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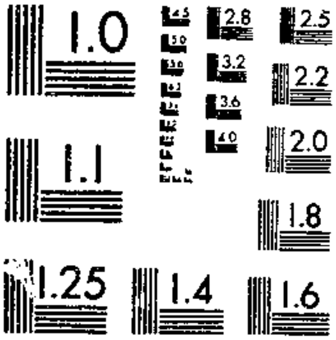

MICROCOPY RESOLUTION TEST CHART
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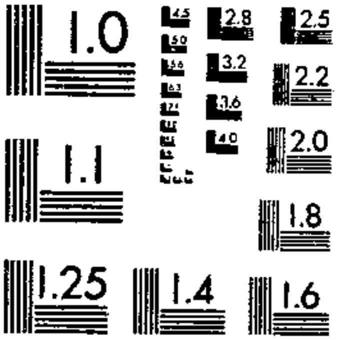

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The Effect of Certain Heart Rot Fungi on the Specific Gravity and Strength of Sitka Spruce and Douglas-Fir[1]

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CONTENTS

INTRODUCTION

During the first World War one of the most important problems in the production of military aircraft was the proper selection of airplane timber. Methods of selecting and grading employed for ordinary

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[1] Received for publication Dec. 2, 1940.

[2] This bulletin is based on data collected by R. H. Colley, formerly pathologist, Division of Forest Pathology, T. R. C. Wilson, R. F. Luxford, and Carl Hartley. It is a condensation of the following reports which cover the respective data more fully than the present discussion and if desired can be made available:

Colley, R. H., Hartley, Carl, Wilson, T. R. C., and Luxford, R. F. THE EFFECT OF HEART-ROTTING FUNGI ON CERTAIN PHYSICAL AND MECHANICAL PROPERTIES OF SITKA SPRUCE AND DOUGLAS FIR. Bur. Plant Indus. and Forest Serv. Rpt., 99 pp., illus. 1936. [Typewritten.]

Colley, R. H., Wilson, T. R. C., and Luxford, R. F. THE EFFECT OF POLYPORUS SCHWEINITZII AND TRAMETES PINI ON THE SHOCK RESISTANCE, COMPRESSION PARALLEL TO GRAIN STRENGTH, AND SPECIFIC GRAVITY OF SITKA SPRUCE. (Series III) Proj. L-243-J1, 29 pp., illus. 1925. [Typewritten.]

E. P. Meinecke, principal pathologist, formerly of the Division of Forest Pathology, initiated and supervised the field work and the general plan of the laboratory work of the early part of the study. In addition, the following cooperated or assisted in the study: C. Audrey Richards and Alma M. Waterman, of the Division of Forest Pathology; E. E. Hubert, N. R. Hunt, A. S. Rhoads, W. H. Snell, and Minnie W. York, formerly of the Division of Forest Pathology; and L. J. Markwardt and J. A. Newlin, of the Forest Products Laboratory.

[3] In cooperation with the Forest Products Laboratory, maintained by the Forest Service, United States Department of Agriculture, at Madison, Wis., in cooperation with the University of Wisconsin.

lumber were not sufficiently exacting. The significance of stains and discolorations in wood, such as Sitka spruce (*Picea sitchensis* (Bongard) Carrière) was practically unknown, and this fact was particularly disturbing since some of the discolorations were recognized as manifestations of incipient infection by certain decay fungi. Because of this situation the Division of Forest Pathology, with the help of the Forest Products Laboratory, undertook in 1918 a study of the specific gravity and strength in the heartwood of infected Sitka spruce and Douglas-fir (*Pseudotsuga taxifolia* (LaMarck) Britton) trees, in relation to the zones of decay and their visible characteristics. Decays selected for detailed study were those caused by *Fomes pini* (Thore) Lloyd (formerly known as *Trametes pini* (Thore) Fr.) and *Polyporus schweinitzii* Fr., the two most important heart rot fungi attacking western conifers (*4*).[4] A small amount of work permitting limited conclusions was also done on decay in Douglas-fir caused by *Fomes laricis* (Jack.) Murr.

The final effect of each of these fungi was known to be the complete or almost complete destruction of the wood structure. However, their effect in early or incipient stages in which the only visual evidence of the presence of decay is a slight stain or discoloration was not known. Objectives of the study included quantitative evaluation of the effects on various strength properties of decay in its various stages and some exploration of the correlation between strength properties and degrees of decay as measured by visual criteria or otherwise.

The earliest results of the study were made available to the inspectors of the Bureau of Aircraft Production, and some of them have been published (*2*, *3*, *7*). Subsequent results, emphasizing the general effects of decay on the specific gravity and strength of heartwood, are presented here. This study, so far as is known, was the first intensive attempt to measure the effects of decay on strength, and is perhaps the most comprehensive strength analysis that has been made on wood decayed under natural conditions. One of the most illuminating of its unique features was a systematic and extensive sampling of some of the infected trunks, permitting comparatively detailed graphic analyses of the distribution of the decayed and sound wood and associated specific gravity and strength values throughout the affected portion of the tree.

The main value of a study of decayed material taken from the standing tree lies in the fact that natural conditions are dealt with. In recent years analyses of strength changes have been conducted on wood artificially infected and decayed in the laboratory (*1*, *5*, *6*, *9*), usually following heat sterilization. This method provides a way of ascertaining the strength-reducing potentialities of a particular fungus, and it can be designed to give reliable data on certain progressive effects of the decay. However, only by dealing with wood infected in the tree is it possible to show the typical dispersion of heart rot and of its effects about the zones of infection and in relation to the sound wood.

TYPES OF DECAY STUDIED

Fomes pini produces a so-called white pocket rot, in the final stages of which the heartwood characteristically is riddled with spindle-shaped pockets that are lined with strands of nearly pure cellulose

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[4] Italic numbers in parentheses refer to Literature Cited, p. 24.

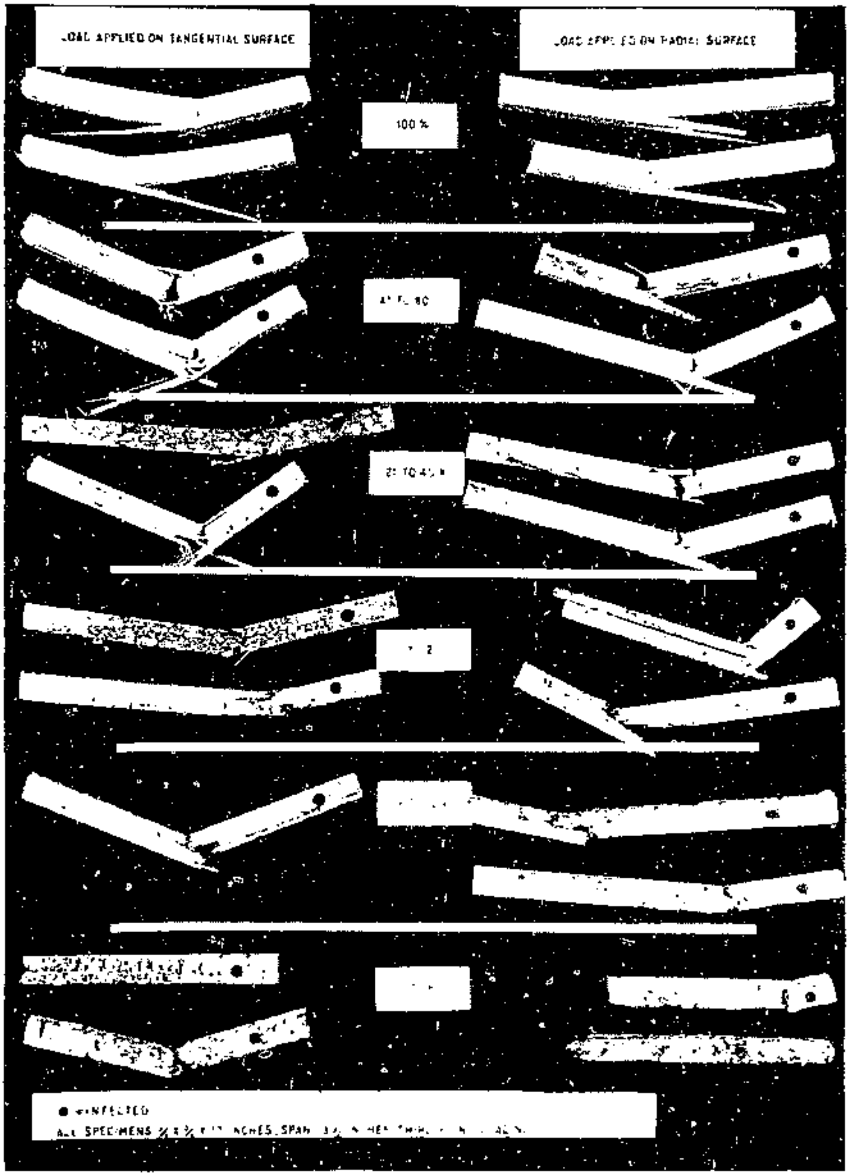

FIGURE 1.—Toughness-test failures of Sitka spruce specimens infected with *Fomes pini*. Specimens are grouped in order of relative toughness, with values for uninfected control specimens taken as 100.

stage [illegible] In Douglas-fir and Sitka spruce the decay in its early or incipient stages imparts to the wood a pronounced reddish-purple or reddish-brown discoloration. The discoloration in Douglas-fir may

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[illegible]

extend vertically from 10 to 20 feet in advance of the development of pockets, although 3.5 feet was found to be the average. The radial advance of the discoloration apparently is limited to 2 to 3 inches (4). On the ends of the logs the areas of infected wood commonly are crescent-shaped or circular.

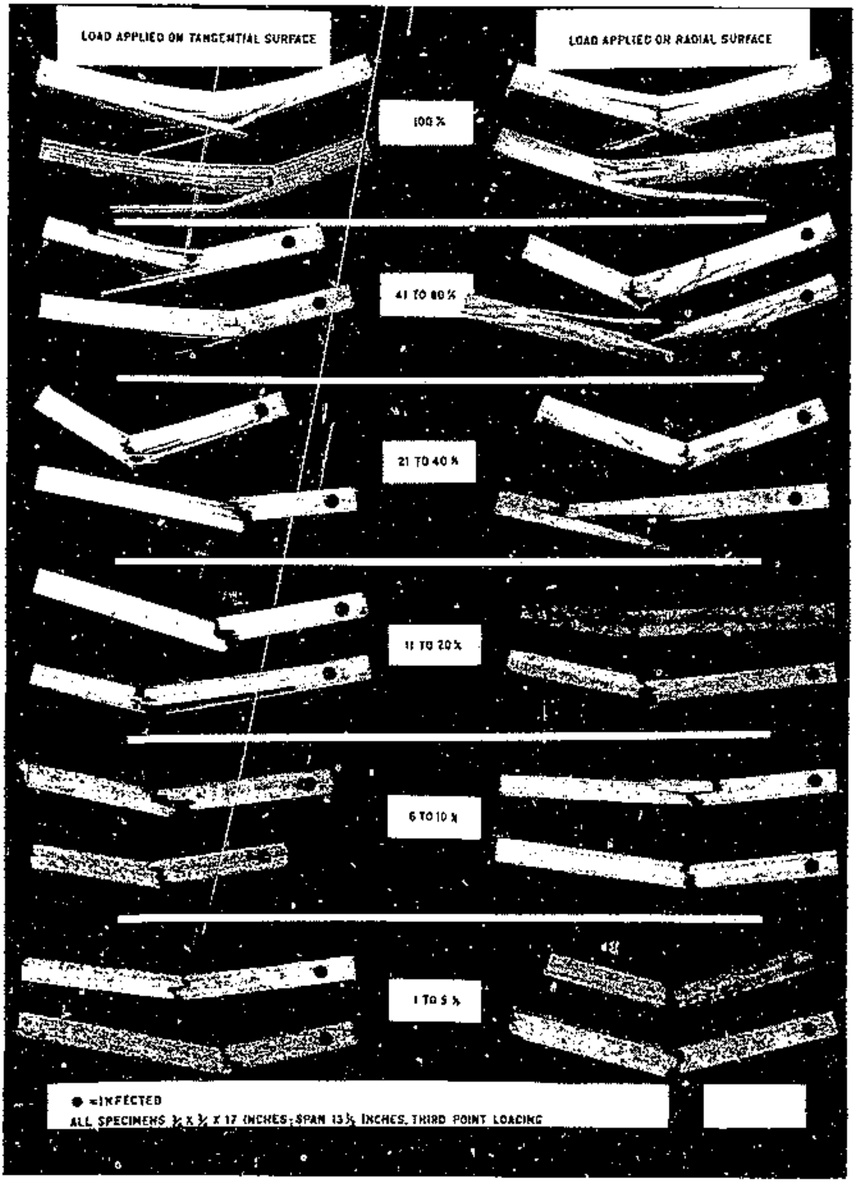

FIGURE 2.—Toughness-test failures of Sitka spruce specimens infected with *Polyporus schweinitzii*. Specimens are grouped in order of relative toughness, with values for uninfected control specimens taken as 100.

Polyporus schweinitzii produces a brown, crumbly rot, the wood ultimately shrinking and cracking to form rough cubes that may readily be crushed between the fingers (fig. 2). The incipient stage is first denoted by a pale-yellow or brown discoloration that is often difficult to detect, especially after the wood is dry. In Douglas-fir the incipient stage commonly extends longitudinally about 2 feet beyond the typical stage, and sometimes as much as 8 feet (*4*). The visibly infected wood is preceded for some distance by an invisible zone of infection. On the ends of the logs the infected area is circular in outline, and in vertical section the rot column is roughly in the shape of a cone, with the base at the butt of the tree.

Fomes laricis also produces a brown, crumbly rot. The incipient stage is accompanied by a brownish discoloration that usually is scarcely discernible. The incipient stage commonly extends more than 3 feet longitudinally beyond the typical decay and is itself preceded by several inches of invisible infection. On the ends of logs the rot is essentially circular in outline.

METHODS

Three series of tests were made in all, each having the same general objective but approaching the problem from somewhat different angles. More attention is given to series 3 than to the others, because it was the most extensive and was so designed as to give more information and to permit a better presentation and interpretation of the results. Where necessary, more detailed information than is contained in the following general description of methods is given with the presentation of results.

TABLE 1.—*Essential characteristics of the 3 series of decay studies*

Test series No.	Wood species	Decay fungus	Matching of specimens	Kinds of test	Moisture condition of specimens when tested
1	Sitka spruce Douglas-fir.	*Fomes pini*	Controls taken from approximately the same growth rings and at the same height as the infected specimens.	Static bending, impact bending, compression parallel to grain, and specific gravity.	Green and air-dry.
		Polyporus schweinitzii.	Controls taken from approximately the same growth rings, in bolts above the infected specimens.		
2	Douglas-fir	*Fomes pini* *Polyporus schweinitzii.*	Controls taken from approximately the same growth rings, in bolts above the infected specimens.	Toughness and specific gravity.	Green.
		Fomes laricis	Controls taken from sound outer wood at the same height as infected specimens; hence not from same growth rings.		
3	Sitka spruce	*Fomes pini*	Controls taken from approximately the same growth rings and at the same height as the infected specimens.	Toughness, compression parallel to grain, and specific gravity.	Air-dry.
		Polyporus schweinitzii.	Controls taken from approximately the same growth rings, in bolts above the infected specimens.		

A summary of the principal characteristics of the three series is given in table 1.

In addition to the tests enumerated in table 1, tests of shearing strength and hardness were included in series 1. Because these tests were few in number and the resulting data inconclusive, they are omitted from consideration in this bulletin.

Selection and Preparation of Material

The trees selected for study were obtained from coastal timber stands of California and Oregon. All were felled with the greatest care, not only to avoid breakage but also to minimize the chances of any incipient failures whose effect might be confused with that of the organisms being studied.

To orient the logs in the cutting-up process, guide lines were marked the full length of each. These lines were so drawn that they would be continuous if the bolts cut from the logs were placed together in their original positions. By similar appropriate marking, as the logs were cut up, it was possible to reconstruct schematically the relative positions of the individual test specimens and of the decay zones. In all cases the boards were quarter-sawed so as to provide specimens with faces as nearly radical and tangential as possible.

Effort was made to select material and to group data in such a manner that infected wood would be compared with such sound wood as could be assumed to have the same average properties as the infected wood possessed before the fungus attack. Thus, in order to minimize the effect of natural differences, the comparisons were limited insofar as possible to sound and infected material from the same growth rings. But, owing to differences in the location and distribution of the decays, the source of the controls varied. For example, *Fomes pini* infected regions from which test specimens for series 1 and 3 were taken tended toward a crescent shape in cross section and were situated to one side of the tree, a circumstance that made it possible to use for controls sound wood from approximately the same height in the tree and from the same annual rings. On the other hand, the *Polyporus schweinitzii* infection zones and those of *F. pini* in series 2 were circular in cross section and centrally located; hence it was necessary to take the controls from sound wood above the infected zones but, nevertheless, in approximately the same growth rings. In decay caused by *F. laricis* the distribution of the infection was essentially like that of *P. schweinitzii*, and the controls were, therefore, obtained in a similar manner.

One or more of three methods were used to determine infection in the bolts, boards, and specimens: Visual inspection, culture tests, and microscopical examination. In tracing the boundaries of infection small sections were taken from the estimated limits and either examined microscopically or cultured on malt-extract agar. The results of the cultures were recorded as positive or negative, depending on whether the fungus did or did not grow from the wood.

Specimens to be tested green, that could not be handled promptly, were submerged in water until needed. Specimens to be tested air dry were stacked in a semicircular arrangement on the floor in front of two electric fans (series 1) or in open piles in a special conditioning room (series 3) until an equilibrium condition was reached. The moisture content of the specimens was determined from 2-inch sections taken from near the region of failure in each stick, as soon as possible after testing.

TESTING PROCEDURE AND DEFINITION OF PROPERTIES STUDIED

STATIC-BENDING TESTS

For the static-bending tests, which were made only in series 1, the specimens were 1 inch square and 23 inches long. These were tested with equal loads applied at the third points on a span of 21 inches, the rate of deflection at those points being 0.15 inch per minute. The test was discontinued when, after reaching a maximum, the load had decreased to one-half its maximum value. Properties computed from these tests and considered in evaluating the effect of decay are:

Modulus of rupture, which is a measure of the bending strength under the particular conditions of test. Because infected and control specimens were of the same size, the comparisons based on modulus of rupture are, in effect, comparisons of the loads required to cause failure.

Modulus of elasticity, which is a measure of the stiffness of the wood, and which for specimens of the same size is proportional to the load required to cause a specified small deflection, such as 0.1 inch for specimens of the size used.

"Total work," which is the work or energy (in units of inch-pounds) absorbed by the specimen up to the point where the test was discontinued.

IMPACT-BENDING TESTS

For the impact-bending tests, which were made only in series 1, the specimens were 1 inch square and 23 inches long. They were tested on a span of 21 inches by dropping a 25-pound weight or hammer so shaped as to strike the specimen at both third points of the span. Following an initial drop from a height of 1 inch the height was successively increased by 1-inch increments until complete failure of the specimen occurred. The final height of drop was the value used in evaluating the effect of decay.

COMPRESSION-PARALLEL-TO-GRAIN TESTS

In the compression-parallel-to-grain tests, which were made in series 1 and 3, specimens were subjected to longitudinal compression until a maximum load was reached. The specimens in series 1 were 1 inch square and 4 inches long and were compressed at the rate of 0.018 inch per minute. In series 3 the specimens were ¾ of an inch square and 3½ inches long and were compressed at a rate of 0.10 inch per minute. Maximum crushing strength, which is the maximum load divided by the cross-sectional area of the specimen, is the value on which comparisons of sound and infected specimens are based. The same comparisons would result if actual maximum loads were taken as the basis.

TOUGHNESS TESTS

In the toughness test the specimen is broken in bending by a single impact applied by a pendulum type of machine as shown in figure 3.

Bearing blocks or rollers attached to a yoke around the specimen applied the force at the third points of the span in series 3 in which the span was 13½ inches with specimens ¾ inch square by 17 inches long. In series 2 the force was applied at the center of a 10-inch span, the specimens being ¾ of an inch square by 12 inches long. The pendulum is released from a predetermined angle and the angular position to which it swings after the specimen is broken is read from

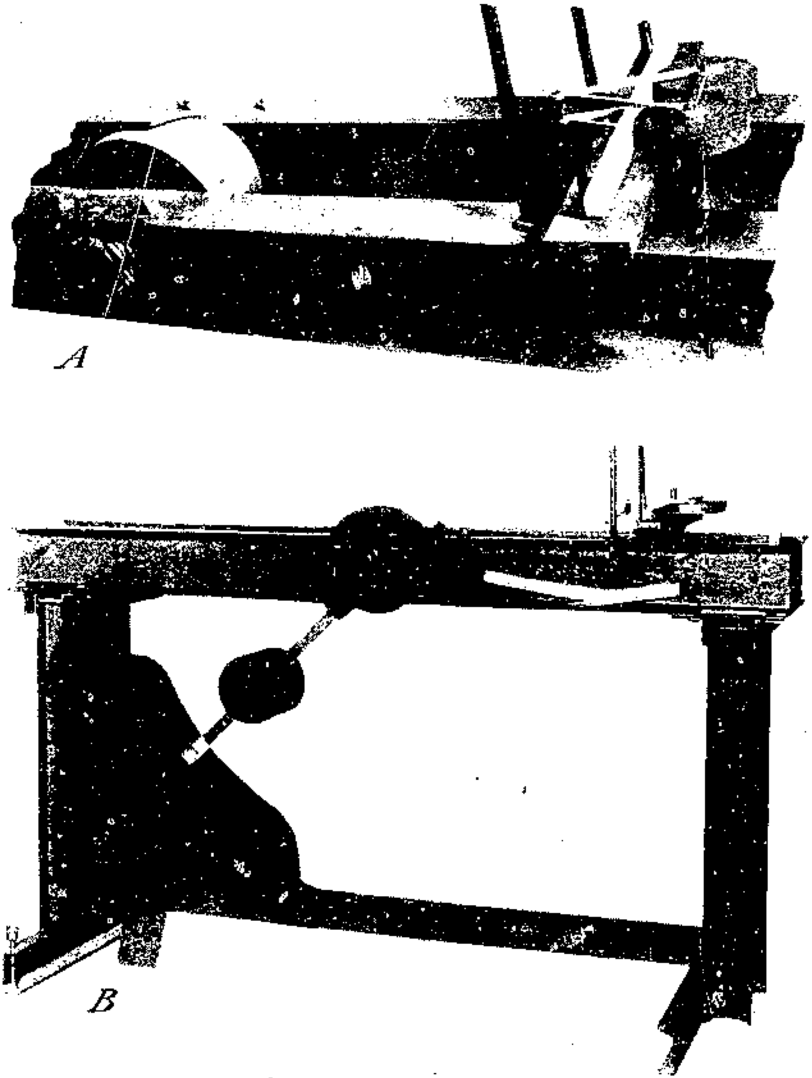

FIGURE 3.—Forest Products Laboratory toughness-testing machine fitted with third-point loading apparatus: *A*, Close-up of apparatus for applying load; *B*, view of complete machine.

a graduated arc. From these known angles the heights of the center of gravity of the pendulum assembly before release and after breaking the specimen are found. The difference between these heights multiplied by the weight of the assembly is the energy absorbed by the specimen and is the value on which the comparisons between sound and infected specimens are based.

SPECIFIC-GRAVITY DETERMINATIONS

Specific-gravity determinations were made on each specimen subjected to mechanical test in series 1, 2, and 3 and on specimens for special studies of specific gravity in series 1.

In all instances the weight used in computing specific gravity was that of the oven-dry wood. For series 1 the volume was that of the oven-dry wood and in series 2 and 3 the volume as measured when the mechanical tests were made.

CORRELATION AMONG PROPERTIES

Attention may be called to the fact that "total work" as found from static-bending tests, height of drop in impact bending, and the values from the toughness test are all measures of "shock resistance" or of the energy or work required to cause failure. This depends not only on the load required to break the specimen but on how far the piece can bend or deflect before breaking.

Reduction of Data to Percentage Basis

To simplify the comparison of the properties of infected specimens with those of sound material, the test value for each infected piece was expressed as a percentage of the average value for the proper control group. This principle of reduction to a percentage basis was applied in all cases presented here except in certain analyses of specific gravity.

Except in the series 1 studies of *Fomes pini* decay, no attempt was made to combine the results from different trees. In the case of *F. pini* it was possible to combine the results for the respective stages of decay, which were comparatively well defined. But the decays by *Polyporus schweinitzii* and *F. laricis* are essentially uniformly progressive and no pockets are formed; consequently, they furnish no common basis for grouping of values.

RESULTS

Effect of Fomes Pini on Specific Gravity and Strength at Different Stages of Decay and Pocket Formation (Based on Series 1)

The effect of *Fomes pini* on strength in bending and compression at different stages of decay, as found from the tests of series 1, is summarized in figure 4.[6] These data are based on an analysis of one Douglas-

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[6] In combining the percentages, since they are simple ratios, the weighted geometric mean (8) is used. In averaging, a percentage based on 10 infected and 10 control sticks would have a weight of 10 by ordinary procedure. But, to take an extreme case, it is obvious that a comparison based on 2 infected sticks and 18 controls, the arithmetical mean of which would be 10, is not as reliable as a comparison between the first 2 sets mentioned. In summing up the data the second percentage, that based on the 2 infected sticks and 18 controls, must be given a lower weight. The harmonic mean, the reciprocal of the mean of the reciprocals, in this case $\frac{1}{1/2(1/2+1/18)}$ or 3.6, gives a weight proportional to the reliability of the comparison.

fir and two Sitka spruce trees. However, it should be pointed out in this connection that here and in the remainder of the study the trees are not completely represented in the zones sampled because of the

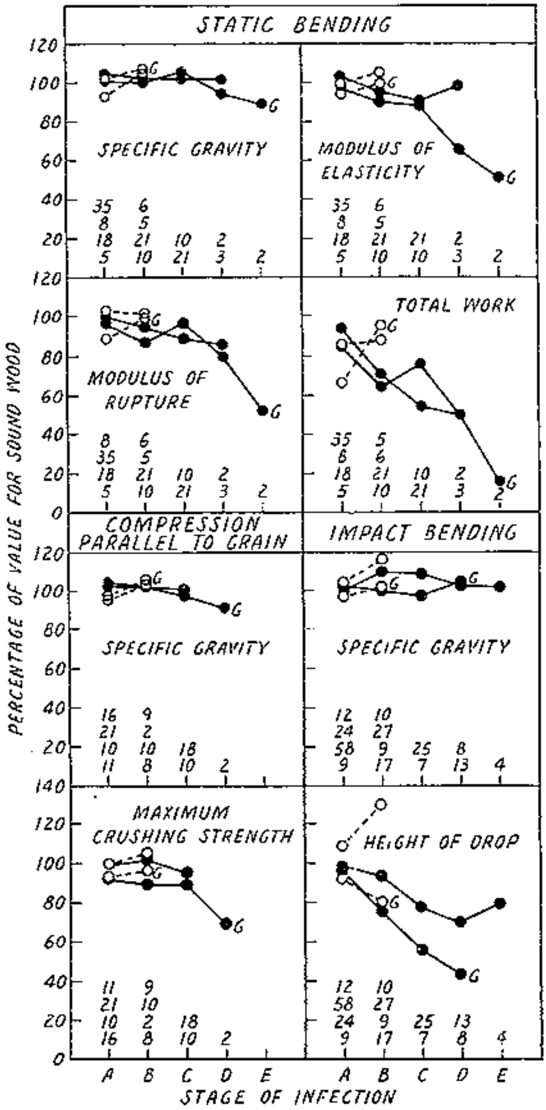


FIGURE 4.—Mean relative strength and specific-gravity values for specimens taken from Sitka spruce (dots connected by solid lines) and Douglas-fir (circles connected by broken lines) trees infected with *Fomes pini*. Values based on tests of green specimens are designated by letter *G*. Stages of infection designated by letters are: *A*, Early incipient decay; *B*, late incipient decay; *C*, decay with few pockets; *D*, decay with many pockets; and *E*, decay with very many pockets. The numbers below each graph are the sums of the harmonic means (see footnote 6) of the numbers of sound and infected specimens on which the respective values were based, and are arranged in the same vertical order as the points to which they pertain.

necessity of discarding a large number of specimens having knots, irregular grain, or some other defect that would preclude a satisfactory test.

Aside from a few inconsistencies, no definite explanation of which is available, the general trend of the specific gravity and strength properties of Sitka spruce is downward with increasing severity of the fungus attack. It may be noted particularly that this downward trend is most abrupt for total work in static bending and height of drop in impact bending, both of which are measures of shock resistance. It is least apparent in specific gravity and maximum crushing strength in compression parallel to the grain.

In Douglas-fir, which is represented only in the two earliest stages of decay, the trend is in several instances the reverse of that expected, and in some instances values higher than for sound material are indicated. The reason for this anomaly is not known.

The results of a series of determinations of specific gravity in a different Sitka spruce tree infected with *Fomes pini* are summarized in figure 5. The 22 blocks on which the determinations were made were taken consecutively along the trunk at intervals of approximately 1 foot. The samples represent material from the same growth rings.

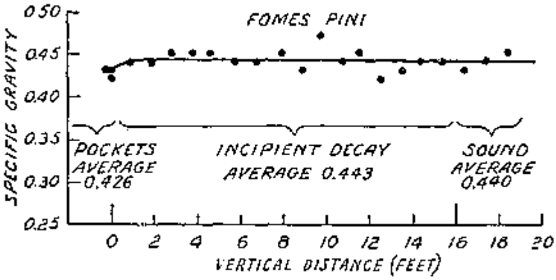


FIGURE 5.—Specific-gravity values of sound Sitka spruce wood and that infected with *Fomes pini;* progressing vertically in the trunk from wood showing typical rot to sound wood.

There is no indication of a reduction in specific gravity until the time of pocket formation. After pocket formation the specific gravity may decrease rapidly, although in the present case this tendency was just becoming apparent. In the incipient stage of *Fomes pini* decay, although not brought out by these specimens, one often finds samples showing a greater density than the adjacent sound wood, possibly because of an accumulation of extractives in the incipient-decay areas.

Effect of Polyporus Schweinitzii on Specific Gravity and Strength at Various Distances Longitudinally in the Trunk from the Zone of Typical Decay (Based on Series 1)

The results of a study of *Polyporus schweinitzii* are represented in figure 6.

From this figure it may be seen that the initial effect of the decay on strength in general tended to be somewhat greater than that by *Fomes pini* (fig. 4). In the case of the earliest decay, as represented by stage

A for *F. pini* and by bolt 1 for *Polyporus schweinitzii*, the strength changes were not greatly different except for shock resistance as measured by height of drop, which was considerably more affected by the

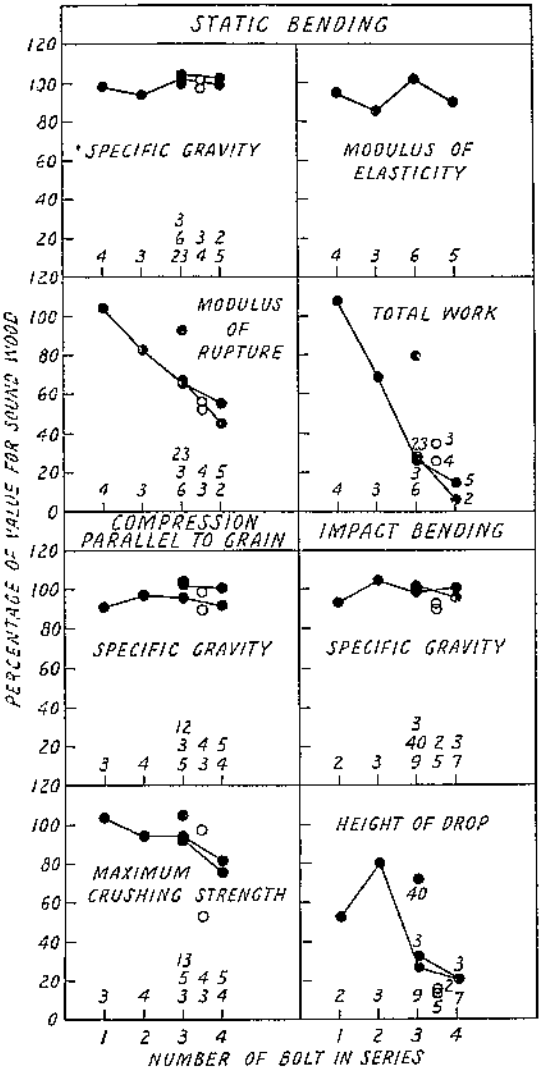


FIGURE 6.—Mean relative strength and specific gravity values for specimens taken from consecutive 28-inch bolts ranging from bolt 1 at the upper limits of infection to bolt 4 having typical decay at its center, in Sitka spruce and Douglas-fir trees decayed by *Polyporus schweinitzii*. The two graphs, the longer one pertaining to air-dry and the shorter one to green specimens, represent a spruce tree. The unattached dot opposite bolt 3 denotes the mean value for air-dry specimens from bolts 2 and 4 of a second spruce. The circles denote mean value for specimens from bolts 3 and 4 of a Douglas-fir tree; the upper and lower ones relate to air-dry and green specimens, respectively, except that this order is reversed for the impact-bending values. Control specimens were from above the limit of the infection. The numbers near the bottom of each section have the same significance as in figure 4.

latter fungus. In the case of the late incipient decay, as represented by stage *B* and possibly by bolt 2, the strength losses produced by *P. schweinitzii* were uniformly greater, though not always very much so, than those produced by *F. pini.* Further specific comparisons cannot be attempted, and even the preceding are made with some hesitation as, even if the differences on the whole were more pronounced and less variable, it is recognized that the assignment of analogous stages of decay to these two fungi, in a case such as this one, where the classification of specimens was on two different bases, is likely to be a questionable procedure.

The results of a special set of specific-gravity determinations on specimens from a single Sitka spruce tree infected with *Polyporus schweinitzii* are summarized in figure 7. Thirty-seven specimens were taken along the trunk, for the most part at intervals of 1 foot and from the same growth rings.

The mean specific gravity for the infected pieces ranged downward to values, in wood that was typically rotted to a point where it was difficult to prepare specimens, about 19 percent lower than those of the sound wood. It is significant that reductions were found in the most incipient stages of infection, which is quite different from the case of *Fomes pini* as indicated in figure 5.

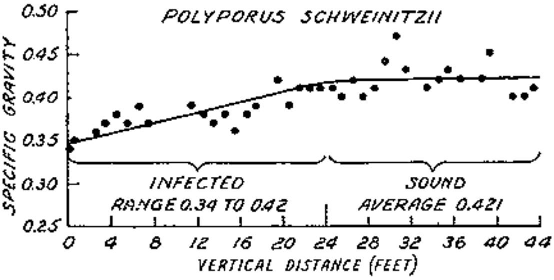


FIGURE 7.—Specific-gravity values of Sitka spruce wood infected with *Polyporus schweinitzii;* progressing vertically in the trunk from wood showing typical rot to sound wood.

Effect of Fomes Pini, Polyporus Schweinitzii, and Fomes Laricis on Specific Gravity and on Toughness and Its Variability at Various Radial Positions in Centrally Rotted Trunks (Based on Series 2)

The mean relative toughness and specific-gravity values obtained in each of four radially contiguous zones in infected Douglas-fir trees are given in figure 8. Each pair of curves represents a single log.

"Rot center" signifies material from the typically rotted central portion; "rot margin," material from just inside the boundary line of the decayed portion; "sound margin" is just outside the margin of infection and the material classified under this head includes only uninfected sticks; and "sound outer" consists of sound pieces from a layer just outside the "sound margin."

Controls for specimens from bolts infected with *Fomes pini* and *Polyporus schweinitzii* were taken in each case from an uninfected bolt a short distance above the last infected bolt and from corresponding radial positions. Similar selection of controls was not possible with *F. laricis*, since the logs were infected throughout their lengths. Consequently, it was necessary to take as controls pieces from the "sound outer" zone of log *A* and the "sound margin" zone of log *B*.

Figure 8 indicates substantial reductions in toughness from the sound-outer and sound-margin regions to the rot margin and except for *Fomes pini* further decrease to the rot center. Specific gravity was affected but slightly even at the rot center.

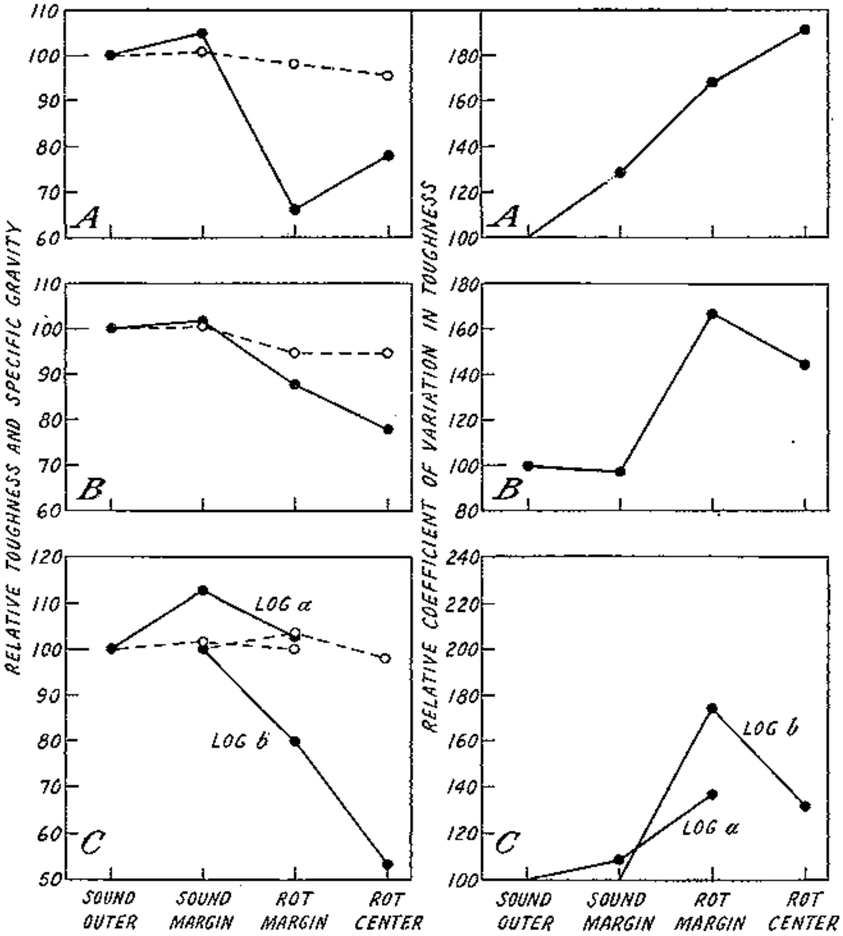


FIGURE 8.—Specific gravity and toughness and variation in toughness in Douglas-fir logs, from the sound outer wood to the infected centers at the same height. Continuous lines connect toughness values and broken lines specific-gravity values. All results expressed as percentage of the corresponding values for sound wood. Diagrams *A*, *B*, and *C* represent logs attacked by *Fomes pini*, *Polyporus schweinitzii*, and *Fomes laricis*, respectively.

A graphic study of the variability in toughness values within these same zones in the trunk also appears in figure 8. On a theoretical basis one might suppose that the presence of a fungus, acting as an additional cause, would result in a greater variation in strength. The respective graphs indicate that this may commonly be the case. It is interesting to note, however, that this trend is not necessarily maintained progressively through all the stages of decay represented. Only in the case of *Fomes pini* was the coefficient of variation greater in the advanced-decay zone than it was in the marginal- or incipient-decay zone.

EFFECT OF POLYPORUS SCHWEINITZII AND FOMES PINI ON SPECIFIC GRAVITY, MAXIMUM CRUSHING STRENGTH IN COMPRESSION PARALLEL TO GRAIN, AND TOUGHNESS OF WOOD BOTH LONGITUDINALLY AND RADIALLY LOCATED ABOUT THE ZONE OF INFECTION (BASED ON SERIES 3)

Two Sitka spruce trees were used for this portion of the study. One tree had been butt-rotted by *Polyporus schweinitzii* and the other had been infected in the trunk, about 75 feet from the ground, with *Fomes pini*. The orientation and numbering of the boards that were sawed out and of the test specimens in the boards are shown by figure 9. Further details of the sizes of the trees and the parts used in the investigation are shown in figures accompanying the presentation of results.

Because of space limitations, it is not practicable to show all the data on which the conclusions will be based; the samples chosen are typical of the results as a whole.

The circumference of the top diagram represents one annual growth ring that circumscribed all infected material as well as all sound material supplying control specimens. This ring was used as a guide ring from which the position of each specimen was measured.

POLYPORUS SCHWEINITZII

Figure 10 shows in its central portion a cross section and a longitudinal section of the Sitka spruce tree infected with *Polyporus schweinitzii*. The portion of the trunk investigated was the central cylinder enclosing the portion of the rot column above the level *a–b* and extending above it into sound wood to the level *c–d*. This was divided longitudinally into seven bolts, *A–1* to *A–4* and *B–1* to *B–3*, each of which was subdivided into boards and specimens as indicated in figure 9. The bolt designations as placed in the diagram indicate the midheights of the respective bolts. Figure 11, presenting cross-sectional diagrams of bolts *A–1* and *A–2*, further illustrates the methods followed in analyzing and picturing the results.

The following procedure was used in preparing such diagrams. Test values for all specimens at the same distance from the outer boundary, guide ring, in each of the sound bolts *B–1* to *B–3* were averaged. These averages were then combined to give a control value for specimens at that distance from the boundary. The test value for each specimen, whether sound or infected, in bolts *A–1* to *A–4* was then divided by the corresponding control value and the resulting ratio entered in a diagram, like those of figure 11, in the space indicating the position of the specimen in the cross section. In each such diagram "contours" were then drawn to enclose all ratios with values less than the percentage by which the contour is designated.

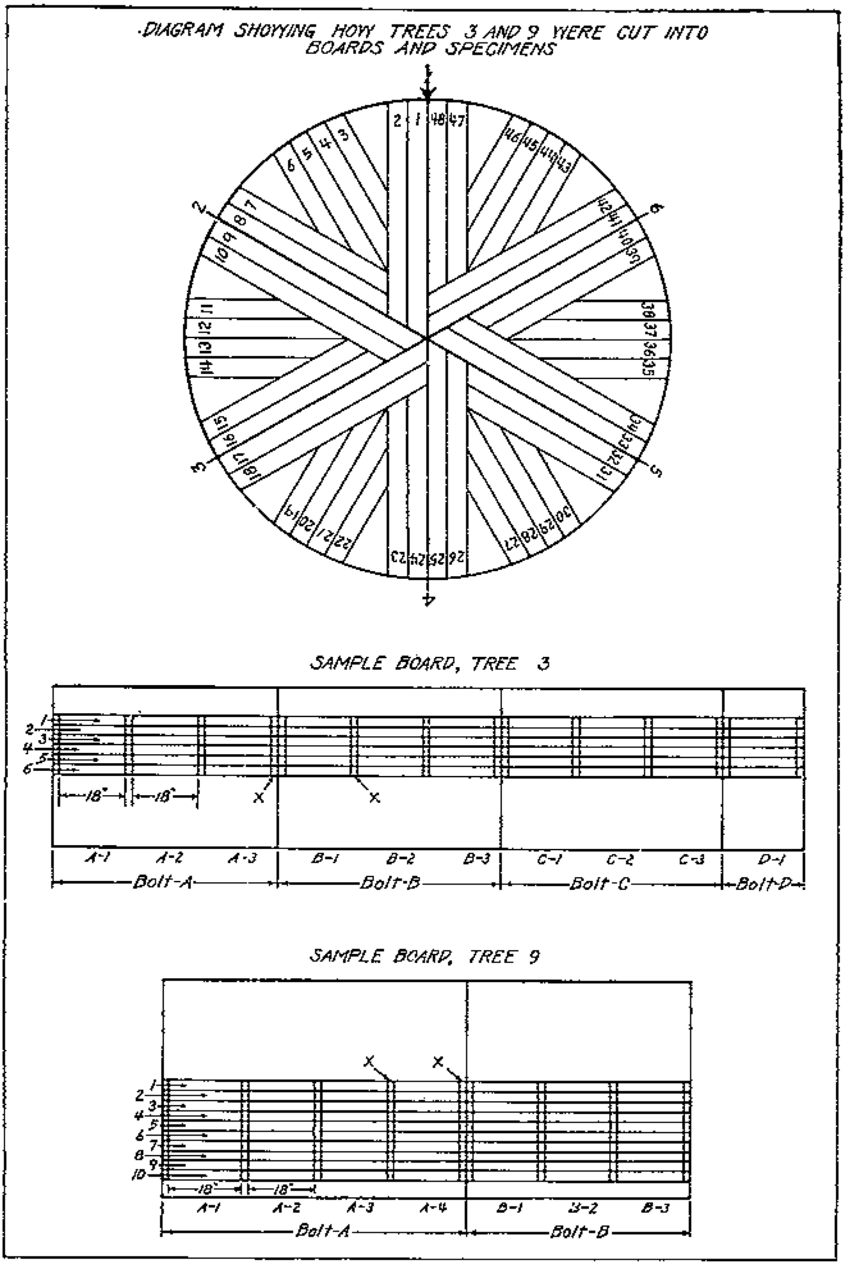


FIGURE 9.—Diagram showing how trees of test series 3 were cut into bolts, boards, and test specimens. At the top is a cross-sectional diagram of a trunk showing positions and numbering of the test boards, from trees 3 and 9. The numerals 1 to 6 outside the circumference mark the terminals of the three guide or reference lines. The two lower diagrams show representative boards from each tree, 3 and 9, with distribution of specimens. *A*, *B*, *C*, and *D* designate the positions of bolts in the trunk and *A–1*, *A–2*, *A–3*, etc., sub-bolts in the respective bolts. The (*x*) blocks were used for cultural analysis of the presence of infection.

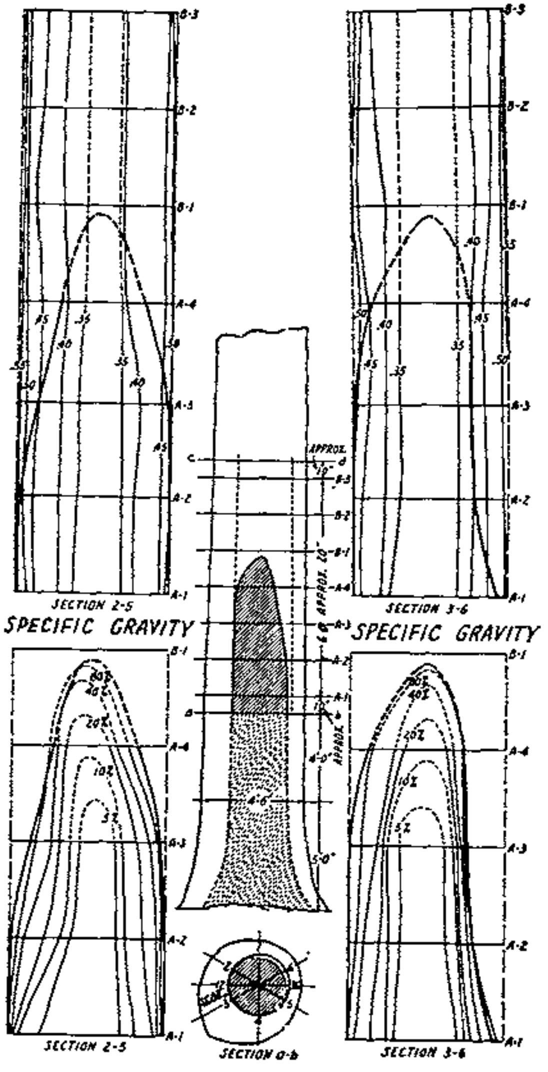


FIGURE 10.—Longitudinal-section diagrams of the tested parts of a Sitka spruce tree infected with *Polyporus schweinitzii*, showing location of infected material and sub-bolts, and contours of specific gravity and toughness. Toughness values are expressed as percentages of control values. The diagram at the middle center represents a longitudinal plane passing through boards 12 and 36 (diagrammed in fig. 9, top), the region of infection being indicated by shading. The diagram at the lower center represents a cross section through the tree at *a–b* and indicates the positions of longitudinal sections shown in the outer four figures. The heavy continuous line in each case indicates definitely established limits of infection. The broken portion of these same lines and of the contour lines indicates the approximate limits, which could not be accurately drawn because of lack of data.

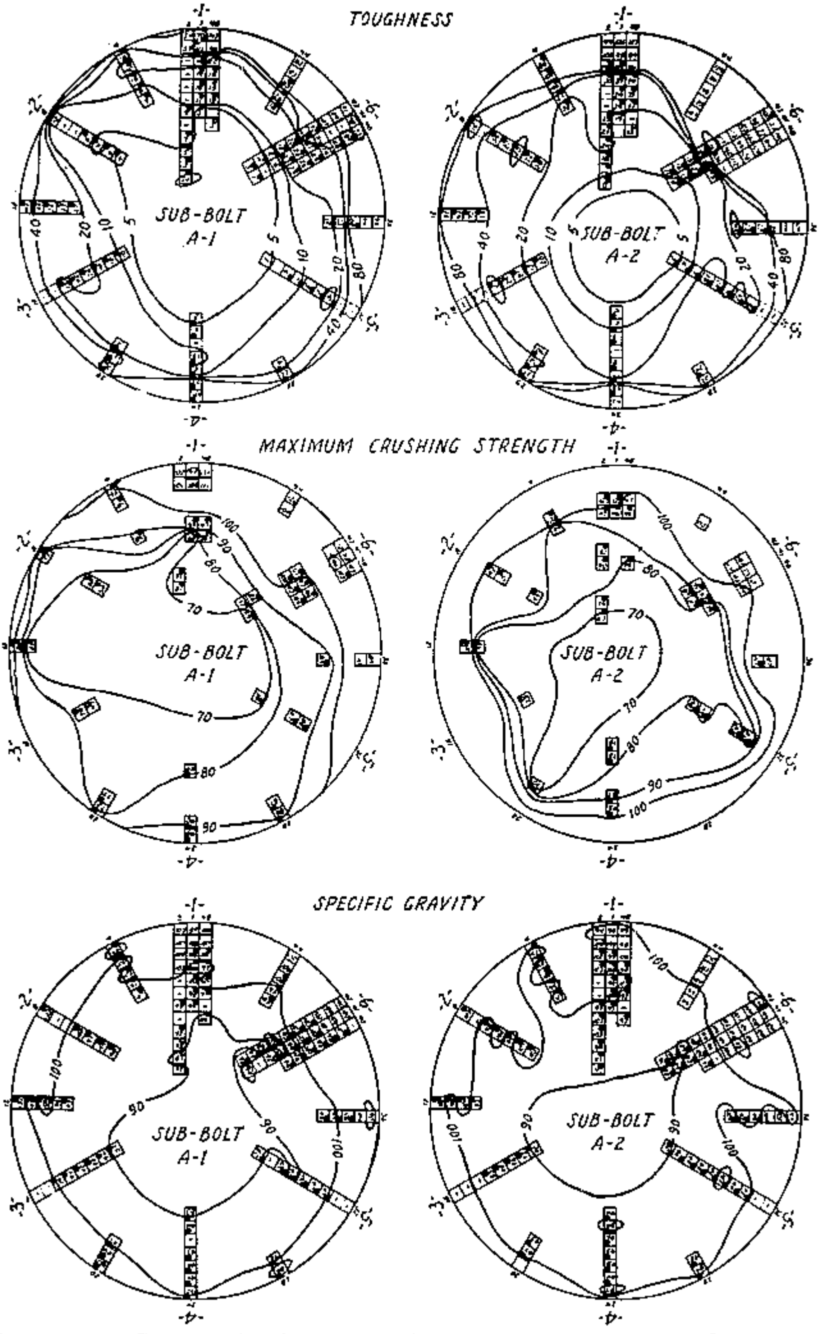


FIGURE 11.—Cross-sectional diagrams of sub-bolts *A–1* and *A–2* of a Sitka spruce tree infected with *Polyporus schweinitzii*, showing contour lines delimiting approximate zones of equal-decay effects on toughness, maximum crushing strength, and specific gravity. Values are expressed as percentages of control values. The circumferences of these diagrams represent the guide ring (fig. 9, top). Dots mark the positions of specimens that contained infection.

In sub-bolt *A–1* (figs. 10 and 11), which contained the greatest amount of decay in the material studied, it may be noted that a considerable area of the cross section depicting toughness lies within the contour bounding wood that retained no more than 5 percent of the original value. The area within the 5-percent contour in sub-bolt *A–2* is considerably smaller, and in sub-bolt *A–4* (not represented in figure 11), which was near the limit of the infection, there were no values as low as 5 percent, the lowest being about 20 percent.

Both the cross-sectional and the longitudinal diagrams indicate close agreement between the limit of infection and the 80-percent contour lines for toughness. Apparently a reduction of at least 20 percent in toughness can be expected in Sitka spruce in which infection with *Polyporus schweinitzii* has progressed only to the point where it can be detected by microscope or culture.

The reduction in maximum crushing strength caused by *Polyporus schweinitzii*, shown in figure 11, was much less than the reduction in toughness. Although the contours are based on fewer tests and are therefore not so accurately placed as the toughness contours, a striking difference between these two properties with respect to the amount of decrease caused by the fungus is nevertheless indicated. Although in exceptional cases a reduction to 40 or 50 percent of the original compression value was found. most of the values are outside the 70-percent contour lines.

The average specific gravity of the heavily decayed wood was approximately 90 percent of its original value, and the average toughness in the same region only about 5 percent of its original value. In the most severely decayed wood specific gravity and toughness were about 80 percent and 1 percent of their original values, respectively.

FOMES PINI

Longitudinal and cross-sectional diagrams of the Sitka spruce tree infected with *Fomes pini* are shown in figure 12. Because the distribution of this decay differed from that of *Polyporus schweinitzii*, a different procedure was followed in studying and picturing the results. Each bolt tested contained sound and infected wood and was treated as a unit in the analysis. The average of all sound specimens at approximately the same distance from the guide ring was first determined and then the test value for each specimen at this distance, whether sound or infected, was divided by the average to give a ratio which, as in the case of *P. schweinitzii*, was entered in the proper position in a cross-sectional diagram. All such ratios lying on the same radius were then averaged, separately for sound and infected specimens, to provide values such as are plotted in figure 11, where the value of each average ratio is indicated by distance from the center of the diagram.

The difference between the presentation on the basis just described and by contours, as with *Polyporus schweinitzii*, should be clearly kept in mind in interpreting the results. To avoid confusion it is further pointed out that intensity of *Fomes pini* decay with respect to sub-bolt number happens to be the reverse of that for *P. schweinitzii*, because the portion of the *F. pini* decay studied was developing downward toward the butt of the tree whereas the *P. schweinitzii* decay was developing upward from the butt.

The diagrams of figure 13 indicate that in the early stages of infection (sub-bolt *A-3*) the losses in toughness on the whole were about 20 to 30 percent, losses in maximum crushing strength about 10 to 20 percent, and reductions in specific gravity did not exceed about 10 percent. In view of the fact that the values for uninfected material within the same region were on the whole considerably lower than the control values, the apparent deficiency in toughness is probably not due to the decay alone.

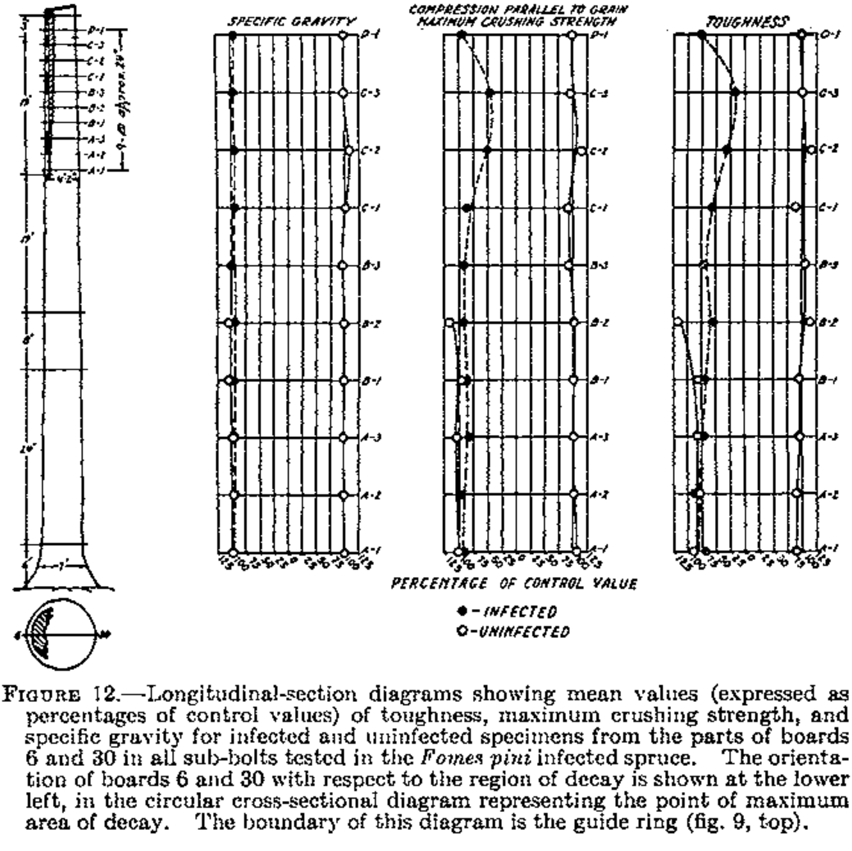
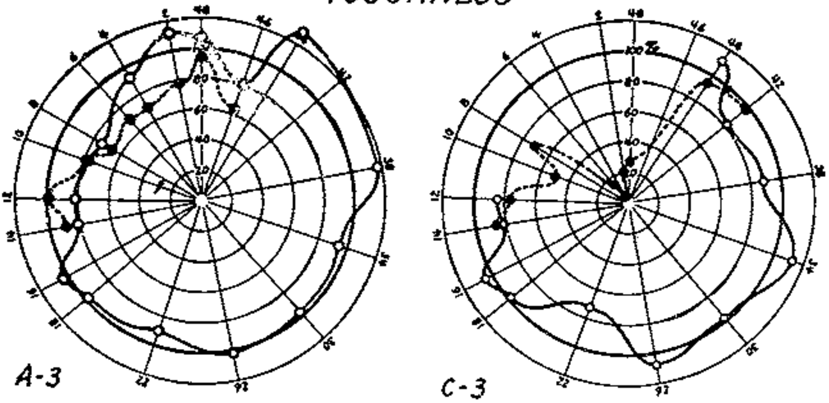


FIGURE 12.—Longitudinal-section diagrams showing mean values (expressed as percentages of control values) of toughness, maximum crushing strength, and specific gravity for infected and uninfected specimens from the parts of boards 6 and 30 in all sub-bolts tested in the *Fomes pini* infected spruce. The orientation of boards 6 and 30 with respect to the region of decay is shown at the lower left, in the circular cross-sectional diagram representing the point of maximum area of decay. The boundary of this diagram is the guide ring (fig. 9, top).

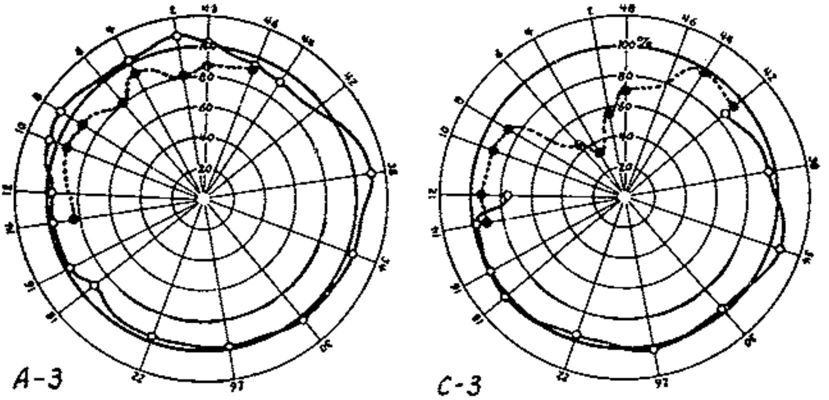
The strength of the wood in the maximum stage of decay tested is represented by board 4 in sub-bolt *C-3* (fig. 13). The average losses found here amounted to 95 percent in toughness, 67 percent in maximum crushing strength, and 33 percent in specific gravity. Toughness in the most severely decayed wood, specimens of which could be broken by hand, was virtually zero, and maximum crushing strength was only about 2 percent of the control value.

A graphic summary of the relation of relative toughness, maximum crushing strength, and specific gravity in the region of greatest infection at different heights in the tree is given by the longitudinal-section diagram of figure 12. The plotted values are averages only for the portions of boards represented and not for complete cross sections of the tree.

TOUGHNESS



MAXIMUM CRUSHING STRENGTH



SPECIFIC GRAVITY

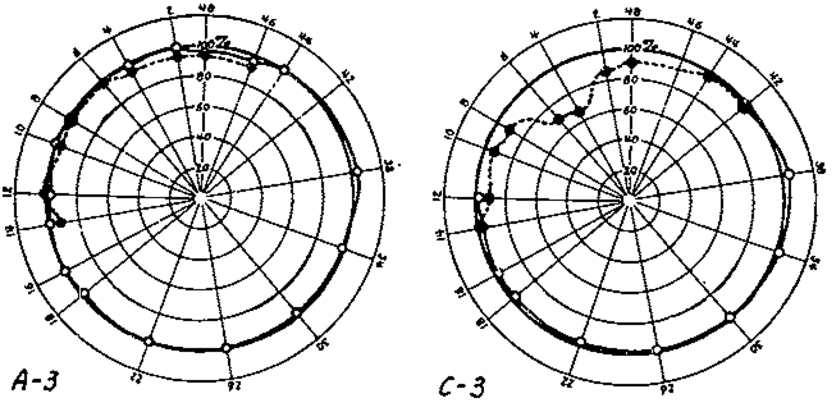


FIGURE 13.—Effect of *Fomes pini* on Sitka spruce. Polar diagrams, showing mean relative values (percentages of control) for sub-bolts *A-3* and *C-3*. Dots refer to the infected specimens and circles to the uninfected specimens. External numbers designate individual boards, as outlined in figure 9, top. The position of the sub-bolts with respect to the region of decay may be seen in figure 12, left.

The toughness and maximum crushing-strength values representing bolt *C–3* disclose decided reductions, whereas the specific gravity value indicates little reduction. However, if a single specimen containing a large quantity of resin had been omitted, as was done in the case of the cross-sectional analysis of this sub-bolt (fig. 13) the reduction in specific gravity would appear to have been about 30 percent.

In figures 1 and 2 typical test specimens are grouped according to the percentages of original toughness strength that they retained. It is apparent from figure 2 that although there is a progressive increase of brittle appearance of the failures in passing from the sound material to that which is most decayed by *Polyporus schweinitzii* and of lowest toughness, there is little correlation between the appearance of the unbroken parts and the degree of decay or loss of toughness. However, in the case of the *Fomes pini* specimens (fig. 1), it may be noted that the extent of pocket formation definitely parallels the reduction in toughness.

CONCLUSIONS AND SUMMARY

The only visual indications of the presence of *Polyporus schweinitzii* are yellowish longitudinal streaks in the wood in the very early stages of decay and light brownish discolorations in somewhat later stages. Finally the infected wood breaks up into cubical masses. In the early stages of *Fomes pini* infection Douglas-fir and Sitka spruce become reddish brown, while the later stages are characterized by the presence of the white pockets typical for this fungus.

The progress of strength reduction by *Polyporus schweinitzii* is not marked by any definite changes in the appearance of the wood. There are, of course, marked differences between slightly infected and badly decayed material, but classification into definite strength groups on the basis of appearance would be quite uncertain and subject to large error. In other words, there are no sharp breaks or signposts in the gradation of color or other visual characteristics from perfectly sound to decayed wood. These statements also apply to *Fomes laricis*, which resembles *P. schweinitzii* in its effect on wood. On the other hand, the beginning of the formation of white pockets marks a fairly definite stage in the progress of strength reduction by *F. pini* and can be used as a guide.

Although there is a progressive increase of brittle appearance of the failures in passing from the sound material to that which is most decayed by *Polyporus schweinitzii* and of lowest toughness, there is little correlation between the appearance of the wood and the degree of decay or loss of toughness. However, in the case of the *Fomes pini* specimens, the extent of pocket formation definitely parallels the reduction in toughness.

The initial effects of decay by *Polyporus schweinitzii* were greater than those by *Fomes pini*, particularly on the toughness of the wood. At the outer limit of *P. schweinitzii* infection a reduction in the toughness of Sitka spruce of approximately 20 percent was found, whereas a similar reduction in toughness due to *F. pini* would not be expected ordinarily before the formation of the white pockets. It is concluded that a reduction of at least 20 percent in toughness, as measured by shock resistance, can be expected in Sitka spruce in which infection by *P. schweinitzii* has progressed no more than to the point where it can be detected by microscope or culture; furthermore, that, in general, wood showing the incipient stage of *F. pini* decay, known commercially as firm red heart, will show losses in maximum crushing strength in compression parallel to grain and modulus of rupture in static bending not much greater than 10 or 15 percent and, at least when dry, no more than a 10 to 25 percent loss in impact bending up to the time the pockets are formed.

Specific gravity was not greatly affected in the incipient stages of decay by *Fomes pini*, whereas there was evidence of an essentially uniform decrease in specific gravity from the zone of earliest decay to the zone of greatest decay by *Polyporus schweinitzii*. However, it is doubtful whether anyone, if limited strictly to a study of the specific gravity data, in the light of available information on the normal variations of specific gravity, would suspect the presence of *P. schweinitzii* decay in the upper 6 feet of the infected portion of the trunk or would be able to determine the boundaries of infections.

Judging from the more extensive results of the tests of series 3, average reductions by *Polyporus schweinitzii* in the most severely attacked wood included in the tests were about 10 percent in specific gravity, 30 percent in maximum crushing strength in compression parallel to grain, and 95 percent in toughness, as compared with reductions by *Fomes pini* in the late pocket stage of about 30 percent, 70 percent, and 95 percent, respectively. Thus it is evident that under the action of the same fungus the several mechanical properties suffer different percentage reductions and that the relation between any two strength properties with respect to loss from fungus action varies with the fungus in question. Consequently a study of the effect of one fungus on the several properties and the effect of a second fungus on a single property does not form a reliable basis for estimating the effect of the latter fungus on the other properties.

Tests made on wood in the green condition seemed to show more effect by the fungi than when they were made on dry wood, although the differences were not large.

Although *Fomes pini* and *Polyporus schweinitzii* both cause large reductions in strength in advanced stages of their development, sound wood close to an infected area is normal in strength properties. This indicates that a large part of the material from somewhat decayed trees is of as high quality as material from perfectly sound trees and can be safely used even where strength is of high importance, provided that the limits of decay are established.

From the analysis of variability it seems safe to conclude that there was a tendency, although not a consistent one, toward greater coefficient of variation in toughness as a result of decay by all three fungi studied. In the case of *Fomes laricis*, however, this tendency was not apparent further than the outermost zone of decay, the variability in the deeper rotted portions, although greater than in the sound wood, being considerably less than in the marginal decay.

The large reductions in strength and, particularly, shock resistance caused by *Polyporus schweinitzii* even in its early stages, and with no appreciable reduction in specific gravity or change in appearance illustrate the necessity of some test by which the very earliest stages of decay can be detected. Some staining method would be the most useful from a practical standpoint. It is therefore desirable that a comprehensive search be made for reagents that might serve such a purpose, dealing not only with *P. schweinitzii* but with other decay fungi as well.

Some method which can be relied upon to select suitable material where maximum strength is essential is most urgently needed. On the basis of present knowledge some mechanical test using representative samples[7] of the stock under consideration seems to offer the most promise. Because shock resistance is the mechanical property which is affected first and to the largest extent by fungus attack, a test that will give a measure of this property is the most desirable. The toughness test previously mentioned in this bulletin (p. 7) has been found to be the simplest and the most rapid test of this kind, and it is recommended as a most important aid in selection. It is important, however, that the test be accompanied by a careful visual examination of the material and supplemented by specific gravity determinations.

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[7] Because of the obvious danger of inducing incipient failures, no mechanical test should be made on the wood destined for use.

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