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Section 1 Biology

Limiting Conditions for Decay in Wood Systems

Paul I Morris[1] Jerrold E Winandy[2]

1. Forintek Canada Corp.
2665 East Mall, Vancouver, BC
V6T 1W5 Canada,

2. USDA Forest Products Laboratory
Forest Service
Madison, WI 53705-2398 USA

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Paul I Morris[1] and Jerrold E Winandy[2]

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ABSTRACT

Hygrothermal models can predict temperature and moisture conditions in wall components subjected to real weather data, but specific data and a fundamental understanding of how temperature and wood moisture content dictate the progression of decay under these conditions is required for modellers to predict consequences of decay on building performance. It is well understood that wood will decay above 30% moisture content and will not decay below 20% moisture content. Moisture contents between 20% and 30% represent a grey area. This paper describes cooperative work underway at our two Institutes to define limiting conditions of humidity/moisture and temperature that allow the initiation and progression of decay to diminish the structural performance of wood and wood composites as used in North American light-framed construction. Some preliminary results on time to initiation of decay in wood composites and moisture thresholds for wood materials under steady state environmental conditions are presented. Such a fundamental understanding of the limiting thresholds and eventual rates of decay above those thresholds is mandatory before legitimate models can be developed to predict the expected or residual serviceability of new or old building materials, respectively.

KEYWORDS: Decay, time, temperature, moisture content, relative humidity

1 INTRODUCTION

Using mathematical models for heat, moisture and air transport in wood-frame systems, and real weather data, building scientists can predict how variation in material properties and wall designs affect the moisture content (MC) and temperature of wall components (*inter alia* Karagiozis and Kumaran 1997) and roof systems (TenWolde 1997). The next critical step is to predict what effect that moisture will have on the structural performance of the building system (Nofal and Kumaran 1999, 2000). This requires data on the limiting conditions for decay.

It is widely understood that for decay fungi to grow effectively in wood, the MC must be above the fibre saturation point, around 28% to 30% MC (Griffin 1977, Zabel and Morrell 1992. It is now considered that the lower limit of 20% moisture content provides a margin of safety against fungal decay (Wood Handbook, ASHRAE Handbook). The 20% rule was developed at a time when the majority of wood was air-dried and may well have become infected with decay fungi

during the drying process. Decay produces water, so it is more difficult to stop than it is to prevent from starting. Today, we recognise that while existing decay may continue until the wood is dried below 20%, infection of kiln dried (normally sterile) lumber cannot occur until the MC is higher than around 25% (Viitanen 1997). Nevertheless the 20% to 30% region represents a grey area for decay.

Data on *Coniphora puteana* (the cellar fungus) on sapwood of European wood species have been developed through extensive work at VTT in Finland (Viitanen and Ritschkoff 1991, Viitanen 1997). However, the Finnish results need to be confirmed for Canadian and US wood products. In addition, the work needs to be done using fungi prevalent in buildings in North America.

For the purposes of developing a model for strength loss of wood components, the decay process under fluctuating conditions can be divided into three stages (Nofal and Kumaran 2000):
(1) Establishment
(2) Growth and decay
(3) Survival

The key issue in stage 1 is the time required for the wood rotting basidiomycetes (WRB) to become established on the wood and this is controlled by the development of suitable conditions for germination of WRB spores and the probability of their arrival at that location. Spore germination requires the coincident occurrence of MC above a threshold, adequate temperatures, nutrient availability, non-durable wood and the absence of antagonistic influence of other fungi. Establishment of WRB is normally preceded by a sequence of micro-organisms such as bacteria, moulds and staining fungi that are very effective at rapidly colonizing wet wood and excluding WRB (Clubbe 1980). Not until these bacteria and fungi have used up the non-structural carbohydrates, and are becoming moribund, can decay fungi get a foothold.

Other than that from Finland, relatively little work has been reported in the literature on establishment under marginal moisture conditions. Viitanen (1997) demonstrated colonisation of non-sterile sapwood of European wood species by artificial inoculation with *C. puteana* when the MC remained at 25% for around three months. Heartwood with a higher natural durability would be expected to take much longer for establishment. Different decay fungi may also respond differently.

Once the conditions are suitable for WRB establishment, the probability of arrival of a WRB spore has to be considered. Basidiospores can constitute up to 50% of the air-spora at certain times of the year (Gregory 1973), but many of these will not be WRB. Even when equally susceptible wood samples are exposed outdoors, not all of them become infected immediately. Figure 1 illustrates the change in percentage of untreated hem-fir L-joint (simulated window joint) samples showing decay with time (Morris 2000). Despite being prepared to be as close in properties as possible, only 40% showed signs of decay after two years and 53% after three years. This suggests that there is approximately 0.18 probability of infection each year. Wood components within a wall would be expected to have considerably lower exposure to the air-spora unless there is a deficiency or opening in the façade allowing them to enter the wall.

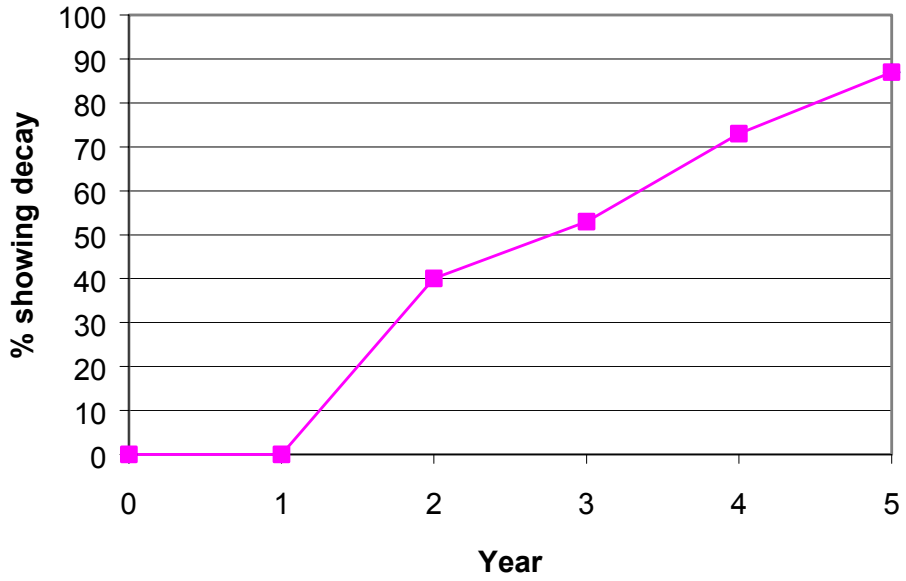


Figure 1: **Percentage of Untreated Pine Sapwood L-Joint Samples Showing Decay When Exposed Outside in Vancouver BC.**

The key factors in stage 2 are the wood MC, the durability of the wood and the type of decay fungus. To date, the overwhelming majority of experiments on the effect of fungi on the strength properties of wood have been done using wood in contact with a source of liquid water and surrounded by air at close to 100% RH (*inter alia* Schmidt *et al* 1983). Optimum moisture contents for decay range from 40 to 80% (Zabel and Morrell 1992, Viitanen and Ritschkoff 1991). Under ideal moisture and temperature conditions in the laboratory, established brown-rot fungi can cause extremely rapid loss in strength (Winandy and Morrell 1993, Curling et al 2001).

From a literature review, Wilcox (1978) reported loss in compression strength, important for wall plates, up to 60% in one week, in sapwood exposed to WRB mycelium under ideal conditions (optimum MC and no antagonistic moulds). Under the same conditions, moderately durable heartwood lost 25%. For compression parallel to grain, important for studs, sapwood might lose up to 40% and moderately durable heartwood up to 15% in one week under ideal conditions. Of course, ideal conditions rarely occur in properly built envelopes. At just above threshold moisture contents, in the presence of competing fungi, the rate of strength loss will be much slower (Viitanen and Ritschkoff 1991).

The key factors in stage 3 of the model, survival, are the type of decay fungus (its resistance to desiccation and temperature variation), and the speed with which the wood dries out. Some decay fungi are better than others at resisting antagonistic secondary mould fungi that can attack once the wood dries below the minimum for growth of WRB (around 25%) and before it drops below the minimum for mould growth (around 16%). The faster the drying rate, the shorter the time for attack by secondary moulds. When dried rapidly, some WRB can survive, without causing strength loss, for years at moisture contents to which wood in buildings will equilibrate once moisture sources are removed (Viitanen and Ritschkoff 1991). We are not aware of any

data on loss of viability of WRB under cyclical wetting and drying conditions. Long term planning for Forintek's work includes investigation of the effect of cyclic wetting and drying on establishment, growth, decay and survival of WRB.

Forintek Canada Corp. has a current project titled Limiting Conditions for Decay investigating the time to establishment and threshold MC for WRB on Canadian wood products under non-sterile conditions. This project is focussing on oriented strand board (OSB) and plywood because hygrothermal models using real weather data (Nofal *et al.* 2001) and full scale experiments on drying of panels with initially uniform moisture distribution (Hazleden and Morris 2001) have shown the sheathing stays wet longest.

The Forest Products Laboratory of the US Department of Agriculture currently has a series of projects underway to determine rates of decay under a wide range (from optimal to marginal) of moisture conditions. FPL scientists have been studying the critical MC threshold for brown-rot decay to progress at or near 25C when exposed to liquid mycelial cultures (Curling et al 2000, 2001). Their technique is to start with 200-mm long air-dried pine specimens and allow them to absorb moisture over a 2.5-mm long center section from a moisture-limited vermiculite media. The vermiculite media is held at various water-holding capacities, which in turn limits the rate of wetting and maximum wood MC. They later found that brown-rot decay quickly progressed at 32% wood MC, initiated but progressed more slowly at 29% MC, and they were unable to initiate decay after 4 weeks at 26% MC followed by a slow desiccation down to 22% MC at the 10^{th} week (Winandy *et al* 2002). Because the primary objective of the FPL work is to predict rate of decay, rather than time to initiation of decay, fungal inoculation is in the form of massive liquid mycelial suspension that is not necessarily representative of initial spore-initiated infection. However, it may well approximate the spread of decay from infected wood to new substrates.

2 MATERIALS AND METHODS

2.1 Forintek

The objective was to develop a method to identify the time to detectable loss in strength properties using standard testing procedures. Since time was the unknown factor, it was necessary to evaluate the condition of the material at frequent intervals over a long exposure period. Although stiffness is less affected by decay than failure load capacity, using non-destructive stiffness testing allowed a high frequency of evaluation with the minimum number of replicates. Test pieces were exposed to conditions believed to be conducive to decay, inoculated with WRB, and tested for stiffness every two weeks and for bending load capacity at wider intervals. The preliminary experiment to develop the test method used only OSB.

Test specimens 50 mm x 457 mm x 12.7 mm were cut from 12 panels of OSB from the same production run and distributed among the test groups. The samples were placed in a conditioning chamber, smooth side up, on racks made from plastic tubing. Extra fans were added to improve air circulation. The chamber was operated at 20C and a relative humidity (RH) as close as possible to 100%. Because of the difficulty in measuring RH above 90%, the

RH was estimated based on the equilibrium moisture content (EMC) of spruce wood blocks determined by oven-drying. Based on the EMC of 27%, essentially fibre saturation point (Griffin 1977), and readings from a RH and temperature meter (Viasala model HM414) accurate to ± >3% above 90% RH, the RH was estimated at 99.9%. OSB samples were weighed at regular intervals to determine when EMC was reached. The point at which the OSB EMC stabilised was taken as time zero.

At t_0 and every two weeks thereafter, two groups of samples were inoculated on the upper, smooth side with either a brown rot fungus *Gleophyllum trabeum* (Pers. : Fr.) or a white rot fungus *Trametes versicolor* (L.: Fr.) Pilat. The inoculum consisted of 1 mm cubes of fungal mycelium plus agar from cultures growing on 1.5% malt agar plates. This was in lieu of spore inoculum, which was deemed too difficult to do on a reliable basis. One group was left uninoculated. Immediately prior to each inoculation, sets of 30 samples from each group were non-destructively tested for bending stiffness. A load of 10-18 pounds was applied using four point loading, to the OSB, placed inoculated side down, using method B of ASTM 3043 (ASTM 1999). The load was selected to be within the linear part of the load-deformation curve and to cause no detectable reduction to the ultimate capacity. This is confirmed by extensive testing. When removed from the conditioning chamber, these samples were kept at EMC by wrapping in plastic except during the bending test. Approximately every 100 days, sets of 30 samples were tested for bending load capacity (and stiffness) using the same test method. The moisture content of the failed specimens was determined by oven-drying.

2.2 FPL

Defect-free southern pine (*Pinus* spp) sapwood test specimens (200 x 25 x 9.5mm) were air dried to approximately 12% moisture content. The eight specimens per pan were exposed to various wood-moisture scenarios using the FPL soil pan decay technique (Curling et al 2000, 2001) (Figure 2). Deionised water was specifically added to each pan to bring the moisture content of the vermiculite up to 15%, 25%, 50%, 66%, 75% or 88% of the water holding capacity (WHC) of the media (determined from 6 random samples of the media using the method described in ASTM D2017-91 (ASTM 1994)). The specimens and pans were steam sterilised for ¾ hour at 105C. The wood specimens were then placed, using aseptic technique, onto the pre-formed ridge in the vermiculite. At each of the 6 moisture conditions evaluated, seven specimens were placed into each pan. The centre sections of the specimens (middle 50 mm) were then covered to a depth of 20 mm with sterile vermiculite, at a moisture content equal to that of the base vermiculite (Figure 2). The sterile, uninoculated pans were placed into a controlled conditioning room maintained at 25C and 70% RH for 3 weeks. Individual 200 mm specimens were aseptically removed at various times over a 21 day period and then cut into 8 equal (25 mm) lengths (Labelled A-H as shown in Figure 2). The moisture content of each 25 mm block was immediately determined.

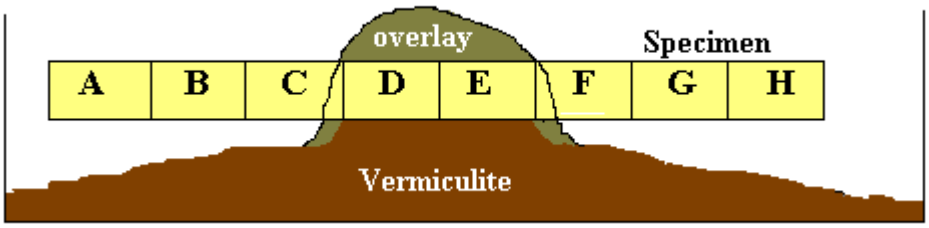
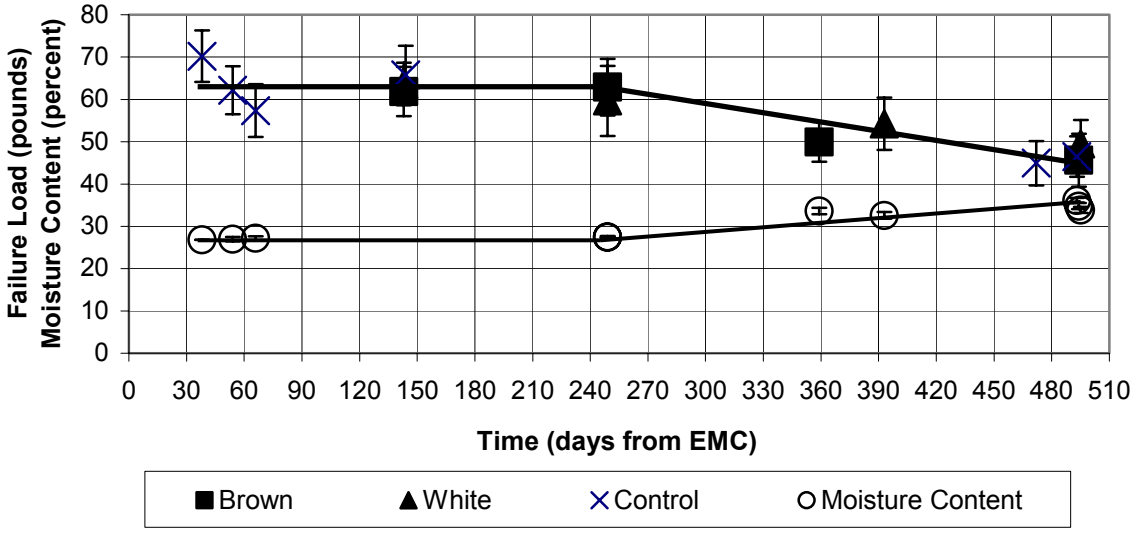


Figure 2. Diagram Showing Experimental Set Up During Exposure and the Location of Sub-Samples After Removal and Cutting (from Curling et al 2001).

3 RESULTS

3.1 Forintek

The inoculated WRB failed to establish during the course of the experiment, however basidiomycete mycelium was observed on the underside (screen side) of some samples after ten months from t_0. Mean bending stiffness began to drop after approximately eight months but this was only noticeable retroactively. Fruitbodies developed on some samples and these proved to be a natural infection of a basidiomycete, identified as being closely related to the Atheliaceae or Sistotremataceae. There was considerable variation in the proportion of samples showing basidiomycete growth related to the location in the chamber. Dividing the samples into two sets revealed a distinct drop in bending stiffness (data not shown) and bending load capacity (Figure 3) for the 15 samples nearer the door, presumably because the infection was caused by spores that came in when the door was momentarily opened to gain access to the chamber. The data for the 15 samples nearest the door indicate initiation of loss in load capacity at approximately eight months. The moisture content of the failed specimens remained at 27% up to the eight-month evaluation, rising to 32% at 13 months and 34% at 16 months as decay progressed (Figure 3).



Note: Material inoculated with white-rot and brown-rot fungi and controls all became naturally infected with an as-yet unidentified basidiomycete. They can are therefore be considered as a single population.

Figure 3: Mean Loss in Bending Capacity of 15 OSB Samples Nearest the Door Exposed at 20C and 100% RH and Inoculated Every Two Weeks with White-rot or Brown-rot Fungus. Error bars represent 95% Coefficient of Variance.

3.2 FPL

The MC of the individual sections varied along the length of the sample. The moisture profiles for samples exposed at 100, 75, and 25% of WHC are shown in Figure 4. The middle section (D & E) which were in direct contact with the vermiculite overlay had the highest infusion of moisture and eventually had the highest final MC. Each moisture condition tested exhibited the same trend to some varying degree. The MC of each section increased rapidly over time until a peak moisture was achieved. Moisture entering the wood in middle area (sections D & E) progressively wicked out towards the ends of the samples (Sections A and H). Eventually an equilibrium moisture condition was achieved. The MC of sections not in contact with the vermiculite increased but not as rapidly or to the same level as sections D & E which had vermiculite contact. This work has resulted in the development of a model to predict wood MC in the most-heavily decay prone middle sections (Winandy et al 2002). In that work, they have been able to promote wood brown-rot decay at pine MCs of 32% and at 29% held steady over 8-10 weeks with slight desiccation thereafter. However, they did not achieve measurable decay in wood that achieved 26% MC for 2-3 weeks with progressive desiccation down to 22% MC over the next 8 weeks. This work has shown that periodic addition of sterile moisture during the cake-pan decay technique can compensate for desiccation. It allows us to more precisely control the wood moisture content in our attempt to understand decay rates and critical wood-moisture thresholds for decay.

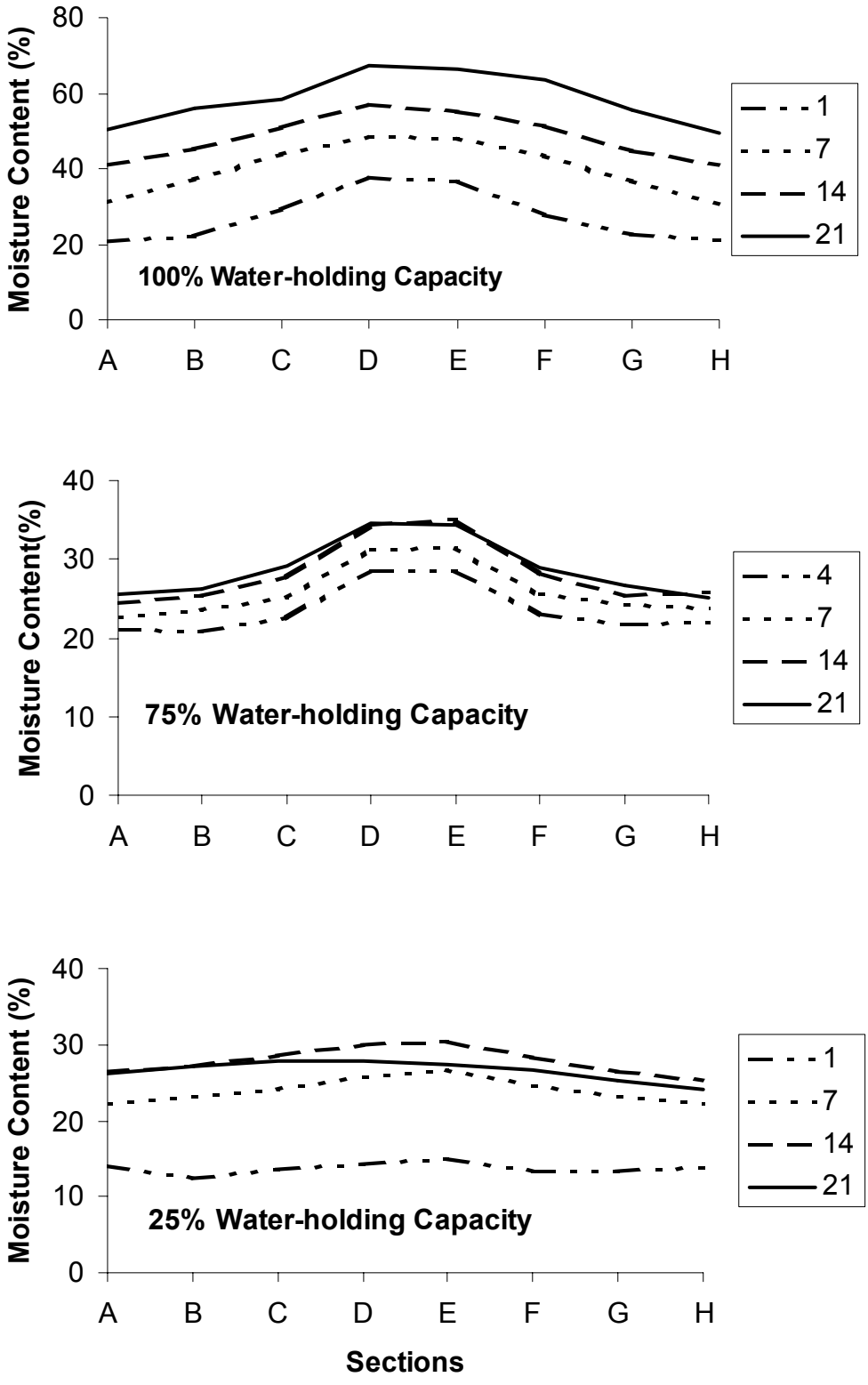


Figure 4: **Wood MC From 1 to 21 Days of Exposure at Various Soil Water-Holding Capacities**

4 SUMMARY

The preliminary work at Forintek to develop the test method has confirmed that decay of OSB can be initiated at 27% MC when exposed to an estimated 99.9% RH at 20C. However, under these conditions OSB did not start to decay for 8.5 months despite inoculation every two weeks with WRB. Full-scale tests with OSB and plywood have now been set up at 90, 95 and 99.9% RH. The test chambers have been fitted with ventilators to provide a natural air spora on a more controlled basis. Inoculation will still be done, but on the screen side. Initiation of more frequent strength testing will be triggered by visual observation of basidiomycete growth.

FPL research has developed a laboratory technique to access the effect of decay on wood strength (Curling et al 2000, 2001). Subsequent work has shown that wood MC can be controlled using this technique by controlling the available soil moisture from the partially saturated vermiculite media to the dry wood specimens (Winandy et al 2002). Work is now progressing to identify the limiting threshold of wood MC required for decay to progress when initiated via inoculation rather than when decay initiates via spore development, to model the rate of decay at various moisture contents, and eventually to understand the effect of exposure temperature on each.

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6 REFERENCES

American Society for Testing and Materials. 2001. ASTM D 2017-81 (re-approved 1994). Standard method of accelerated laboratory test of natural decay resistance of woods. ASTM, West Conshohocken, PA, USA.

American Society for Testing and Materials. 1994. ASTM D 2017-81. Standard method of accelerated laboratory test of natural decay resistance of woods. ASTM, Philadelphia, PA, USA.

American Society for Testing and Materials. 1999. ASTM D 3403-95. Standard methods of testing structural panels in flexure. ASTM, Philadelphia, PA, USA.

ASHRAE 1995. 1995 ASHRAE Handbook - Heating, ventilating, and air-conditioning applications. SI Edition, Chapter 3. pp. 3.1-3.13 Atlanta: American Society of Heating, Refrigerating, and Air - Conditioning Engineers, Inc. Atlanta, GA. USA.

Clubbe, C. P. 1980. The colonisation and succession of fungi in wood. International Research Group on Wood Preservation. Document No IRG/WP/1107. Stockholm, Sweden.

Curling, S., C. Clausen and J. Winandy. 2001. The effect of hemicellulose degradation on the mechanical properties of wood during brown rot decay. International Research Group on Wood Preservation. Document No IRG/WP/20219. Stockholm, Sweden.

Curling, S., J. Winandy and C. Clausen. 2000. Technique to access the effects of brown rot decay on the mechanical properties of wood. International Research Group on Wood Preservation. Document No IRG/WP/00-20200. Stockholm, Sweden.

Gregory, P. H. 1973. The air spora near the earth's surface. in: The Microbiology of the Atmosphere 2nd Edition. Leonard Hill. Aylesbury, UK.

Griffin, D. M. 1977. Water potential and wood decay fungi. Ann. Rev. Phytopathol. 15: 319-329.

Hazleden, D. and P. I. Morris. 2001. The influence of design on drying rates in wood frame walls. In: Performance of Exterior Envelopes of Whole Buildings. ASHRAE conference VIII. ASHRAE, Atlanta, GA. USA.

Karagiozis, A. N. and M. K. Kumaran. 1997. Application of hygrothermal models to develop building envelope design guidelines. pp. III 13-III 24 in 4th Japan/Canada Housing R&D Workshop (Sapporo, Japan).

Morris, P. I. 2000. Ten year performance of L-joints made from borate diffusion treated wood. International Research Group on Wood Preservation. Document No. IRG/WP/00-30225. Stockholm, Sweden.

Nofal, M. and M. K. Kumaran, 1999. Durability assessments of wood-frame construction using the concept of damage-functions. In: Proceedings of the 8th International Conference Durability of Building Materials and Components. Lacasse, M. and D. Vainer. (Eds.) NRC Research Press. Ottawa, ON. Canada.

Nofal, M., M. Straver and M. K. Kumaran. 2001. Comparison of four hygrothermal models in terms of long-term performance assessment of wood-frame constructions. Proceedings of the 8th conference of Canadian building science Solutions to moisture problems in building enclosures. Straube J., (Ed.), pp. 118-138.

Nofal, M. and M. K. Kumaran. 2000. On implementing experimental biological damage-functions models in durability assessment systems. Proceedings of Bugs, Mold and Rot III in press.

Schmidt, E. L., H. J. Hall, R. O. Gertjejansen, C. G. Carll and R. C. DeGroot. 1983. Biodeterioration and strength reduction in preservative treated aspen waferboard. Forest Products Journal. 33 (11/22): 45-53.

TenWolde, A. 1997. FPL roof temperature and moisture model—description and verification. Res. Pap. FPL–RP–561. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 48 p.

Viitanen, H., 1997. Modeling the time factor in the development of brown-rot-decay in pine and spruce sapwood – The effect of critical humidity and temperature conditions. Holzforschung. 51(2): 99-106.

Viitanen, H. and A. C. Ritschkoff. 1991. Brown rot decay in wooden constructions: Effect of temperature, humidity and moisture. Swedish University of Agricultural Sciences, Departments of Forest Products, Report No. 222, pp. 57.

Wilcox, W. W. 1978. Review of literature on the effect of early stages of decay on wood strength. Wood and Fiber. 9(4): 252-257.

Winandy, J. E., S. Curling and P. K. Lebow 2002. Controlling wood moisture content during durability testing using the FPL soil pan decay technique. Submitted to Forest Products Journal.

Winandy, J. E. and J. J. Morrell 1993. Relationship between incipient decay, strength, and chemical composition of Douglas-Fir heartwood. Wood and Fiber Science 25(3): 278-288.

Wood Handbook: Wood as an Engineering Material. 1999. Forest Products Society. Madison WI. USA.

Zabel, R. A. and J. J. Morrell. 1992. Wood Microbiology: Decay and its Prevention. Academic Press. San Diego, CA. USA.