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Microscopic observation of wood-based composites exposed to fungal deterioration

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Abstract This study was conducted to investigate the susceptibility of various wood composite panels exposed to wood-deteriorating fungi. Five wood-attacking fungi (three mold fungi, one brown rot fungus, one white rot fungus) were inoculated into four types of commercial wood composite panels (plywood, oriented strand board, particleboard, and medium-density fiberboard). One solid wood sample was included as a control. The attacking patterns of the fungi in each panel was observed by scanning electron microscopy. The weight losses due to the exposure were compared. All wood composites were more or less susceptible to all fungi inoculated. The attacking mode of the fungi was highly dependent on the types of wood composite, which had inherently different shapes of voids owing to different shapes and characteristics of the raw furnish materials used. Plywood and medium-density fiberboard showed a large weight loss after an 8-week exposure to decay fungi. Plywood is the most susceptible to white and brown rot fungi. This study indicates that all wood composite panels should undergo careful consideration to prevent fungal deterioration when they are used for exterior and humid interior applications.

Key words Wood composite · Medium-density fiberboard · Oriented strand board · Plywood · Particleboard · Fungi: mold, brown rot, white rot

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Introduction

The shortage of quality timber such as large-diameter trees and incentives for using small-diameter trees are driving the need to develop various wood-based composite panels such as oriented strand board (OSB), particleboard, and medium-density fiberboard (MDF). Various types of raw furnish materials are used for these composite products. For example, wood strands (or wafers), particles, and fibers mixed with proper synthetic resins are consolidated in the hot press to make OSB, particleboard, and fiberboard, respectively. Being reconstituted with specific materials, wood composite products can be engineered with a wide range of properties to fulfill the requirement of end uses. Particleboard has become a major material for furniture, and OSB is increasingly used as a building material for residential house, subflooring, and floor or wall paneling.[1] However, these materials are susceptible to biological attack by wood-decaying microorganisms such as mold and white rot and brown rot fungi, particularly in outdoor applications.

Merrill et al.[2] reported that fiberboard attacked by several mold fungi lost about 12%–18% of its weight, resulting in a loss of strength of about 50%. The mold fungi consumed mainly hemicellulose and α-cellulose, whereas lignin was hardly attacked.

Behr and Wittrup[3] found that the weight loss after 3 months' exposure to decay fungi linearly increased with the increasing amount of jack pine in both redwood and northern white cedar particleboard, establishing a linear regression between weight loss and the mixing composition. They also reported that the specific gravity of the particleboards had a profound effect on the resistance to decay and to termites, the higher specific gravity being more resistant. The resistance of MDF to decay and to termites was also studied by Behr,[4] who reported that MDF boards made of heartwood of northern white cedar were more resistant than those made of 50% cedar/50% hardwood. It was attributed to the presence of extractives in heartwood.

Using eight different boards, Wang[5] found that the relative humidity (RH) of air played an important role in the growth of mold and stain fungi and the rapidity of their growth. He also reported that RH higher than 90% at 15°–25°C produced remarkably rapid fungal growth. Nevertheless, limited results are available on the influence of microfungal deterioration on wood-based composites even though the increasing occurrence of microorganism attack in wood products has become a notable problem. Thus, the extent of microbiological deterioration should be analyzed so the composites can be used for exterior applications. In particular, the resistance of OSB to decay or mold fungi has not yet been studied because this composite was developed relatively recently (i.e., the 1980s). Furthermore, ultrastructural study using electron microscopy has seldom been done to observe how decay and mold fungi deteriorate wood-based composite products. This study was carried out to observe microscopically the biological deterioration of wood-based composites exposed to various kinds of decay and mold fungi.

Materials and methods

Four different wood composite boards and one solid wood sample were used for this study: plywood (thickness 17.5mm, density 508kg/m^3), OSB (thickness 11.1mm, density 624kg/m^3), particleboard (thickness 15.9mm, density 670kg/m^3), MDF (thickness 15.9mm, density 749kg/m^3), and spruce [*Picea glauca* (Moench) Voss] solid wood (thickness 12.4mm, density 385kg/m^3). Commercial boards of each type of composite were employed for this experiment, and fresh small specimens (2 × 3 × panel thickness, in centimeters) were cut from each type of board. Five fungi (one white rot, one brown rot, and three mold fungi) were used: The white rot fungus was *Phanerochaete chrysosporium* and the brown rot fungus *Tyromyces* (*Fomitopsis*) *palustris*; the three mold fungi were *Thrichoderma* spp., *Aspergillus* spp., and *Penicillium* spp. The two wood-decay fungi (white and brown rot fungi) and three mold fungi were obtained from the Department of Forest Products and Technology, Chonnam National University, Kwangju, Korea, and from the Forintek Canada Corp., Quebec, Canada, respectively. These fungi were inoculated to each type of board for fungal growth according to standard soil-block test procedures[6] with five replications. All board samples were brought to an equilibrium moisture content in a mini environmental chamber before fungi inoculation. The inoculated board samples were kept in the same chamber at RH 70% and 28°C for 8 weeks for fungal growth.

For weight loss measurement and electron microscopic observation, every specimen was taken out at 2, 4, 6, and 8 weeks. The formula to calculate weight loss was as follows:

$$W_L = 100(W_1 - W_2)/W_1 \tag{1}$$

where W_L is weight loss in percent, and W_1 and W_2 are the sample weights before and after fungal treatment. Samples were fixed with paraformaldehyde 4% and glutaraldehyde 1%. Postfixation was done with 1% osmium tetroxide (OsO_4). Fixed samples were dehydrated, critical point-dried, gold coated, and observed with a Hitachi S-2400 scanning electron microscopy (SEM) under 15kV.

Results and discussion

The wood-based panels were subjected to various fungal attacks, and the different board types exhibited different susceptibility to fungi. Figure 1 shows the average weight loss of wood-based composites after an 8-week exposure to fungi. As expected, two wood-decaying fungi (*P. chrysosporium* and *T. palustris*) caused larger weight loss for all types of boards than did mold fungi. In general, plywood and OSB resulted in drastic weight losses for these two wood-decay fungi. Particularly, the largest weight loss (about 36% with a standard deviation of 0.05%) occurred in plywood exposed to brown rot fungi. OSB followed a trend similar to that of plywood. Particleboard had the least weight loss after both white and brown rot fungal exposure, but the MDF samples showed a comparatively larger weight loss: about 14% (SD 0.03%) after brown rot fungus exposure. Solid wood samples also showed a comparable weight loss with both decaying fungi. The measured weight loss suggested that the infection or deterioration by these fungi causes lower mechanical properties of wood-based composites.[7] Mold fungi produced generally low weight losses (about 5%, with 0.02% SD) compared with those due to decaying fungi (Fig. 1). Plywood, OSB, and MDF samples lost more weight than particleboard when exposed to the three mold fungi. *Trichoderma* spp. and *Penicillium* spp. caused the largest weight loss in plywood. Solid wood samples had the least weight loss incurred by all three mold fungi.

The extent of weight loss due to decaying fungi varied depending on the frame substrates of each panel composite. Peeled veneers with knife-checks were compacted closely

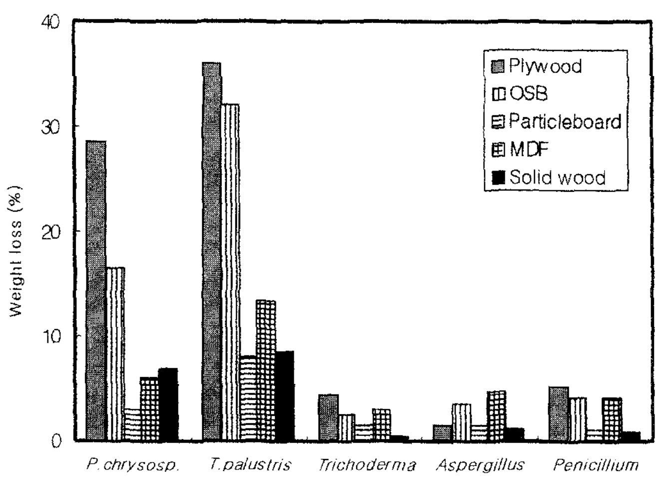

Fig. 1. Weight loss of wood composite boards exposed to various fungi

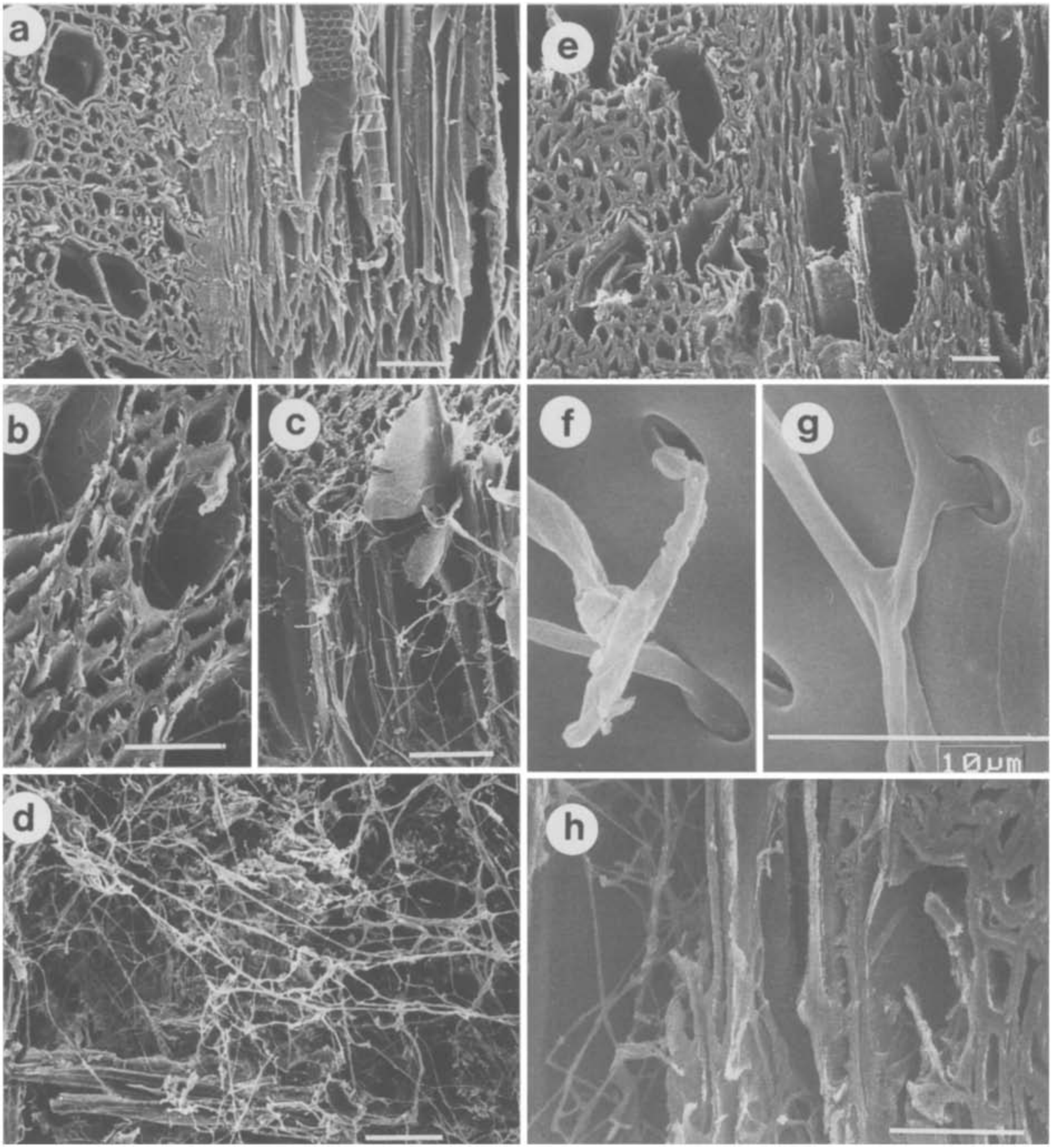

Fig. 2. Scanning electron micrographs of plywood and oriented strand board (OSB) samples exposed to the wood-decay fungi *Phanerochaete chrysosporium* and *Tyromyces palustris*. **a** General view of sound plywood. **b**, **c** Hypha of *P. chrysosporium* colonizing vessel. **d** Many of the parenchymal cells are destroyed by *P. chrysosporium*. **e** General view of OSB. **f**, **g** Hypha growth of *T. palustris* through the bordered pit in OSB. **h** Hypha growth of *T. palustris* within vessel lumens in OSB. *Bars* 10 μm

during hot-pressing and yielded no artificial voids in the plywood. Therefore, it may be that the cross section of hardwood veneer with large openings is the pathway of the fungi on the edge side of plywood. Flakes of OSB have, by far, a larger dimension than raw materials of particleboard and MDF and therefore can produce somewhat large voids in OSB even after the hot-pressing process. These voids might help wood-decaying fungi grow by providing abundant paths for fungal hyphae to penetrate the board. The larger weight loss of MDF exposed to brown rot fungi might be attributed to the higher cellulose composition of softwood species. Currently, most MDF panels are composed of about 75% softwood fibers and about 25% hardwood fibers bonded with urea-formaldehyde resin. Thus, the larger number of softwood fibers in MDF panels may cause the preference of brown rot fungi for attacking softwood

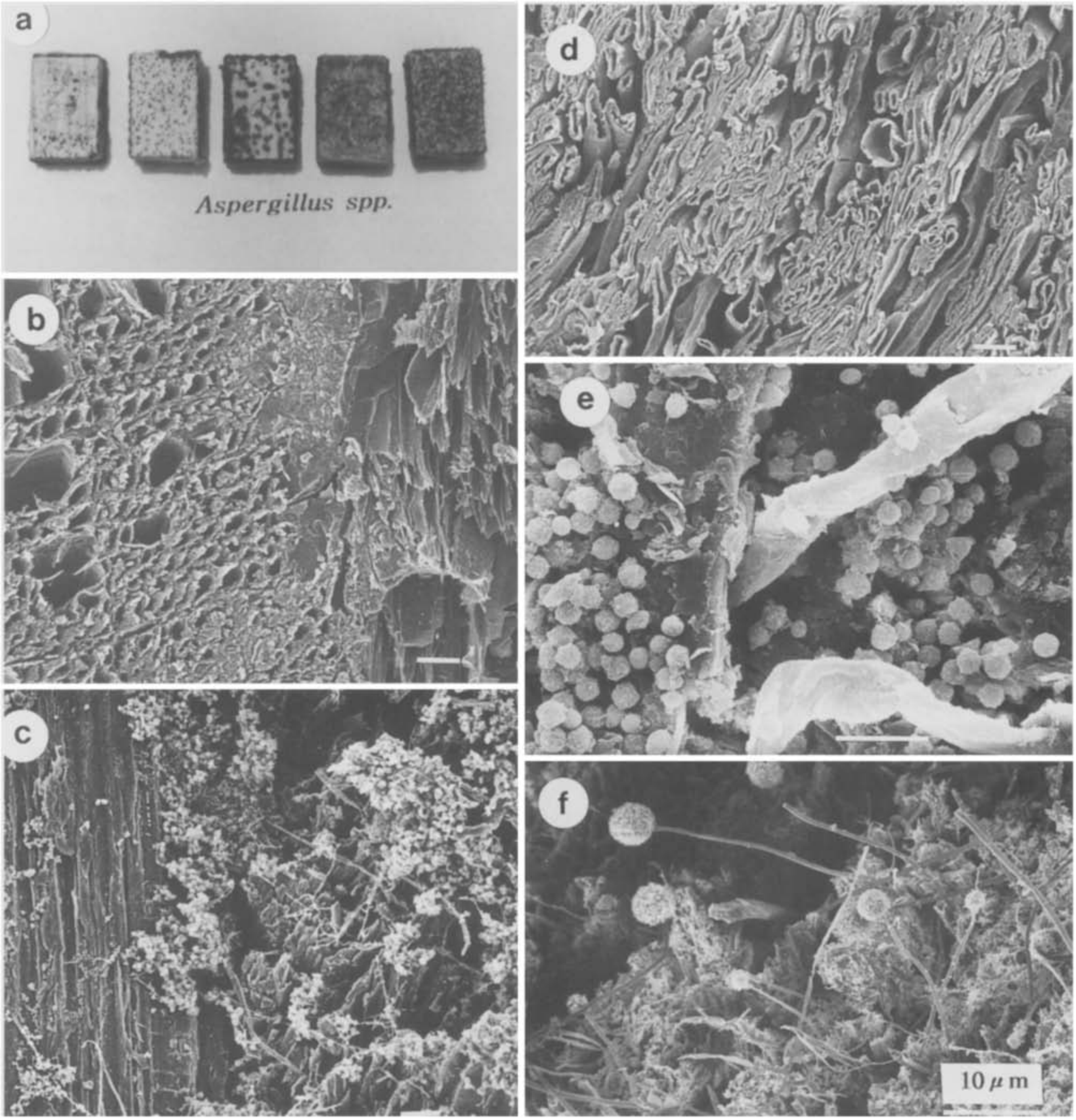

Fig. 3. Visual decolorization of wood-based composites and scanning electron microscopy of plywood and medium-density fiberboard (MDF) exposed to the mold fungi *Aspergillus* spp. **a** Visual decolorization of wood-based composites. **b** Sound plywood with knife-checks. **c** Growth of *Aspergillus* mycelium and spores on plywood was limited within the cross section of veneer layers. **d** General view of MDF. **e** Mode action of *Aspergillus* penetrating the interfacial void. **f** Advanced stage of MDF exposed to the mold fungi *Aspergillus* spp. *Bars* 10 μm

species. White rot fungi have a preference for attacking hardwood species.

It is also seen from the weight loss measurements that mold fungi can degrade all wood-composite boards, although the degradation is less than 5%. Particularly, the large weight loss of MDF might be explained by both fiber-making and board-sanding processes. MDF fibers are being manufactured by the refining process under pressure. This refining process defibrillates wood fibers from middle lamella between cells by the use of mechanical forces under heat. Thus, this process exposes wood fiber surfaces, which are then susceptible to attack by mold fungi. The combination of refining and hot-pressing processes may expose polysaccharide components, such as hemicellulose or cellulose segments, which can be nutrients for mold fungi. Furthermore, the hardened surfaces of MDF panel made by hot-pressing are removed by a sanding process in the production line. This sanding process could facilitate the growth of mold fungi on MDF surfaces.

Figures 2 and 3 are electron micrographs of wood-based composites exposed to the various fungi. In Fig. 2 are electron micrographs of plywood and OSB samples exposed to white rot fungi for 2 weeks and brown rot fungi for 4 weeks, respectively. Two wood-decay fungi (*P. chrysosporium* and *T. palustris*) attacked most of the wood composite samples treated. As indicated by the weight loss, the extent of deterioration by these decay fungi was most severe in plywood (Fig. 2a–d) and OSB (Fig. 2e–h). During early decay (2 weeks) of the plywood sample, most of the fungal mycelium were observed inside vessel lumens in the veneer, which had transverse sections on plywood edges. This observation indicates that large voids such as vessel lumens could promote the penetration of fungal hyphae, especially in hardwood plywood such as the aspen veneers used in this study. Microscopic examinations revealed that the brown rot fungus *T. palustris* was the most aggressive decay fungus of all the board materials used here.

As stated above, large voids between the flakes of OSB could play a similar role in the lumens of vessels in plywood. Figure 2h shows fungal hyphae present in a void of OSB. Particleboard appeared to be resistant to decay fungi, which might be attributed to the internal structure of the panel. Another reason might be the preservation of original surfaces without sanding, which is the case for MDF. In general, microscopic examination indicated that the internal structure of wood-based composites had a strong influence on the attack by wood-decay fungi.

In contrast, all three mold fungi limited their attack to board surfaces. A visual inspection revealed that surface discoloration was a typical deterioration of mold fungi in all board types (Fig. 3a). Mold fungal growth in plywood was concentrated exclusively on the exposed cross sections of the veneer layers (Fig. 3c). This finding suggests that the void space in the cross section provides a path for fungi to colonize the plywood surface. All three mold fungi covered the entire surface of MDF and showed good mycelial growth on the surface. Mold fungi (*Aspergillus* spp.) caused black discoloration on the surface of MDF (Fig. 3a). It was also observed that mold fungi (*Aspergillus* spp.) could penetrate the interfacial void between fiber bundles in MDF samples (Fig. 3e). The growth of this mold fungus showed a dense mycelium, most extensively on the surface of MDF (Fig. 3f). In contrast, the solid wood sample showed less susceptibility to mold fungal growth. This results are consistent with other reported results.[8] After an 8-week exposure, the spore and hyphae of mold fungi were extensively distributed on the surfaces of all board types.

Conclusion

The results showed that most commercial wood-based composite boards were more or less susceptible to microorganisms than solid wood. Particularly, plywood and OSB were most severely attacked by two wood-decaying fungi, with large weight losses after 8 weeks of exposure. It was also shown that mold fungi can degraded wood-based composite board even though it was not severe. The three mold fungi used in this study caused less than 5% weight loss after the same period of exposure. Typical deterioration of these mold fungi manifested as discoloration of board surfaces, which could damage the board's ability to resist fungal attack. The resistance of plywood to fungal attack was mainly dependent on the anatomical characteristics of the wood species used in the wood veneer. The attack of mold fungi was confined to board surfaces regardless of the type of board.

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