, were seriously degraded by molds, stain and decay fungi after a summer storage period of five months. The logs with bark were more degraded than the debarked logs, and the log ends were more degraded than the middle sections. After storage for 5 months, 55% to 83% of the wood in untreated logs was degraded. The biological treatment was effective, with only 4% to 16% of the wood in treated logs affected by various deleterious fungi. Strands cut from untreated logs contained 50% to 75% of grey or blue stained strands, whereas those cut from biologically treated logs contained 10% to 25% of such strands. Panels made of biologically treated logs had the lower thickness swell (TS) and water absorption (WA) values compared to panels made of fresh-cut logs and untreated stored logs. The other physical and mechanical properties of the panels made in this test were comparable. With regard to mold resistance, all panels made from fungal treated logs had better mold resistance than those made from freshly cut and untreated logs.

3.2 Treatment of Wood Strands with Fungal Antagonists

Many micro-organisms have been used for biological protection of solid wood against decay, stain and mold. In addition to *Gliocladium roseum*, an albino strain of *Ceratocystis resinifera* is another fungus used for biocontrol of wood stain, and the main antagonistic mode of this fungus was competition for nutrition (Morin et al., 2006). *Phaeotheca dimorphospora* is a fungal antagonist used for biological control of tree diseases (DesRochers and Ouellette, 1994), and this fungus had demonstrated strong antibiotic activity against many parasitic and saprophytic fungi *in vitro* and in hardwood and softwood seedlings by producing toxic metabolites (Yang et al., 1993). However, these studies were all conducted on solid wood, and little research was done on biological treatment of composite panels.

One study conducted in Forintek recently involved treating aspen wood strands with the three antagonistic fungi listed above to increase strand panel durability against mold and decay (Yang et al., 2007b). Aspen wood strands were treated with spores/mycelia suspensions of these three fungi and stored at 25 ºC for 4 weeks before panel manufacturing. The results of this study showed that all three fungal species grew well on aspen strands in 4 weeks, and the strands from all treatments had a natural wood color after incubation. Compared with control panels, panels made of strands treated with *G. roseum*, *P. dimorphospora* and *C. resinifera* had better or similar bonding property (IB), higher TS and WA, similar or slightly lower dry modulus of rupture (MOR) and dry modulus of elasticity (MOE), and higher wet MOR. Panels made of strands treated with these three fungal antagonists reduced mold infection for 6 weeks. However, the decay resistance of panels was not improved by this pre-treatment of aspen strands with fungal antagonists.

3.3 Treatment of Panels with Fungal Extracts

Many fungi produce antibiotic compounds and these compounds can be used as anti-microbial agents against diseases of plant, animal and human being. As described above, *Phaeotheca dimorphospora* is one of such fungi. One study recently conducted at Forintek was to test the ability of extracts of *P. dimorphospora* to suppress the growth of various molds and decay fungi *in vitro*, and to evaluate the possibility of using the extracts of *P. dimorphospora* to treat OSB panels and reduce mold infection of the panels when wetting occurs.

In this study (Yang et al., 2007), culture metabolites of *P. dimorphospora* were extracted, and the antibiotic activity of the extracts was tested in Petri plates against various molds and decay fungi. The OSB panels were then dip-treated with the extracts and exposed to a humid environment for mold growth testing in a period of 8 weeks. The results showed that the mycelial growth of all fungi tested (molds, white-rot and brown-rot fungi) was inhibited by the extracts of *P. dimorphospora* on agar plates. Panel samples dipped with the fungal extracts showed little mold growth on them, whereas untreated control panels were seriously affected by various molds. This study demonstrated a high potential for utilization of fungal extracts for protection of composite panels against mold and decay. Further research and development on this work should be conducted.

4. Conclusions

This paper summarizes various promising potential biological treatments and manufacturing processes for improving the resistance of composite panels against mold and decay. In general, using biological methods to increase panel durability against fungal degradation is feasible. The studies showed that logs stored in mills for panel manufacturing could be protected by a biological agent patented by Forintek. White/black spruce bark was more fungal resistant than the bark of other wood species. Panels made of white cedar strands in the face layers and aspen strands in the core layer at different ratios were mold and decay resistant. White/black spruce faced panels were highly mold resistant and somewhat decay resistant. Treatment of wood strands with fungal antagonists before manufacturing delayed and reduced mold infection on panels. The post-treated panels with extracts of white cedar and of a fungal antagonist showed little or no mold growth. Panels treated with cedar extracts and then brushed with a coating were mold and decay resistant.

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