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CAUSES OF BRASHNESS IN WOOD
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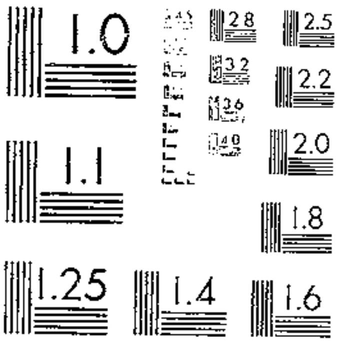

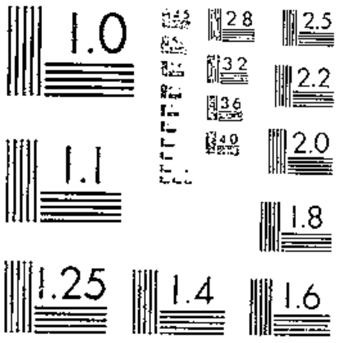

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CAUSES OF BRASHNESS IN WOOD

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CONTENTS

INTRODUCTION

Wood, like other structural materials, contains visible defects and other abnormalties of structure that necessitate careful inspection of the material. One of these abnormalities is a condition known as brashness. The purpose of this bulletin is to present a discussion of brashness, including chiefly its known causes and methods for recognizing brash pieces. The elimination of brash wood from structures in which it might cause loss of life or property is essential for satisfactory service and efficient use of wood. A knowledge of the factors that cause brashness may also be valuable in preventing wood from becoming brash during its growth or subsequent thereto.

BRASHNESS AND TOUGHNESS

In popular usage the term brash generally means the characteristic that causes a piece of wood to break abruptly across the grain, with relatively low resistance to such breaking. Occasionally the

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

term is used for wood that shows brittleness in fracture, without reference to its strength, or, very loosely and probably incorrectly, for wood that is relatively weak in bending, without reference to the manner in which it breaks. Experience has taught, however, that brittleness in fracture and weakness usually go together, and the two are commonly associated in thought even when only one is mentioned. Ordinarily the term applies to wood bent along the grain, although it is occasionally applied loosely to wood bent across the grain, such as cupped lumber that splits easily in straightening.

Speaking technically, brash wood breaks suddenly and completely across the grain with brittleness in fracture and with a comparatively small deflection. Consequently it absorbs relatively little energy in bending. Wood that is characterized as tough, on the other hand, breaks gradually, with continued splintering, and only after comparatively large deflection in bending has occurred. Consequently such wood absorbs a large amount of energy before it breaks. Figure 1 shows characteristic fractures in tough and in brash hickory. Yet there is no sharp line of demarcation between brash and tough wood, all gradations between the two occurring within a species. The differences between extremes are greatest in woods that are commonly considered exceptionally tough, such as hickory and ash. Figures 2 and 3, which are discussed later in this bulletin, give more information about the specimens of Figure 1.

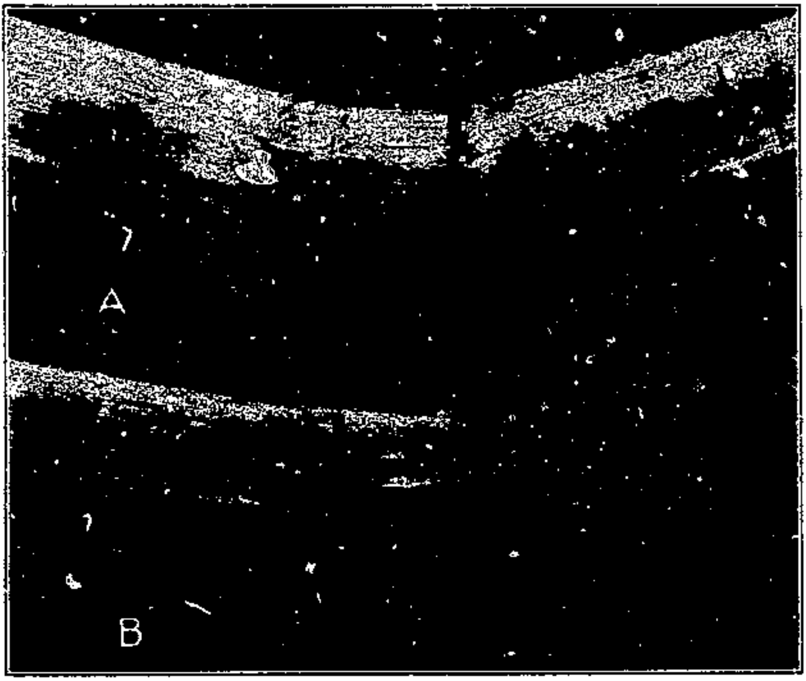

FIGURE 1.—Typical fractures in hickory tested under impact bending: A, Normal wood after a 50-inch drop of the hammer; B, brash wood after an 18-inch drop

Ordinarily all species of wood splinter more or less on breaking, although there is considerable variation in that respect among species. Within a species, however, some pieces of wood may be very brash. Brashness, therefore, is an extreme or abnormal condition found only in a relatively small percentage of the wood of a species. As far as the absorption of energy is concerned, brashness is not comparable in different species of wood; for example, a brash piece of rock elm may absorb much more energy than a brash or even a tough piece of basswood.

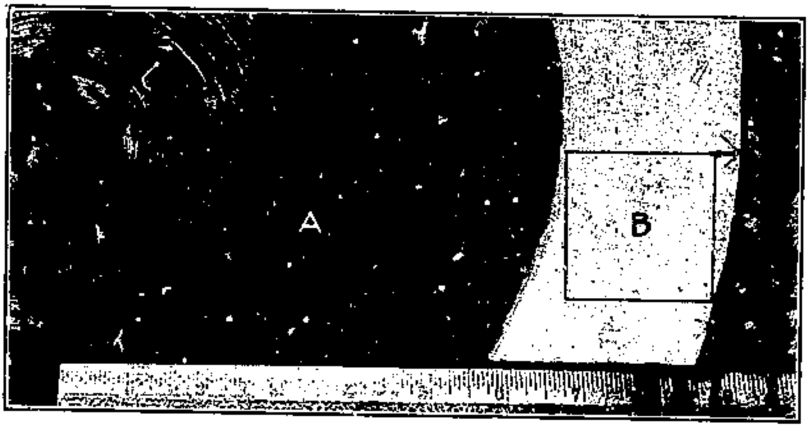

FIGURE 2.—Part of the end surface of a hickory log showing the portions from which the specimens of Figure 1 were taken; A, The normal wood; B, the brash wood

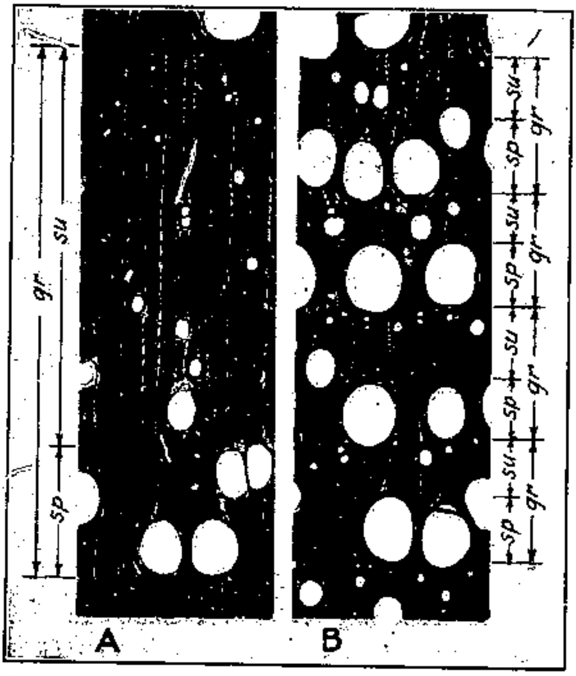

FIGURE 3.—Thin cross sections of representative portions of the hickory specimens in Figure 1; A, a wide growth ring having a high percentage of summer wood, from specimen A; B, narrow growth rings having small percentages of summer wood, from specimen B. *gr*, Growth ring; *sp*, spring wood; *su*, summer wood. × 20

Brashness in wood, incidentally, is synonymous in meaning with brittleness in other materials, such as glass, chalk, and cast iron, in so far as the abrupt type of failure and weakness in bending are concerned but, whereas brittleness may be a normal condition of such materials, brashness is an abnormal condition of wood. As used in this bulletin, brittleness refers primarily to the fracture and only by inference to the properties of the wood that cause such a fracture, while brashness definitely includes degree of toughness as well as type of fracture. Brittleness, then, is less restricted in its meaning than brashness. Further, as used here, brashness refers primarily to a comparison made within a species rather than between species.

PROPERTIES OF BRASH WOOD

Table 1 shows the differences in certain mechanical properties of brash and of tough white ash and Sitka spruce tested in static bending. All ash specimens classified as brash broke abruptly across the grain, and all classified as tough broke in long slivers, producing extremely splintered fractures. In the spruce the difference in the appearance of the fractures of brash and of tough specimens was not so marked. This table indicates that the largest difference in the properties of the brash and the tough wood occurred in work to maximum load. In the ash the next largest difference was in deflection at maximum load, and then in fiber stress at maximum load (modulus of rupture). The relatively small deflection and the low maximum strength of the brash specimens account for the small amount of work absorbed in bending them to the maximum load they could carry. Far less difference in the mechanical properties of the brash and the tough ash and spruce occurred in modulus of elasticity, fiber stress at elastic limit, work to elastic limit, and, for the ash, deflection at elastic limit, showing thereby that the large differences between the brash and the tough woods occurred after their elastic limits had been passed. Figure 4 shows graphically the difference in these properties in the brash and the tough ash tested.

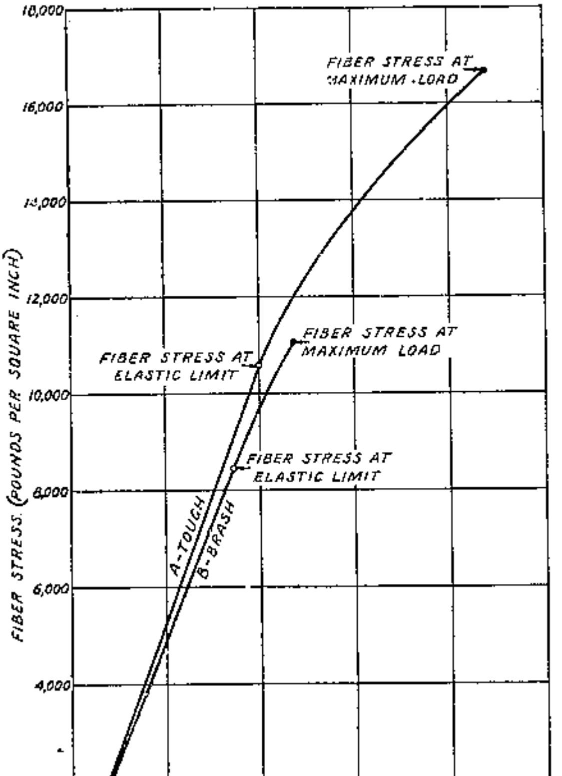

FIGURE 4.—Variation of average stress with deflections for the white ash specimens of Table 1

The brash and the tough specimens of each species in Table 1 were selected so as to come to about the same average in specific gravity, in order to make the values for the same property and between properties more directly comparable. If brash and tough specimens had been selected at random for these species, the brash specimens would undoubtedly have ranked still lower in all mechanical properties because the brash group would then have contained a larger percentage of specimens low in weight and therefore weaker in all respects than the tough group, since wood light in weight for a species is usually brash. Figures 5 and 6 show that all the lightweight specimens of ash and of Sitka spruce tested for toughness were brash. Further, the moisture content was approximately the same for all specimens of each species, so that the moisture present affected equally the amount of bending and the type of fracture.

TABLE 1.—*Average values of mechanical properties of brash and of tough, small specimens of clear wood tested in static bending*

Species of wood	Classification of specimens	Specimens tested	Specific gravity[1]	Fiber stress at—		Modulus of elasticity	Deflection at—		Work to—		Moisture content
				Elastic limit	Maximum load		Elastic limit	Maximum load	Elastic limit	Maximum load	
		No.		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.*	*In.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Per cent*
Commercial white ash	Brash	15	0.562	8,440	11,180	1,910	0.86	1.19	3.50	7.1	6.9
	Tough	20	.566	10,660	10,650	2,050	.99	2.17	5.18	22.1	6.7
Percentage relation of brash to tough			99.3	79.2	67.1	93.2	86.8	54.8	67.6	32.1	
Sitka spruce	Brash	17	.390	5,200	8,730	1,270			1.22	6.45	11.5
	Tough	14	.391	5,640	9,820	1,440			1.26	10.31	11.7
Percentage relation of brash to tough			99.8	92.2	88.9	88.2			96.8	62.6	

[1] Based on volume when air-dry and weight when oven-dry.

The term commercial in connection with some of the ash specimens and all of the oak means that the wood was designated as white ash and white oak when acquired, although it may have included or may have consisted entirely of botanical species other than true white ash (*Fraxinus americana* Linn.) and true white oak (*Quercus alba* Linn.), respectively. The various species constituting commercial white ash and commercial white oak can not be distinguished by means of the wood alone.

The strength values given in this bulletin are presented solely for the comparison of brash and of normal specimens, and do not necessarily represent typical values for any species. The Forest Products Laboratory has already published strength values, based on hundreds of tests, for design of structures and for comparison of species (*17*, *18*).[3] The values given here, averages of a smaller number of tests, should be used only for the special purpose for which they were obtained, the comparison of specimens, matched in some respects, of brash and of normal wood. Further, in the testing of successive groups of specimens different sizes of specimen and methods of loading were sometimes used, partly because of improvement in technic as the work progressed and also because

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[3] Italic numbers in parentheses refer to Literature Cited, p. 38.

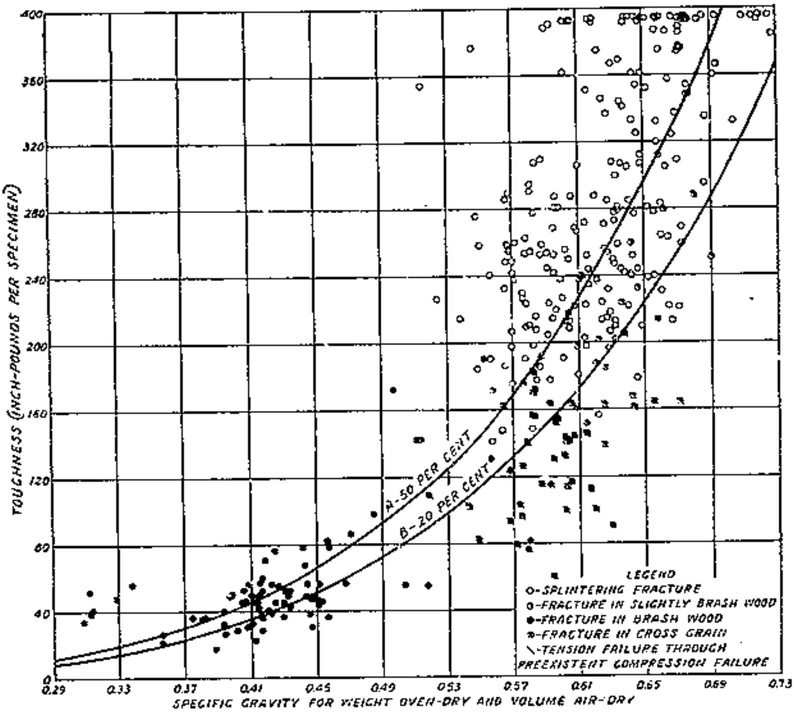

FIGURE 5.—Relation to toughness to specific gravity of white ash loaded on the tangential surface: A, Median line—50 per cent of the points lie above the curve and 50 per cent below it; B, arbitrary low limit—20 per cent of the points lie below the curve

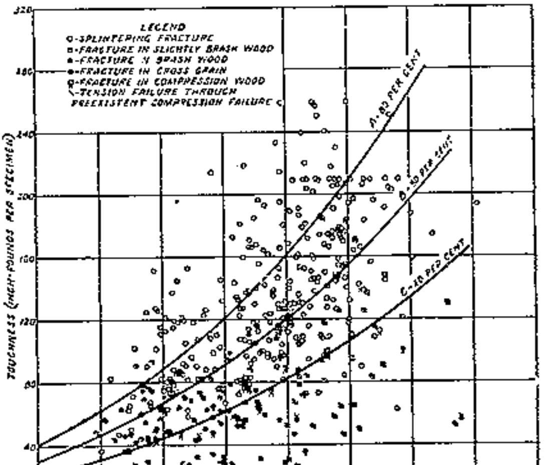

FIGURE 6.—Relation of toughness to specific gravity of Sitka spruce loaded on the tangential surface: A, Arbitrary high limit—20 per cent of the points lie above the curve; B, median line—50 per cent of the points lie above the curve and 50 per cent below it; C, arbitrary low limit—20 per cent of the points lie below curve

of the size of material available. Hence comparison of the values obtained should be limited strictly to the comparisons drawn in this bulletin.

Under static loads, such as those to which beams in buildings are most often subjected, the work absorbed in bending is not an important property, but rather the stiffness (modulus of elasticity) and ultimate strength (modulus of rupture). On the other hand, when a wood beam is subjected to sudden bending in such a way that the energy of the load can be absorbed, the amount of work involved in bending becomes an important factor in preventing serious failures. Under impact a piece of tough wood that has no greater maximum strength in static bending than a brash piece may successfully resist a shock that would break the brash piece. For example, among the Sitka spruce specimens for which average values are given in Table 1 were one tough and one brash specimen, each having a modulus of rupture of 9,320 pounds per square inch; yet the work absorbed in bending to maximum load was 10.4 inch-pounds per cubic inch for the tough specimen and only 6.6 for the brash one. Consequently, brash wood is especially objectionable under impact.

Table 2 shows the difference in resistance to impact or shock of selected brash and tough ash specimens, as indicated by the maximum drop of a hammer required to break specimens of a specified size under a given method of loading. The fractures of the specimens classified as brash and tough in this table showed brittleness and splintering, respectively. The groups of specimens selected were of approximately the same specific gravity. In specimens selected at random there would be a still greater difference because of the lower average specific gravity and hence lower resistance to shock of brash wood for a species as a whole.

TABLE 2.—*Average shock resistance of brash and of tough, small specimens of commercial white ash tested in impact bending*

Classification	Specimens tested	Specific gravity[1]	Maximum drop of hammer
	Number		*Inches*
Brash	12	0.571	12.7
Tough	10	.574	32.5

[1] Based on volume when air-dry and weight when oven-dry.

Under impact, wood may be bent somewhat beyond its elastic limit without serious injury to the wood or, even if the wood is injured, without serious injury to life or property if it resists complete failure. On the other hand, if its elastic limit is exceeded in a beam subjected to a static load that is maintained, the beam will eventually fail. Under a slowly increasing load, or a static load beyond the elastic limit, the warning that tough wood supplies in progressive splintering gives it a great advantage over a brash piece, which fails without warning. The properties beyond the elastic limit, therefore, often are exceedingly important in the use of wood, and it is in those properties that tough wood excels the most.

One of the chief fundamental characteristics of brash wood is that it has a low ratio of tensile to compressive strength along the grain. Ordinarily the strength of wood in tension is from two to four times that of its strength in compression; in brash wood the ratio is considerably less. Since brash wood usually is relatively low in tensile strength, it breaks on the tension side before much deflection takes place, and hence little work can be absorbed before failure occurs.

ACCIDENTAL FACTORS AFFECTING TYPE OF FAILURE AND TOUGHNESS OF WOOD

Although the type of failure in a piece of wood is an indication of the quality of the wood, there are various accidental factors affecting the character of the failure that are not related to quality. For example, a short beam in fracturing will produce shorter slivers than a long one of the same depth. (Fig. 7.) Fractures in short beams are sometimes so abrupt as to appear brash on superficial examination; the bristlelike slivers in such a fracture are extremely short.

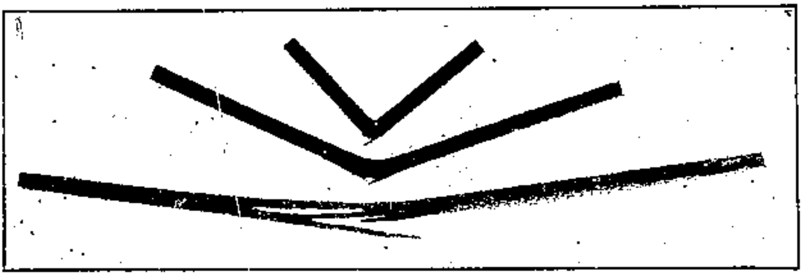

FIGURE 7.—Short, medium, and long white-ash beams showing the effect of varying the length of span on type of fracture in bending

Moderate cross grain may cause long splinters to form, thereby giving the wood an especially tough appearance, even though the actual amount of work involved in the failure may not have been exceptionally large. In fact, slight cross grain in a beam is common, and frequently a fracture of the splintering type starts in such grain. Occasionally in tough wood that is very straight grained no long splinters form, the fracture extending more or less directly across the grain. Although the fracture in such wood may give it a superficial appearance of brashness, the piece may actually have had high toughness. Such a fracture can be distinguished from a true brash one in that portions of the fibers protrude from the break, forming minute bristlelike splinters visible to the unaided eye.

Whether a small stick of wood is loaded on the tangential (flat-grained) or the radial (edge-grained) surface also makes some difference in its capacity to resist shock and in its type of failure, at least in certain species. Specimens of species that separate easily between or within the growth rings are likely, if loaded on the tangential face, to fail in shear along the grain before they fail in tension. This is true especially of specimens short for their depth.

Small specimens of white ash loaded on the radial face showed an average toughness 90 per cent of the average value for matched specimens loaded tangentially; the average specific gravities of the two groups were the same, 0.601. The corresponding values for Sitka spruce specimens, also well matched, were 58 per cent toughness and 0.418 specific gravity. Similar differences in the toughness of specimens having the load applied on the tangential and the radial faces have been noted in Douglas fir, whereas in black walnut and yellow birch no such consistent difference in toughness was found.

In tangentially loaded specimens of Sitka spruce and Douglas fir, as a rule more splinters were formed than in radially loaded specimens, which broke off more abruptly. The abrupt breakage tended to give an appearance of brashness, although actually most of the wood was of good quality. (Fig. 8.) In ash no such difference in type of failure was found between radially and tangentially loaded specimens.

The specimens used in these tests were very small, five-eighths by five-eighths inch in cross section. Previous tests on specimens of larger size had showed no such difference. Probably the difference does not obtain in structural sizes.

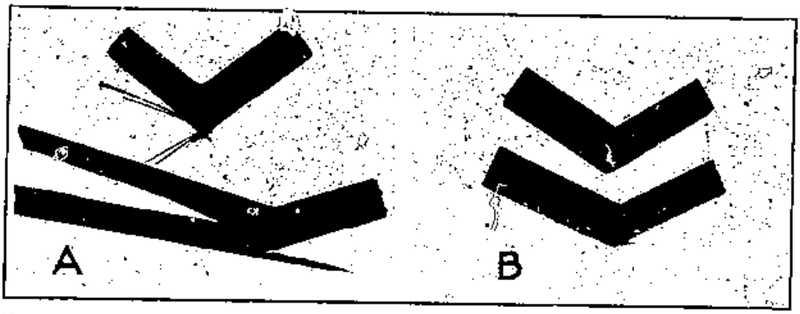

FIGURE 8.—Typical fractures in coast-type Douglas fir tested in a toughness machine: A, Loaded on tangential surface; B, loaded on radial surface

Another accidental factor that may affect the toughness and other bending properties of very small beams containing only a few growth rings is the location of a relatively thick layer of spring wood or summer wood on either the tension or the compression side. Spring wood is relatively weak and when it occurs in either the upper or the lower portions of a small beam, which are the most highly stressed parts, it may cause serious weakening.

In any given kind of wood that is below the fiber-saturation point, deflection under load increases with the moisture content of the wood. The ultimate strength of the fiber decreases, however, so that toughness, which is dependent on load and deflection, is not greatly affected either way by moisture in the wood. Moisture, which is not a part of wood and should therefore be regarded as an accidental factor, affects considerably the type of failure and also certain strength properties of wood; resistance to shock is a property that it does not affect appreciably. Dry wood usually breaks more suddenly and to a greater degree than moist wood, a fact that gives it some of the characteristics of brash wood, but the type of failure normally is splintering. Even when wood that has been dried is resoaked it has more brittleness in fracture than similar wood broken when green.

CAUSES OF BRASHNESS INVESTIGATED

A large number of specimens of brash wood have been examined at the Forest Products Laboratory and compared with tough specimens of the same species, in order to determine the factors responsible for their brashness. In all instances the specimens had been tested in accordance with one of the standard methods for ascertaining the mechanical properties of wood, including a determination of their specific gravity and moisture content (*2*, *16*, *17*, *18*). The specimens were examined for differences in cellular structure and for injury to the cell walls caused by fungi or mechanical agencies. Specimens were also heated at different temperatures and for different periods of time to determine the effect of heat on the strength and the manner of failure of wood. Although many tests were completed, only the results necessary to make clear certain deductions are presented in this bulletin.

SPECIES DIFFERENCES

Although the various species of wood differ greatly in their capacity to absorb work and the extent to which they splinter when bent to the breaking point, no species can be called brash throughout. In even such light species as aspen, redwood, and western red cedar considerable splintering frequently occurs.

ENVIRONMENTAL FACTORS

Different trees of any one species may grow under very different environmental conditions. Even the same tree during its period of life may be subjected to a wide range of growth conditions, especially with respect to the amount of light and moisture that neighboring trees permit it to receive. Changes in the soil as a result of repeated ground fires, flooding, change in drainage, or change in the composition of the forest also affect the growth of trees. The permanent or even temporary bending of trees by the wind may also affect their growth. All these variations in environment affect the kinds and the sizes of cells produced, which in turn determine principally the strength and the other properties of wood, although thus far relatively little is known as to just what effect specific environmental factors have on the quality of the wood (*1*, *14*, *20*, *21*, *22*, *29*).

Many of the causes of brashness of wood are related in one way or another to environmental factors affecting tree growth, as is brought out in succeeding pages.

WIDTH OF GROWTH RINGS

The width of the annual layers of growth in itself can have no effect on the strength or the manner of failure of wood, except, as already stated, in thin pieces of species in which the growth rings are composed of well-differentiated portions of spring wood and summer wood. In such pieces wide rings may be responsible for an unusually thick layer of one kind of wood occurring on one or both tangential faces of a specimen. If a load is applied on the tangential face of such a specimen its strength and manner of failure may be affected greatly by the type of wood in the outer portions, where the stress is greatest. In wood with narrow rings the spring wood and the summer wood alternate more frequently, thus precluding the occurrence of thick layers of either one near a tangential face. In wood of uniform structure, such as that of many native and most tropical species, the width of the annual growth layer is immaterial in this respect. Further, if the load is applied on a radial surface so that the growth rings are parallel to the thrust of the load, it makes no difference whether the tangential sides consist of spring wood or of summer wood, other things being equal.

Rate of diameter growth, however, as indicated by the width of rings, may affect to a great extent the amounts and the quality of different kinds of tissue formed and thereby in turn affect the manner of failure, the strength, and other properties of wood.

In very slowly grown wood of softwoods and of ring-porous hardwoods, such as oak, ash, and chestnut, the spring wood, which is relatively weak and brash in such woods, usually predominates to such an extent that a piece as a whole is brash. Figure 1 shows a typical abrupt fracture, denoting brittleness, in slowly grown hickory wood, in contrast with a splintering fracture, denoting toughness, in wood, having wider rings, from the same tree. The relative width of the rings and the position of the two specimens in the log, from which they were cut, are shown in Figure 2, and photomicrographs of cross sections of the two specimens appear in Figure 3. In the Sitka spruce specimens studied the toughness value was found to drop off as the rings became very narrow.

In diffuse-porous hardwoods, such as yellow poplar, black walnut, and birch, very slowly grown wood usually has a relatively high percentage of porous tissue and a low percentage of fibrous tissue, thereby making the wood as a whole brash. Figure 9 pictures the difference in porousness of narrow-ringed and wide-ringed yellow poplar. In black walnut an increasing number of pores per unit area of the cross section was found to occur as the width of the rings decreased.

On the other hand, rapid growth, causing wide growth rings, does not necessarily mean a high degree of toughness. In conifers of very rapid growth the spring wood usually is relatively wide. This tends to make the wood light and brash. Further, compression wood (p. 22), which also has relatively wide rings, tends to be brash although it is heavy. In hardwoods, on the other hand, wide rings, as a rule, mean heavy, strong wood. Exceptions occur, however; for instance, the wide-ringed wood formed in swelled butts of ash and tupelo gum from very wet swamps is light and brash.

Too much reliance should not be put on ring width in judging the quality of wood, since for any ring width large variations in strength may occur, because different growth conditions may produce similar rates of growth but different proportions of the various types of tissues found in wood (*21*). Table 3 shows that in the ash, the oak, and the Sitka spruce tested in bending large differences occurred in the average work or toughness values of the brash and the tough specimens, without significant difference in the average width of the rings.

PERCENTAGE OF SUMMER WOOD

In judging the mechanical qualities of those species of wood in which the spring wood and the summer wood are well differentiated, a considerably better criterion than width of growth ring is the percentage of summer wood. Wood with a small percentage of summer wood and consequently a high percentage of spring wood usually is light in weight, weak, and brash. Figure 10 shows brash spring wood in tough specimens of ash and Douglas fir. Table 3, however, shows that the percentage of summer wood is not always the deter-

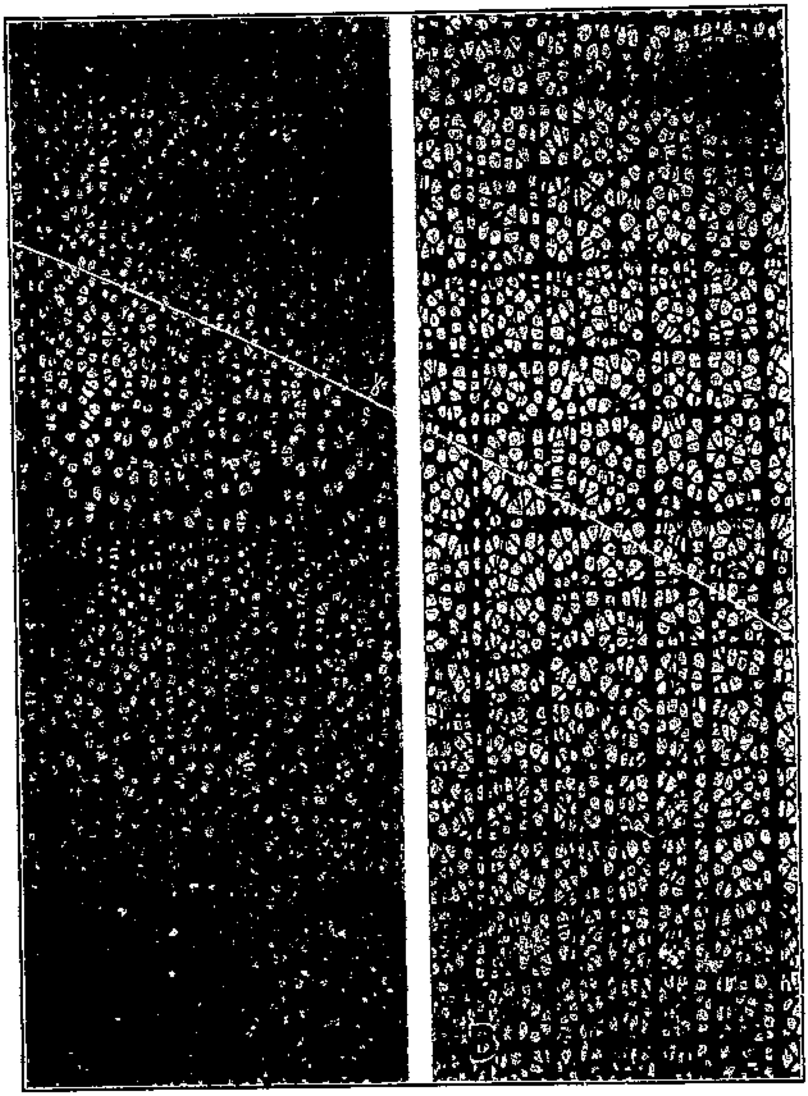

FIGURE 9.—Cross sections of yellow poplar: A, Wide-ringed wood of specific gravity 0.41; B, narrow-ringed wood of specific gravity 0.31, having more pores and fewer wood fibers (the small cells) than the heavier wood. × 20

mining factor in brashness; brash and tough specimens may have virtually the same percentage of summer wood and yet have widely different toughness values. This is due to the fact that preexistent compression failures (p. 27), which bear no relation to the amount of summer wood present, were a common cause of brashness in specimens of the species in Table 3; that a deficiency of wood fibers, even though the percentage of summer wood was normal, obtained in many of the oak specimens; and that compression wood (p. 22), which always has a high percentage of summer wood, occurred in some of the brash Sitka spruce specimens.

Table 3.—*Average number of growth rings per inch and percentage of summer wood in brash and in tough specimens of various species of wood of approximately the same specific gravity but of widely different shock-resisting capacity*

Species of wood	Nature of test	Classification of specimens	Specimens examined	Average specific gravity [1]	Average work to maximum load	Average maximum drop of hammer	Average toughness value	Rings per inch	Average amount of summer wood
			Number		*In.-lbs. per cu. in.*	*Inches*	*In.-lbs. per specimen* [2]	*Number*	*Per cent*
Commercial white ash.	Static bending.	Brash	15	0.562	7.1			12.7	66.4
		Tough	20	.566	22.1			12.0	59.9
	Impact bending.	Brash	12	.571		12.7		10.7	66.0
		Tough	10	.574		32.0		11.4	60.4
Commercial white oak.	Toughness	Brash	51	.656			124.1	15.6	52.3
		Tough	49	.655			339.9	14.7	54.2
Sitka spruce	Toughness	A selected number of the 20 per cent lowest in toughness for specific gravity.	170	.389			48.3	10.1	
		do	167	.387			47.8		12.9
		A selected number of the 20 per cent highest in toughness for specific gravity.	178	.373			134.9	13.3	
		do	176	.373			133.6		14.0
	Static bending.	Brash	17	.390	6.4			16.4	
		Tough	14	.391	10.3			15.5	

[1] Based on volume when air-dry and weight when oven-dry.

[2] Size of specimen: White oak, ¾ by ¾ by 12 inches; Sitka spruce, ⅝ by ⅝ by 10 inches.

In some hardwoods, as swamp ash, the summer wood may be wide but not dense. (Fig. 11.)

SAPWOOD AS COMPARED WITH HEARTWOOD

No generalization on the relative toughness of sapwood and of heartwood or on the occurrence of brash wood in either can be made. In old, slowly growing trees the sapwood is frequently low in toughness and may even be brash, on account of the large percentage of spring wood or other porous tissue that it contains. The brash specimen in Figure 1 is the more recently formed sapwood of an old, mature hickory tree, whereas the splintered specimen, which was taken from the same tree, is heartwood formed when the tree was young.

In young, vigorously growing trees, the sapwood often ranks higher in toughness than the heartwood. This is also true in softwoods because the sapwood does not include the wide rings often occurring at the center, which usually have a high percentage of spring wood and are brash. It also holds for trees in general because the heartwood of young trees contains more knots and other irregularities in the grain than the sapwood does.

The effect of differences in infiltrated materials in sapwood and heartwood is discussed under the head of Chemical Composition, page 35.

CELLULAR STRUCTURE OF WOOD LOW IN DENSITY FOR ITS SPECIES

By density of wood is meant essentially the amount of cell wall present in comparison with the space in the cell cavities; specific gravity is often used as a measure of density. Considerable variation in density occurs within each species of wood because of differences in the growth conditions of individual trees. Obviously the smaller the amount of wood substance in a given volume of wood the weaker it will be, other things being equal (*8*). General relations between the strength properties and the specific gravity of the different species of wood have been worked out at the Forest Products Laboratory (*19*). Within a species the same general relationships also hold but, as a rule, in addition to weakness, wood of density that is low for a species also shows brittleness in fracture. (Figs. 5 and 6.) In comparing different species, however, brashness does not always accompany low density; that is, the wood of species light in weight, such as red cedar, basswood, and cottonwood, is not considered characteristically brash, although these species may not sliver so much as some of the heavier and tougher

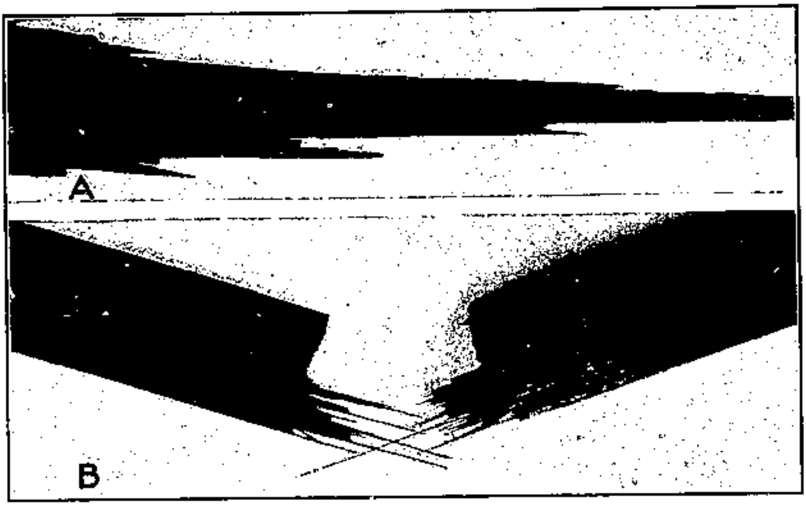

FIGURE 10.—Abrupt breaks through successive layers of spring wood, giving the spring wood an appearance of brashness, and long fractures through layers of summer wood, on which toughness largely depends: A, Splinter of white ash; B, test specimen of Douglas fir, reference is made to lower half, or tension failure in specimen

woods. The characteristic brashness of wood low in weight for a species is due to the preponderance of certain types of fibers and other cells, which are relatively scarce or even entirely absent in normal wood of the same species.

In order to discuss more fully the structure of wood of low density and the relation of such wood to brashness, it will be necessary to consider the softwoods and the hardwoods separately.

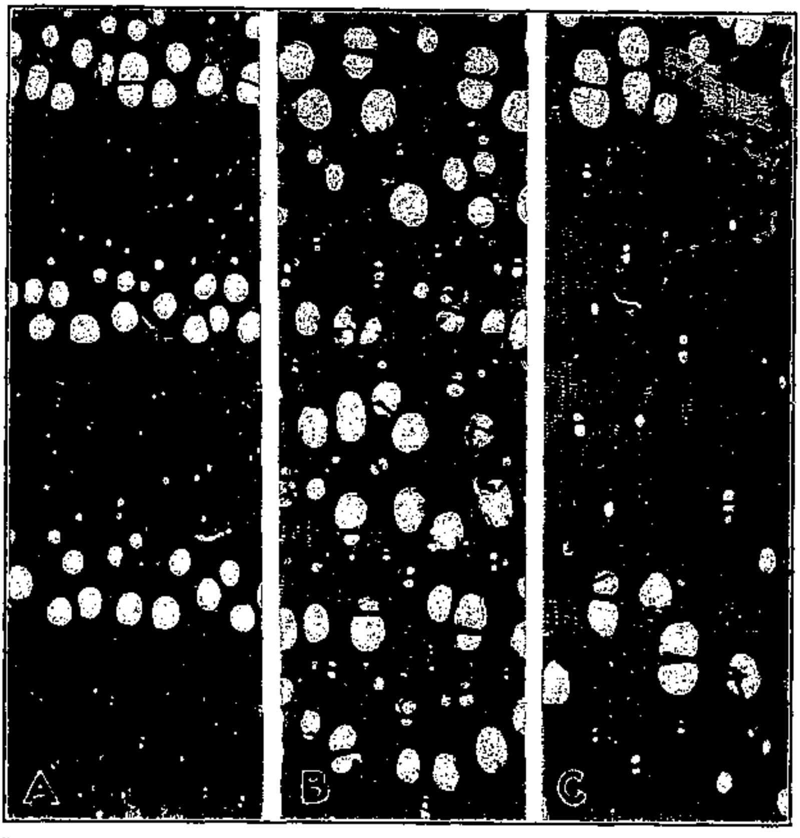

FIGURE 11.—Cross sections of white ash: A, Wood of average density and ring width; B, wood low in density because of narrow growth rings and a small percentage of summer wood; C, wood low in density because of large cavities and thin walls in the fibers, even though the growth rings are wide—a type of wood found in swelled butts of trees growing in inundated swamps. × 20

SOFTWOODS

In the softwoods, or conifers, two types of fibers, called tracheids, are normally present. They are those having large cavities and thin walls, formed in the inner part of each growth ring and making up the spring wood, and those having thick walls and small cavities, formed in the outer part of each growth ring and making up the summer wood. Obviously the larger the percentage of summer wood in a piece of wood, the heavier and stronger it will be, other things being equal.

In addition to the differences just mentioned, spring wood differs from summer wood in the structure of the fiber walls. All wood fibers and also, as far as is known, other cells in wood are made up of fibrils, which wind around the cell cavity.[4] The slope of the windings varies greatly, from an angle of 3° to 15° with the cell axis in normal summer wood of softwoods to 15° to 35° in normal spring wood. These figures apply to the major portion of the cell wall. Ritter (*24*) found an extremely thin layer of fibrils extending around the outside of some fibers at an angle of nearly 90° with the longitudinal axis of the fiber.

FIGURE 12.—Thin longitudinal section at a tension failure in Sitka spruce, showing the spiral fracture of individual fibers. × 125

The difference in the slope of the fibrils in the spring wood and in the summer wood is also responsible for differences in the strength and the manner of failure of these two types of wood. Although these fibrils are too small to be seen individually even with a high-power microscope, investigation by other means has shown that when a piece of wood fails in tension the individual fiber walls frequently are torn apart obliquely (*5, 26*) (figs. 12 and 13), the direction of the failure in each fiber corresponding largely to the orientation of the fibrils. This indicates that there is a line of weakness between adjacent fibrils; the indication is substantiated by X-ray diffraction investigation (*6*).

Obviously the fibrils must also break somewhere, as well as separate from each other, in order for a fracture to be complete, but the greater the slope of the fibrils the smaller will be the failure

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[4] These fibrils should not be confused with the spiral thickening found on the inner surface of the wall in some cells of certain species.

within them and the greater the failure between them. If the fibrils should make an angle of nearly 90° with the cell axis, a condition approached in some hardwood vessels, then failure in tension along the grain would be almost entirely between fibrils and the resistance offered by the cell wall would be relatively small.

In a large number of coniferous woods examined, the twist was always found to be in a right-hand direction. Therefore, in contiguous walls of two adjoining fibers the slope of the fibrils, when viewed from the same side, would be in opposite directions in the two walls. This fact, however, seemingly does not vitiate the statement that the strength decreases with the slope of the fibrils, other things being equal.

FIGURE 13.—Thin longitudinal section at a tension failure in spongy white ash, showing the spiral fracture of individual fibers and the corresponding slope of the slitlike pits in the fiber walls. The photograph was taken by polarized light. × 350

Another reason why thin cell walls are weaker is that they contain relatively less of the secondary cell wall which, because of its fibrillar structure of moderately oblique slope, presumably is stronger than the rest of the cell wall.

Spring wood of softwoods, therefore, is weaker than summer wood for three reasons: (1) The relatively small amount of wood substance present, as evidenced by the thin cell walls and the large cell cavities, (2) the relatively large slope of the fibrils in the secondary wall, and (3) the presence of a relatively greater proportion of the middle lamella and the immediately adjoining layer with their presumably lower tensile strength. On account of the relatively great slope of the fibrils spring wood always breaks off abruptly (fig. 10), whereas splinters, if produced, occur in the summer wood. With very little summer wood present the whole piece may be brash. These structural features, therefore, probably explain the brashness of softwoods light in weight for their species.

Incidentally, spring-wood fibers contain more pits than summer-wood fibers, but the available evidence is that the number of pits has little if any effect upon the strength of a fiber. In fact, it is not at all certain that a normal spring wood pit is weakening, since the fibrils immediately surrounding the pit orifice run concentrically around the opening, thereby binding the cell wall more firmly than in the unperforated portion (*9*).

HARDWOODS

Woods belonging to the hardwood group have a more complicated structure than those of the softwood group. In addition to the fibers in hardwoods, there are present in considerable numbers specialized vessels, also called pores, for conducting sap, and vertical parenchyma cells for storing food, which are respectively absent and scarce in softwoods. Each species of hardwood shows considerable variation in the amount of fiber, of vessel, and of parenchyma tissue, the relative amounts of each depending on the growth conditions under which the wood was formed.

Hardwoods may be light in weight for two reasons: (1) The preponderance of nonfibrous tissue (vessels, tracheids, and parenchyma) over wood fibers, and (2) the presence of wood fibers with thin walls and large cavities in place of the more normal ones with thicker walls and smaller cavities. The first condition occurs usually as a result of slow growth (figs. 3, B; 9, B; and 11, B) and the second is found in the swelled butts of hardwoods growing in very wet swamps. (Fig. 11, C.)

The vessels usually have a very oblique orientation of the fibrils, which often approaches an angle of 90° with the longitudinal axis. In ring-porous woods, vessels are abundant in the spring wood, which accounts for its characteristic brashness, no matter how tough the wood as a whole may be. (Fig. 10, A.) If little summer wood is present, as usually is the case in very slowly grown wood of such species, the whole piece is light, weak, and brash. The toughness of ring-porous wood, therefore, depends largely on the summer wood, as does toughness in conifers. In diffuse-porous hardwoods, in which the vessels are scattered more or less evenly among the wood fibers, an overabundance of vessels (fig. 9, B), a condition that comes from adverse growth conditions, also makes for brashness.

In the wood from swelled butts of ash, tupelo gum, and some other hardwoods growing in very wet swamps of the South, not only are the wood fibers large-lumined and thin-walled, but the fibrils make angles of 20° to 50° with the cell axis, as compared with 3° to 10° in the summer wood of normal tough ash. This orientation of the fibrils causes additional weakness and abrupt failures across the grain in bending for the same reasons given for the spring wood of softwoods. Figure 13 shows the oblique orientation of the pits in spongy ash, and Figure 14 shows the brash type of failure characteristic of such wood.

CELLULAR STRUCTURE OF WOOD OF MEDIUM AND OF HIGH DENSITY FOR ITS SPECIES

Brashness is not confined to wood of low density; it occurs also in wood of medium and of high density, although not so commonly. Further, although brash wood of high density ranks low in shock-resisting capacity for its specific gravity, it still may actually have higher shock resistance than a tough specimen of lower specific gravity and correspondingly lower toughness of the same species. This fact is shown by some of the brash specimens of high specific gravity in Figures 5 and 6. To determine causes of brashness other than those associated with low specific gravity, selected brash and tough specimens of moderate to high specific gravity of various species were studied.

SCARCITY OF WOOD FIBERS IN OAK

Some test specimens of oak not low in specific gravity were brash because they contained relatively small amounts of wood fiber. In them, weaker cells, mostly parenchyma and vascular tissue, occurred to a greater extent than usual. On account of their structure, wood fibers are considered the principal strength-giving elements of hardwoods. Oak has a peculiar arrangement of tissues in that its wood fibers are bunched, appearing on cross sections as islands interspersed with other tissues. This arrangement of the tissues makes it possible to determine approximately how much of the volume of a piece of oak consists of wood fibers, scattering strands of parenchyma cells included. Figure 15 shows cross sections of two pieces of oak, considerably magnified, in which black lines outline the islands of wood fibers. A much larger proportion of the cross section of the tough piece is occupied by the wood-fiber areas. Measurements over areas larger than that of the illustration gave percentages of 32.4 and 12.6 for wood fiber of the tough and the brash specimens, respectively. Such differences are not necessarily due to differences in rate of growth, since wide-ringed oak may have little wood fiber, although as a rule very slowly grown oak has only a small percentage of wood fiber. They are due to certain differences in growth conditions that affect the formation of wood fiber, although just what conditions make for the production of a large proportion of wood fiber is not known.

FIGURE 14.—Abrupt fractures in white ash of low density

Oak with little wood fiber has a dull and lifeless appearance on smoothly cut end surfaces, and on cutting shows a more cheesy consistency than oak with a large percentage of wood fiber. For purposes for which a high degree of strength is not required such oak is often preferable because it works more easily, and in addition possibly shrinks and warps less.

Oak and a number of other hardwoods have two kinds of wood fibers: One, with a thick wall of apparently uniform composition, is normal, while the other, although it has an outer wall similar to that of the first except for its thinness, has also an inner layer that gives a typical cellulose reaction with certain stains and evidently has shrinkage characteristics different from those of the outer wall, to judge by the way this wall often pulls away from the outer one. The second kind of fibers have been called gelatinous and mucilaginous, although these terms are not properly descriptive.

Proceeding on the assumption that the presence of gelatinous fibers might affect the toughness of oak, stained microscopic sections of some 50 brash oak specimens and 50 tough specimens of about the same range in specific gravity were examined to see whether gelatinous fibers predominated in either group. No relation between the percentage of gelatinous fibers and toughness was found; the gelatinous fibers occurred sporadically in both groups.

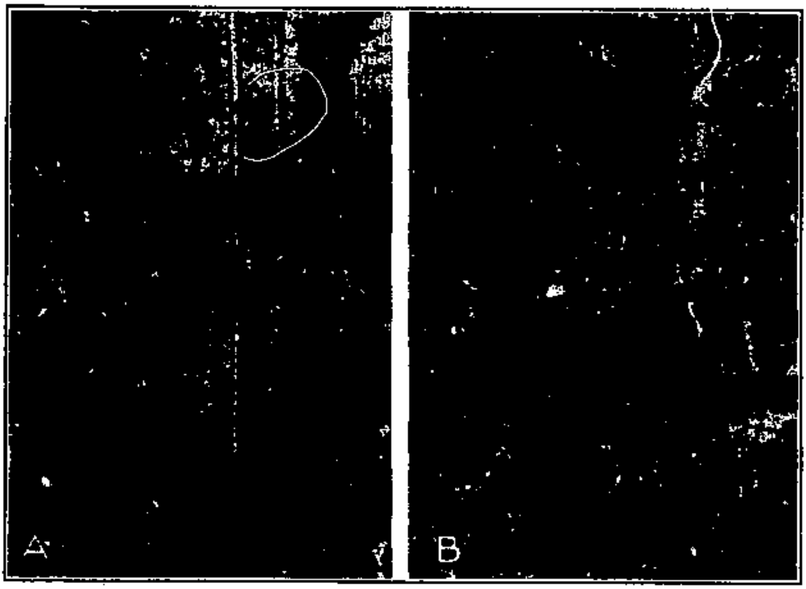

FIGURE 15.—Thin cross sections, in negative, of white oak specimens having the same specific gravity (0.66) and nearly the same width of growth ring but with widely different percentage volumes of wood fibers. The wood fibers occupy the light-colored areas, which are outlined in black. The toughness of the brash wood was 63 per cent that of the other. A, Tough specimen; B, brash specimen. About × 20

VOLUME OCCUPIED BY WOOD RAYS

Since the ray cells in wood are oriented mostly with their long axes radial with respect to the growth rings, they presumably do not contribute so much to the strength of a piece stressed along the grain, especially in tension, as most of the cells that lie with their long axes parallel to the grain, for the same reason that wood in general is not so strong in compression and in tension at right angles to its fibers as parallel to them. An investigation was therefore made of the relative volumes occupied by the rays in brash and in tough wood of several species to determine whether the volume occupied by the rays might appear to be related to brashness.

For this purpose, as for most of these studies, brash and tough specimens of the same specific gravity were selected for each species of wood investigated so as to eliminate as far as possible all differences except the one under investigation.

Table 4 gives the average relative amounts of ray tissue in brash ash, oak, and Sitka spruce, respectively, as compared with those in tough wood of the same species and same specific gravity.

TABLE 4.—*Relative amounts of ray tissue in brash and in tough specimens of ash, oak, and spruce, respectively, of the same average specific gravity*

Species of wood	Nature of test	Classification of specimens	Specimens examined	Average specific gravity[1]	Average work to maximum load	Average maximum drop of hammer	Average toughness value
			Number		*In.-lbs. per cu. in.*	*Inches*	*In.-lbs. per specimen*[3]
Commercial white ash	Static bending	Brash	15	0.562	7.1		
		Tough	20	.566	22.1		
	Impact bending	Brash	12	.571		12.7	
		Tough	10	.574		32.6	
Commercial white oak.	Toughness	Brash	46	.660			124.9
		Tough	43	.660			348.3
Sitka spruce from Washington.	do	Brash	36	.380			91.1
		Tough	30	.380			214.3
Sitka spruce from Alaska.	do	Brash	36	.410			95.5
		Tough	30	.411			214.7

Species of wood	Ray cells in a circular tangential area 0.7 mm in diameter	Ray cells in all small rays per circular tangential area 0.7 mm in diameter	Average volume occupied by large rays in terms of total volume	Rays per rectangular tangential field 0.8 by 4 mm having specified number of cells in height[2]				
				1-5	6-10	11-15	16-20	More than 20
	Number	*Number*	*Per cent*	*Number*	*Number*	*Number*	*Number*	*Number*
Commercial white ash	213.5							
	202.9							
	216.2							
	220.2							
Commercial white oak		191	8.18					
		175	5.68					
Sitka spruce from Washington				34.2	42.7	11.4	1.9	0.3
				35.7	43.7	12.7	1.6	.4
Sitka spruce from Alaska				39.0	38.3	13.2	3.2	.9
				37.5	40.7	13.5	3.1	1.0

[1] Based on volume when air-dry and weight when oven-dry.

[2] The rectangle was oriented with the narrow side running transversely across the rays and fibers so that a minimum number of rays were cut. The cut rays were counted as entire rays of whatever number of cells were visible.

[3] Size of specimen: ¾ by ¾ by 12 inches.

The relative volumes occupied by all the rays in white ash and by the small rays in oak were determined by counting the number of ray cells in several circular areas on tangential sections of the wood cut from the tension side of the specimen near its point of failure. Counts for such areas were averaged for each specimen. In the oak the volume of the large rays was determined by finding the total width of such rays along a number of transverse lines on a tangential surface and then expressing the result in terms of the total length of the lines. In Sitka spruce, instead of counting the number of ray cells per unit area, the rays were counted by height classes, in terms of number of cells, which with large numbers gives virtually the same results. Fusiform rays containing resin ducts were omitted from the table since they averaged only one to one and a half per unit field.

The ash had no appreciable difference in the number of ray cells in the brash and in the tough material, which shows that these structural elements were not responsible to any considerable extent for the large differences in shock resistance.

In the oak many of the brash specimens had an appreciably larger volume of large rays and a slightly greater number of small ray cells than the tough specimens. It is impossible, however, to say how much the greater volume of large rays contributed to brashness since, in general, a decrease in volume of wood fiber accompanied an increasing volume of ray tissue. This relationship also explains why the specific gravity of the brash and the tough oak specimens was the same, although the pieces differed greatly in the amount of wood fiber present; the ray tissue is almost as dense as the wood-fiber tissue, and in addition the ray cells as well as the vertical parenchyma cells that partly replaced the wood fibers in many of the brash specimens, unlike the wood fibers, contained considerable amounts of deposits, which add to the weight but not to the strength.

In the Sitka spruce, in general, there was no appreciable difference in the amount of ray tissue present in the brash and the tough specimens. Hence that factor can be disregarded as a possible cause of brashness except possibly in abnormal growth, such as that which occurs as a result of injury or very unfavorable growth conditions. No such abnormal material, however, was observed in this study.

COMPRESSION WOOD

One of the outstanding causes of brashness in coniferous woods is compression wood, which is a relatively wide-ringed type of wood formed on the lower, or compression, side of leaning coniferous tree trunks and of branches. (Fig. 16.) Compression wood is further characterized by a high proportion of summer wood, less dense than normal, in each growth ring; rounded instead of flattened summerwood tracheids; numerous intercellular spaces among the summerwood tracheids (fig. 17); and spiral striations and spiral cracks running at a rather oblique angle in the walls of the summer-wood tracheids. Because of the high percentage of summer wood that it contains, even though this summer wood is not so dense as normal summer wood, compression wood frequently ranks relatively high in specific gravity, especially in species that normally do not have heavy wood. All stages of compression wood from that barely distinguishable from normal wood to that showing a pronounced difference may be found in all softwood species. It does not occur in hardwoods.

Compression wood, when broken in bending, invariably displays brittleness, although the break usually does not extend straight across the piece but either zigzags back and forth, producing blunt splinters, or more often extends directly across the grain from the tension side inward a short distance and then branches out in two directions diagonally across the piece, like a wide Y. (Figs. 18 and 19.)

In the green condition compression wood compares favorably with normal wood in most of its mechanical properties, on a unit-size basis, and frequently excels; the one outstanding exception is stiffness, in which compression wood is relatively low. On a unit-weight basis normal wood is usually superior. Upon drying, however, compression wood does not increase in strength so much as normal wood, and consequently dry compression wood, on a unit-size basis, is frequently weaker than normal wood. On a unit-weight basis, dry compression wood is often greatly inferior in strength. For most uses the properties of dry wood are more important than those of wet wood, and consequently the following data refer only to dry wood. The property of toughness, or shock resistance, which is the property most concerned in brashness, is

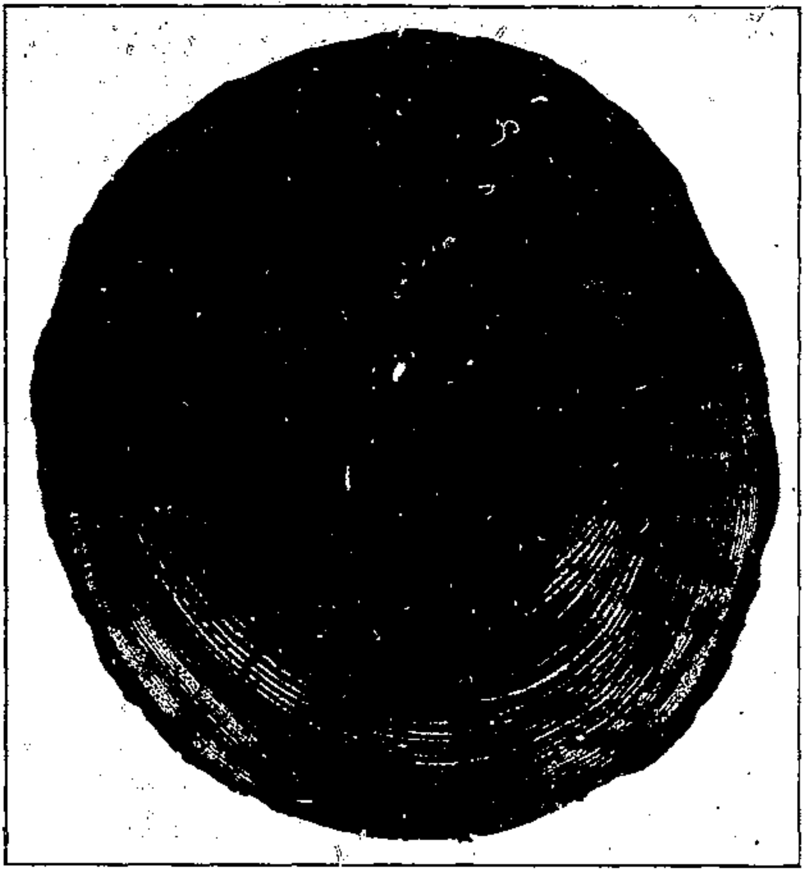

FIGURE 16.—Compression wood, appearing as dark, wide portions of growth rings, in a cross section of an eastern spruce log

a highly variable one, and although some compression wood is the equal of normal wood in this respect other compression wood is inferior. Because of its erratic nature and because it usually fails suddenly and completely when it does fail in bending, compression wood should not be used for any purpose for which tough wood is required. Figure 6 shows that Sitka spruce specimens containing compression wood usually gave low values in the toughness test,

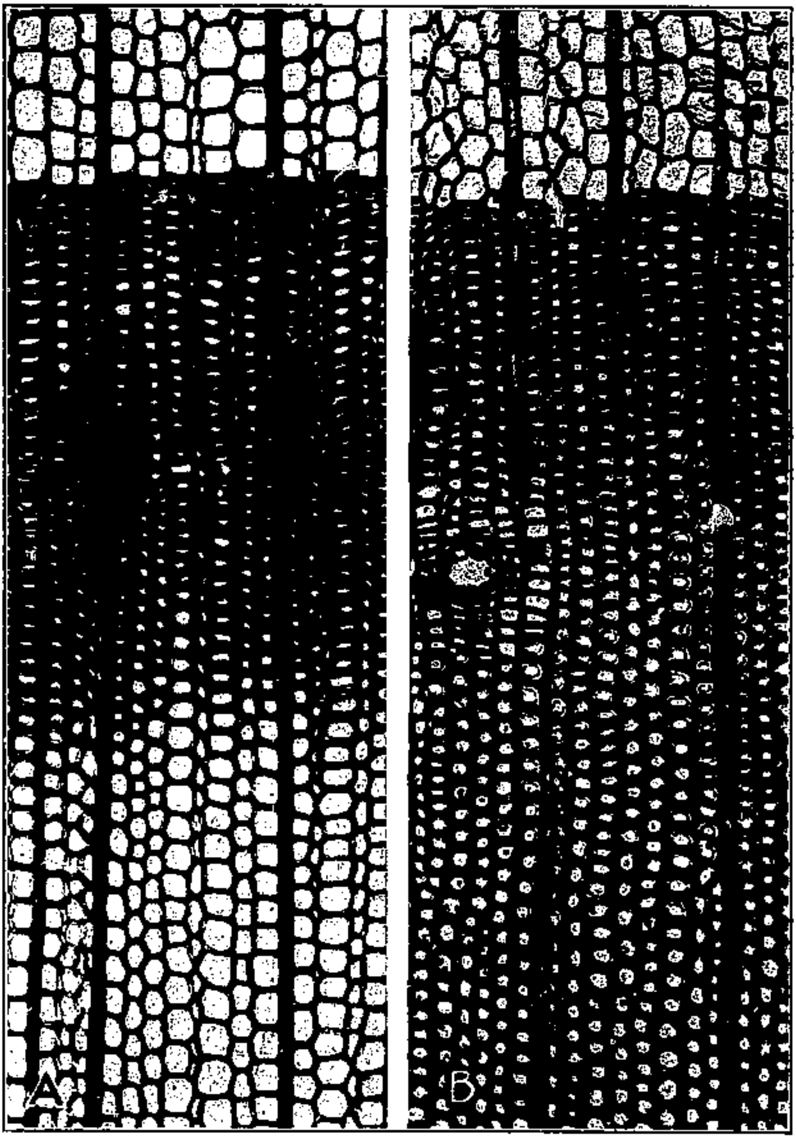

FIGURE 17.—Thin cross sections showing rounded summer-wood fibers and intercellular spaces in compression wood but not in normal wood of Douglas fir: A, Normal wood; B, compression wood. × 100

although many of them were above the average in specific gravity. This graph represents some 450 specimens, cut from seven trees, very few of which contained pronounced compression wood. After the specimens represented in Figure 6, as well as about 450 matched specimens tested on the radial face, had been divided into three groups, namely, the 20 per cent lowest in toughness for their specific gravity, the 20 per cent highest in toughness for their specific grav-

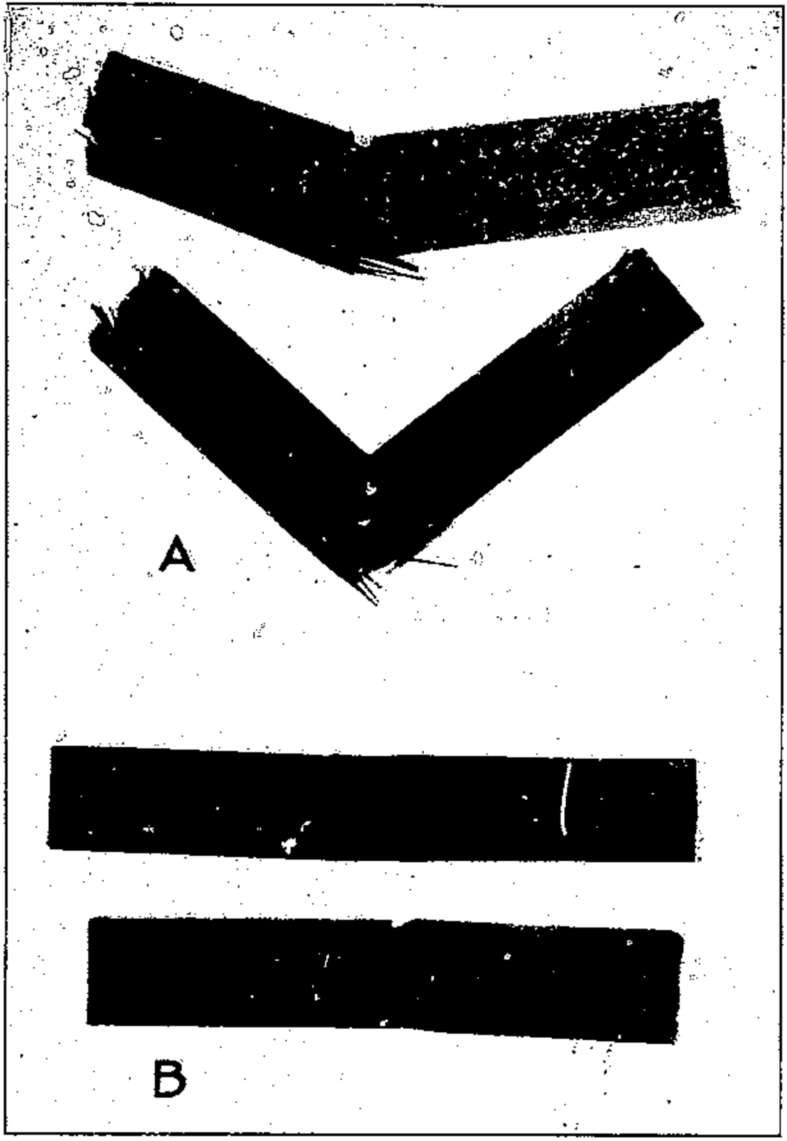

FIGURE 18.—Typical fractures in Sitka spruce loaded on a tangential surface: A, Normal wood; B, compression wood

ity, and the intermediates, the percentage of specimens containing compression wood in each group was found to be as follows: In the lowest 20 per cent, 17.6 per cent of the group; in the intermediate 60 per cent, 2.3 per cent of the group; in the highest 20 per cent, none. Although these figures do not necessarily indicate the relative prevalence of compression wood in Sitka spruce, they do indicate the effect of compression wood in reducing the toughness values.

Undoubtedly the great slope of the fibrils in the walls of the fibers in compression wood, which is indicated by the spiral striations already referred to, causes some weakening, but this is compensated for in part by the comparatively high specific gravity of that wood. One of the chief mechanical characteristics of compression wood is that it is not stiff; it bends before it breaks more than normal wood bends, probably because of the great slope of the fibrils; the resulting spring-like structure presumably allows the fibers to stretch more easily and to a greater extent before they break.

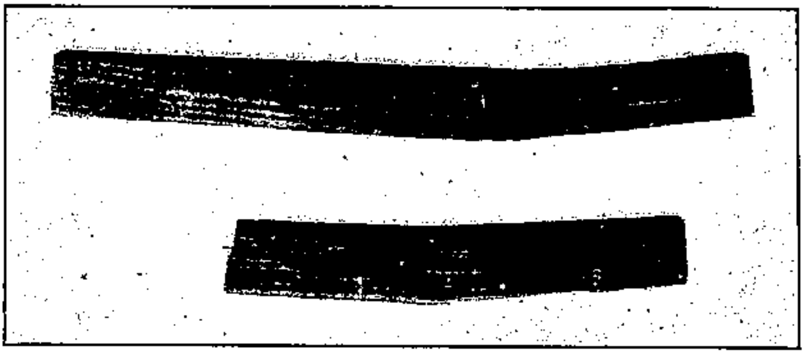

FIGURE 19.—Typical simple-tension failures in compression wood of Douglas fir, also characteristic of other brash wood

FIBER LENGTH

A common but fallacious opinion about wood is that its bending strength depends largely upon the length of its fiber. Although the tensile strength of cordage and fabric depends to a large extent on the length of the fibers from which they are made, it is not true of wood. When a piece of wood fails in bending, it fails first in compression along the grain, which does not involve slippage between the fibers. When tension failure occurs in bending, the fibers do not again slip by one another, as in a cord; transverse fracture of the individual fibers occurs, showing that the strength of the fiber and not its length is the determining factor. This is due to the fact that the fibers are grown together tightly; the bond uniting them would have to shear over comparatively large areas if slippage should occur.

In this study the fiber length was determined for only one group of brash and another of tough Sitka spruce specimens; both groups had about the same average specific gravity. No significant differences in average length were found, although the brash specimens did have a slightly shorter average, possibly because the fibers in compression wood, which occurred in some of the brash specimens, are shorter than those in normal wood. Forsaith (*8*), who found even greater differences in fiber length of brash and of tough specimens of various species in working with exceptionally light brash and heavy tough wood within a species, also came to the conclusion that fiber length has no direct relation to strength. Gerry (*10*) reached a similar conclusion with respect to Douglas fir after comparing fiber length and strength data of the same specimens.

THICKNESS OF FIBER WALLS AND DIAMETER OF FIBER CAVITIES

Since the material forming the walls of wood cells is fairly uniform in density, it follows, in general, that wood light in weight has either thinner cell walls or larger cell cavities, or both, than heavier wood. That such is the case is readily apparent on examining thin cross sections of light wood and heavy wood under the microscope. The specific gravity of wood, therefore, is usually a sufficient indication within a species of the amount of cell wall present and to a large extent of the strength, and it is much easier to make such a determination than to take measurements under the microscope.

There is a possibility, however, that of two pieces of wood having the same specific gravity, one may contain less wood substance than the other, the deficiency in wood substance being made up by other materials deposited in the cell cavity or even in the cell wall. It is reasonable to assume that materials deposited in the cell cavities do not add to the strength of wood, although they add to the weight, unless the deposits are so abundant as to fill entirely a large percentage of the cell cavities. In that event they may affect certain strength properties by the mechanical support they give to the cell walls. In the oak with a low percentage of wood fiber but a high percentage of ray tissue, already referred to, the abundant material in the parenchyma-cell cavities probably added to the weight but not to the strength.

Averages of the measurements of thickness of cell walls and diameter of fiber cavities, made in the study of brashness, are given in Table 5 for black walnut, oak, and Sitka spruce. Although the number of measurements were limited, these averages show no appreciable differences between the brash and the tough specimens. The parenchyma cells and the tracheids that may develop in oak in place of wood fibers have thinner walls and larger cavities than wood fibers usually have, and for that reason, as well as because the walls of such cells are built up differently, oak, having a small percentage of wood fiber, is deficient in strength, irrespective of its specific gravity.

In wood of different specific gravities, within a species, there may be large differences in the thickness of the cell walls or in the size of the cell cavities, with corresponding differences in strength; Forsaith (*8*) found this in southern cypress, yellow poplar, and white ash.

EXISTING COMPRESSION FAILURES

A compression failure is a permanent deformation of cell walls produced in compressing wood along the grain beyond its elastic limit. The compression may occur as a result of direct end loading, as in a post, or as a result of transverse loading, as in a beam. The deformation may be a distinct buckling of the fibers, pronounced enough to be readily visible to the unaided eye (fig. 20, B), it may be only faintly visible, or it may be merely a slight localized crinkling in the cell wall, visible only with a microscope, preferably a polarizing one, in thin sections of the wood, in which it appears as fine crosshatchings of the fiber wall without any noticeable displacement of the fiber as a whole. (Fig. 21.) Compression failures themselves are discussed in detail elsewhere (*3*, *26*).

TABLE 5.—*Average thickness of fiber wall and average diameter of fiber cavity in brash and in tough specimens of the same specific gravities, of various species of wood tested in the toughness machine*

Species of wood	Classification of specimens	Specimens examined	Average specific gravity[1]	Average toughness value	Average thickness of fiber wall				Average diameter of fiber cavity
		Number		*In.-lbs. per specimen*[2]	*Millimeter*				*Millimeter*
Black walnut	Brash	40	0.583	229.6	[3] 0.0035				[3] 0.0097
	Tough	49	.585	465.3	[3] .0035				[3] .0090
Commercial white oak.	Brash	51	.656	124.1	[4] .0048				[4] .0041
	Tough	49	.655	339.9	[4] .0050				[4] .0043
					Spring wood		Summer wood		
					Radial	Tangential	Radial	Tangential	
Sitka spruce from Washington.	Brash	20	.379	87.0	0.0024	0.0024	0.0045	0.0068	----------
	Tough	20	.379	203.5	.0024	.0023	.0048	.0070	----------
Sitka spruce from Alaska.	Brash	20	.417	95.9	.0028	.0026	.0046	.0065	----------
	Tough	20	.417	216.9	.0027	.0027	.0044	.0064	----------

[1] Based on volume when air-dry and weight when oven-dry.
[2] Size of specimen: Black walnut, ¾ by ¾ by 16 inches; other species, ¾ by ¾ by 12 inches.
[3] The fibers measured were selected at random throughout the growth ring.
[4] These values represent only nongelatinous fibers in summer wood, which were selected at random.

Wood containing compression failures apparently is weak in tension along the grain, presumably because the injured fibers are easily torn apart in tension. Therefore, if any compression failures are present on the tension side of a beam, that beam is likely to fail under a comparatively small load and, since compression failures extend across the grain, tension failures through them also extend across the grain, thereby giving the wood an appearance of being brash.

Figure 20, C, shows the brittle type of fracture in three specimens of Sitka spruce that had previously been compressed along the grain until the maximum load was reached and well-developed compression failures were visible. Figure 20, B, pictures one of the specimens after such compression. Figure 20, A, shows splintering fractures in matched specimens not previously compressed along the grain.

Since a beam almost always develops distinct compression failures on the compression side before it fails in tension, the final tension failure on the compression side follows an initial compression failure and is therefore an abrupt fracture, as is shown in the upper halves of the fractures in each of the specimens of Figure 20, A, thus causing the wood on that side to appear brittle. Splintering, therefore, occurs only on the tension side of a specimen, and the abrupt failure across the grain on the compression side of a beam is no criterion of the quality of the wood or of the presence of compression failures in the beam before the final load that caused failure was applied.

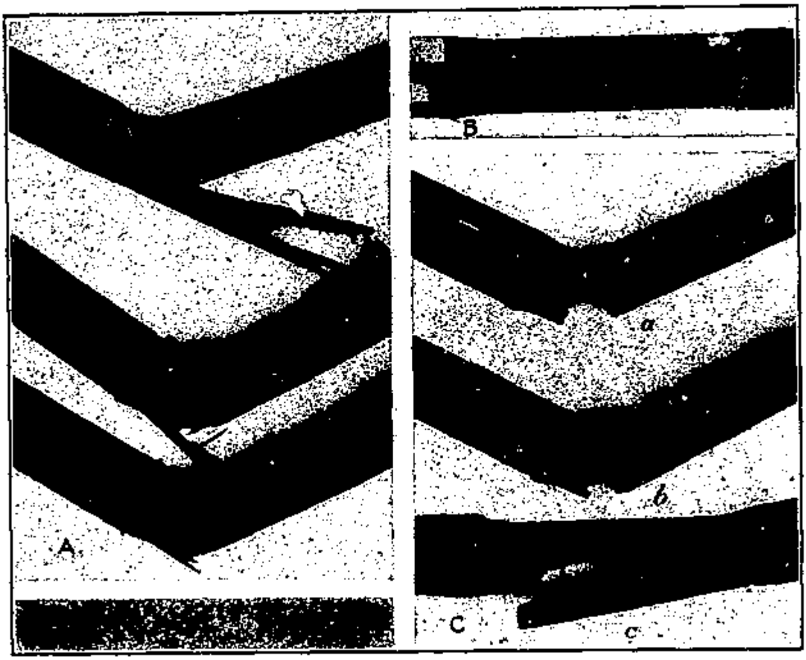

FIGURE 20.—The effect on the type of fracture, in bending tests, of preexistent compression failures in Sitka spruce. A, Specimens of normal wood matched with those of C; B, a typical compression failure caused purposely; C, fractures through compression failures previously caused purposely; *a*, specimen B after fracture; *b* and *c*, other specimens after fracture

Frequently at the Forest Products Laboratory abrupt fractures in beams have been traced to preexistent compression failures on the tension side, which were visible only with the microscope. (Fig. 21.) This type of compression failure is especially dangerous because of the difficulty of detecting it beforehand.

That compression failures are a frequent cause of brashness is shown for ash by Figure 5 and for Sitka spruce by Figure 6. Similarly preexistent compression failures were frequently found associated with low toughness values and brash failures in Douglas fir and oak. Some of these data are given in numerical terms in Table 6.

Further and more positive evidence of the effect of preexistent compression failures in reducing the toughness of wood is contained in Table 7, which gives the toughness value of the Sitka spruce specimens illustrated in Figure 20, A and C. The specimens previously compressed parallel to the grain gave toughness values only 40 per cent as high as those of matched specimens not so compressed; this value, of course, will vary with the degree of the previous failure in compression.

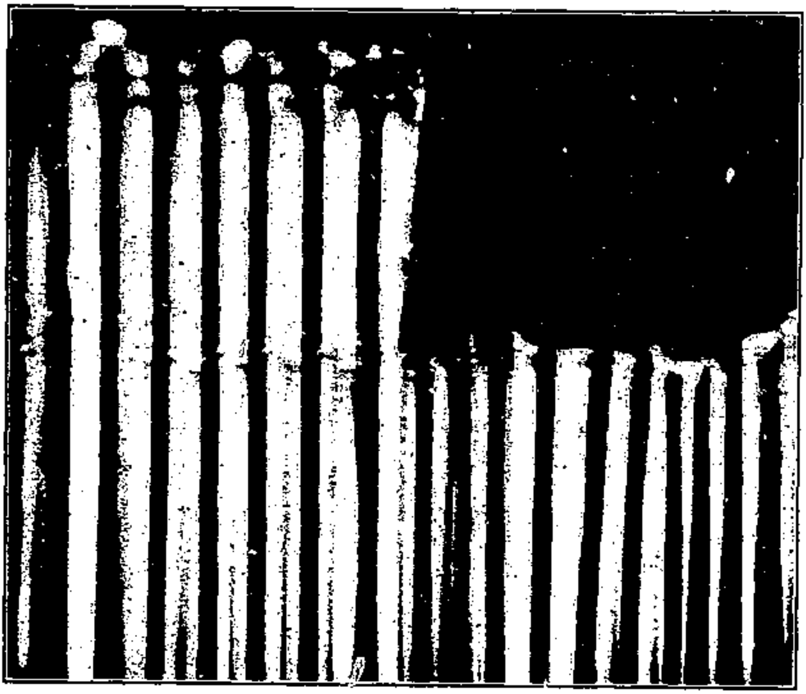

FIGURE 21.—Thin longitudinal section of fibers at a tension failure through a preexistent compression failure, which is indicated by the crosshatching in the fiber walls. The tension failure jumped from one compression failure to another. The photograph was taken by polarized light. × 210

TABLE 6.—*Percentages of specimens, low in toughness for their specific-gravity values, that failed through preexistent compression failures on the tension side, as indicated by visual inspection of the failures*

Species of wood and source	Classification of specimens	Specimens examined	Specimens failing in tension through preexistent compression failures	
		Number	*Number*	*Per cent*
Sitka spruce:				
Washington	Brash	36	17	47.2
Alaska	do	36	22	61.1
Oregon	20 per cent lowest in toughness for specific gravity.	170	110	67.6
Douglas fir, coast type.	10 per cent lowest in toughness for specific gravity.	75	16	[1] 21.4
White ash	20 per cent lowest in toughness for specific gravity.	156	81	51.9

[1] The low percentage for the Douglas fir group was due to the presence of a relatively high percentage (33.3 per cent) of cross-grained specimens in that group.

TABLE 7.—*Average toughness of Sitka spruce specimens previously stressed to maximum load in compression parallel to the grain, and of matched specimens not so stressed*

Classification of specimens	Specimens examined	Average specific gravity [1]	Average moisture content	Average toughness	Type of failure
	Number		*Per cent*	*In.-lbs. per specimen* [2]	
Previously compressed	11	0.385	17.2	82.0	Abrupt.
Control	11	.383	16.4	203.8	Splintering.
Percentage relation of other values to control values.	....	100.5	....	40.2	

[1] Based on volume when air-dry and weight when oven-dry.
[2] Size of specimen, ⅝ by ⅝ by 16 inches.

White-ash specimens of a similar moisture content and similarly compressed to maximum load did not have abrupt fractures or low toughness values, presumably because the compression failures were much more minute and more scattered; a tough wood, like ash, characteristically develops numerous small compression failures, especially when it is not at a low moisture content, unless the compression is carried well beyond the maximum stress.

Usually when a beam is bent considerably beyond its elastic limit and is then turned around it will fail under a comparatively small load because of the compression failures, now on the tension side, formed in the first bending. This fact suggests that turning a board or ladder when it becomes bent in service is inadvisable. On the other hand, bending tests on tough hickory beams have shown that the beams could be bent in one direction till the maximum load was reached and then bent in the opposite direction without noticeable weakening.

Compression failures may be caused by excessive bending of trees by the wind or by snow loads, by the differences in inertia and in air resistance of the crown and the trunk below the crown when trees are felled, by felling trees over irregularities in the ground level, and by severe bending of timber products in their manufacture or use.

CROSS GRAIN

Under the designation cross grain is included spiral, diagonal, and interlocked grain, and such other local deviations of the grain from parallelism to the main axis of a stick as may be caused by wavy grain, curly grain, knots, and wounds.

Cross grain frequently is a cause of weakness in wood members, especially in bending, but it does not produce fractures characteristic of brash wood. Occasionally the grain may run almost directly across a stick, especially in pieces cut from the vicinity of knots. When broken in bending, such pieces may appear brash on superficial examination, yet careful inspection shows that the break was not across the grain but that the grain itself ran across the member.

HEIGHT IN TREE

No definite statement concerning the occurrence of brash wood at different heights of a tree can be made. The wood in the swelled butts of ash and other species growing in very wet swamps is almost invariably brash. In trees growing under less moist conditions the wood in the butt usually is the toughest, but that fact does not necessarily mean that the wood higher up frequently is brash.

Compression wood usually is most abundantly developed in the lower part of the trunk, and therefore brashness from this cause would be expected to be more common in butt logs.

DISTANCE AND DIRECTION FROM CENTER OF TREE

Considerable variations in the weight and the strength of wood may occur in successive distances from the center of a tree, but no consistent generalization as to the relationship of toughness or brashness to the distance from the center can be made.

In conifers the wide-ringed wood frequently formed at the center and in both conifers and hardwoods the narrow-ringed wood found next to the bark of old, mature trees often is brash on account of its low density, already mentioned.

Compression failures apparently are of more common occurrence at the center of trees. Decay also, if present in tree trunks, is more common near the center, but numerous exceptions occur to all these generalizations.

No consistent or pronounced difference in the structure or the density of wood in different cardinal directions from the center of the tree has ever been noted, and therefore brash wood probably does not occur more commonly in one direction from the center than in another.

RATIO OF TENSILE TO COMPRESSIVE STRENGTH

The shock resistance, or toughness, of wood is dependent on the strength of wood in tension and in compression, upon the ratio between the two strength values, and upon the extent to which compression failures develop before failure takes place in tension. (P. 8.) Two pieces of wood may have the same strength in tension, but if one is weaker in compression it will bend farther before it breaks on account of the greater development of compression failures in it, although it will break under a smaller load. Since shock resistance is a measure of work absorbed, which in turn depends on the force exerted and the distance through which the force acts, it is entirely possible for a piece weak in compression to have greater shock resistance than one stronger in compression but of the same tensile strength.

To make satisfactory tests in tension along the grain of wood is exceedingly difficult, but compression tests can be made readily. To determine whether some of the brash specimens were relatively strong in compression, which would mean that their ratio of tensile to compressive strength would be comparatively high because they ranked low in toughness, compression-parallel-to-the-grain tests were made on short pieces cut from the toughness specimens of white oak and Sitka spruce. Table 8 shows the average values of maximum crushing strength obtained. In each instance the specimens designated as brash and low in toughness for their specific-gravity values had slightly lower average crushing strength than the matched tougher ones. This indicates that the brash specimens on an average must have been especially weak in tension along the grain.

Table 8.—*Maximum crushing strength along the grain and toughness values of brash and of tough oak, and of Sitka spruce low and high in toughness for its specific gravity*

Species of wood	Classification of specimens	Specimens tested	Average specific gravity [1]	Average toughness value	Average maximum crushing strength parallel to grain	Average moisture content of specimens tested in compression
		Number		*In.-lbs. per specimen* [2]	*Lbs. per sq. in.*	*Per cent*
Commercial white oak	Brash	51	0.656	124.1	9,128	6.1
	Tough	49	.655	339.9	10,044	5.9
Percentage relation of brash to tough.			100.2	36.5	90.9	
Sitka spruce	20 per cent lowest in toughness for specific gravity.	174	.390	48.4	5,917	9.7
	20 per cent highest in toughness for specific gravity.	177	.373	134.3	6,128	9.5
Percentage relation of low to high.			104.6	36.0	96.6	

[1] Based on volume when air-dry and weight when oven-dry.

[2] Size of specimen: White oak, ¾ by ¾ by 12 inches; Sitka spruce, ⅝ by ⅝ by 10 inches.

HIGH TEMPERATURE

Common opinion is that exposure to high temperatures, even if they are no higher than those maintained in commercial wood-drying kilns, may make wood brash. In order to determine the effect of fairly high temperatures on the manner of failure and certain strength properties of wood, Sitka spruce and white ash test specimens having a moisture content of 16 to 20 per cent were exposed to temperatures of 220° and 280° F. for from one to eight days and were then tested for toughness and maximum crushing strength along the grain. The results were compared with those for control specimens (*13*, *23*).

In the heated Sitka spruce specimens the type of failure was not appreciably different from that of matched control specimens even when the test pieces were heated to 280° F. and held at that temperature eight days. In the heated ash the type of failure also was not noticeably affected in test specimens heated to 220° and held there eight days or exposed to a temperature of 280° for one day, but those exposed to a temperature of 280° for two, four, or eight days failed with progressively less pronounced splintering than did the unheated specimens, although the fracture did not extend directly across the grain, as in a typically brash piece of wood, even after eight days of exposure to a temperature of 280°.

Of far more importance than the type of failure is the reduction in strength effected by high temperature. Table 9 gives the average toughness and maximum crushing strength parallel to the grain of groups of specimens subjected to high temperature; these values are expressed in terms of those of longitudinally matched control specimens. After the test specimens had been subjected to heat, all the pieces were stored under constant atmospheric conditions, which differed somewhat for the two species. The spruce control specimens came to a moisture content of 15.3 per cent and the ash controls to 10.4 per cent, while the heat-treated specimens reached the values tabulated. These results indicate the effect of heat treatment in reducing the hygroscopicity of the wood; the reduction in moisture content caused by a temperature of 280° F. was approximately one-third for each species.

TABLE 9.—*Averages of certain physical and mechanical properties of Sitka spruce and white ash subjected to high temperature for different periods of time, expressed as percentages of the average values of matched control specimens*

Species of wood	Temperature employed										
	220° F.						280° F.				
	Time in heat chamber	Specimens tested[1]	Specific gravity[2]	Toughness	Maximum crushing strength parallel to grain[3]	Actual moisture content at time of test	Specimens tested[1]	Specific gravity[2]	Toughness	Maximum crushing strength parallel to grain[3]	Actual moisture content at time of test
	Days	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sitka spruce	1	24	99.7	95.1	95.7	14.8	24	98.0	74.8	81.8	10.0
	2	24	100.0	89.8	89.6	14.3	24	98.4	69.5	74.6	10.6
	4	24	100.5	85.4	86.0	13.3	24	98.7	66.9	83.8	9.1
	8	24	99.7	76.9	85.0	13.2	24	94.9	51.2	74.8	9.7
White ash	1	24	100.0	91.4	106.4	7.7	24	98.8	36.8	110.0	5.5
	2	24	99.0	76.9	111.4	7.0	24	95.0	23.9	93.0	5.7
	4	24	98.6	73.4	108.6	8.4	24	94.2	30.3	78.8	7.0
	8	24	97.8	69.4	110.1	7.8	24	93.6	27.4	87.0	6.3

[1] A few individual toughness values were discarded in obtaining averages, because of defects in the test specimens.

[2] Based on volume at the moisture content at which the test was made and weight when oven dry.

[3] Adjusted by means of previously derived formulas to a moisture content of 15.3 per cent for Sitka spruce and 10.4 per cent for white ash, which were the average moisture-content values of the respective control groups. The difficulty of making accurate adjustments for moisture content may account for erratic values in this column.

Toughness usually decreased with increase in time of treatment and increase in temperature. Maximum crushing strength showed no such consistent relation between time of treatment and degree of temperature. The toughness of the spruce exposed for eight days to 280° F. was decreased to about one-half and the maximum crushing strength to about three-fourths that of the control specimens. For the ash the reduction was more than two-thirds and about one-eighth for these properties, respectively. In general, the heat-treated ash was reduced more in toughness and less in crushing strength than the spruce. The fact that the toughness was reduced more than the crushing strength of both species indicates that the tensile strength was affected considerably, the ratio of tensile to compressive strength thereby being brought closer to unity, particularly in the ash treated at 280°.

All these results, therefore, indicate that temperatures such as those usual in kiln-drying, which are below the 220° F. of one set of the tests, do not make wood brittle. Dry-kiln temperatures may weaken the wood slightly (*28*), but they do not cause it to break abruptly across the grain in bending. When abrupt fractures occur in wood as a result of exposure to extremely high temperatures it becomes darkened throughout so much and its odor changes to such an extent that the cause of brashness can be readily recognized.

CHEMICAL COMPOSITION

The chemical composition of wood does not vary a great deal within a species; in fact, the chemical differences between species lie principally in the materials deposited in the cell cavities and cell walls, especially in the heartwood. The basic materials, cellulose and lignin, from which the cell walls are made are nearly the same quantitatively in all woods. The probable effect of the slight differences in percentages of cellulose and lignin that have been observed in brash and in tough wood are masked by marked differences in the physical structure of the cell walls, which undoubtedly affect the mechanical properties a great deal. For example, spring wood, which is brash, has been found to contain a higher percentage of lignin than summer wood (*25*), and compression wood, which also is brash, likewise has a lignin content higher than that of normal wood as a whole (*7*, *12*). From these facts alone it might be inferred that lignin reduces the toughness of wood were it not for the additional fact that the structure of the more highly lignified wood, in these instances, is such as to leave little doubt that structure is the cause of the brashness.

In the study of brashness in oak the ash content was determined for 50 brash and 49 tough specimens of the same average specific gravity, to see if either group contained enough mineral matter to affect its weight or its strength appreciably. On on average the ash content of the brash specimens was 0.60 per cent and that of the tough ones 0.34 per cent of the weight of the wood when oven dry. The high average for the brash group was due primarily to 7 specimens in which the ash content ranged from 1.1 to 1.8 per cent. These 7 specimens contained an average of only 8.9 per cent wood fiber, whereas the average percentage of wood fiber for the remaining 43 brash specimens was 19.3 and that for all the tough specimens 28.4 per cent. The corresponding average toughness values were 87.0 inch-pounds per specimen for the 7 brash pieces having high ash content, 130.7 for the remaining 43 brash ones, and 339.9 for all the tough ones.

The cell wall is the only place in which mineral matter would be expected to affect the strength of the wood. A microscopic examination of the specimens having a high ash content showed that in most of them crystals were noticeably abundant in the ray and the wood parenchyma cell cavities, in which location they could hardly cause brashness. Evidently the high ash content of certain specimens was associated with other factors, brought about by growth conditions, that made the wood brash.

Materials deposited in the cell wall, on the other hand, may increase certain strength properties of wood to a greater extent than the weight. Tests of sapwood and of both leached and unleached heartwood of such woods as redwood, western red cedar, and black locust, which contain an appreciable amount of water-soluble extractives in the heartwood much of which is undoubtedly deposited in the cell wall, indicate that the infiltrated materials are responsible for the fact that certain strength properties of these species are greater than their weights indicate (*15*). Shock resistance is affected the least, whereas strength in compression is affected the most by the presence or removal of extractable materials.

DECAY

Decay in wood is a well-known cause of brashness. In extreme instances it reduces strength so much that the wood can be crushed with the fingers.

Figure 22, A, shows an abrupt fracture in the lower front edge of a red oak specimen tested in static bending. Advanced decay in that portion of the stick caused this type of fracture, which is in contrast with the typical splintering of the rest of the fracture. Not always, however, does decay-infected wood break so abruptly across the grain; the effect of decay on the kind of fracture depends on the particular species of fungus causing the decay and on its stage of development.

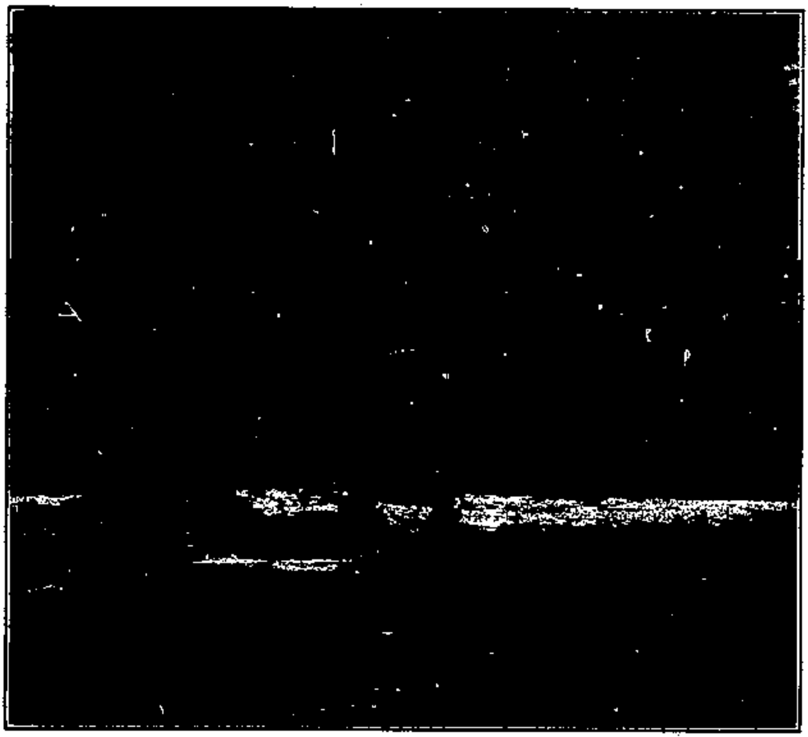

FIGURE 22.—Red oak, fractured in bending, with splintering in the sound wood and an abrupt break through the decay-infected wood in the lower front portion of the specimen: A, Side view; B, bottom view

In the early stages of decay toughness is the property most reduced, although in advanced stages all mechanical properties drop off rapidly. Compression parallel to the grain is affected much less than toughness, especially in the early stages, which again indicates that the tensile strength is greatly reduced.

Because of the known effects of decay on the strength of wood, every piece that is decay infected, even to a slight degree, should be regarded with suspicion. Different kinds of wood-destroying fungi attack wood differently, so that no simple rules for the recognition of decay in its early stages can be laid down. In diagnosing decay in wood by means of discoloration the publications of Boyce (*4*) and of Hubert (*11*) are among those of value (*27*).

SUMMARY

Brashness is an abnormal condition that causes wood, in bending, to break suddenly and completely across the grain when deflected only a small amount; in consequence the piece absorbs little energy or work.

Abrupt and complete failure is an objectionable characteristic under both static and suddenly applied loads, because it does not give warning, as a splintering failure does; the small amount of energy absorbed is especially objectionable under the shock, in which the work involved in bending is an important factor in preventing complete failure of beams.

Wood may be brash as a result of adverse conditions during growth or of the action of extrinsic agencies after growth. It may be relatively weak in various mechanical properties without showing abrupt fractures when broken in bending, but when abrupt fractures do occur in wood they show that its shock resistance, at least, is below normal, although it may be more nearly normal in other mechanical properties.

The following are the principal factors responsible for brashness in wood. Recognition of these factors is important in the detection of brash wood before failure. There is, however, no sharp line of demarcation between brash and tough wood. The degree of refinement to be used in culling brash wood depends on the value of the material and the service for which it is intended.

Wood low in density for its species almost invariably is brash, especially when dry. This is due to the smaller amount of wood substance in such wood and to the greater slope with respect to the cell axes of the fibrils in the walls of the cells in the predominating tissues. Low density is usually associated with very narrow growth rings (slow growth) in timber of any species, with very wide rings (fast growth) in softwoods, and with swelled butts of trees growing in very wet swamps. No sharp lines as to density (or specific gravity) or width of rings can be drawn between brash and tough wood, however, since the two kinds of wood merge imperceptibly. Species of wood that are normally low in density are not characteristically brash, although they are relatively weak.

In some oak the wood fibers are comparatively few in number, other tissues that do not contribute so much to strength having taken their place. Since these tissues, together with their cell contents, are not necessarily much lower in weight than the empty wood fibers that they replace, a piece weak for this cause may nevertheless be as heavy as a normal piece.

Compression wood is wide-ringed wood having a relatively large percentage of summer wood which, however, is not so dense as normal summer wood. It is formed on the lower side of leaning trees of all softwood, but not of hardwood, species. Compression wood is brittle and, when dry, usually ranks low in toughness and some other strength properties. On account of its brittleness, erratic strength properties, excessive longitudinal shrinkage, and tendency to warp, it should be excluded from all uses in which such characteristics are objectionable.

Wood subjected to either severe bending or end compression develops compression failures in the fiber walls, the failures extending more or less directly across the grain. Fibers so distorted fail relatively easily in tension along the grain, and when on the tension side of a beam they not only cause early failure under stress but also, since the existing compression failures extend across the grain, cause abrupt fractures on the tension side. A fracture is always abrupt on the compression side because of the compression failures that develop in bending.

Compression failures, if well developed, can readily be seen on the surface of lumber or timber, especially when the pieces have been planed. On the other hand, compression failures are sometimes so minute that, outside of a microscopical examination, their presence can be detected only by the abrupt fractures produced in bending either the piece in question or small test sticks cut from it.

Prolonged high temperature may make wood brash, but temperatures such as those ordinarily maintained in commercial dry kilns do not cause abrupt fractures in wood, although the strength of the wood may be reduced thereby. The indications are that abrupt fractures are not produced by heat unless a temperature high enough to darken the wood throughout is used.

Decay in wood is a well-known cause of brashness. Shock resistance is the first mechanical property affected by the progressive disintegration of wood by fungi. Wood may show a reduction in this property even before the decay has advanced far enough to be readily recognized by inspection or before the type of fracture is affected by it. No wood, therefore, that shows the slightest signs of infection by decay should be used where a high degree of toughness is required.

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