AN ABSTRACT OF THE THESIS OF

Camille M. Sexton for the degree of Master of Science in Botany and Plant Pathology presented on January 21, 1988
Title: The Development and Use of Breaking Radius and Impact Bending Tests for Measuring Wood Strength Loss Caused by Basidiomycetes Isolated from Air Seasoning Douglas-fir

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Douglas-fir utility poles are routinely air seasoned before treatment with chemical preservatives. Basidiomycetous fungi invade these poles and may cause strength loss during air seasoning or later if treatment temperatures are insufficient to kill the decay fungi. The purpose of this study was to develop a rapid test to asses the ability of these fungi to degrade wood.

Two tests measuring wood toughness, the first mechanical property affected by decay fungi, were chosen. The breaking radius test measures the radius of curvature a specimen can withstand without failing. The impact bending test measures the amount of energy required to cause failure as a pendulum arm strikes the specimen. Variables affecting these tests such as specimen size, grain angle, moisture content and length of incubation with a suspect decay fungus were investigated. Methodologies were designed to reduce variability and give rapid results with each test.

Douglas-fir test specimens (1.7mm x 9.4mm x 5.1cm) were incubated for 4 weeks with basidiomycetes isolated from air seasoning Douglas-fir poles. Sixteen specimens per fungal isolate were sampled oven dry for breaking radius and 12 were sampled above the fiber saturation point for impact bending. Between one and 16 isolates per species were tested.

Twenty-three fungal species were ranked according to decay capacity and this information was related to isolation frequency. Two brown rot fungi, Poria placenta and Poria carbonica, degrade wood rapidly and are common in air seasoning Douglas-fir. Several white rot fungi including Haematostereum sanguinolentum and Peniohpora spp. are common in Douglas-fir poles, but much less damaging to the wood.

Monokaryons and dikaryons of 15 species were compared by decay capacity and no consistent relationship was found. Isolates of each species were also compared to asses within species variability. Differences were found within species with high decay capacities.

Large numbers of basidiomycetes invade air seasoning Douglas-fir poles, but most cause little strength loss. This information can be used in assessing when poles or other wood products may be at risk of strength loss and in need of chemical treatment.

The Development and use of Breaking Radius and Impact Bending Tests for Measuring Wood Strength Loss Caused by Basidiomycetes Isolated from Air-seasoning Douglas-fir

by

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GENERAL INTRODUCTION

The research reported here is part of a Cooperative Pole Research Program at Oregon State University dealing in part with studies on the production of Douglas-fir poles that have been seasoned by the most effective methods and that should remain decay free in service (8).

The impetus for this research was the recent popularity of drying poles by air seasoning. Although air drying is less expensive than kiln or Boulten drying (heating poles in preservatives in oil under vacuum), there is concern that decay fungi may colonize the poles during the air seasoning period, and that the lower temperatures used to treat air seasoned poles with water borne preservatives may not be sufficient to kill these fungi (17,29).

The initial phase of the air seasoning study dealt with isolation and identification of decay fungi occurring in poles air seasoned for various time periods, and when and how infestation occurred (23). One objective of the study reported here was to determine the ability of these fungi to decay wood.

A rapid decay test was needed because many different fungi were isolated from the air seasoning poles. The standard weight loss test for wood decay (2) requires 12 weeks, but wood strength, especially toughness, is affected by decay before significant weight loss occurs (16). Consequently loss of toughness was chosen as a measure of decay. Using smaller wood specimens than are usually employed in

this type of testing further shortened the time required. Reliability of loss of toughness as a predictor of decay ability was increased by using two different tests (impact bending and breaking radius) tests which measured similar wood properties. A second objective of this thesis research was to provide detailed descriptions of how best to use the impact bending and breaking radius tests.

Fungi were ranked according to decay capacity and this information was related to isolation frequency. The decay capacity of monokaryons and dikaryons of 15 species were compared and variation among isolates of the same species identified.

The threat that fungal colonization during air seasoning poses to Douglas-fir poles was estimated. Knowledge of the ability of fungi commonly isolated from Douglas-fir to reduce wood strength can be used to predict decay severity in other wood products and will aid in determining initial and remedial decay control treatments in poles.

LITERATURE REVIEW

Wood decay tests

As a result of attack by decay fungi, wood may change color, become softer, decrease in density, change in odor, absorb water faster, have a lower caloric value based on volume, and lose weight and strength (7). This review will concentrate on changes which have been used to detect decay, especially loss of strength.

Many aspects of wood strength and chemistry as well as weight loss have been used to quantify decay. These tests can be divided into destructive (using similar specimens before and after decay) and non-destructive (using the same specimen throughout).

Non-destructive tests have the advantage of eliminating the effect of wood variability since the same piece of wood is compared before and after decay. The most commonly used test of this type is weight loss. Total weight loss may be as high as 65% following attack by brown rot fungi and 99% by white rot fungi. A disadvantage of weight loss is that it is not detectable in the early stages of decay (16).

Other non-destructive tests have been tried, but none with much success. These include changes in volume and shape, hygroscopicity and elasticity (16).

Many more destructive tests have been attempted. The great variation between different wood samples introduces a large source of error between control and inoculated samples, but nevertheless many tests have been successful. The standard for judging the

effectiveness of a wood decay test is generally weight loss. Wilcox (33) published an excellent review in which he brought together research reporting both weight and strength loss. Strength losses were converted to percent loss to facilitate comparison of results from different studies and reported for a number of different tests at equivalent weight losses.

Toughness or shock resistance is the ability of wood to absorb a large amount of mechanical energy or endure repetition of shocks (30). Stated another way it is the total amount of energy a material can absorb before failure (21). It is a combined measurement of bending strength and plasticity (15). Toughness is the first mechanical property of wood affected by decay fungi (7,16,28).

Toughness may be measured in several ways: (i) by an increment drop test in which a weight is dropped on the specimen from increasingly greater heights, (ii) by a single drop impact in which the energy remaining after the specimen breaks indicates toughness and (iii) by torsion or twisting in which the ends of the specimen are turned in opposite directions (30). Breaking radius, a test in which the specimen is bent around increasingly large radii until failure occurs, measures toughness more than bending strength (16).

Toughness measurements were first made by Colley during World War I to detect defects in aircraft wood, but the complete results were not published until 1941 (16). Using the height of hammer drop and a toughness machine, Colley found loss of strength many feet ahead of visible rot and almost a complete loss of toughness when specific gravity was little affected (16).

Several devices have been invented for measuring toughness. The Forest Products Laboratory (Madison WI) toughness machine has been used extensively (10). A load is applied to the specimen by means of a chain operating over a rotating drum with the same center of rotation as a pendulum arm. The difference between the initial and final angle of the pendulum provides a measure of the energy absorbed by the wood (10). The Amsler Universal Wood Testing Machine applies an impact bending load. The energy absorbed is determined by the extent to which the free swing of the pendulum is inhibited (10). Several other devices employ a falling hammer (15).

Variability tends to be high in toughness testing. For Douglas-fir wood the coefficient of variability in total energy (inch pounds) is 30-76% for toughness (FPL) and 29-41% for impact bending (Amsler) (10).

Breaking radius is another method for determining toughness. At first breaking radius was used to measure the strength of sound wood (22), but it was adapted to decay studies (26,25) and was shown to increase by 700% at 2% weight loss (25). Breaking radius is clearly related to toughness as measured by impact (26).

Pechmenn and Schaile (as cited in 16 and 33) found toughness to be reduced by 6-37% in 10 days, before weight loss was detectable. Waterman and Hansbrough (31) noticed a loss of toughness in incipient decay caused by Poria placenta (Fr.)Cooke and concluded that strength loss was important if microscopic examination revealed more than one bore hole per microscopic field. Richards (1954) found a 50% loss in toughness at 2% weight loss caused by several brown and white rot

fungi.

Losses in toughness caused by brown rot fungi are reported to be 75% at 4% weight loss for softwoods, and 36% at 2% weight loss for hardwoods (33). Toughness loss caused by white rot fungi is 75% at 6% weight loss for softwoods, and 70% at 4% weight loss for hardwoods. As measured by impact bending, toughness losses range from 20-70% at 4% weight loss (33).

Some disagreement exists as to whether white rot fungi or brown rot fungi cause more toughness loss. Hardie (15) states that white rot fungi particularly affect toughness. Colley (as cited in Hartley 16) found brown rot fungi to have a greater effect. Penchmann and Schaile (1950 as cited in 14) also found brown rot fungi to cause more rapid loss in toughness. Richards (24) found no difference between white and brown rot fungi. The data reviewed by Wilcox (33) seem to support the conclusion the below 5% weight loss brown and white rot fungi cause similar reductions in toughness, while above 5% weight loss brown rot fungi have a greater effect.

General bending strength is the ability of a wooden beam to withstand a load applied to the center at a steady rate while supported at both ends (15). During bending fibers on the concave side are compressed while fibers on the convex side are under tension (4). Losses in bending strength caused by decay are detectable before weight loss (16). Reductions of 30-40% occur at 10% weight loss (33).

Modulus of rupture is the computed maximum fiber stress in the extreme upper and lower surface of a beam (30). It is derived from

the bending test described above (30) and losses range from 24-70% at 10% weight loss.

Compression perpendicular to the grain is a force which compresses the fibers (30). The capacity of wood to resist this force diminishes with decay by about 35-66% at 10% weight loss (33).

Crushing strength is the ability of wood to withstand compression parallel to the grain (21). Losses in crushing strength due to decay range from 24-40% at 10% weight loss (33).

Tensile strength is the ability of wood to withstand tension applied parallel to the grain (5). This test is often done with very thin strips of wood and loss of strength has been detected in 4 days (16). Bravery and Grant (5) report a loss of 96% in 5 weeks caused by the fungus Coniophora cerebella. Tensile strength losses range from 20-82% at 10% weight loss (33).

Hardness or resistance to indentation decreases rapidly due to decay, but is often highly variable (16). Reported losses are about 25% at 10% weight loss (33).

Modulus of elasticity is a measure of wood stiffness. It is the ratio of stress per unit area to deformation per unit length (30). In some studies decay fungi have an earlier and stronger effect on this property than on weight loss. Losses range from 10-66% at 6% weight loss (33).

Changes in the chemical properties of wood have also been used to detect decay. Alkali solubility increases in brown rotted wood before weight loss is evident, but not in white rotted wood. The pH of a hot water extraction of sawdust has also been effectively used

to detect brown rot. The pH decreases to a minimum at 5% weight loss (16).

Decay assays using small wood specimens

Decay assays using small wood specimens have been developed to achieve results in less time. Mulholland (20) exposed 0.25 by 0.25 inch sitka spruce specimens to Poria placenta. Work to maximum load was reduced 26% and modulus of rupture 13% in 14 days when 2% of wood weight had been lost.

Bravery and Grant (1971) used scots pine specimens measuring 100 by 10 by 0.2 mm decayed by the fungus Coniophora cerebella. Tensile strength was reduced 96% after 5 weeks of incubation. And in another test using baltic redwood test specimens (75 by 5 by 5 mm) were incubated with decay fungi and sampled weekly for 5 weeks. Work to maximum load was the first measured property affected and it was reduced by 90% in 4 weeks (6).

Scheffer and Duncan (27) used thin veneer strips to measure the breaking radius and toughness of aircraft wood. Safo-Sampah and Graham (25) modified this technique by using birch coffee stirrers measuring 1.6mm thick by 9.1mm wide. The decay fungi Poria placenta and Poria carbonica Overh. caused a 700% increase in the radius around which specimens could bend without failure after 2 weeks incubation.

DEVELOPMENT OF A RAPID TEST FOR WOOD DECAY

INTRODUCTION

Developing a test for assessing the ability of fungi to decay wood in less time than the standard 12 week weight loss test (2) was a major objective of this study. A quicker test is necessary to meet another objective; testing a large number of different fungi isolated from Douglas-fir poles.

Wood strength is decreased faster than weight is lost in decaying wood (16). Because toughness or shock resistance is the mechanical property of wood most rapidly affected by decay, tests based on this property were evaluated.

Two tests for toughness, one direct and one indirect were used and compared. The direct method is a pendulum impact test which involves comparing the difference in the height attained by a swinging arm after breaking a specimen with that attained when no specimen is present. The indirect method is a breaking radius test. The wood is bent around a series of mandrels of decreasing size until it fails.

Tests for loss of wood strength can be accelerated by using small test specimens. For these tests, commercially available birch (Betula sp.) coffee stirrers and specially cut Douglas-fir (Pseudotsuga menzesii Mirb. Franco) specimens of similar size were used. These sticks were incubated in petri plates with the potential decay fungi.

Tests similar to these have been used before (9,25,26). The

purpose of this study was to identify and reduce the variation encountered to make the impact bending and breaking radius tests useful for large scale testing.

Variation in toughness testing tends to be high. Drow et.al. (10) report the coefficient of variation in total energy absorbed to failure (inch-pounds) to range from 30 to 76% for Douglas-fir. This variation stems from many sources. The physical properties of wood exhibit a high degree of variability stemming from the growth conditions of the wood; climate, soil, water supply, available nutrients and inherited characteristics (4). Wood is not a homogeneous material, but contains early and late wood as well as knots and other defects. Variation in the size of wood samples contributes to variation in toughness. Grain direction is known to have a large effect on toughness (13), and wood moisture content, both during incubation and testing can also affect the final results.

Investigations into the effects of the above sources of variation have resulted in a methodology for each strength test designed to make the results as uniform as possible. The Douglas-fir sticks were tested for breaking radius oven dry and for impact bending above fiber saturation point. Wood at 60% moisture content was added to the plates and kept from contacting the agar surface. Variations in the physical properties of wood were dealt with by selecting wood free from defects and by increasing sample size.

The specific methods used, results, and discussion for each experiment are reported together in the Results and Discussion section.

GENERAL MATERIALS AND METHODS

Breaking radius test

The breaking radius tests were conducted on a series of wooden mandrels with radii ranging from 3.5 to 0.125 inches (Fig. 1). The wooden test specimens were bent around successively smaller mandrels until failure occurred. Care was taken that the entire stick was in contact with the mandrel during bending. Decayed or less tough wood broke over the larger mandrels and thus had a larger breaking radius than did sound wood.

Impact bending test

Impact bending tests were conducted on a pendulum device built at the Oregon State University Forest Research Laboratory (Fig. 2). A swinging arm strikes the wooden test specimen positioned at the nadir of the arc. The height attained by the arm after striking the specimen, as indicated by the pointer, is a measure of the energy remaining after the specimen is broken or deformed. Comparing the height (ha) reached when a sample is broken with that when the arm is unimpeded (ho) gives an estimate of the energy used in breaking the sample (Fig. 3).

Two pendulum arms were used; one weighing 1,042g was used with birch wood, and a second weighing 520g was used with Douglas-fir wood. This pendulum test is related in principle to the Forest Products Laboratory toughness machine and the Amsler Universal Testing Machine (10).

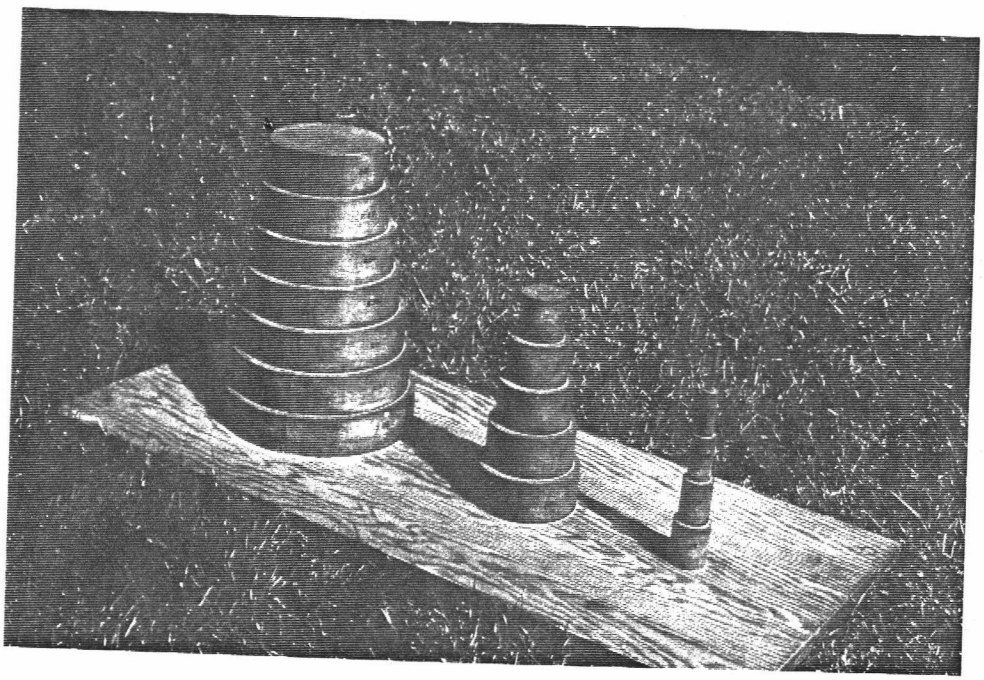

Figure 1. Apparatus for the breaking radius test.

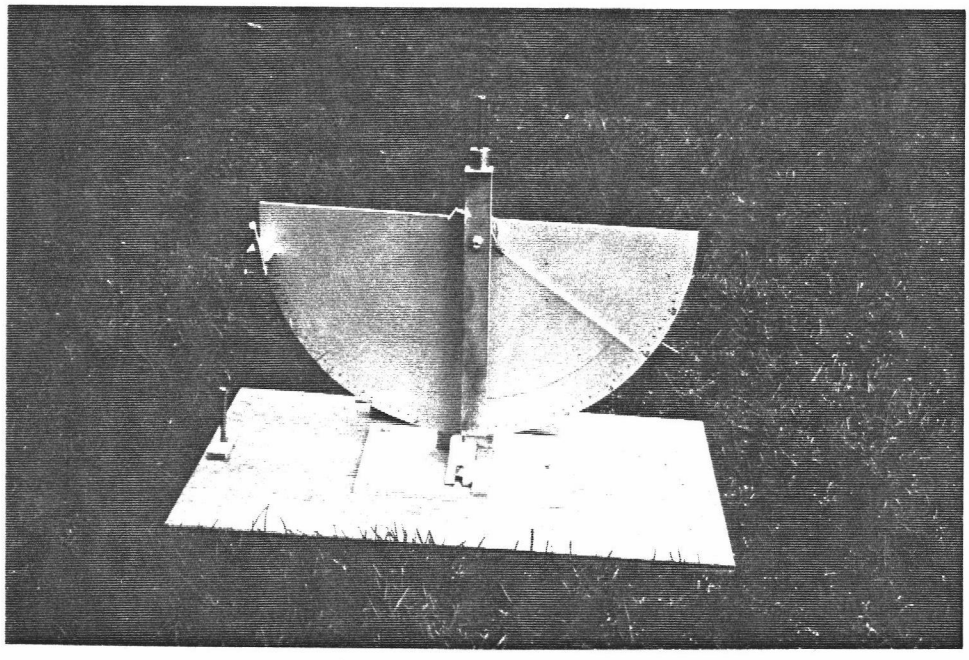

Figure 2. Apparatus for the impact bending test.

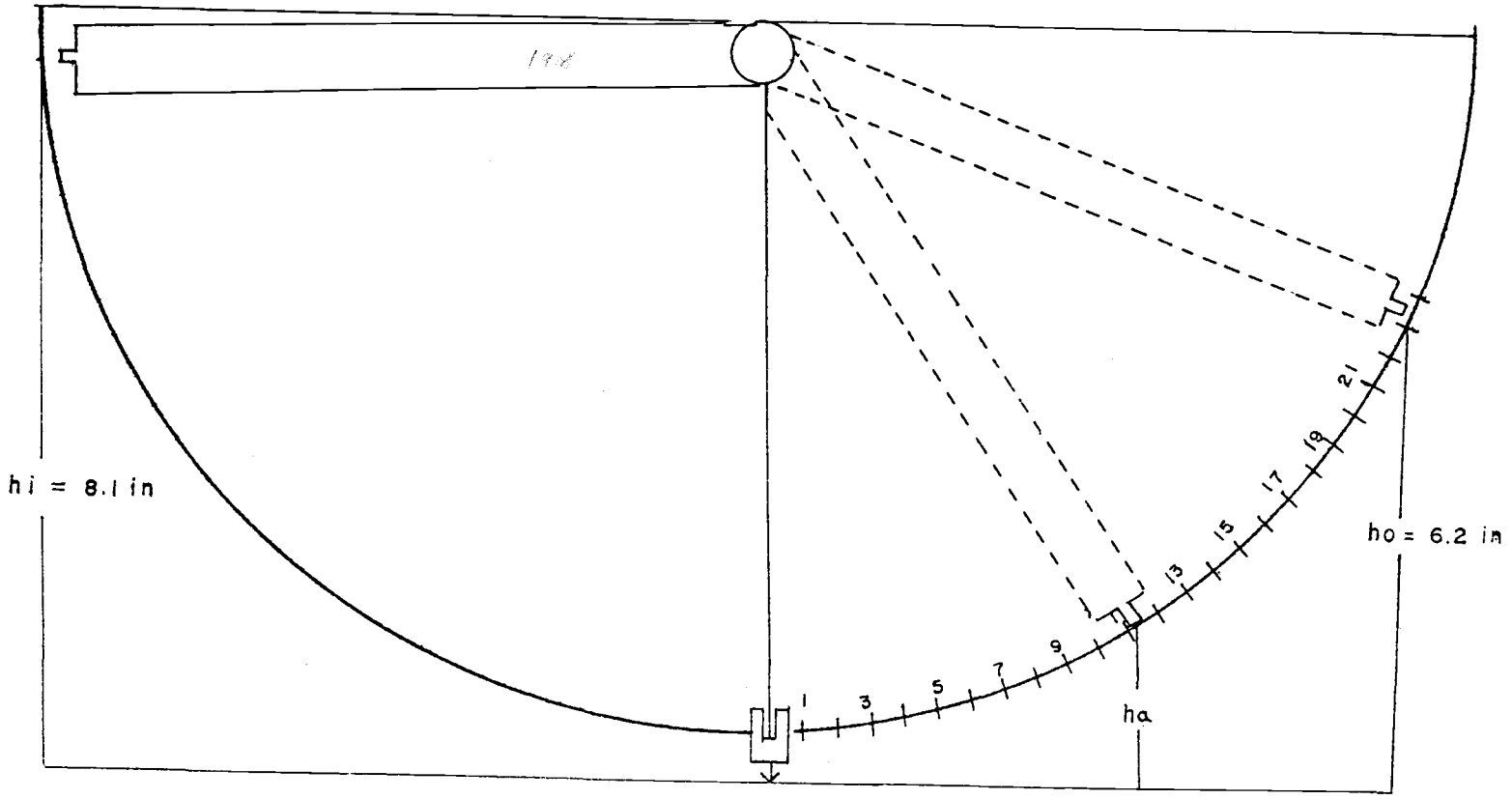

Figure 3. Operational diagram of the impact bending pendulum machine.

h_i = initial height of pendulum arm
h_o = final height of pendulum arm when no specimen is in place
h_a = final height of pendulum arm with specimen in place

Wooden test specimens

Specimens of birch and Douglas-fir were used in developing these tests. The birch sticks were manufactured coffee stirrers similar to those used by Safo-Sampah and Graham (25) with average measurements of 1.6mm thick by 9.1mm wide. These sticks had many defects and grain angle variations which required extensive sorting to obtain uniform specimens. The tangential or radial faces of the wood were subjected to the stress of testing.

Specimens were specially cut from Douglas-fir heartwood with straight grain and a specific gravity (1) of about 0.436. They averaged 1.7mm thick by 9.4mm wide. With few defects, the Douglas-fir sticks required little sorting. The radial face of the wood was tested

Fungal infestation of wood specimens

Initially, experiments were conducted to determine the optimum conditions for the breaking radius and impact bending tests. The following method resulted from these tests which are reported in detail in the first part of the results section.

All test fungi were grown on a culture medium containing 12.5g malt extract and 10g agar made up to 1 liter and autoclaved for 20 minutes at 15 psi. The sterile medium was poured into sterile disposable petri dishes containing four sterile raschig rings (6mm glass tube cut into short pieces) for supporting the wood specimens. The hot malt agar splashed around the rings, coating them with medium and holding them in place. The medium was inoculated in the center

with a test fungus. Seven plates were prepared for each fungal isolate.

Douglas-fir heartwood specimens were soaked in water for 5 minutes prior to autoclaving for 20 minutes at 15 psi to attain a moisture content of 50-60%. One week after inoculation, each culture plate received four sterile wood specimens set on the raschig rings equidistant from the central inoculum (Fig. 4).

The cultures were incubated for 4 weeks at 27C before testing wood toughness. For breaking radius tests, 16 specimens per fungal isolate were removed from the culture plates and oven dried over night at 100C. The specimens were tested for breaking radius immediately upon removal from the oven.

For the impact bending test, 12 specimens per isolate were removed from the culture plates and soaked in water for 15 minutes to ensure that their moisture contents were above fiber saturation. The impact bending values for these specimens were then determined using the pendulum device.

The fungal isolates used in this study can be obtained from the Forest Research Laboratory, Oregon State University, Corvallis Oregon 97331.

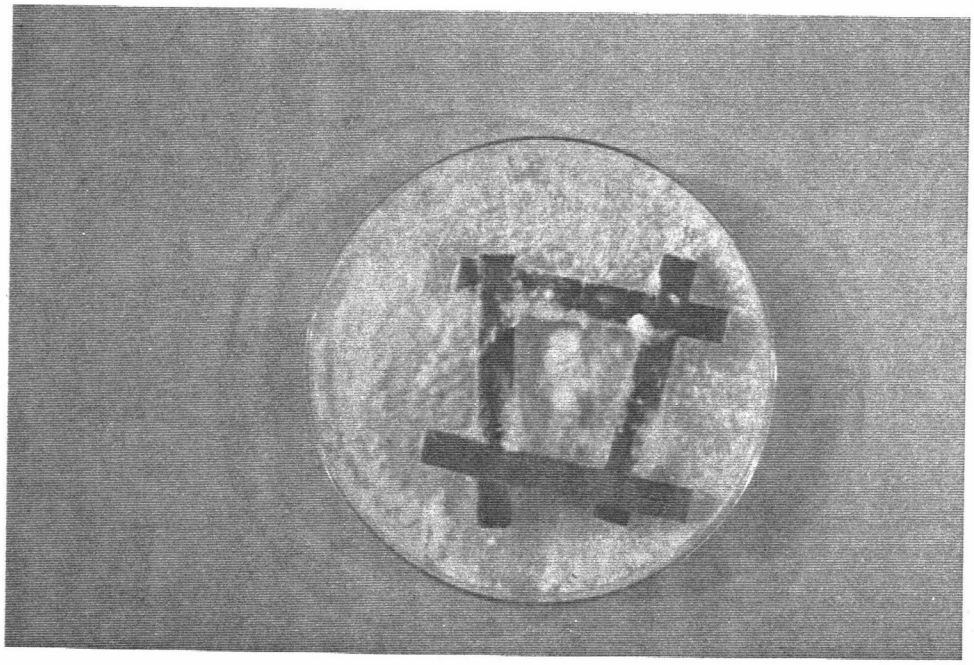

Figure 4. Test specimens incubating with a potential decay fungus.

RESULTS AND DISCUSSION

Size of wood specimens

To determine the influence of thickness and width of the wood specimens on their strength, 100 birch sticks selected for grain straightness were measured for width and thickness with a screw micrometer to the nearest 0.001 inch. Fifty specimens were tested for impact bending, all at moisture levels above the fiber saturation point. Fifty specimens were also tested for breaking radius, 25 oven dry and 25 above fiber saturation.

The thickness and width of the specimens were regressed separately with impact bending values and breaking radii. The following equations were obtained:

$$\text{Thickness} = 0.042 - 7.906 \times 10^{-5} \text{ impact bending value}$$

$$\text{Width} = 0.235 - 3.620 \times 10^{-4} \text{ impact bending value}$$

$$\text{Thickness} = 0.040 + 1.105 \times 10^{-3} \text{ breaking radius}$$

$$\text{Width} = 0.235 - 8.412 \times 10^{-4} \text{ breaking radius}$$

The slopes of all four lines are statistically equal to zero (t testα = 0.05) which indicates that the breaking radius and impact bending values will not differ significantly due to width or thickness variations within the small range of sizes found for these specimens.

Wood grain angle

To determine the influence of grain direction on the strength properties of the wood specimens, 100 birch sticks were selected for uniform size and their approximate grain angle was recorded.

Specimens were sorted into the following categories: (i) annual rings showing (the face tested was more tangential than radial), (ii) no annual rings showing and grain angle flat, and (iii) no annual rings showing with angled grain.

Twenty-five specimens all measuring 0.042 inches thick were tested oven dry for breaking radius and 25 measuring 0.043 inches thick were tested above fiber saturation. Fifty specimens all measuring 0.042 inches thick were tested above fiber saturation for impact bending.

Specimens with no annual rings showing had a significantly higher breaking radius than those showing annual rings, but they were not significantly stronger than a random sample of specimens (Table 1). No significant differences were evident between flat and angled grain specimens in either test, and selecting specimens of one type failed to lower the variance of the samples.

For birch wood, visible grain angle differences affected the strength tests, but as much as expected based on previous work (13). It is standard practice in wood decay experiments to select uniformly grained material and to test the same face (radial, tangential or cross). The only significant difference found was a higher breaking radius by using truly radial specimens over those presenting a tangential face (Table 1). In no case was the variability lowered by selecting one type of stick over another indicating that variability does not depend on grain angle. Comparing any group of sticks to a randomly selected sample does however show a significant reduction in variance. This does not hold true for impact bending.

TABLE 1

Effect of grain angle variation of birch wood (1.6 mm x 9.1 mm) on breaking radii and impact bending values[a]

Grain	Mandrel[b]		Pendulum[c]	
	Breaking radii(in)	S^2	Impact bending	S^2
Annual rings vs.	0.7_s	0.03_{ns}	2.8_{ns}	23.49_{ns}
no annual rings[d]	0.9	0.02	5.3	37.80
Flat grain vs.	0.8_{ns}	0.03_s	7.9_{ns}	57.91_{ns}
angled grain	0.7	0.01	4.2	30.91
Random sample	0.9	0.07	4.6	33.49

s. Significantly different students t test $\alpha = 0.05$.
ns. Not significantly different: students t test $\alpha = 0.05$ for means, F test $\alpha = 0.05$ for S^2.
a. Average of 25 specimens in each test.
b. Data reported for specimens broken dry only. Many tested wet did not break over the smallest radius.
c. Wood tested at 40% moisture content.
d. Annual rings showing or not on the face tested.

Size and grain angle do not have to be considered if custom cut Douglas-fir wood is used. Variation in size over the range tested did not cause any detectable variation in toughness as the slopes of all regression lines equaled zero. Grain angle was a problem with birch sticks, but the Douglas-fir specimens were more uniformly cut eliminating much of the variability. Small grain angle differences do undoubtably contribute to the overall variation, but it is easier to increase the sample size than to sort the wood microscopically.

Moisture content during testing

The effect of wood moisture content on toughness was investigated in the following experiment. Birch specimens selected for straightness of grain were treated in one of the following ways: (i) oven dried, (ii) placed between wet paper towels for 2 minutes, (iii) moistened over water in a desiccator, (iv) soaked for 5 or 25 minutes, or (v) soaked under vacuum until saturated. Douglas-fir specimens were either soaked for 15 minutes or used at equilibrium moisture content (no treatment). Twenty-five birch sticks and 20 Douglas-fir of each treatment were sampled in each toughness test, and their moisture contents determined.

Specimens of each wood species were also decayed and sampled at different moisture contents. Nineteen birch sticks decayed by Poria placenta (Madison isolate FP94267a) were sampled at each of four moisture contents in each test. These sticks were oven dried and rewet to obtain the different moisture contents. Four sticks were added to each culture plate 2 weeks after inoculation and strength

tests were made after 6 weeks of incubation. Douglas-fir specimens were decayed by P. placenta (FP94267a) or Poria carbonica (OSU 1978) and 20 specimens of each were tested on both the mandrel and pendulum without altering the moisture content of the sticks as they were removed from the culture plate and oven dry.

Non-decayed birch specimens at moisture contents near or above the fiber saturation point often failed to break over the smallest mandrel (Table 2). the impact bending value for these specimens was high (low toughness) at 0% moisture content and decreased with increasing moisture content, with a slight rise at complete saturation.

Non-decayed Douglas-fir specimens showed the same general trend (Table 2). Many specimens above the fiber saturation point failed to break over the smallest mandrel. Impact bending values decreased with increasing moisture content, though the range was much smaller than that for birch wood.

Decayed birch sticks showed no relationship between either breaking radius or impact bending value and moisture content during testing (Table 3). Decayed Douglas-fir sticks have a lower breaking radius or greater toughness when wet than when oven dry (Table 4). None of the decayed specimens failed to break when bent around the smallest radius.

Toughness generally increases with increasing moisture content up to the fiber saturation point, then remains constant (21). Both birch and Douglas-fir specimens were too tough at moisture contents approaching or exceeding fiber saturation to fail on the smallest

TABLE 2

Effect of moisture content on breaking radii and impact bending values for non-inoculated birch[a] and Douglas-fir[b] wood wet by different techniques[c]

Wetting technique	Mandrel		Pendulum	
	Breaking radii (in)	Moisture content (%)	Impact bending	Moisture content (%)
	Birch specimens			
Oven dry	0.8	0	20.9	0
Between wet paper towels 2 minutes	d	24	12.1	23
Over water	d	27	7.3	26
5 minute soak	d	40	3.7	48
25 minute soak	d	63	4.3	58
Saturated	d	118	7.5	120
	Douglas-fir specimens			
Oven dry	1.2	0	10.7	0
15 minute soak	d	41	9.9	45
30 minute soak	d	64	8.0	69
60 minute soak	d	96	7.0	103

a. Wood measured 1.6mm x 9.1mm.
b. Wood measured 1.7mm x 9.4mm.
c. Average of 25 specimens for birch and 20 for Douglas-fir.
d. Some or all of the specimens did not break on the smallest radius.

TABLE 3

Effect of moisture content on breaking radii and impact bending values obtained for birch wood (1.6 mm x 9.1 mm) incubated with *P. placenta* for 6 weeks then oven dried and rewet[a]

Wetting technique	Mandrel		Pendulum	
	Breaking radii (in)	Moisture content (%)	Impact bending	Moisture content(%)
Oven dry	2.5	0	20.8	0
Over water 2 hours	3.3	14	24.2	12
Over water to fsp	2.3	29	24.2	30
15 minute soak	2.5	49	24.1	48
Saturated	2.6	142	24.2	135

a. Average of 19 specimens.

TABLE 4

Effect of moisture content during testing on breaking radii of Douglas-fir specimens (1.7 mm x 9.4 mm) incubated with *Poria placenta* or *Poria carbonica* for 6 weeks[a]

Wetting technique	*Poria placenta*		*Poria carbonica*	
	Breaking radii(in)	Moisture content(%)	Breaking radius(in)	Moisture content(%)
Oven dry	1.5	0	1.2	0
sampled as occurring in plates	0.7	132	0.8	128

a. Average of 20 specimens.

mandrel (0.125 inches in radius). The impact bending value for oven dry specimens was equal whether the wood was sound or decayed by P. placenta (Tables 2 and 3). When toughness was increased by wetting to above fiber saturation point a large difference was evident between sound and decayed wood.

Moisture content during testing had a profound influence on the results of both strength tests (Table 2). Oven dry wood will be used in all breaking radius tests because it always breaks, whether sound or decayed. Wood will be tested for impact bending above the fiber saturation point because this gave the largest differences between sound and decayed samples.

Moisture content during incubation

Control over the wood moisture content during incubation was attempted by varying the degree of direct contact between the wood and the culture medium surface. Each wood specimen in this study was sampled for strength and moisture content. With birch sticks, five methods were tested by placing the sticks: (i) broad side flat on the agar surface, (ii) on glass supports, (iii) standing on the thin edge on the agar surface, (iv) on wooden supports, and (v) flat on a rippled agar surface. Douglas-fir sticks were tested flat on the agar surface and on glass supports with the wood at three moisture contents obtained by not soaking or by soaking for 5 or 30 minutes before autoclaving.

Birch specimens in each of the five situations were incubated with P. placenta (FP94267a) or P. carbonica for 4 weeks. Twenty-four sticks were used for each method with each fungus in both strength

tests. Douglas-fir specimens were incubated with P. placenta or P. carbonica and sampled at about 2 and 5 weeks. Four sticks at each of the three moisture contents were sampled at 2 weeks and 12-16 sticks at 5 weeks for each fungus. Only the breaking radius test was used for Douglas-fir.

Raising birch wood above the agar on glass supports was the only method that gave significant differences in both tests and with both fungi used (Table 5). Lower moisture contents resulted in greater strength loss caused by P. placenta, but less strength loss caused by P. carbonica. All the other methods used to control moisture content increased the rate of decay for at least one combination of strength test and fungal species (Table 5).

The only technique that lowered the wood moisture content and increased the rate of decay by P. placenta was placing the sticks on glass supports. In all other cases moisture content was so high that lack of oxygen was probably a limiting factor in decay rate. Raising the sticks on glass supports lowered the decay rate by P. carbonica. The moisture content in this treatment was so low that free water became limiting. The moisture content of the P. carbonica decayed wood was less than one half that of the wood decayed by P. placenta, perhaps because P. placenta had more aerial hyphae to trap moisture within the petri plate.

Douglas-fir wood was also decayed while raised on glass supports, and was exposed to the test fungi at two moisture contents. The decay rate was enhanced for both fungi when the sticks added to the culture plates at room equilibrium moisture content(9%) were

TABLE 5

Effect of methods used to control moisture content of birch wood (1.6 mm x 9.1 mm) during incubation with Poria placenta and Poria carbonica on breaking radii and impact bending values[a]

Method used	Mandrel				Pendulum			
	P. placenta		P. carbonica		P. placenta		P. carbonica	
	B.R.[b]	M.C.[c]	B.R.	M.C.	I.B.V.[d]	M.C.	I.B.V.	M.C.
Flat on medium	1.9	120	0.8	105	19.8	114	17.7[5]	97
Raised on glass	3.5[s]	72	0.7[6]s	32	24.3[s]	73	3.7[s]	29
Standing on edge	2.0	134	1.1[s]	111	21.0	124	11.5[s]	105
Raised on wood	2.2	132	1.7[s]	107	19.7	122	7.8[s]	112
Wavy agar	2.4	130	0.9[s]	119	21.2	131	15.7	109

a. Average of 24 specimens.
b. B.R. = breaking radius.
c. M.C. = moisture content.
d. I.B.V. = impact bending value.
e. Average of 16 specimens.
f. Average of 12 specimens.
s. Significantly different from specimens flat on medium surface (students t test = 0.05).

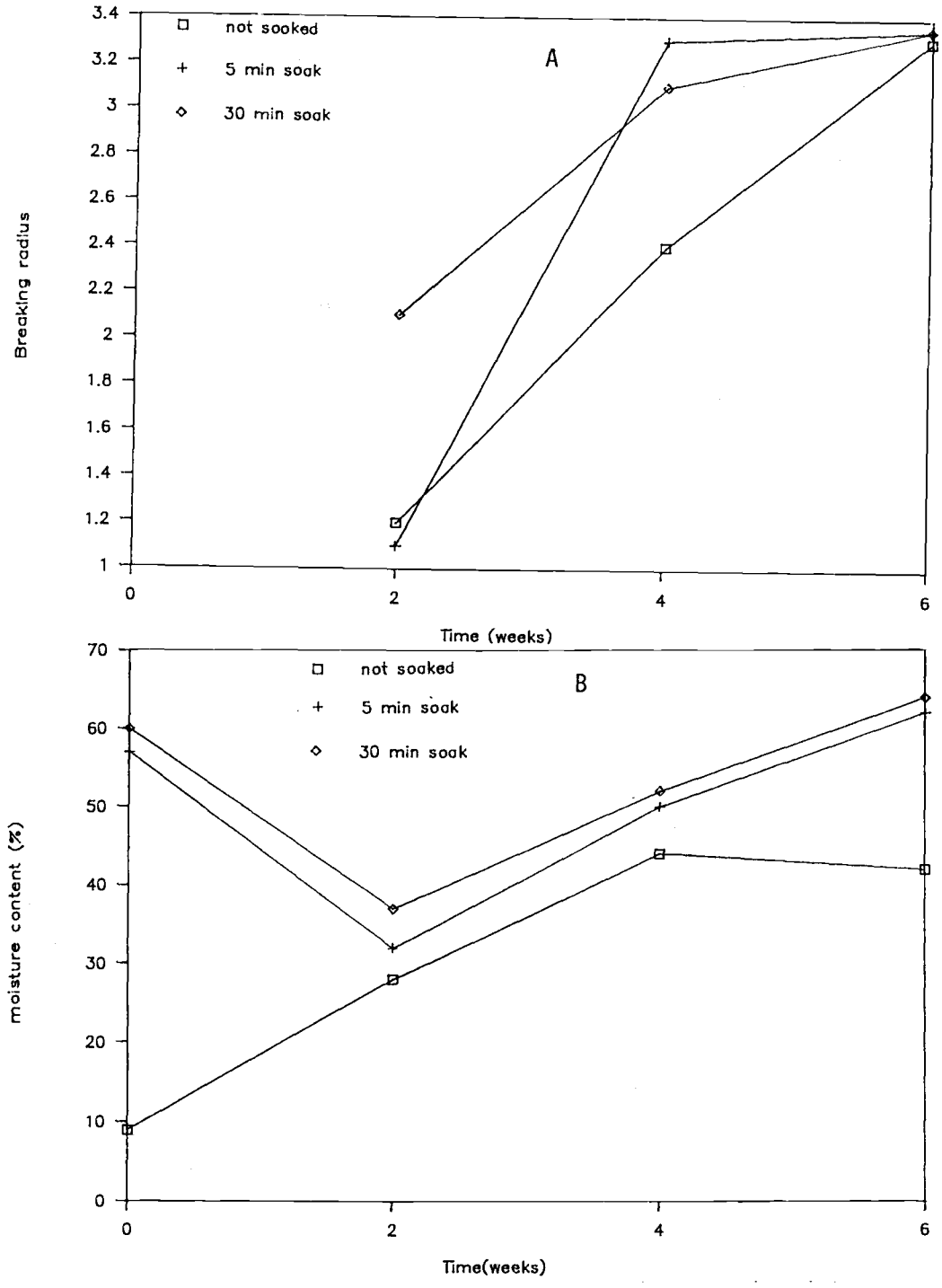

Figure 5. Changes in A) breaking radii and B) moisture contents of Douglas-fir sticks (1.7mm x 9.4mm) incubated with Poria placenta on glass supports and sampled oven dry (average of 12 specimens).

raised above the agar, and was further speeded by wetting the sticks to 55-60% moisture content (Fig. 5). Little difference in breaking radius or moisture content was found between wood soaked 5 or 30 minutes. Breaking radius increased uniformly over time when the sticks were not soaked prior to incubation. Soaked wood decayed by P. placenta lost strength faster than non-soaked wood initially, then leveled off, ending after 6 weeks at the same breaking radius as non-soaked wood. At 4 weeks the breaking radius of soaked sticks was significantly greater than that of non-soaked sticks. The non-soaked specimens reached the fiber saturation point after 2 weeks of incubation. Decay was inhibited at low moisture contents accounting for the relatively slow start of the non-soaked wood (Fig. 5). A very small increase in moisture content during incubation with P. carbonica was realized by soaking the wood. This increase did however bring the sticks above the fiber saturation point and a significant increase in breaking radius resulted (Fig. 6).

Lowering the moisture content during incubation to between 40 and 70% resulted in an increased rate of decay (Table 5). Wood should be supported on glass and added to the plates at a moisture content of between 55 and 60% obtained by soaking for 5 minutes prior to autoclaving to achieve a fast decay rate.

Incubation time

A major objective of this study was to design a rapid test for decay capacity, consequently wood was incubated with decay fungi for various times to find the minimum effective incubation time.

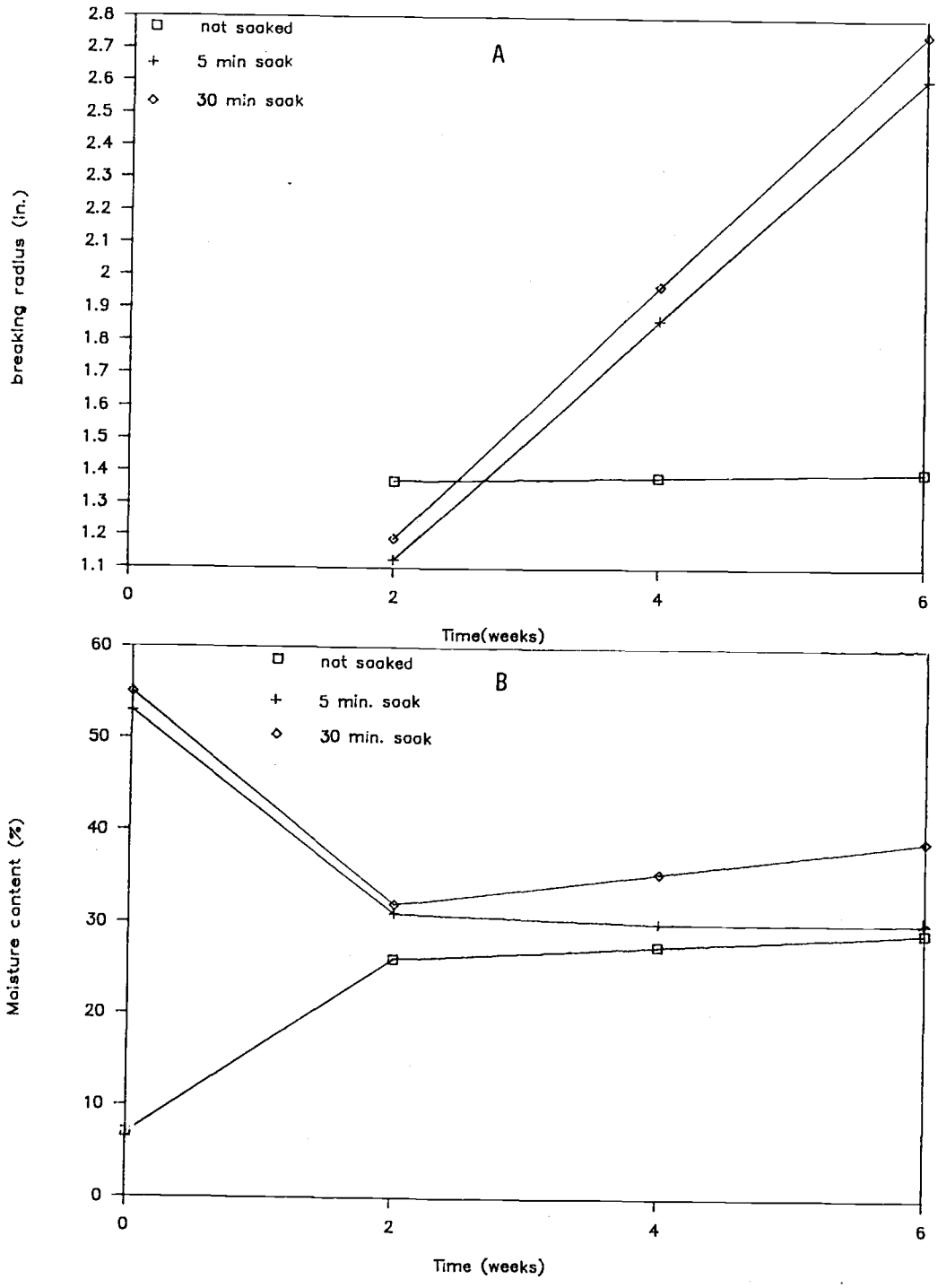

Figure 6. Changes in A) breaking radii and B) moisture contents of Douglas-fir sticks (1.7mm x 9.4mm) incubated with Poria carbonica on glass supports and sampled oven dry (average of 12 specimens).

Birch and Douglas-fir specimens were incubated with P. placenta or P. carbonica and sampled for strength loss and moisture content at regular intervals. Twenty-four birch specimens, placed flat on the agar, were tested with each fungus each week for 6 weeks in each test. Birch specimens were tested oven dry for breaking radius and as they came out of the plate for impact bending. Twenty-four Douglas-fir specimens , placed flat on the agar, were tested at 2, 4 and 8 weeks after incubation with each fungus. Only the breaking radius test was used and specimens were sampled oven dry and above the fiber saturation point.

Birch sticks tested for impact bending showed significant differences from the uninoculated control at 3 weeks whether decayed by P. placenta or P. carbonica (Fig. 7a). Breaking radius was significantly different at 1 week when P. placenta was the test fungus and at 5 weeks when P. carbonica was used (Fig. 7b). The moisture contents of these specimens increased rapidly to over 100% in under 3 weeks (Fig. 8).

Douglas-fir specimens tested for breaking radius above the fiber saturation point (average moisture content = 130%) showed significant results in comparison to an uninoculated control in 2 weeks (Fig. 9). The uninoculated control for this treatment was an average of those sticks that failed on or before the smallest mandrel (0.125 inches), excluding those specimens which did not break. Many sound or slightly decayed sticks were too tough to break when above the fiber saturation point making these conditions less desirable in spite of the quicker results. Dry specimens show significant results in

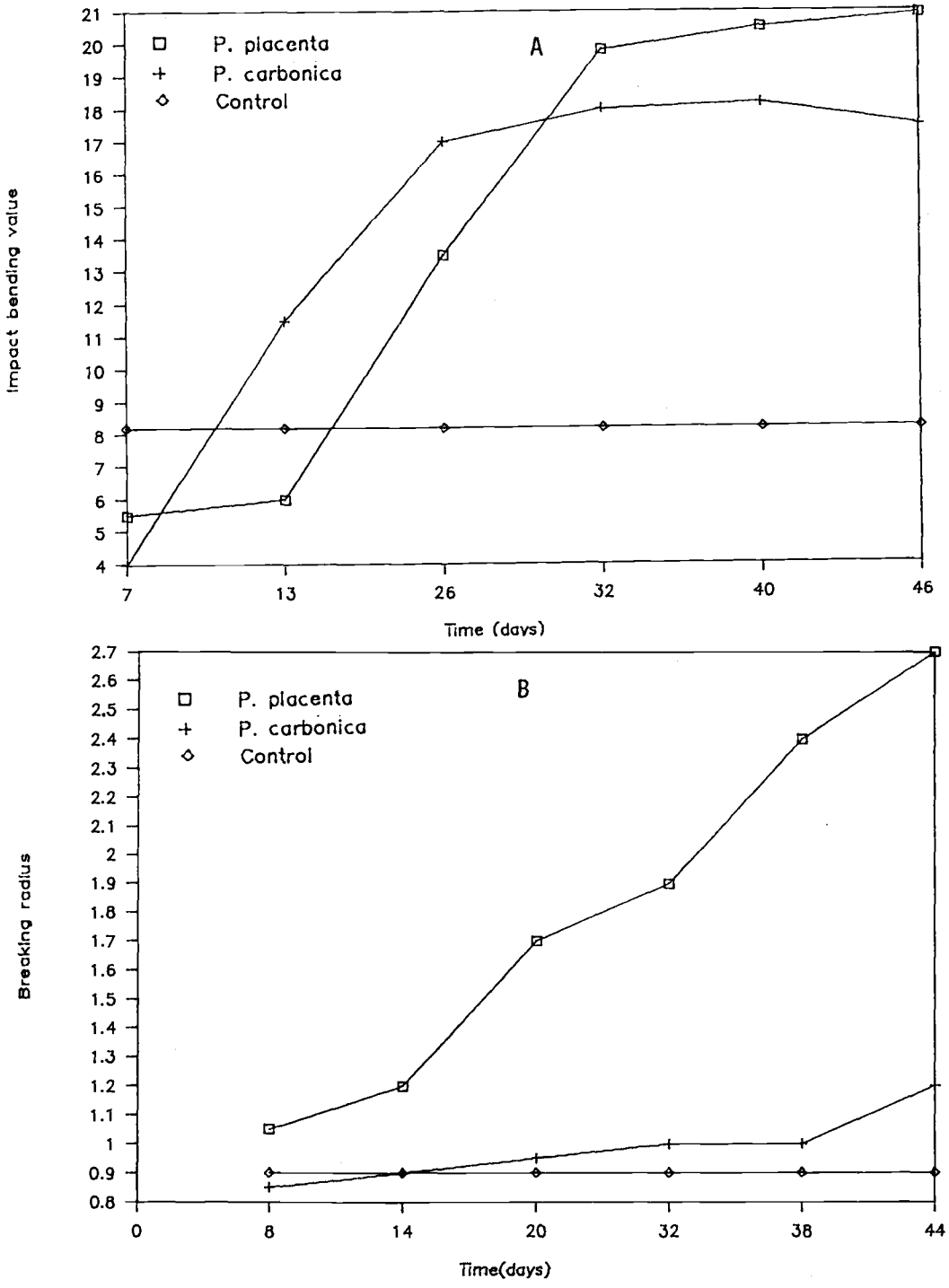

Figure 7. Relationship of A) impact bending values and B) breaking radii of birch sticks (1.6mm x 9.1mm) to time of incubation with Poria placenta or Poria carbonica (average of 24 specimens)

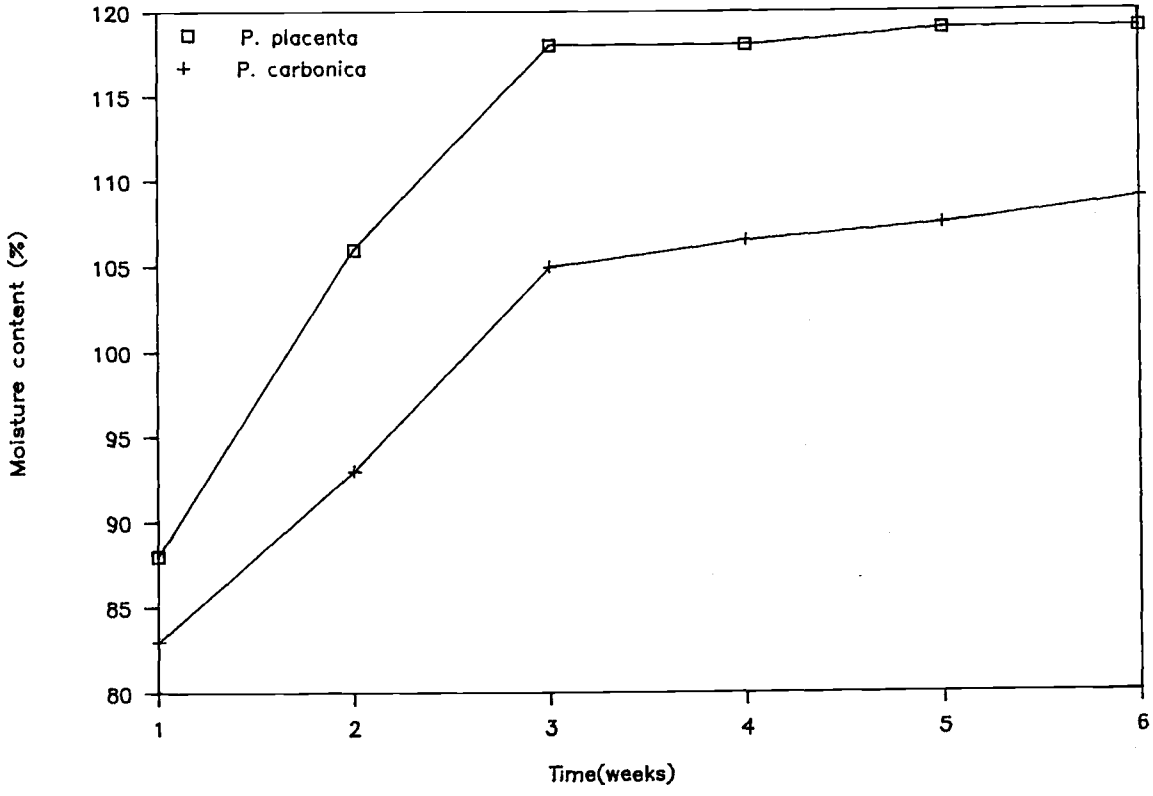

Figure 8. Relationship of wood moisture content to length of incubation of birch sticks (1.6mm x 9.1mm) with Poria placenta or Poria carbonica (average of 24 specimens).

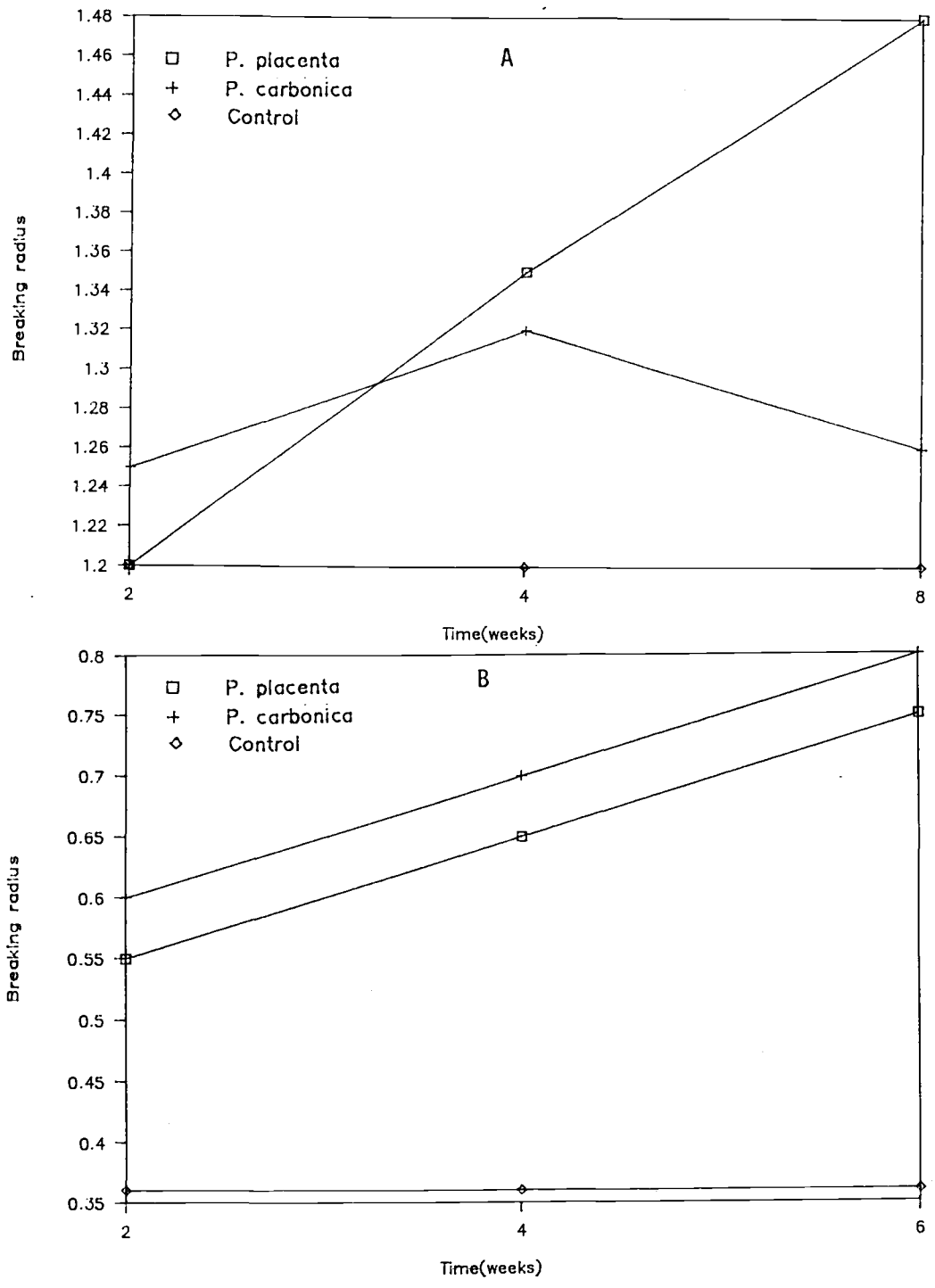

Figure 9. Relationship of breaking radius to time of incubation with Poria placenta or Poria carbonica for Douglas-fir sticks (1.7mm x 9.4mm) sampled A) oven dry or B) above the fiber saturation point (average of 24 specimens).

comparison to an uninoculated control after 4 weeks.

The number of weeks necessary to produce significant results varied from 1 to 5 depending on the type of wood, the test used, wood moisture content, and the decay fungus. Even the longest time (i.e. 5 weeks for birch wood decayed by P. carbonica tested for breaking radius) can be considered a short incubation time.

Incubation for 1 month is sufficient for distinguishing decayed and non-decayed wood with both breaking radius and impact bending tests.

Correlation of weight loss with strength loss

To determine the relationship between loss of toughness and weight loss the same test specimens were sampled for both parameters. Douglas-fir specimens were incubated with P. placenta. Twelve specimens were sampled weekly for 8 weeks beginning 2 weeks after the wood was placed on the agar surface. The plates were inoculated 1 week before the wood was added. Each specimen was numbered and oven dried to constant weight (nearest 0.0001g) prior to the start of the experiment. On the sampling date, the final oven dry weight and breaking radius was recorded for each specimen. Percent weight loss was calculated by the formula:

$$\frac{\text{initial oven dry weight - final oven dry weight}}{\text{initial oven dry weight}} \times 100$$

Wood incubated with P. placenta gained weight through 4 weeks but lost 1.2% by the end of the 5th week. Weight loss increased to 7.7% by 9 weeks (Fig. 10). Strength showed a weak relationship with incubation time in this experiment (Fig. 11). The general trend was

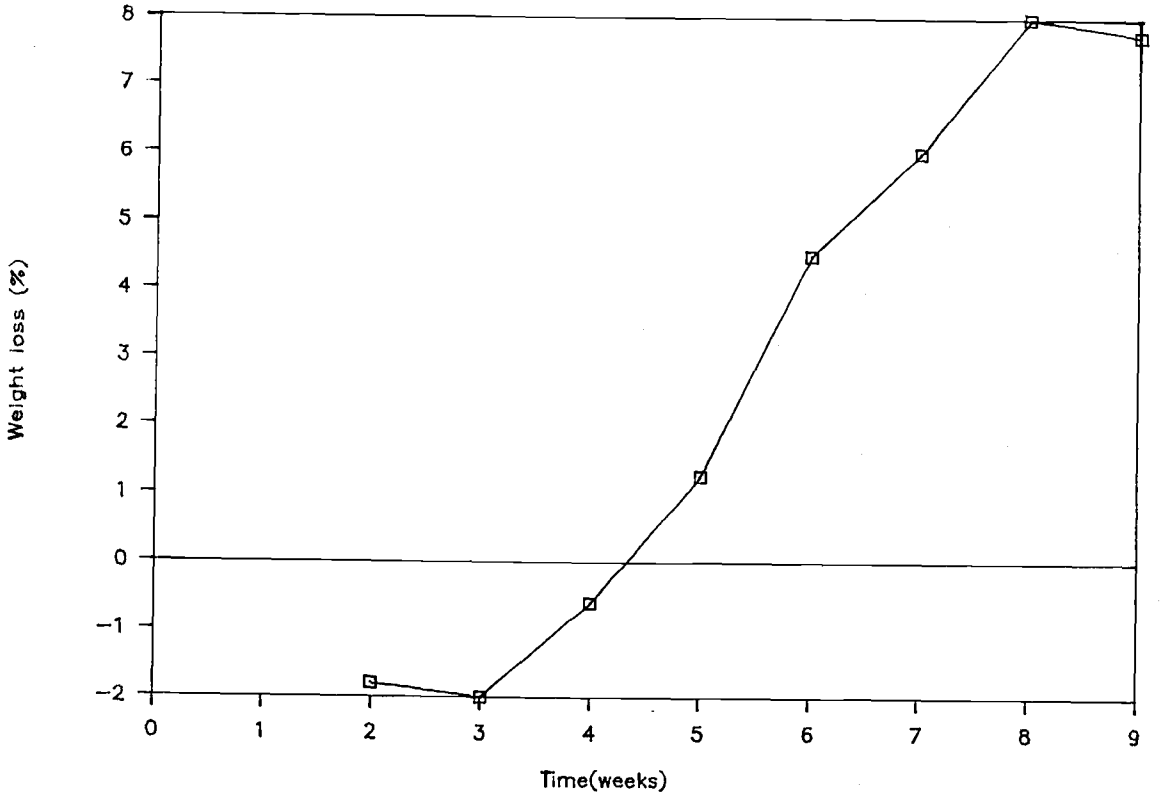

Figure 10. Relationship between weight loss and length of incubation with Poria placenta for Douglas-fir sticks (1.7mm x 9.4mm) (average of 12 specimens).

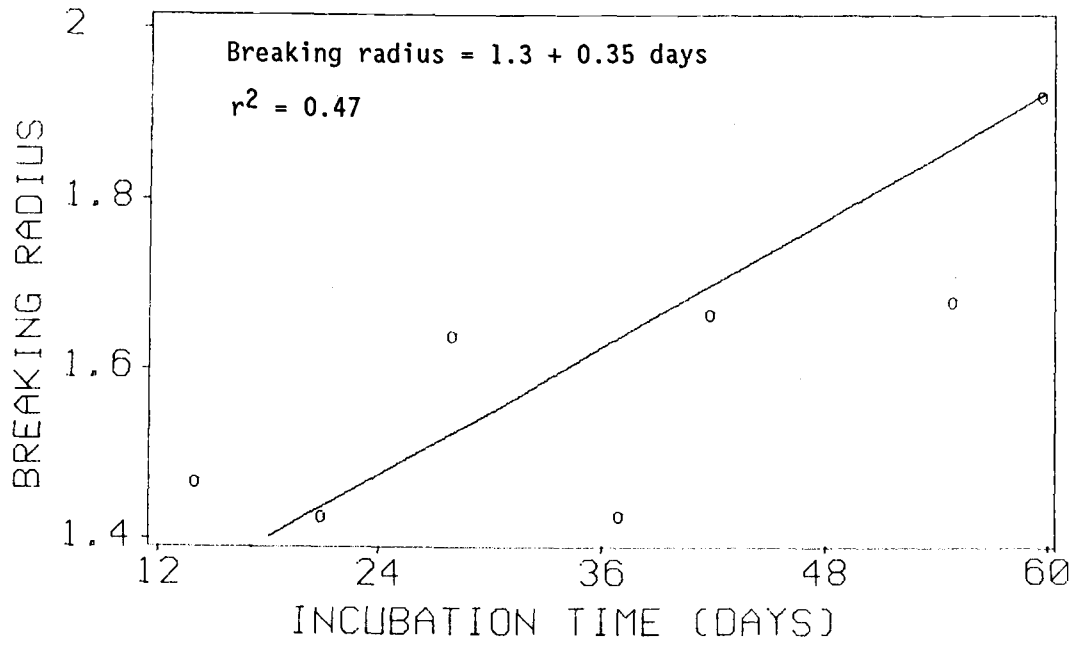

Figure 11. Relationship between breaking radii and length of incubation with Poria placenta for Douglas-fir sticks (1.7mm x 9.4mm) sampled oven dry (average of 12 specimens).

toward increasing breaking radius, but there was considerable variation (Fig. 11). The equation of the line is:

$$\text{Breaking radius} = 1.3 + 0.05 \text{ weeks}$$

and the r^2 is 0.47. The slope of this line is significantly greater than zero (t test $\alpha = 0.0595$).

Regressing breaking radius with weight loss gave the equation:

$$\text{Breaking radius} = 1.5 + 0.03 \text{ weight loss}$$

and an r^2 of 0.49 (Fig 12). The slope of this line is significantly greater than zero (t test $\alpha = 0.0524$). Although weight loss rose steadily over time, strength loss was erratic. The drop in breaking radius that occurs at 6 weeks was not significant (Fig. 12). A larger sample size may have resulted in less variation in breaking radius and thus a more consistent relationship with weight loss.

The breaking radius of 1.48 inches after 2 weeks was significantly higher than the uninoculated control (breaking radius 1.18 inches) before weight loss was detectable. This shows that toughness is in fact lost very early in the decay process.

Testing a variety of fungal isolates

As a trial run, a number of known decay fungi were tested using the methodology developed in the previous experiments. The effectiveness of raising the specimens above the agar surface on glass supports was also investigated with these isolates.

The culture medium in plates was inoculated with the test fungi (Table 6) and Douglas-fir specimens were added, four per plate, 10-12 days later. Twelve sticks for each isolate were incubated directly

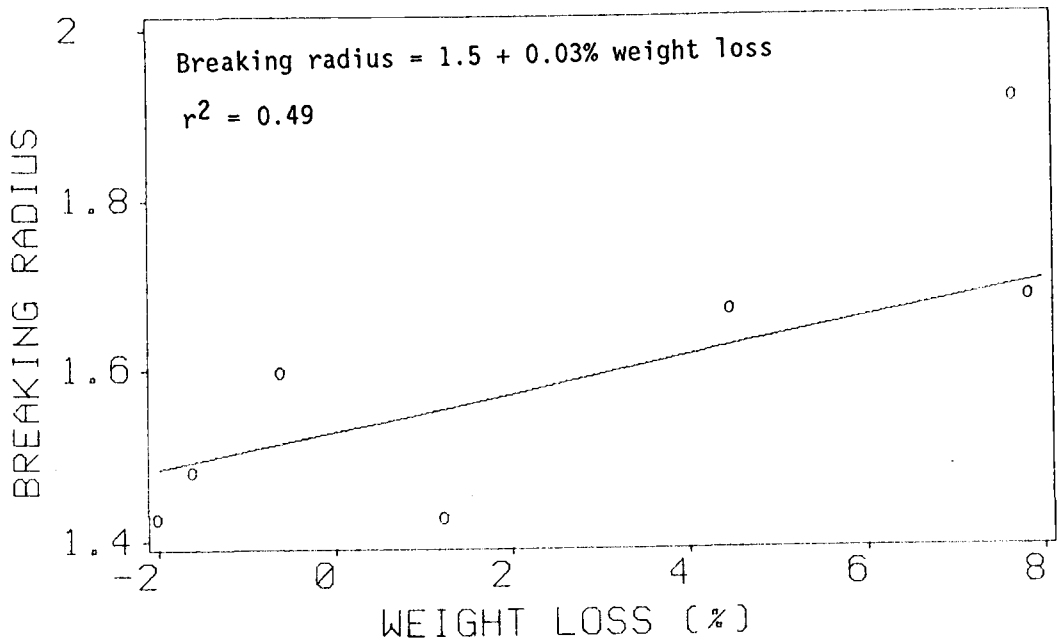

Figure 12. Relationship between breaking radii and weight loss for Douglas-fir sticks (1.7mm x 9.4mm) incubated with Poria placenta and sampled oven dry (average of 12 specimens).

TABLE 6
Breaking radii and moisture contents of Douglas-fir wood incubated with selected fungal isolates on glass supports or on the culture medium surface

Fungal isolate	Supported on glass			Resting on medium		
	BR_a	MC_b	No. days fungus on wood / No. days in plate	BR	MC	No. days fungus on wood / No. days in plate
Poria xantha FP 105494 sp	2.2_s	39	24/45	1.6	133	31/31
P. xantha single spore #8	3.5_s	55	38/42	1.7	147	31/31
Antrodia serialis FP 104443 sp	3.2_s	86	41/43	2.1	174	35/37
Fomitopsis roseus (OSU)	1.2_s	40	25/49	1.1	140	30/31
F. cajanderi monokaryon (OSU)	2.7_s	71	36/45	1.5	137	35/37
F. pinicola RLG 5047 sp	1.5	37	31/45	1.2	140	30/31
Sistotrema brinkmanii (OSU)	1.4	49	31/45	1.3	145	35/35
Gloeophyllum saepiarium (OSU)	1.6	121	38/42	1.5	156	34/35
Schizophyllum commune (OSU)	1.3	45	29/45	1.4	149	35/35
Phlebia radiata L-15608 sp	1.3	59	36/45	1.4	161	37/37
Coriolus versicolor (OSU)	1.2	57	39/43	1.2	85	37/37
C. versicolor monokaryon (OSU)	1.1	36	31/45	1.2	146	37/37

a. Average of 12 specimens.
s = Breaking radii of specimens supported on glass or resting on medium are

on the agar surface and 12 were raised on glass supports. The number of days necessary for each fungus to reach the wood was recorded. The breaking radius and moisture content of each specimen was determined 4-6 weeks after placement in the plates.

Of 12 isolates tested, 8 decayed wood significantly faster when supported on glass than when touching the agar surface. Three isolates decayed wood resting on the agar surface faster, but not significantly so, and one showed no difference (Table 6).

The fungi took longer to reach the wood when it was supported and thus had less time to cause strength loss. Six fungi reached the wood in 10 days while the slowest, Fomitopsis rosea(Alb. et Schw.:Fr.)Karst, took 24 days but still caused significantly more strength loss than with wood resting on the surface (Table 6).

The wood moisture content for specimens in contact with the agar averaged 143% while that of the specimens on glass averaged 58% (Table 6). The near saturation moisture contents caused by contact with the agar are inhibiting to most fungi.

The incubation time of 4-6 weeks used in this experiment is adequate or even excessive for detecting decay. Many isolates caused breaking radii much higher than the uninoculated control and one, Poria xantha (Fries)Cooke single spore #8, gave an average of 3.5 inches, the largest radius in the test. Complete failure is not the object of the test, but rather detectable strength loss in the shortest time.

The average standard deviation encountered in this test (0.348823) was used to calculate the necessary sample size for the

breaking radius test. The error of estimation was set to be less than 0.2 inches in breaking radius with a 95% probability. The resulting sample size was 13 which was rounded up to 16 since four specimens are put in each plate.

Sample size for impact bending was determined in a similar manner. The greatest variation encountered in testing wood decayed by P. placenta or P. carbonica was used. The standard deviation of 3.440827, an error of estimation of 2 units impact bending and a 95% probability level gave a calculated sample size of 12 specimens.

WOOD STRENGTH REDUCTION BY BASIDIOMYCETES ISOLATED FROM AIR SEASONING DOUGLAS-FIR POLES

INTRODUCTION

The objective of this phase of the research was to determine which basidiomycete species from Douglas-fir might cause strength loss during an air seasoning period and beyond. As heating times and temperatures decrease to save energy costs, the probability of fungi surviving treatment and damaging poles in service increases. Knowing which species are likely to cause this problem as well as how common they are will aid in making decisions about initial and remedial pole treatments.

MATERIALS AND METHODS

Many of the materials and methods used in this test are as described in the General Materials and Methods section.

The fungi used were basidiomycetes isolated from increment cores taken from air seasoning Douglas-fir poles (23). Some of these poles were full length and were sampled while air seasoning in the Pacific Northwest. These poles ranged in age from freshly cut to 24 months after peeling. Others were cut to 4 foot lengths, sterilized and set out in pole yards for 3 month periods year round (23).

Between one and 17 isolates of each fungal species were tested. More isolates were tested for fungi used earlier in the study to determine the magnitude of variation. Seventeen isolates of Peniophora spp. were tested because this genus includes many species

and variation was expected to be high. In fact, the coefficient of variation was 4.9% for breaking radius and 19.3% for impact bending. For other species, 10 isolates were initially used. Based on the variability encountered using 10 isolates, the minimum necessary sample size was calculated. For both tests a 95% probability was set. The error of estimation was set at 0.05 inches breaking radius and 0.5 units impact bending. The calculated sample sizes were 4.05 for the mandrel and 5.12 for the pendulum. For the remaining species to be tested, six isolates from different pole yards were used. If fewer than six isolates were available, all were tested.

Wood from two different cuttings or batches was used in these tests. Although no physical difference could be found between these specimens, disparate results were obtained. Uninoculated wood from the first cutting had a breaking radius of 1.18 inches and an impact bending value of 7.4. Wood from the second cutting tested under the same conditions gave values of 1.12 inches and 3.9 respectively. So that all fungal species could be directly compared, the data obtained using the first wood was converted by comparing results obtained with identical isolates of Poria placenta and Coriolus versicolor(L. ex Fries) Quel. and sound wood of both types. The graphs and equations used for conversion are presented in Fig. 13.

The data obtained from these tests were analyzed in several ways. Each isolate was compared to a common control by use of a students t test and the number of isolates significantly greater (α = 0.05) than the control determined. Species averages were not directly compared to the control because of differing sample sizes.

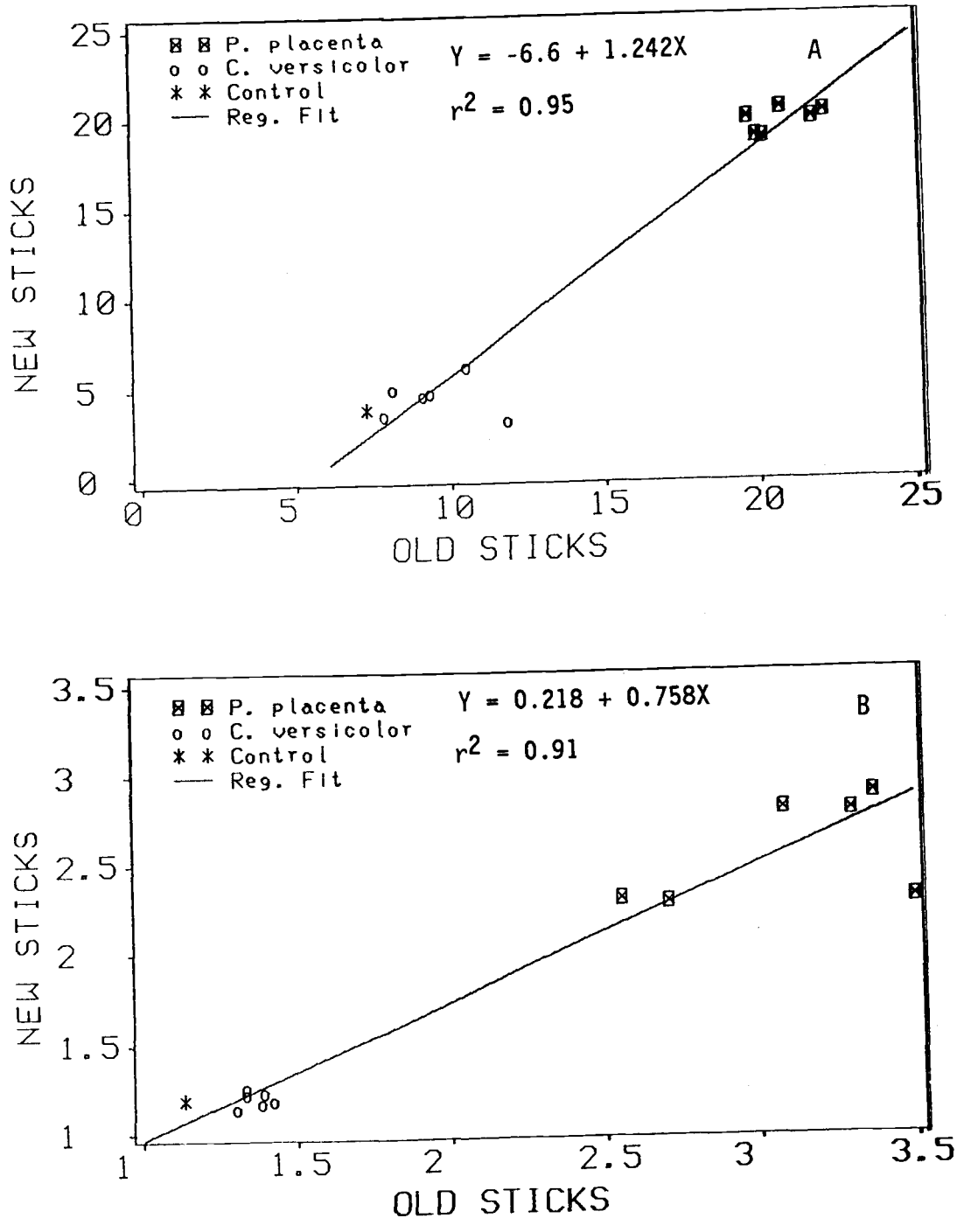

Figure 13. Relationship between A) impact bending values and B) breaking radii for two cuttings (new and old) of Douglas-fir sticks decayed and sampled under the same conditions. Equations were used to convert data obtained with old sticks for comparison with that from the new.

The control consisted of 24 specimens while the species totals went up to 256 specimens. Mono- and dikaryons of the same species were compared by a z test ($\alpha = 0.05$) for differences between means of large samples. All isolates were pooled for the z test. Differences between isolates of the same species were detected by using an F statistic ($\alpha = 0.05$) for comparison of more than two sample means.

RESULTS AND DISCUSSION

Values obtained from testing for breaking radius and impact bending value ranged widely from slightly below the control to far above. The number of specimens sampled for each value ranged from 12 to 256 and depended on the number of isolates tested for each species (Table 7). The non-decayed control wood had a breaking radius of 1.12 inches while the highest possible value was 3.5. Breaking radii ranged from 1.12 inches for Pleuroflammula puberula to 2.82 inches for Poria xantha monokaryon. These results can also be expressed as a 0% and a 251% increase over the control respectively. The non-decayed control specimens had an impact bending value of 3.93 where 23 is the highest possible value. Impact bending values ranged from 2.53 for Phlebia "A" monokaryon to 20.85 for P. xantha monokaryon (Table 7). These results are a 36% decrease and a 530% increase over the control respectively.

Classification of fungi by decay capacity

For the results of these tests to be meaningful, fungi must be classified as potential decayers or non-decayers. This designation

TABLE 7

Number of isolates tested, average breaking radii and impact bending values[a], standard deviations and percent of isolates greater than the control for all species tested

Species	No. of isolates	Average I.B.V.[a]	% isolates > control[b]	Average B.R.[c]	% isolates > control[b]
Antrodia serialis	4	7.59 (6.656)	50 (+)	1.68 (0.460)	100 (+)
A. serialis monokaryon	1	3.71 (1.234)	0 (NA)	1.22 (0.221)	0 (NA)
Coriolis versicolor	7	4.60 (5.053)	29 (-)	1.21 (0.183)	86 (-)
C. versicolor monokaryon	9	6.73 (5.145)	56 (-)	1.26 (0.270)	89 (-)
Crustoderma dryinum	7	16.84 (5.117)	86 (+)	2.18 (0.753)	100 (+)
C. dryinum monokaryon	1	6.89 (5.004)	100 (NA)	1.50 (0.365)	100 (NA)
Cystostereum pini-canadense	2	3.86 (2.092)	0 (-)	1.30 (0.152)	100 (-)
Fomitopsis cajanderi	5	11.03 (6.687)	100 (+)	1.68 (0.491)	100 (+)
F. cajanderi monokaryon	5	7.05 (5.581)	60 (-)	1.44 (0.312)	100 (-)
Fomitopsis pinicola	2	15.22 (5.622)	100 (+)	2.30 (0.830)	100 (+)
F. pinicola monokaryon	6	6.40 (5.053)	50 (+)	1.82 (0.635)	100 (+)
Gloeophyllum saepiarium	9	2.88 (5.095)	11 (+)	1.36 (0.344)	89 (-)
Haematostereum sanguinolentum	7	4.52 (5.079)	14 (-)	1.29 (0.247)	75 (-)
Heterobasidion annosum	6	1.58 (1.935)	0 (-)	1.58 (0.243)	67 (-)
Peniophora spp.	17	3.68 (4.610)	12 (-)	1.26 (0.229)	82 (-)
Phanerocheate sordida	9	3.98 (5.373)	22 (-)	1.26 (0.187)	67 (-)
Phellinus weirii	1	9.37 (5.154)	100 (NA)	1.19 (0.214)	0 (NA)
Phlebia "A"	3	4.19 (2.695)	0 (-)	1.14 (0.185)	0 (-)
Phlebia "A" monokaryon	14	2.53 (3.712)	0 (-)	1.26 (0.213)	0 (-)
Phlebia albida	1	2.87 (0.473)	0 (NA)	1.21 (0.221)	0 (NA)
P. albida monokaryon	1	4.05 (2.331)	0 (NA)	1.33 (0.151)	100 (NA)
Phlebia gigantea	3	3.64 (2.618)	0 (-)	1.29 (0.215)	100 (-)
Phlebia radiata	4	4.14 (3.116)	0 (-)	1.33 (0.429)	50 (-)
P. radiata monokaryon	6	2.71 (3.119)	0 (-)	1.18 (0.178)	17 (-)
Phlebia subserialis	6	3.59 (1.182)	0 (-)	1.23 (0.212)	67 (-)
P. subserialis monokaryon	1	4.03 (2.246)	0 (NA)	1.22 (0.221)	0 (NA)
Type 16	3	3.72 (1.251)	0 (-)	1.25 (0.171)	67 (+)
Type 16 monokaryon	6	3.84 (1.955)	0 (-)	1.22 (0.187)	50 (+)
Pleuroflammula puberula	1	4.82 (3.462)	0 (NA)	1.12 (0.158)	0 (NA)
Poria carbonica	9	8.17 (5.095)	68 (+)	1.88 (0.749)	100 (+)
P. carbonica monokaryon	8	9.43 (4.452)	88 (+)	1.53 (0.510)	100 (-)
Poria cinerascens	5	2.71 (3.408)	0 (-)	1.20 (0.205)	21 (-)
P. cinerascens monokaryon	6	4.81 (3.538)	33 (-)	1.29 (0.186)	100 (-)
Poria placenta	10	19.59 (2.704)	100 (+)	2.60 (0.683)	100 (+)
P. placenta monokaryon	10	20.36 (1.728)	100 (+)	2.39 (0.692)	100 (+)
Poria xantha	6	17.31 (5.218)	100 (+)	2.48 (0.698)	100 (+)
P. xantha monokaryon	5	20.85 (2.073)	100 (+)	2.82 (0.733)	100 (+)
Schizophyllum commune	6	4.32 (1.984)	0 (-)	1.22 (0.192)	33 (-)
S. commune monokaryon	6	3.41 (1.375)	0 (-)	1.22 (0.204)	67 (-)
Sistotrema brinkmanii	6	4.07 (1.620)	0 (-)	1.23 (0.196)	50 (-)
Stereum hirsutum	10	5.73 (4.909)	30 (-)	1.22 (0.229)	30 (+)

a. I.B.V. = impact bending value. Figures in parentheses are standard deviation.
b. Figures in parentheses indicate the presence (+) or absence (-) of a difference between isolates of a species. NA = not applicable, only one isolate tested.
c. B.R. = breaking radius. Figures in parentheses are standard deviation.

was based on the percentage of isolates which weakened wood significantly. Nearly all species tested had at least one isolate able to reduce the strength of wood. Fungal species that failed to reduce wood strength were rarely encountered in air seasoning Douglas-fir thus only a few isolates were available for testing. The species tested have been divided into three arbitrary categories of decay capacity for ease in sorting out the data (Table 8). The categories were constructed around natural breaks in the data and defined as follows:

Serious decayers are those fungi of which 50% or more of the isolates significantly reduced wood strength as measured by both tests.

Moderate decayers are those in which 30% or more of the isolates significantly reduced wood strength as measured by both tests or at least 50% as measured by one test regardless of the other.

Non-decayers have below 30% on both tests or not greater the 50% on either one.

Eight species were classified as serious decayers. Seven of these are brown rot fungi, which are believed to cause the majority of decay problems in Douglas-fir utility poles. The eighth was a Coriolus versicolor monokaryon, a white rot fungus. C. versicolor is common in woody debris and is considered an efficient wood rotter (32). It is also often used as a representative white rot fungus in wood decay tests. The brown rot fungi including three Poria species and two of Fomitopsis are known to cause decay in standing trees or timber. P. carbonica is known especially for causing decay in Douglas-fir utility poles (12,9).

TABLE 8

Decay capacity classification and frequency of isolation for all species of fungi tested

Species	% of isolates causing < BR[a]	% of isolates causing < IBV[b]	% poles colonized[c]
Serious decayers			
Poria xantha monokaryon	100	100	0.1
Poria placenta	100	100	3.5
P. placenta monokaryon	100	100	3.8
P. xantha	100	100	0.1
Crustoderma dryinum	100	86	0.1
C. dryinum monokaryon	100	100	0.1
Fomitopsis cajanderi	100	100	1.6
Fomitopsis pinicola	100	100	0.1
Poria carbonica	100	67	10.1
P. carbonica monokaryon	100	87	1.1
F. pinicola monokaryon	100	50	0.4
F. cajanderi monokaryon	100	60	0.1
Coriolus versicolor monokaryon	89	55	2.1
Antrodia serialis	100	50	0.1
Moderate decayers			
C. versicolor	86	29	3.4
Gloeophyllum saepiarium	89	11	2.1
Heterobasidion annosum	67	0	0.2
Poria cinerascens monokaryon	100	33	0.4
Phlebia albida monokaryon	100	0	0.1
Phellinus weirii	0	100	0.1
Cystostereum pipi-canadense	100	0	0.5
Phlebia gigantea	100	0	0.1
Type 16	67	0	0.1
Phlebia subserialis	67	0	0.5
Schizophyllum commune monok.	67	0	0.5
Phlebia radiata	50	0	0.1
Sistotrema brinkmanii	50	0	12.5
Type 16 monokaryon	50	0	0.1
Phanerocheatae sordida	67	22	4.2
Haematostereum sanguinulentum	75	14	24.2
Peniophora sp.	59	12	16.8
Phlebia "A" monokaryon	86	0	0.5
Stereum hirsutum	30	30	4.2
Non-decayers			
P. radiata monokaryon	17	0	0.4
P. albida	0	0	0.1
P. cinerascens	20	0	0.1
S. commune	33	0	1.4
P. subserialis monokaryon	0	0	0.1
A. serialis	0	0	0.1
Pleuroflamulla puberula	0	0	0.1
Phlebia "A"	0	0	0.1

a. BR = breaking radius.
b. IBV = impact bending value.
c. Przybylowicz 1985.

Eighteen species fell into the moderate decay category. All but one, Gloeophyllum saepiarium (Wulf.:Fr.)Karst, are white rot fungi. Several of these are known to be common decayers of trees or woody debris. Heterobasidion annosum (Fr.)Bref. causes an important root rot of coniferous trees (32). Stereum hirsutum (Willd. ex Fr.)S.F. Gray and S. (Haematostereum) sanguinolentum (Alb. & Schw.:Fr.)Pouz. are both common but weak wood rotters and are considered to play an important role in woodland ecology (32). H. sanguinolentum inhabits living trees and accounts for 74% of the rot resulting from wounding Douglas-fir trees (18).

Eight species were classified as non-decayers. Because monokaryons and dikaryons were tested separately, many species fall into two categories. Most of those classified as non-decay fungi based on one life stage (either monokaryon or dikaryon) also fall into either the serious or moderate categories based on the other life stage. All were white rot fungi except Antroidia serialis (Fr.)Donk. monokaryon, of which only one isolate was available.

How rapidly or completely a particular fungus degrades wood is more meaningful if some estimation of its population size is available. Przybylowicz (23) reported the frequency of basidiomycetes isolated from air seasoning Douglas-fir (Table 8). Fungal isolates used in this study were drawn from the same population.

The three fungi isolated most frequently, H. sanguinolentum, Peniophora sp. and Sistotrema brinkmanii (Bres.) J. Erikss. cause moderate decays, but did little damage to wood in 1 month. Large

populations acting over several years may cause considerable decay.

Serious decayers which were also frequently isolated are P. carbonica and Poria placenta. Both of these fungi could cause extensive damage to poles even over short time periods.

Correlation of breaking radius and impact bending

The breaking radius and impact bending tests are highly correlated when all isolates are considered ($r^2 = 0.79$) (Fig. 14). The relationship between the tests is:

Impact bending value = -9.36 + 10.84 breaking radius.

The ability to decay wood, as measured by a significant difference from the uninoculated control, was more difficult to show with the impact bending test. The sample sizes and variances of the two tests account for this. The coefficient of variation averaged 44% (range 8-126%) for impact bending compared with 20% (range 11-36%) for breaking radius. A high coefficient of variation makes significant differences more difficult to prove. Although the sample size of 12 specimens/isolate was indicated by estimates of standard deviation in preliminary sampling, actual variability proved higher. A larger sample size may have lowered the standard deviation.

Comparison of decay capacities of white and brown rot fungi

White and brown rot fungi fell into distinct categories on each test. In general the eight brown rot fungi had a greater ability to decay wood than the 18 white rot fungi (Figs. 15 and 16). The white rot fungi span only a narrow range of breaking radii, but a

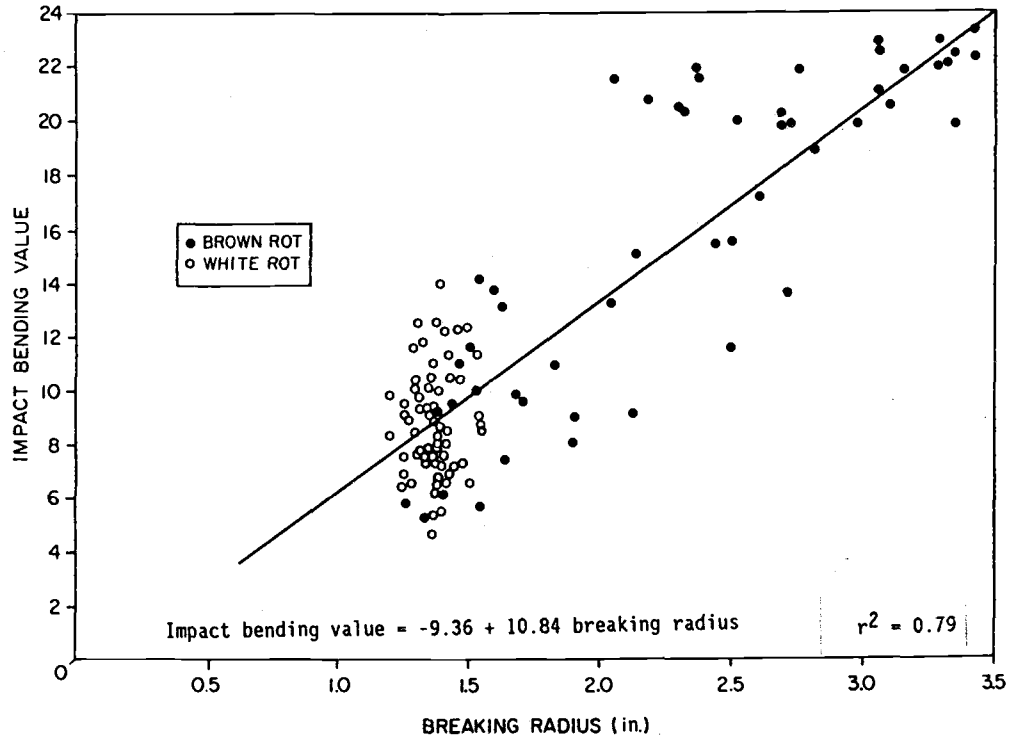

Figure 14. Correlation between impact bending values and breaking radii of 117 isolates of 10 representative species of basidiomycetes isolated from air seasoning Douglas-fir.

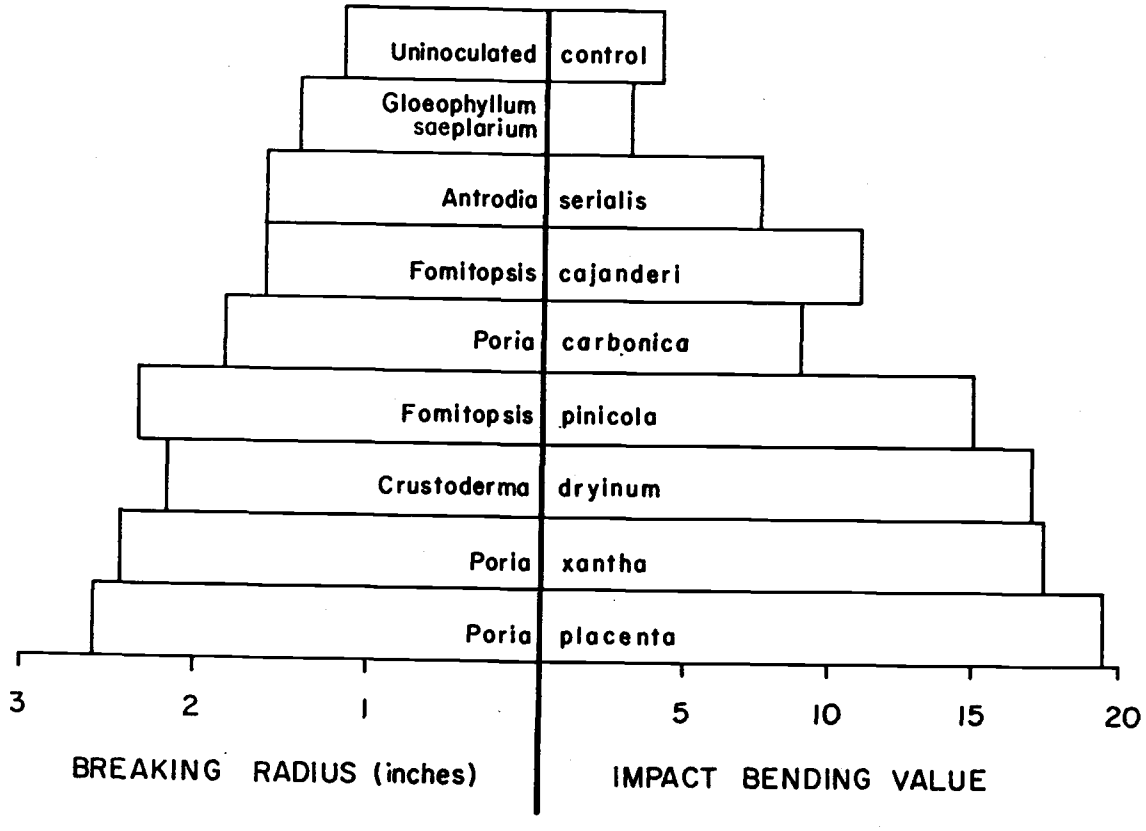

Figure 15. Relative wood decay ability as measured by breaking radius and impact bending value of brown rot fungi isolated from air seasoning Douglas-fir poles.

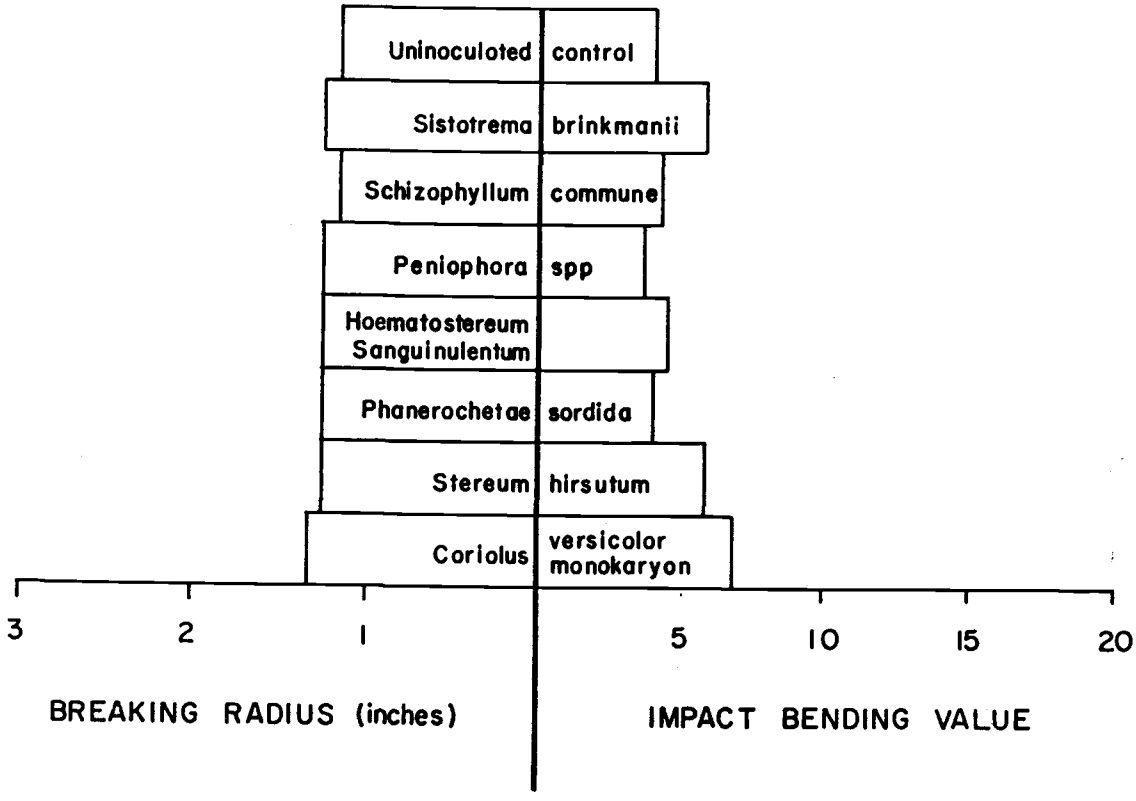

Figure 16. Relative wood decay ability as measured by breaking radius and impact bending value of selected white rot fungi isolated from air seasoning Douglas-fir poles.

comparatively wider range of impact bending values. The correlation between the two tests is poor when only white rot fungi are considered. (r^2 = 0.02). Brown rot fungi cover a wide range of values on both tests and show a much higher degree of correlation (r^2 = 0.70) (Fig. 14).

Differences between white and brown rot fungi can be explained by the rates of decay of the two types and the mechanics of the tests. The methodologies of the tests were devised using brown rot fungi as test fungi because these are thought to cause the most damage to utility poles. Brown rot fungi were also expected to be isolated more frequently than white rot fungi; in fact greater numbers and species of white rot fungi occurred in air seasoning Douglas-fir poles. Brown rot fungi decay wood more quickly than white rot fungi, especially in the early stages. Toughness has been reported to be effected equally by the two types of decay fungi (15,24), but this was not the case in this study. The short incubation time of 4 weeks may have caused the slower acting white rot fungi to seem less of a problem than is actually the case.

Another factor contributing to this difference between white and brown rot fungi is the inability of some fungi, mainly white rot fungi, to degrade heartwood. Perhaps had Douglas-fir sapwood been used, more of the white rot fungi would have caused decay. Heartwood was chosen because the sapwood should be completely penetrated by preservative during treatment and thus relatively decay resistant. The heartwood, then, is more vulnerable to decay during service and only those fungi able to survive or enter after treatment and degrade

it will cause problems.

The poor correlation between the tests when only white rot fungi are considered is caused be differing sensitivities in the lower range of strength loss. The pendulum measures a continuum of impact bending values based on the amount of energy required to cause failure. The mandrel measures the discreet value of breaking radius. Too few breaking radii are available to detect subtle differences at the lower end where the white rot fungi cluster. The result is a wider range of impact bending values corresponding to a narrow range of breaking radii and a poor correlation.

Decay capacity of monokaryons and dikaryons

A comparison of monokaryons and dikaryons of the same species shows that neither life stage has consistently greater decay capacity (Fig. 17). Of 15 pairs tested, nine showed the same trend on both tests. Monokaryons of four species caused more decay, while dikaryons of the other five were more damaging. Six pairs showed opposite trends on the two tests, only one significantly so. P. placenta monokaryon caused a greater increase in breaking radius but a lower increase in impact bending than did the dikaryon.

For all comparisons between mono- and dikaryons, data from all isolates of each type were pooled and a z test employed. In one case, Phlebia albida Post:Fr., too few isolates were available for a z test and a t test was used instead.

All of the isolates used in this study were field isolates and thus cannot be assumed to be closely related. Most studies involving

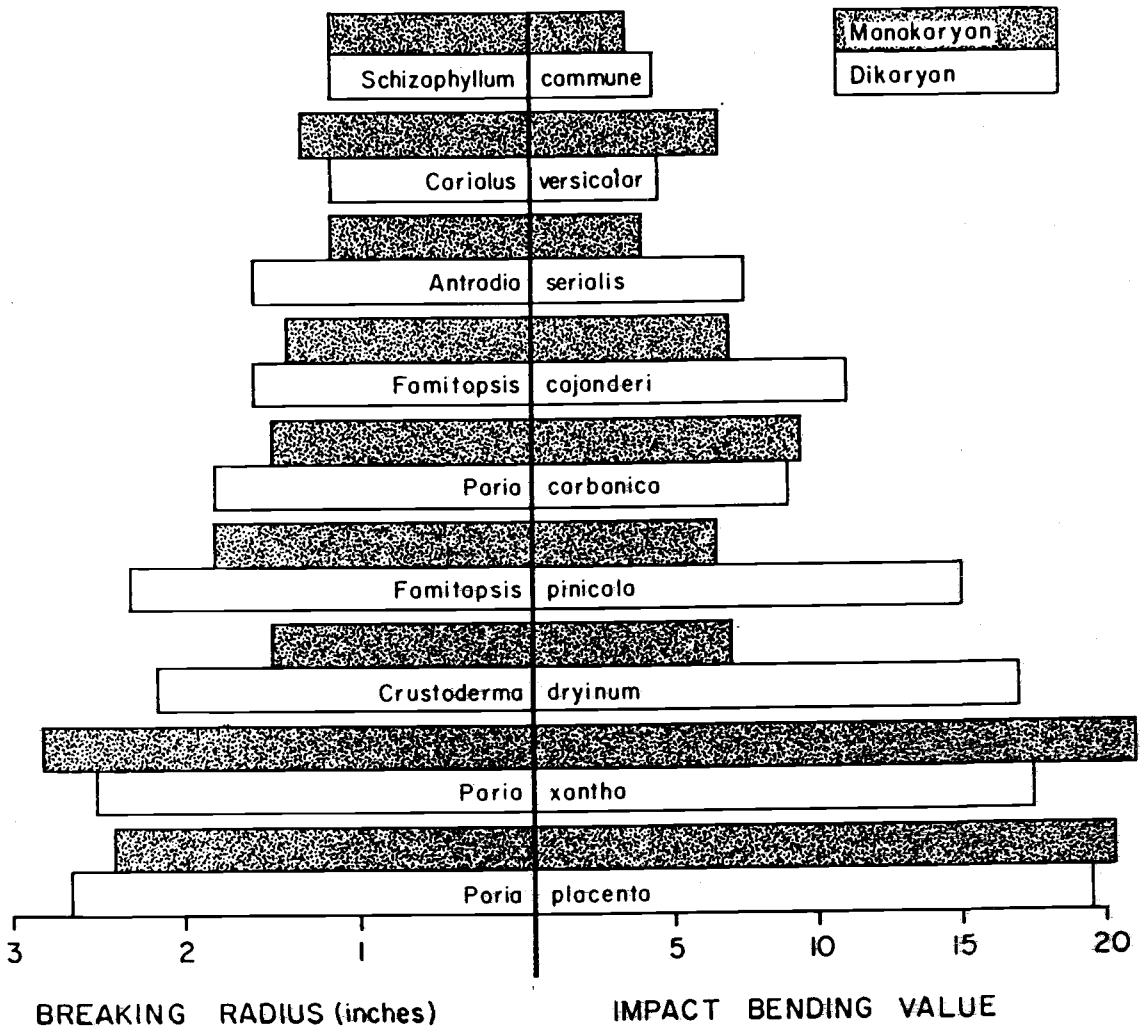

Figure 17. Relative wood decay ability as measured by breaking radius and impact bending value of selected monokaryon-dikaryon pairs isolated from air seasoning Douglas-fir poles.

differences between monokaryons and dikaryons employ synthesized cultures of known relationship (3,11). Elliot et al (11) found dikaryons of Serpula lacrymans (Wulf.:Fr.) Schroet. to cause less weight loss than both component monokaryons in 57% of the cases. In 33% of the cases, the dikaryon fell between the monokaryons, and 10% of the time the dikaryon caused more weight loss. Amburgey (3) found no consistent relationship between weight loss caused by component monokaryons and the resulting dikaryon of Lenzites trabea Pers. ex Fries. Based on these and the present study, both mono- and dikaryons of wood decay fungi must be presumed to both be capable of destroying wood unless proven otherwise.

Differences in decay capacity of isolates of the same species

Of the 45 isolates tested (monokaryons and dikaryons considered separately), 22 showed no difference between isolates in breaking radius and 26 were not different in impact bending. Those showing a significant difference between isolates numbered 16 for breaking radius and 12 for impact bending (F test $\alpha = 0.05$). Only one isolate of the remaining seven fungi was available for testing (Table 7).

A difference between isolates is more likely for species which decay wood relatively more rapidly. All of the fungi classified as serious decays show a difference between isolates among the monokaryons, the dikaryons or both. Presumably, when more biological activity is occurring more room for variation exists. In most cases a high percentage of the isolates were significantly greater, usually by a wide margin, than the control. The difference between isolates in these cases suggests not that some individuals decay wood rapidly

and others not at all, but rather a more subtle difference in decay rate. Stereum hirsutum was an exception with only 30% of isolates causing significant strength loss as measured by breaking radius. In this case a few isolates were well within the decay range while the majority caused no strength loss.

CONCLUSIONS

Brown rot fungi isolated from Douglas-fir cause more rapid strength loss than do white rot fungi. As the incubation time was only 4 weeks it is not known if the white rotters would eventually surpass the brown rotters or how long this might take. Most white rot fungi reduced wood strength in 4 weeks.

Some fungi which had a slight effect on wood strength are present in such large populations as to be capable of causing much damage to poles. These include Haematostereum sanguinolentum, Peniophora spp. and Sistotrema brinkmanii. Poria carbonica and P. placenta are present in large numbers and decay wood rapidly. These two fungi pose the greatest threat to air seasoned Douglas-fir poles.

Each species must be considered individually to determine which life stage (monokaryon or dikaryon) is more damaging to wood. Monokaryons must be considered at least as capable of damaging wood as dikaryons unless proven otherwise.

Differences between isolates of the same species are usually subtle variations in decay rate. Although the differences are significant (F test $\alpha = 0.05$), they do not imply that some isolates decay wood rapidly and others not at all. One exception to this was found. Isolates of Stereum hirsutum are either well within the decay range or near the uninoculated control.

Correlation between the breaking radius and impact bending tests is high ($r^2 = 0.79$) when all isolates are considered. The poor correlation when only white rot fungi are used is due to differing sensitivities of the two tests in the low range of strength loss

where most white rotters fall.

In retrospect the tests could be improved in several ways. At least some of the white rotters could be incubated with wood for more than 4 weeks to determine how far they lag behind brown rotters. The values obtained at 4 weeks may relate to results from longer decay periods so it may not be necessary to slow the testing down for all white rot fungi. The impact bending test could be made more accurate by increasing sample size or reducing variation in some other way. When used with birch sticks and the heavier arm, variation was much lower than with Douglas-fir and the lighter arm. Perhaps the weight of the arm was not exactly suited to the specimens, or Douglas-fir wood has a larger source of hidden variation.

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