Strength Reduction in Slash Pine (*Pinus elliotii*) Wood Caused by Decay Fungi

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Abstract

Small wood specimens selected from slash pine (*Pinus elliotii*)trees at three growth rates (fast, medium, and slow) were inoculated with brown-rot and white-rot fungi and then evaluated for work to maximum load (WML), modulus of rupture (MOR), and modulus of elasticity (MOE). The experimental variables studied included a brown-rot fungus (*Gloeophyllum trabeum*) and a white-rot fungus (*Trametes versicolor*) and six exposure periods (2, 4, 6, 8, 10, and 12 weeks) in which weight loss measurements were recorded. All samples were tested for nondestructive MOE (MOEsw) prior to static bending and the results were compared via regression analyses. There were significant differences in weight loss, WML, MOR, and MOE reductions due to tree growth rate and decay periods. The weight loss, WML, MOR, and MOE losses of all three growth rate classes treated with brown-rot fungi were greater than those exposed to white-rot fungi with the exception of very early decay (i.e., 2 weeks after inoculation). The mechanical property reduction was greater for fast grown wood than that of slow grown wood. As expected, strength decreased as exposure time to the fungi increased. The specimens exposed to brown-rot decay showed most of the strength reduction in the initial 6 weeks and after 10 weeks. The samples inoculated with the white-rot fungi showed a continual slight strength reduction for the entire 12 weeks. The results showed that the ratio of the loss in mechanical properties compared to weight loss were 7.2: 1 for WML, 6.4: 1 for MOR, and 3.8: 1 for MOE, for slash pine sapwood exposed to *G. trabeum*, and that of wood specimens exposed to *T. versicolor* were 3.0: 1 for WML, 2.2: 1 for MOR, and 4.1: 1 for MOE. Regression analysis indicated good correlations between MOEsw and static bending MOE after the 12 week exposure period.

Introduction

Society's ever increasing demand for wood fiber has resulted in an increased emphasis on plantation forestry and other efforts to accelerate tree growth rate and wood fiber production. Concurrent with the increased demand for wood fiber is the increased public awareness regarding wood durability. The public interest in wood durability has been largely fueled by media reports alleging harmful health effects to children exposed to preservative-treated wood.

With regards to wood durability, previous studies have shown that even during early incipient decay of wood small changes in the chemical composition of wood can result in measurable reduction in strength before measurable weight loss has occurred (Wilcox 1978; Winandy 1993; Kin 1996; Curling 2002). There are many important factors that affect wood decay. Of particular importance are wood chemical composition, specific gravity or wood density, tree growth rate, and wood moisture content. The affect of accelerated tree growth rate on wood anatomical properties, specific gravity, and mechanical properties has been well investigated.

Recently, various studies on relationships of growth traits, anatomy, specific gravity, and the mechanical properties have been investigated (Megraw 1985; Lei et al. 1997; Zhu et al. 1998; Yu et al. 2003).

More recently, research has been conducted to establish relationships between decay resistance and wood properties. Guilley et al. (2004) found that wood decay is significantly affected by the presence of wood extractives. Yu et al. (2003) reported that the phenotypic and genetic correlations between growth rate of brown rot on heartwood blocks and wood density were positive, but the genetic correlation between wood density and the growth rate of white rot on heartwood blocks was negative but not significant.

There have been few studies on the relationship of tree growth rate and wood decay resistance. Therefore, objective of this research was to determine the effect of tree growth rate, wood fungus species, and exposure period to decay fungi on slash pine wood mechanical properties. It is anticipated that this research can assist future efforts to 1) develop a model to determine residual wood strength based on time of exposure to decay fungi and 2) develop a comprehensive genetic tree improvement program for slash pine incorporating tree growth rate and decay resistance.

Materials and Methods

Preparation of wood specimens

Wood discs measuring 58 cm (22.8 in.) long were removed at 2 m (6.6 ft.) intervals from the stem of six slash pine (*Pinus elliotii*) trees growing in Jiangxi, China. The disks were divided into three growth rate classes. The average growth ring width was 5.60, 4.38, and 3.33 mm from age 5 to 20 at fast, medium, and slow growth rates, respectively The sapwood from the discs was cut into samples measuring 40 mm (1.6 in.) (radial) × 40 mm (1.6 in.) (tangential) × 580 mm (22.8 in.) (longitudinal). The samples were conditioned to 22% moisture content (MC) at ambient room conditions in a constantly air conditioned laboratory. Afterwards, randomly selected samples from each growth rate class were cut into specimens measuring 10 mm (radial) (0.39 in.) × 10 mm (0.39 in.) (tangential) × 160 mm (6.3 in.) (longitudinal). Wood specimens were put into a condition chamber to equilibrate at 66% relative humidity (RH) and 24°C (12.0% equilibrium moisture content, EMC) before the specimens were dried at 70°C for determining initial weight.

Fungi exposure

A 380×250×200 mm (15.0×9.8×7.9 in.) carton with a polyethylene bag lining was used as a culture vessel with sweetgum veneer feeder strips measuring 360×50×3 mm (14.2×2.0×0.12 in.). The water holding capacity of the loam culture soil was determined in accordance with ASTM 2017-94 (ASTM 1994) and found to be 23%. The polyethylene bags were sterilized in a steam autoclave at 70°C for 72 h. The soil, water, feeder strips, and specimens were sterilized at 1.2 MPa and 121°C for 30 min. After cooling, a measured volume of soil was added to the culture bag, and the soil was formed into a ridge running the length of the long axis. The sweetgum feeder strips were first placed onto the ridge and the experimental slash pine specimens were placed on the feeder veneer perpendicular to the longitudinal direction of the feeder strips so that only the middle section of the specimens was in contact with the feeder strip and no part was in contact with the soil (Curling et al. 2000). The test fungi were inoculated onto the feeder strips at regular intervals.

The treatments were combinations of two decay fungi and six exposure periods (2, 4, 6, 8, 10, and 12 weeks) with ten replicates per treatment. The two fungi were (1) brown rot, *Gloeophyllum trabeum* (Madison 617, ATCC 11539) and (2) white rot, *Trametes versicolor* (FP-101664-Sp, ATCC 42462). In addition, ten samples per treatment were run without fungi as a control. The experiment design is shown in Table 1. A total of 540 small, clear wood specimens were used in the study.

Table 1 Experimental design for determining the effect of growth rate and fungi species on slash pine wood mechanical properties.

Factors	Levels	N
Exposure period	6 (2, 4, 6, 8, 10, and 12 weeks)	6 periods × 3 fungi × 3 rates × 10 replicates = 540 samples
Fungi type	3 (control, white-rot, and brown-rot)	
Tree growth rate	3 (fast, medium, and slow growth rates)	

Mechanical property testing

At the end of the 12 week study, the specimens were removed from the culture boxes and soft brushes were used to gently remove any adhering mycelium. The specimens were oven-dried prior to determining the constant weight at 70°C and were then placed in a conditioning chamber to equilibrate at 21°C and 65% RH (12% EMC) prior to mechanical testing. After conditioning, the specimens were tested in the longitudinal direction using a stress wave timer (Metrigard 239) prior to conducting static bending tests to determine their dynamic modulus of elasticity (MOEsw). The tension side of the decayed wood specimens in the static bending test was the side that had been in contact with the feeder.

Three point static bending tests were conducted over a 259 mm (10.2 in.) span with a crosshead speed of 0.19 in./min. using a computer-driven software package on an Instron testing machine with a MTS upgrade. Data collected included modulus of rupture (MOR), modulus of elasticity (MOE), and work to maximum load (WML).

Results and Discussion

Effect of fungi type on decay

The data for weight loss and strength loss in slash pine wood after a 12 week exposure period to white-rot and brown-rot decay fungi are shown in Table 2. The results demonstrated that considerable bending strength loss occurs before any appreciable weight loss occurs. The weight loss, WML, MOR, and MOE reductions of all growth rate samples caused by the brown-rot fungi were greater than those exposed to the white-rot fungi, with the exception of the early stages of decay (i.e., within 2 weeks of inoculation). One explanation may be brown-rot decay fungi degrade mainly the cellulose and hemicelluloses by depolymerization without extensive loss of lignin, and the effect of hemicelluloses degradation on the mechanical properties of wood during brown-rot decay is significant (Curling et al. 2000, 2001). However, since white-rot decay fungi mainly degrade the lignin component of wood, which has less of a structural role as compared to cellulose, it follows that these samples did not experience any appreciable reduction in mechanical properties during the early stages of fungi exposure even though the samples showed 10 % of weight loss after 12 weeks (Fig. 1).

Table 2. Comparison of mechanical property and weight loss due to fungi type and exposure period.

Dependent Variable	Fungi	Exposure period (weeks)					
		2	4	6	8	10	12
Weight loss (%)[1]	White-rot[2]	0.63[3]	0.66	0.79	1.03	1.08	1.20
	Brown-rot	-0.01	1.12	3.43	6.63	9.72	11.59
WML loss (%)	White-rot	1.33	2.26	1.69	2.51	4.60	3.14
	Brown-rot	6.24	15.96	32.32	32.17	34.18	44.56
MOR loss (%)	White-rot	-0.66	2.06	0.33	1.57	2.76	3.99
	Brown-rot	5.14	14.39	29.07	28.51	28.07	40.37
MOE loss (%)	White-rot	0.96	5.35	-0.63	1.20	7.53	6.04
	Brown-rot	0.27	8.53	15.50	16.69	23.15	25.42

[1]All loss values were calculated based on to the control test. N=360.
[2]N=30 for white-rot and brown-rot fungi with every exposure period, respectively.
[3]Every value in this table is an average value from 30 specimens, which is according to the control test at fast, medium, and slow growth rate, respectively.

As shown in Fig. 2, there was a significant correlation between weight loss and mechanical property reduction. The relationship between mechanical property reduction and weight loss due to brown-rot decay was very significant. There was a 30% reduction in WML and MOR and 15% decrease in MOE even with a 3% weight loss. MOE gradually increased after 7% weight loss. The WML and MOR loss increased 10% after 9.7% of weight loss (Fig. 2). The data (except for the initial 2 weeks exposure period) showed that the ratio in the comparative loss in mechanical properties compared to weight loss was 7.2:1 for WML, 6.4:1 for MOR, and 3.8:1 for MOE, for samples exposed to G. trabeum. The results for samples exposed to T. versicolor was 3.0:1 for WML, 2.2:1 for MOR, and 4.1:1 for MOE.

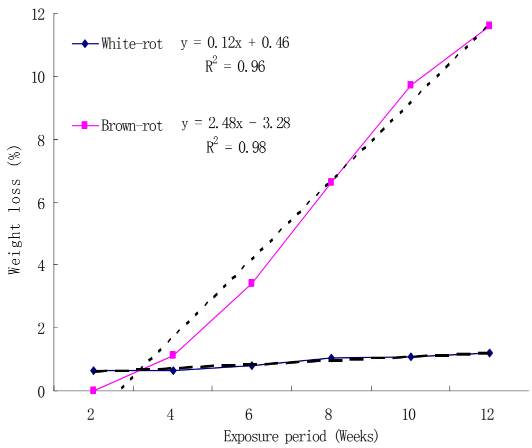

Fig. 1. Comparison of brown rot and white rot fungi on weight loss of slash pine wood (N=360).

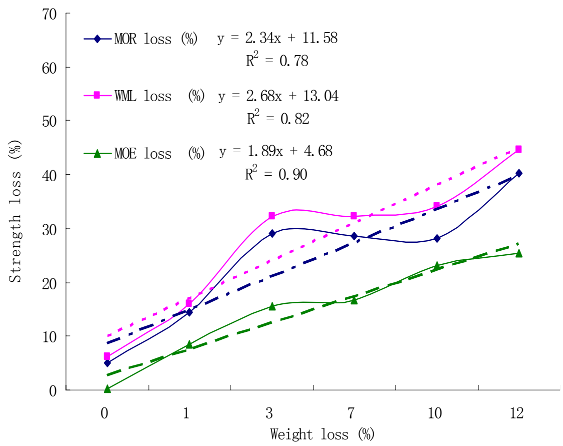

Fig. 2. Strength loss caused by brown-rot fungi (N=180).

It is well known that brown-rot fungi will attack softwoods greater than white-rot fungi. After twelve weeks of exposure, the brown- and white-rot fungi samples had 11.59% and 1.20% mean weight loss, respectively. These values are much less than typical values received from performing the American Wood Preservers' Association E10-06 test. Moreover, the mean weight loss of the white-rot fungi samples in this test is within the typical operational weight loss associated with the AWPA E10-06 test (AWPA 2006). The samples did not show any obvious sign of contamination during the test. However, the vigor of the fungi certainly was poor. The data are considered valid and useful because all samples were treated uniformly and weight loss values were great enough to determine the relationship between weight loss and mechanical properties of slash pine).

Effect of tree growth rate on decay

The effect of exposure time on mechanical property reduction of samples from all three growth rate classes is shown in Table 3. The statistical analysis indicated that both growth rate and exposure period had significant effects on mechanical properties. As expected, the correlation of weight loss with exposure time of slow grown samples was quite good as indicated by the R^2 = 0.9957. However, the weight loss for the slow grown samples occurred sooner and more rapidly than the weight loss for fast growing wood (Fig. 1).

Table 3 Comparison of weight loss and mechanical property loss due to tree growth rate and exposure time (N=360).

Dependent Variable	Growth rate[2]	Exposure time (Weeks)					
		2	4	6	8	10	12
Weight loss (%)[1]	Fast	0.18[3]	0.48	1.78	3.74	7.17	7.67
	Medium	0.60	0.97	2.10	4.05	3.65	5.12
	Slow	0.15	1.22	2.45	3.70	5.38	6.39
WML loss (%)	Fast	1.72	4.35	18.74	18.50	21.55	32.44
	Medium	2.62	9.43	14.80	15.75	14.80	19.10
	Slow	6.24	12.18	17.61	17.87	21.86	21.25
MOR loss (%)	Fast	0.39	3.43	17.07	16.76	18.04	30.77
	Medium	-0.04	8.81	12.46	13.76	8.64	17.83
	Slow	5.43	11.10	14.89	14.87	19.35	19.35
MOE loss (%)	Fast	-1.22	1.61	13.44	12.64	22.48	15.75
	Medium	4.66	8.87	2.89	2.93	4.78	12.40
	Slow	5.58	8.30	7.23	11.31	19.21	18.40

[1]All loss values were calculated according to the control test N=360.
[2]N=20 for each growth rate category within each exposure period.
[3]Every value in this table is an average value from 20 specimens, which is according to the white-rot, and brown-rot decay test, respectively.

The results showed that for slow grown samples WML and MOR loss increased as weight loss increased, and WML and MOR reduction were both greater than MOE loss by the time the samples had experienced a weight loss of 2.5%. However, the average value of MOE loss was 7% before 2.5% of weight loss. MOE was increased by 18.4% after the samples showed 2.5% weight loss. The reductions of WML and MOR were not significant once the samples had achieved 2.5-3.7% weight loss. When weight loss was over 3.7%, WML and MOR decreased rapidly. However, WML and MOR both increased after 10% weight loss. MOE decreased slightly from 3-7% weight loss but increased after 7% weight loss.

In general, fast grown wood showed higher weight loss and mechanical property loss than medium and fast grown samples, particularly for WLM and MOR. Slow grown samples yielded a slightly higher MOE loss than fast grown samples (Table 3).

Nondestructive MOE

The MOEsw determined from stress waves testing for the specimens after decay treatment were less than destructive MOE values from the static bending tests. Correlations of MOEsw and static bending MOE with exposure time and weight loss were significant.

Fig. 2 shows the correlation of MOEsw with static bending MOE was good for control, white-rot, and brown-rot samples, and the r^2 ranged from 0.66-0.80.

As seen in Fig. 2, the r^2 of MOEsw and static bending MOE were nearly identical for control samples and white-rot inoculated samples. One explanation may be the effect of white-rot fungi on mechanical properties was slight during incipient decay. However, it is noted that the R^2 for brown-rot samples MOE (static bending and MOEsw) was greater than that of the control and white-rot samples. The data for brown-rot decay treatment contained less variability ($R^2 = 0.80$) than the control ($R^2 = 0.69$) and white rot ($R^2 = 0.66$).

Conclusions

The objective of this research was to determine the effect of tree growth rate, wood fungus species, and exposure period to decay fungi on slash pine wood mechanical properties. There were significant differences in weight loss, WML, MOR, and MOE reductions between three different tree growth rates exposure period to decay fungi. The weight loss, WML, MOR, and MOE losses of three growth rate samples caused by brown-rot fungi were greater than by white-rot fungi with the exception of very early decay (i.e., 2 weeks after inoculation).

The wood specimens inoculated with brown-rot fungi showed the majority of strength reduction by the time they had experienced 3% weight loss and after 10% weight loss. The samples exposed to white-rot fungi showed a steady and slight strength reduction for the entire period 12 week study period. The data from weeks 2-12 showed that the ratio of the comparative loss in mechanical properties compared to weight loss was 7.2:1 for WML, 6.4:1 for MOR, and 3.8:1 for MOE, for slash pine sapwood exposed to *G. trabeum*, and that of wood specimens exposed to T. versicolor was 3.0:1 for WML, 2.2:1 for MOR, and 4.1:1 for MOE. The weight loss of fast grown wood was slightly greater than that for slow grown wood. WML loss and MOR loss were much greater for the fast grown wood as compared to the slow grown wood. The MOE loss was slightly greater for slow grown wood than fast grown wood. As expected, strength decreased as exposure time to decay treatment increased for all three growth rates.

The nondestructive MOE (MOEsw) and static bending MOE were investigated after the decay treatment. Regression analyses indicated good correlations between MOEsw and static bending MOE.

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