EFFECT OF FUNGAL ATTACK ON MAXIMUM LOAD CAPACITY OF SIMULATED WALL ASSEMBLIES

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Abstract. The effects of moisture intrusion and fungal attack on the maximum load capacity of nailed assemblies was investigated using one white- and one brown-rot fungus against four material combinations over a 35-wk period. Wetting significantly reduced the maximum load capacity of all four material combinations, whereas wetting and autoclaving only affected the oriented strandboard (OSB) sheathing/spruce stud assembly. The white-rot fungus (*Trametes versicolor*) had no significant effect on the maximum load, whereas the brown-rot fungus (*Gloeophyllum trabeum*) produced significant load reductions on shear connector assemblies with OSB sheathing. Results indicate that moisture remains the dominant initial factor in the performance when water intrudes into wall assemblies.

Keywords: Decay, fastener performance, plywood, oriented strandboard, Douglas-fir, Spruce-Hem-Fir, Southern pine, *Gloeophyllum trabeum*, *Trametes versicolor*.

INTRODUCTION

One of the central tenets of good building design, regardless of the building material, is to exclude water from entering into the structure (Zabel and Morrell 1992). Water intrusion in the building cavity can lead to corrosion of metal fasteners and create conditions conducive to fungal and insect attack. Despite the well-known need to avoid water intrusion, current construction practices still result in moisture entry and tighter buildings render this moisture incapable of leaving the structure. There is overwhelming evidence that a vast majority of currently constructed wood-frame structures have moisture-related issues, particularly in some building designs (Bronski and Ruggiero 2000).

Solving moisture issues once they are detected often involves extensive removal of materials as the engineer attempts to determine the extent of moisture-related damage and any subsequent degradation on building properties. Nowhere is this more critical than in the shear walls. Shear walls are designed to provide lateral stiffness to structures under high wind or earthquake loads. The ability of the connector assembly in the shear wall to absorb energy is critical to this performance and moisture-associated changes in properties of the individual components can have major effects on the function of these building elements. Wood strength decreases as it absorbs moisture to the FSP and continued wetting may allow growth of decay fungi (USDA 1999). Fungal attack has been reported to cause substantial losses in material properties at very early stages of decay and may exacerbate moisture effects (Wilcox 1978).

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Although there is general consensus that moisture intrusion is a major problem, there is less agreement on the effects of this moisture on building performance (Leichti et al 2005). Engineers are often faced with the difficult choice of removing or retaining obviously wetted material with little information on the possible effects of both the wetting and any subsequent microbial attack on the building integrity. In the absence of such information, many opt to remove all material that has experienced wetting, whereas others are more conservative in their approach and remove only areas where there is obvious microbial damage. The former approach can be very costly in terms of materials, whereas the latter might result in a building with a diminished capacity to perform under a storm or earthquake load. These issues illustrate the need for more applied information on the impacts of both wetting and biological attack on the properties of building assemblies.

In preliminary work, monotonic tests of aspen oriented strandboard (OSB)/Douglas-fir stud assemblies with single nailed connectors exposed to a brown-rot fungus (*Postia placenta*) for up to 30 wk showed that moisture uptake coupled with heating had dramatic effects on connector properties. Fungal effects on these same assemblies, however, often required 20 – 30 wk to become apparent despite extensive mycelial growth on the materials, particularly the OSB. These results, although surprising, suggested that some early decay did not necessarily necessitate complete replacement of wet/decaying assemblies (Kent et al 2004, 2006). However, these data represented only one set of material/fungal combinations. Clearly, decay capabilities and decay resistance can vary among fungi and materials, respectively (Zabel and Morrell 1992). To extend these results to other materials and fungi, the following tests were performed.

MATERIALS AND METHODS

The materials were purchased locally and then cut to size (Table 1). Composite panels were cut into 100 × 225 mm long by panel-thickness samples. The spruce and Douglas-fir lumber were cut into 225 mm lengths and a small groove (2 mm deep) was cut approximately 22 mm from the center of board surface that would eventually contact the panel. This groove provided a location where the fungus could be introduced into the connector assembly. A total of 120 assemblies was prepared for each material combination. The materials were then used to construct monotonic shear samples connected with a single 2.9 mm dia × 60 mm long brite smooth-shank nail (Senco 8D, SENCO Products Inc, Cincinnati) (Fig 1). The assemblies were soaked in water for 30 d at room temperature producing MCs of 122, 33, 40, and 63% for the OSB, Douglas-fir stud, spruce stud, and southern pine plywood, respectively. The assemblies were then placed into individual plastic bags equipped with a breathable patch. The bags were loosely sealed and then autoclaved for 50 min at 121°C. The bags were then heat-sealed to limit the risk of contamination until they could be inoculated.

Table 1. *Material combinations evaluated for resistance to fungal attack.*

Stud component	Sheathing component
Engelmann Spruce	Aspen OSB (11 mm)
	5-Ply CDX Douglas-fir plywood (12 mm)
Douglas-fir	Aspen OSB (11 mm)
	5-Ply CDX Douglas-fir plywood (12 mm)
	4-Ply CDX Southern pine plywood (12 mm)

OSB, oriented strandboard.

The samples were inoculated with one of two fungi, a brown-rot fungus, *Gloeophyllum trabeum* (Pers ex Fr.) Murr (Isolate Madison 617) or a white-rot fungus, *Trametes versicolor* (L:Fr) Pilat (Isolate R-105). The inoculum was prepared by inoculating 1.5% malt extract with an agar disk cut from the actively growing edge of a culture of the test fungus. The media was incubated for 2 – 3 wk at room temperature (20 – 23°C), and the resulting mycelium was collected by filtration on a sterile filter. The mycelium was washed with sterile distilled water to remove any residual media and then resuspended in sterile distilled water. This

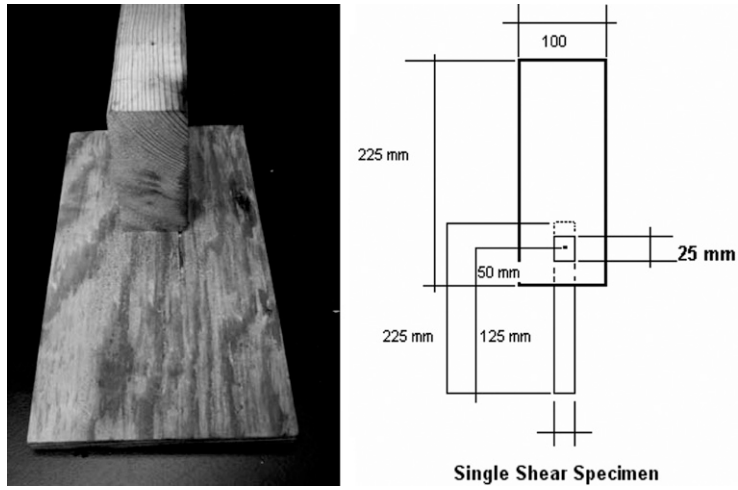

Figure 1. Photograph and schematic of the panel/stud test assembly used to evaluate resistance to fungal attack.

limited the chance that exogenous sugar from the media might influence the decay rate. The mycelium was then briefly macerated in a blender to fragment the hyphae before use. This approach more closely reflected the environment a fungus might face in a wall assembly because fungal fragments were introduced into the assembly instead of active growing mycelium.

The assemblies were inoculated by poking a hole in the plastic bag and injecting 115 L of inoculum into the groove cut in the sheathing component of the assembly. The hole was sealed with a small piece of tape, and the bags were incubated at 30°C and 85% RH. Sixty assemblies of each material combination were inoculated with each fungus and an equal number of noninoculated controls were prepared.

The effects of fungal attack on the assemblies were assessed 0, 10, 20, 25, and 35 wk after inoculation. The samples were first removed from the bags and scraped clean of any adhering mycelium before heating them in an oven for 3 h to stop all fungus growth. The samples were then conditioned to constant weight at 20°C and 65% RH over a 4 – 5 wk period.

The conditioned assemblies were then tested to failure on a Universal Testing Machine that applied the load through a specially designed jig that continuously displaced the specimen (10.4 mm/min) parallel with the longitudinal axis of the solid wood stud (Fig 1) (Polensek 1988; Kent 2004). The load and deflection were continuously recorded and these were used as the measure of heating and fungal effects on each assembly. A total of 10 assemblies was tested per fungus/material combination per time point. Sterilized but nonfungal inoculated assemblies were also tested to assess the effects of preparation on performance.

The data were subjected to analysis of variance to determine if there were differences in maximum load capacity of the assemblies between various materials over time. Means for the nonfungal-exposed controls and the fungal-exposed samples were then compared using a Welch Modified two-Sample t-test at a = 0.05.

RESULTS AND DISCUSSION

The extent of fungal growth varied widely with fungus and substrate over the 35-wk exposure. *T. versicolor* tended to produce thick mycelia and covered substantial portions of the assemblies, whereas *G. trabeum* produced thin mycelia and tended to have sporadic colonization.

The presence of mycelial growth, however, is not always an indicator of substantial wood degradation (Zabel and Morrell 1992).

Moisture absorption during soaking of the assemblies produced swelling of both the solid wood and composite panels, but swelling was more pronounced in composites, especially the OSB. Irreversible thickness swelling is a common feature of OSB (Wu and Piao 1999), causing an overall reduction in the board mechanical properties, but it is unclear what effect this loss in panel properties would have on connector performance. This effect illustrates the inherent dangers associated with moisture intrusion in structures; however, the effects of wetting appear to be muted in larger, partially wetted wall systems. Leichti et al (2006) found no significant loss in shear wall capacity after a wet–dry cycle.

Fungal exposure of the assemblies produced variable effects on maximum load, depending on the fungus and materials involved (Table 2). Assemblies exposed to the white-rot fungus, *T. versicolor*, appeared to show some declines in maximum load over the 35-wk exposure, but the differences were not significant. These results seem at odds with the extensive mycelial growth on the assemblies and illustrate the difficulty of visually assessing the effects of decay in a structure.

The apparent inability of the white-rot fungus to induce substantial damage on softwood-based assemblies was not surprising given the nonsoil contact exposure and the tendency for this fungus to be more active on hardwood materials. However, the lack of effect on assemblies containing aspen OSB was unexpected given the well-known susceptibility of this material to fungal attack (Laks et al 2002). One possible explanation was that OSB exhibited variable moisture absorption, rendering it less suitable for white-rot attack. In many cases, white-rot fungi appear to require slightly higher moisture levels. This requirement often leads researchers

Table 2. *Average maximum loads of various sheathing stud wall assemblies left dry or wetted/autoclaved and inoculated with brown- or white-rot fungi.*

Material combination	Exposure time (wk)	Maximum load (N)†		
		Control	*G. trabeum*	*T. versicolor*
OSB/DF stud	0	1728 (380)	1728 (380)	1728 (380)
	10	1629 (277)	1137 (341)	1920 (230)
	20	2160 (410)	1114 (557)	1697 (322)
	25	1631 (289)	1158 (382)*	1538 (214)
	30	1684 (363)	607 (205)*	1536 (377)
	35	—	836 (317)*	1782 (354)
OSB/Spruce stud	0	1605 (128)	1605 (128)	1605 (128)
	10	1702 (426)	1284 (231)	1653 (198)
	20	1877 (507)	1176 (259)	1899 (323)
	25	1677 (322)	981 (474)*	1450 (210)
	35	1638 (241)	880 (581)*	1679 (230)
SYP plywood/DF stud	0	2404 (240)	2404 (240)	2404 (240)
	10	2688 (296)	2445 (416)	2530 (278)
	20	2388 (406)	2039 (489)	2312 (277)
	25	1913 (275)	1479 (234)*	1935 (215)
	35	1940 (314)	1724 (284)*	2101 (224)
DF plywood/Spruce stud	0	2089 (230)	2089 (230)	2089 (230)
	10	2370 (379)	2382 (262)	2398 (312)
	20	2320 (325)	2252 (383)	2257 (226)
	25	1754 (151)	1684 (210)	1838 (215)
	35	1591 (110)	1710 (227)	1849 (148)

† Values represent means of 10 replications per cell, whereas figures in parentheses represent one standard deviation. Values with an asterisk differ significantly from the control by a Welch modified two-sample t-test at $\alpha = 0.05$.

OSB, oriented strandboard.

to place test blocks beneath the soil when exposing them to this fungus in soil block tests instead of on the feeder strip above the soil surface (AWPA 2005). Creating more suitable moisture conditions may be one approach to increasing the ability of the white-rot to colonize the wood. This would more closely replicate high moisture environments encountered when extensive water intrusion has occurred in a wall assembly.

Exposure of assemblies to the brown-rot fungus, *G. trabeum*, produced declining maximum loads in all material combinations, although the differences were not significant in the Douglas-fir plywood/spruce stud combination (Table 2). Declines in maximum load tended to begin earlier and be much greater in assemblies containing OSB sheathing. OSB/Douglas-fir stud assemblies lost 52% of their original load capacity after 35 wk, whereas OSB/spruce assemblies lost 45% of their original capacity. In comparison, Douglas-fir studs/southern pine plywood assemblies lost only 28% of their original capacity, whereas Spruce studs with Douglas-fir plywood lost only 18% of their capacity over the 35-wk exposure period. A substantial component of all these losses can be attributed to the moisture effects. Although the moisture effect varied with components in the assemblies, they ranged from 5 – 30% and were the primary agent of load loss for the first 10 – 20 wk of the tests.

G. trabeum is a common fungus in aboveground exposures, particularly in walls and windows (Duncan and Lombard 1965). Like most brown rots, it is capable of producing substantial losses in strength at relatively early stages of decay and ultimately produces 60 – 70% weight loss. This fungus seems to be capable of attacking both softwood and hardwoods and its ability to impact both the softwood studs and hardwood OSB sheathing supports this premise. The impact of *G. trabeum* on the Douglas-fir stud/OSB assembly was similar to that found with *Postia placenta*. The latter fungus caused almost 64% loss in maximum load over a 30-wk exposure (Kent et al 2004). In both current and previous research, there was a substantial lag between the time the fungus was introduced and when maximum load was applied. This lag creates an interesting dilemma for engineers seeking to estimate residual capacity in structures where moisture intrusion has occurred.

The times among moisture introduction, introduction of the fungus, and the initiation of substantial fungal degradation are major concerns in assessing the residual capacity of a building. Moisture intrusion clearly had a major impact on properties, but the effect did not increase over time in the absence of a fungus. Mycelial fragments represent the most probable source for inoculation in a structure (except where fungi are already present in green lumber). The fungus must then grow and extend through the wood. Our previous studies would suggest that this extension and colonization phase is relatively rapid (Smith et al 1992); however, the initial impacts on material properties in the absence of exogenous nutrients are less rapid. This delayed effect is particularly true in applications where changes in mass can have the greatest influence on the property of interest, like with our sheathing/stud assemblies where connector behavior is heavily influenced by material mass.

Our results, coupled with those previously reported for *Postia placenta*, would suggest that fungal attack initially progresses slowly; however, fungal effects began to become important within 6 mo of initiation. The effects of *T. versicolor* in these assemblies was much slower, probably as a function of the inability of the fungus to cause substantial degradation of the coniferous components as well as the need for higher MCs by this fungus.

CONCLUSIONS

Moisture intrusion and the associated swelling had substantial impacts on the capacity of individual nailed joints. Fungal attack, although eventually important in some fungal/material combinations, clearly takes much longer to exert an influence on capacity. Although white-rot fungi can colonize these materials, brown-rot

fungi are clearly more of a concern because of their ability to cause more rapid losses in properties. These data could eventually be used to develop predictive curves for assessing the effects of either white- or brown-rot fungi on connector behavior, although it will be necessary to evaluate more fungi before such curves could be used in practice.

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