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EFFECT OF BROWN ROT DEGRADATION ON MASS LOSS AND COMPRESSIVE STRENGTH OF CHINESE POPLAR (*Populus simonii*)

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ABSTRACT

The wood of poplar species are generally perceived as susceptible to decay, however, poplar is still widely used as columns in traditional Chinese buildings. Understanding how decay affects the compressive properties of this material will help engineers better assess wood condition during routine inspection and maintenance. The effects of decay on compressive properties of Chinese poplar were explored using a brown rot decay fungus (*Gloeophyllum trabeum*). Changes in compression strength were fairly linear and more closely correlated with mass loss (R^2= 0.75). The results suggest that residual compressive strength could be roughly predicted using wood density as a surrogate measure.

Keywords: Biodeterioration, decay fungi, *Gloeophyllum trabeum*, mechanical properties, *Populus simonii* .

INTRODUCTION

Decay fungi can have profound effects on wood properties at early stages of decay. Mass loss as low as 1 to 3% can result in bending strength loss approaching 60 to 80% (Wilcox 1978, Yang *et al.* 2006). Brown rot decay fungi tend to be associated with more rapid loss of wood strength properties than white rot fungi, due to their ability to randomly cleave cellulose chains far in advance of fungal growth (Zabel and Morrell 1992). Bending and tensile strength are among the properties commonly used to assess the effects of fungal attack on wood properties; but wood is used in numerous loading situations where other properties are important (Jin *et al.* 1988, Curling *et al.* 2002, Ge *et al.* 2016, Liese and Stamer 1934, Malda *et al.* 2015, Winandy and Morrell 1993, Witomski *et al.* 2016).

Timbers are often used in columns where compression and bending properties are both important (Forest Products Laboratory 2010). Unlike tension or bending strength, compressive strength tends to be more closely related to density and should therefore be more closely correlated with mass loss (Forest Products Laboratory 2010). This would render the decay strategy differences of white and brown rot fungi less important. However, the tendency of brown rot fungi to depolymerize cellulose may have other, more subtle effects on compressive strength (Jin *et al.* 1988).

Poplars are commonly planted in North China where their fast growth and ability to withstand harsh conditions make them attractive an species for reforestation efforts. Poplars are generally perceived to be non-durable, but they have a long history of use as columns in traditional Chinese structures where they are exposed out of soil contact and generally protected from wetting. However, decay does occur in these structures and it is important to understand how fungi affect column properties.

55 The goal of this project was to evaluate the effects of a brown rot fungus on compressive
56 strength parallel to the grain of Chinese poplar (*Populus simonii*).

57 **MATERIALS AND METHODS**

58 Small clear *of Chinese poplar (Populus simonii,* Carrière*)* specimens were cut from a 1 m-long
59 green log section. The log was cut 1.3m above the ground on a 30-year-old poplar tree harvested
60 from Dailing Forest in the Grand Khingan Mountains located in northeast China. Twenty one
61 samples of air-dried *P. simonii* were cut to 20 by 20 by 50 mm long. The samples were oven
62 dried (104 °C) and weighed (nearest 0.001 g) before being sterilized by heating at 121 °C for 90
63 minutes.

64 Decay chambers were prepared by adding 15 g of Chinese poplar sawdust and 8.5 g of corn meal
65 to 150 g of clean river sand (AQSIQ, 2009a). The mixture was placed into a 500 ml Erlenmeyer
66 flask. One hundred ml of a mixture containing 9.4% malt extract and 1 g of unrefined cane sugar
67 were added to the sand mixture. Four pieces of poplar (20 by 20 by 5 mm long), each with a
68 small hole drilled on the surface were placed onto the sand surface to serve as feeder strips for
69 the test fungus. The flasks were sealed with tight fitting cotton plugs before being sterilized by
70 heating at 121 °C for 90 minutes and allowed to cool. The plugs limited the risk of
71 contamination but allowed for some air exchange.

72 The test fungus (*Gloeophyllum trabeum* (Pers.ex. Fr.) Murr. (Isolate # 5.98, Northeast Forestry
73 University, Harbin , China) was grown on 1.5% potato dextrose agar until it completely covered
74 the media surface. Small discs were cut from the edge of the actively growing culture and placed
75 into the holes drilled into the poplar feeder strips. The flasks were covered and incubated at 25
76 °C and 70% relative humidity until the fungus covered the feeder strip surfaces. The test blocks

77 were placed onto the feeder strips (cross section face down) and the flasks were incubated at 25
78 °C and 70% RH for 15 to 90 days.

79 The effect of fungal attack on wood properties was assessed at 15-day intervals by removing
80 eight test samples that were oven dried and weighed as previously described. The difference
81 between initial and final weight loss was used to calculate mass loss. The top 20 mm of each
82 block was cut off and the remainder was conditioned to constant weight at 23 °C and 65% RH
83 (to an approximate moisture content of 12%). The remainder of each block was used for
84 microscopic examination.

85 Compression parallel to the grain was evaluated following procedures described in Chinese
86 Standard GB/T 1935-2009 (AQSIQ SAC (2009)). Briefly, the specimen was placed on a CMT-
87 6305 Testing machine (SUNS Company, Zhuhai, China) and load was applied to the cross
88 section at a rate of 10 mm/minute. Load and displacement were continuously recorded and the
89 test continued until the specimens reached the yield limit. Compressive strength was then
90 calculated using the formula (1):

91 $$\sigma_w = \frac{P_{max}}{bt} \quad (1)$$

92 Where: σ_w is the compressive strength parallel to grain at w % of moisture content in the sample,
93 MPa; P_{max} is the maximum load, N; b is specimen width, mm and t is specimen depth, mm.

94 The compressive strength data were then adjusted using formula (2):

95 $$\sigma_{12} = \sigma_W[1 + 0.05(W - 12)] \quad (2)$$

96 Where σ_{12} is the compressive strength parallel to grain at 12% of moisture content in specimen,
97 MPa; W is actual moisture content of specimens, %.

98 The remaining 20 mm long section exposed to the decay fungus was used to examine fungal
99 colonization. Small cubes were cut from the inner end of the specimens, dried through a graded

100 alcohol series and finally soaked in pentene. The pentene was allowed to evaporate and the dry
101 specimen was sputter coated with gold palladium. The specimens were examined using a Quanta
102 200 Electron microscope at an accelerating voltage of 10.0kV. A minimum of 5 fields were
103 examined for each specimen. This examination was not quantitative; it was only intended to
104 determine where the fungus was most prevalent in the wood cells.
105

106 **RESULTS AND DISCUSSION**

107 Mass loss averaged 2.14% after 15 days of fungal exposure and steadily increased with
108 incubation time to an average of 44% mass loss after 90 days (Table 1).

Table 1: Effect of exposure to *G. trabeum* on mass loss and compressive strength parallel to the grain of Chinese poplar specimens.[a]

Exposure Time	Mass Loss (%)	Compression Parallel to Grain (MPa)
0	-	34.24 (3.72)
15	2.14 (0.68)	35.78 (4.44)
30	8.83 (0.59)	28.10 (2.79)
45	34.91 (6.09)	21.69 (5.48)
60	39.07 (4.02)	16.54 (1.72)
75	41.52 (5.33)	13.86 (2.98)
90	44.12 (6.68)	8.13 (2.56)

[a]Values represent means of 8 specimens per time point, while figures in parentheses represent one standard deviation.

109

110 The rate of decay was initially slow, increased markedly between 30 and 45 days and then
111 slowed. This pattern is consistent with previous tests where mass loss is limited while the fungus
112 grows through the substrate, consuming readily available sugars, and then becomes more
113 substantial once the fungus begins to actively degrade the wood polymers (Bari *et al.* 2017, Li *et*
114 *al.* 2018). The mass losses found after 90 days were also consistent with the classification of

Chinese poplar as non-resistant to fungal attack according to ASTM Standard D2017 (ASTM 2001).

Compressive strength did not change significantly between 0 and 15 days of fungal exposure. While these results suggest that the fungus had little effect on properties, previous results clearly illustrate the tendency of this fungus to cause sharp reductions in flexural properties (Yang *et al.* 2006). Compressive strength decreased by nearly 18% at the 30 day assessment, indicating the fungus had begun to induce more substantial effects on wood properties. Compressive strength declined to only 24% of its original value after 90 days of exposure.

Previous studies have shown that brown rot attack of wood induces near exponential losses in bending and tensile strength and that these effects occur early in the decay process when fungal mass losses remain relatively minor (Ge *et al.* 2018, Wilcox 1978). Compressive strength losses appear to deviate from this trend with losses in compressive strength following a near linear relationship with either mass loss or time (Figure 1).

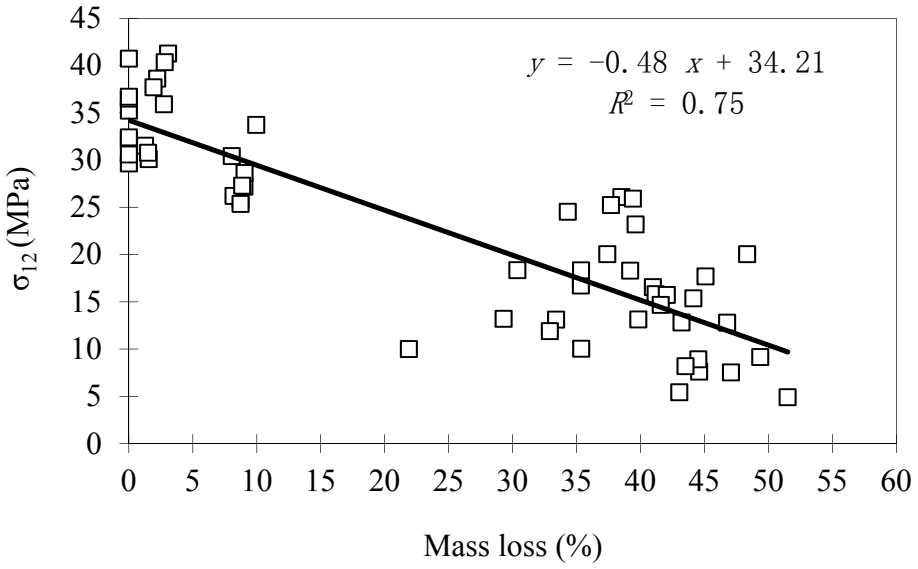
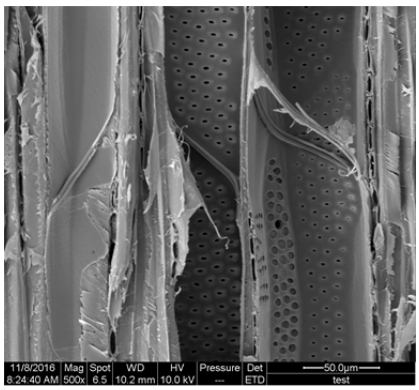
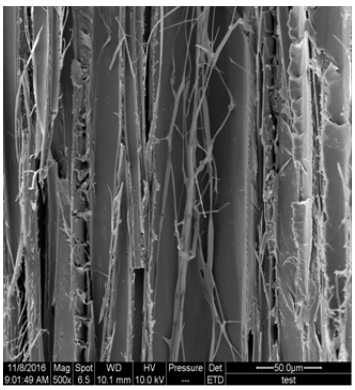


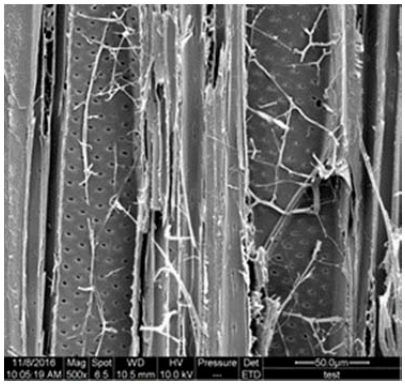
Figure 1: Relationship between mass loss and compressive strength of Chinese poplar blocks exposed to *G. trabeum* in a decay test for up to 90 days.



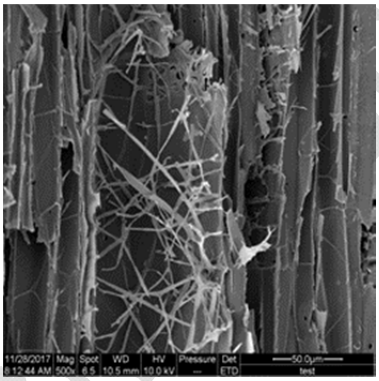
(a) Control



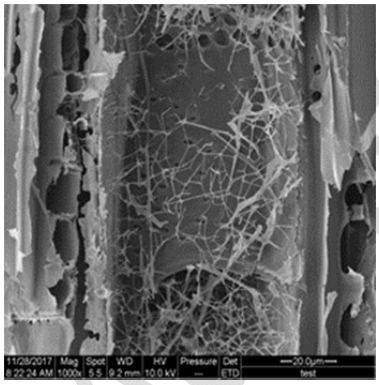
(b) 15days



(c) 30days



(d) 60days



(e) 90days

Figure 2: Examples of the degree of fungal colonization of Chinese poplar blocks exposed to *G. trabeum* for 0 to 90 days.

Fungal colonization, as assessed using SEM, followed similar trends to those observed for mass loss. Fungal hyphae were scattered in tracheids in blocks exposed to the test fungus for only 15

days and then became increasingly common over the next 75 days (Figure 2). Hyphae were abundant in the vessels, especially after 75 and 90 days of exposure. The results were consistent with the degree of both mass and compressive strength losses.

CONCLUSIONS

Exposure of Chinese poplar specimens to *G. trabeum* was associated with steady, closely correlated declines in both mass and compressive strength. The results suggest compressive strength losses can be more easily assessed by changes in mass than fungal associated effects other wood properties.

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