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REVIEW OF LITERATURE ON THE EFFECTS OF EARLY STAGES OF DECAY ON WOOD STRENGTH

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ABSTRACT

Available literature on the effects of early stages of wood decay on various strength properties is reviewed. Results, adjusted to equivalent weight losses, are compared tabularly. Strength in toughness and impact bending appear to be almost totally lost after losses in weight of less than 10%; some other strength properties are affected to only minor degrees.

Keywords: Literature review, biodegradation, wood decay, decay, brown rot, white rot, fungi, hardwoods, softwoods, strength, mechanical properties, weight loss, deterioration.

INTRODUCTION

One of the most frequent questions asked of the wood products pathologist with regard to decay of wood in service is "How much of the strength has been lost?" Estimates of strength loss may be extremely unreliable because: different woods and fungi may act differently; the decay environment and past history play an important role but are rarely known for wood in service; it is difficult to estimate precisely the degree of decay involved; moisture contents may vary considerably over time and may have a profound effect on strength loss; the degree of decay may vary widely over short distances and it will be the weakest point, which probably is not known, and which will control the serviceability of the piece of wood; and it is difficult to predict which strength properties will be the critical ones at the time of failure. Nevertheless, certain generalizations can be drawn from results of controlled tests reported in the literature, and considering the magnitude of some of the changes, rough estimates may be sufficient to reach decisions in a practical design or engineering situation.

Hartley (1958), from an extensive review of literature on the evaluation of wood decay, concluded that weight loss was probably the best basis upon which to compare results in different experiments involving wood decay. Therefore, weight loss has been chosen as the basis of comparison in this review, and some reports based only on length of incubation time necessarily have not been included. All reported strength values have been reduced to strength *loss* expressed as a percent of the comparable value for sound or undecayed control samples. All percentages reported are approximate for several reasons: some workers reported their results graphically and numerical data had to be estimated from small-scale graphs; most workers have reported results in terms of actual average percent weight loss obtained in the experiment—in most cases this information has been adjusted to even percentages for simplicity of presentation in this review; some workers used a variety of woods or fungi, most of which performed somewhat differently, and these multiple results have been averaged, where appropriate, again for simplicity of presentation.

Wilcox (1968) established the possibility of roughly estimating the degree of decay in certain decayed wood on the basis of its microscopical characteristics. Although considerably more work in this area is required on a variety of wood species and decay fungi, it seems reasonable to approximate the stage of decay in given samples by extrapolating the results of this earlier study. However, it should be noted that the microscopical changes resulting from early stages of decay were found to be very slight. Although decay may be detected microscopically in wood with less than 5% weight loss, if one is lucky enough to have included the necessary diagnostic characteristics in the section, one cannot have too much confidence in the results obtained at this level of decay—a positive diagnosis is certain but a negative diagnosis may be highly unreliable. On the basis of this earlier microscopical work (Wilcox 1968), the ability to detect decay from microscopical characteristics, with a high degree of confidence, apparently begins at a weight loss somewhere between 5% and 10%. Therefore, for the purposes of this review, "early stage of decay" has been interpreted as the decay that occurs at or below 10% weight loss.

TOUGHNESS OR IMPACT BENDING

Toughness, or the ability to withstand shock loading, is generally considered to be the strength property most sensitive to early stages of decay. Richards (1954) found a loss in toughness of more than 50% by the time 1% weight loss had been caused by both the brown-rot and white-rot fungi in the softwood tested. Losses of 60% to 85% were reported for all combinations (brown rot, white rot, softwood, hardwood) at 10% weight loss.

Working with 7 brown- and 2 white-rot fungi on both softwoods and a hardwood, von Pechman and Schaile (1950) found substantial losses in impact bending strength in all combinations. In the hardwood, brown rot produced a strength loss of almost 30% after a 1% weight loss, 50–60% after a 2.5% weight loss, and over 80% after an approximate 6% weight loss; white rot produced values of 23% at 0.5% weight loss, 26% at 2.1% weight loss, and 55–60% at 9–10% weight loss. In the softwood, brown rot resulted in strength losses by one fungus of 55% at 1.5% weight loss; in general, however, strength losses were similar to those encountered in the hardwood: about 20–50% at 2% weight loss, 60–70% at 6% weight loss, and 70–80% at 8 or 9% weight loss. Gillwald and Michalak (1963) reported a 43% loss in impact bending strength in a hardwood at a little over 7% weight loss with one brown-rot fungus but only 9% loss with another. Henningsson (1967), who measured impact bending strength of a hardwood attacked by both white-rot and brown-rot fungi, found that the two types of fungi had similar effects on strength up to an approximate 5% weight loss; beyond 10% weight loss the brown-rot fungus caused greater strength loss than the white-rot fungus. The white-rot fungi (7 were used in the experiments) produced losses in impact bending strength of approximately 20% at 1% weight loss, 50% at 6% weight loss, and 60% at 9% weight loss. The brown-rot fungi (3 were used) produced only approximately 6% strength loss at 1% weight loss, but nearly 50% loss at 8% weight loss, and 70% at 9% weight loss.

STATIC BENDING

The strength properties that are probably the next most sensitive to early stages of decay, after toughness, are the expressions of work generated from static bending tests. Scheffer (1936) found that white rot in a hardwood reduced the work to maximum load 35% at 2% weight loss, about 50% at 5% weight loss, and nearly 60% at 10% weight loss. Scheffer chose to express the degree of decay in terms of loss of specific gravity as a percentage of the control value, rather than by weight loss; however, since there is little volume change throughout various stages of white rot, these figures should be essentially comparable to weight loss. Mulholland (1954) found that brown rot in a softwood, at a weight loss of 2%, produced a decrease in work to proportional limit of about 11% and in work to maximum load of about 27%. Kennedy (1958), in a study of woods that consisted mostly of tropical hardwoods, found that the brown-rot fungus used had a considerably greater effect on work to maximum load than the white-rot fungus in early stages of decay. The brown-rot fungus produced losses in work to maximum load of over 50% at 2% weight loss and nearly 75% at 5% weight loss. The white-rot fungus produced comparable figures of approximately 30% loss in work to maximum load at 2% weight loss and slightly over 40% loss at 5% weight loss.

Cartwright et al. (1931), working with brown rot of a softwood, found that the modulus of elasticity (MOE) was affected to a slightly greater extent than the modulus of rupture (MOR). At 2% weight loss a 50% reduction in MOR and a 55% reduction in MOE were encountered. At 6% weight loss the corresponding figures were 61% (MOR) and 66% (MOE). Approximately 70% of the original MOR had been lost after a 10% weight loss. Mulholland (1954), who also worked with brown-rotted softwood, found at 2% weight loss a loss in MOR of about 13% and in MOE of about 4%. Working with white rot of a hardwood, Scheffer (1936) found considerably smaller losses in MOE and MOR as related to percent loss in specific gravity. He found at 2% loss in specific gravity a reduction in MOR of 14% and in MOE of 4%; at 5% loss in specific gravity, 20% (MOR) and 10% (MOE); and at 10% loss in specific gravity, 24% (MOR) and 14% (MOE). Kennedy (1958), working principally with tropical hardwoods, found the effect on MOR of brown rot considerably greater than that of white rot. For brown rot the reductions in MOR were 32% at 2% weight loss, 49% at 4% weight loss, and 61% at 6% weight loss. The corresponding reductions for white rot were 13% at 2% weight loss, 20% at 4% weight loss, and 27% at 6% weight loss.

Several workers reported their results simply as loss in bending strength, which presumably involved measurement of only maximum load. Gillwald and Michalak (1963), working with two brown-rot fungi in poplar, found that one produced a 34% loss in bending strength at slightly more than 7% weight loss while the other produced a 13% loss in bending strength at a similar weight loss. Mizumoto (1966), working with brown-rotted softwood, found losses in bending strength of 5% at 2% weight loss, 16% at 5% weight loss, and 36% at 9% weight loss.

COMPRESSION PERPENDICULAR

Kubiak and Kerner (1963) measured the loss in compressive strength perpendicular-to-the-grain for a hardwood affected by both brown rot and white rot. They found that the effect on this strength property was slightly greater for brown rot than for white rot. The loss in strength due to brown rot was approximately 6% at 2% weight loss, 16% at 5% weight loss, and 19% at 8% weight loss; while comparable figures for white rot were 4% at 1% weight loss, 6% at 3% weight loss, and 12% at 6% weight loss. Toole (1971) performed extensive experiments on the effect of decay on compressive strength perpendicular-to-the-grain and found that the values for reduction in stress at 5% compression had the highest correlation with weight loss. The brown-rot fungi used were all fairly similar in their effects on either the softwood or the hardwood employed in the experiments. Brown rot in the softwood produced a loss in stress at 5% compression of about 18% at 2% weight loss, 24% at 3% weight loss, and 48% at 8% weight loss. Brown rot in the hardwood produced a loss of about 10% at 2% weight loss and 23% at 5% weight loss. The white-rot fungi used were similar in their attack on the hardwood, producing about 27% loss at 6% weight loss and 36% at 10% weight loss, but they were quite different in their effects on the softwood, with strength losses from 12–20% at about 2% weight loss and 32–61% at about 6% weight loss.

OTHER STRENGTH PROPERTIES

Several other strength properties have been investigated by a small number of workers. Compression strength parallel-to-the-grain was investigated by Mizumoto (1966) for brown rot in a softwood. Compression strength was found to have dropped 10% after a 2% weight loss, 22% at 5% weight loss, and 42% at 9% weight loss. Strength loss was found to be somewhat smaller for a white-rotted hardwood: approximately 14% and 20% at specific gravity losses of 6% and 10%, respectively (Scheffer 1936).

Kennedy and Ifju (1962) studied the effects of both brown rot and white rot in both hardwoods and softwoods on the loss in strength in tension parallel-to-grain. The data for the brown-rot fungi were relatively consistent, and a regression analysis showed that the effect of brown rot on tension parallel-to-the-grain was greater in the hardwoods studied than in the softwoods; in the hardwoods a strength loss of approximately 56% was encountered at 2% weight loss and a loss of 82% at 8% weight loss, while in the softwoods approximately 23% loss in strength was encountered at 2% weight loss and 50% at 8% weight loss. On the other hand, the data for white rot showed great variability with species of both wood and fungus. In the white-rotted softwoods the loss in strength in tension parallel at 2% weight loss varied from 4% to 38%, and at 10% weight loss from 20% to 63% strength loss. Strength loss due to white rot in the hardwoods varied from 22% to 42% at 2% weight loss and from 20% to 50% at 10% weight loss. Brown (1963) also studied the effect of brown rot on a softwood and found strength losses somewhat higher than those reported by Kennedy and Ifju (1962). Brown's results indicated a strength loss of approximately 40% at 1–2% weight loss and 60% at 5% weight loss.

Shear parallel-to-the-grain was examined by Mizumoto (1966) with regard to the effect of brown rot on a softwood. The effects of early stages of brown rot on shear strength were relatively small, with reported values of approximately 2% loss in strength at 1% weight loss, 5% at 3% weight loss, and 13% at 7% weight loss.

Mizumoto (1966) also studied the effect of brown rot in a softwood on tangential hardness. A 7% loss in hardness was encountered at 4% weight loss with a 21% loss at 8% weight loss. Scheffer (1936) found comparable effects caused by a white-rot fungus in a hardwood: approximately an 18% loss at 6% loss in specific gravity, and 25% at 10% loss in specific gravity.

CONCLUSIONS

The amount of strength loss at a given degree of decay varies with a number of factors, including the strength property considered, the way in which the degree of decay is specified, the fungus, the wood species, and the exposure or test conditions. Nevertheless, using weight loss as a basis of comparison, as has been done here, test results reported in the literature are consistent enough (Table 1) to allow some generalizations to be made. Because major effects on strength occur very early in decay, and because the ability to detect decay and estimate the degree of decay by microscopical means has definite limitations below about 5–10% weight loss, the stage of decay involved in weight losses below 10% has been emphasized here. Structural lumber in the United States is primarily softwood and decay of softwoods in service is accomplished primarily by brown-rot fungi. The following generalizations therefore focus upon the information available on brown-rotted softwood. Nevertheless, it is apparent that in very early stages of decay there may be little difference in the effects on strength of brown-rot and white-rot fungi or whether the wood is a hardwood or softwood.

The strength properties most severely and rapidly diminished by the onset of decay are toughness and impact bending (subtly different ways of measuring the same fundamental properties). When weight loss reaches 5–10%, one should expect a loss in these strength properties of at least 60–80%. The properties that appear to be the next most sensitive to decay are the measurements of work associated with bending. Here losses of 50–70% can be expected at weight losses of 5–10%. Modulus of rupture and modulus of elasticity also could be expected to be reduced by 60–70%. Most other strength properties may decrease less drastically in early stages of decay, even though all are essentially destroyed by late stages of de-

TABLE 1. *Estimated values for strength losses in softwoods and hardwoods at early stages of decay (indicated by weight loss) by brown-rot and white-rot fungi as a percentage of the values for non-decayed samples*[a]

Approximate weight loss (percent)	Strength property[a]										
			Static bending								
	Toughness	Impact bending	General bending strength	Work to maximum load	Modulus of rupture	Modulus of elasticity	Compression perpendicular (radial)	Compression parallel	Tension parallel	Shear parallel	Hardness
Brown rot:											
Softwoods											
1	57	20–38	—	—	—	—	—	—	—	2	—
2	—	20–50	5	27	13–50	4–55	18–24	10	23–40	—	—
4	75	25–55	—	—	—	—	25–35	—	—	6	7
6	—	62–72	16	—	61	66	48	25	60	—	—
8	—	78	—	—	—	—	48–60	—	50	15	21
10	—	85	36	—	70	—	66	45	—	20	—
Hardwoods											
1	—	6–27	—	—	—	—	—	—	—	—	—
2	36	31–50	—	54	32	—	6–10	—	56	—	—
4	—	60–70	—	69	49	—	—	—	—	—	—
6	—	80	—	75	61	—	16–25	—	—	—	—
8	—	9–89	13–34	—	—	—	19	—	82	—	—
10	60	70–92	—	—	—	—	—	—	—	—	—
White rot:											
Softwoods											
1	55	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	10–20	—	4–38	—	—
4	—	—	—	—	—	—	—	—	8–43	—	—
6	75	—	—	—	—	—	32–61	—	10–49	—	—
8	—	—	—	—	—	—	—	—	14–58	—	—
10	85	—	—	—	—	—	—	—	20–63	—	—
Hardwoods											
1	—	21	—	—	—	—	4	—	—	—	—
2	—	26	—	28–35	13–14	4	5	—	22–42	—	—
4	70	44	—	38	20	—	—	—	17–44	—	—
6	75	50	—	45–53	20–27	10	12–27	14	12–58	—	18
8	—	—	—	—	—	—	—	—	14–49	—	—
10	85	60	—	58	24	14	35	20	20–50	—	25

[a] Values obtained from published experimental results and adjusted to equivalent weight-loss levels.

cay. At 10% weight loss one should expect losses of about 60% in compression perpendicular, 40% in compression parallel, 50–60% in tension parallel, and perhaps 20% in shear and hardness.

Clearly, wood loses most of its ability to withstand shock loads, absorb energy, and support loads in a bending mode at such early stages of decay that they are difficult to detect in all cases and may be overlooked in routine diagnostic procedures. If decay is detectable, the wood should be suspected of lacking almost all strength in all the properties listed above.

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