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CAUSES OF BRASHNESS IN TIMBER

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Summary. The factors influencing the development of brashness in timber are discussed. These are reduction in density; changes in moisture content and temperature; ultrastructural changes; changes in chemical composition; and the presence of compression damage. Examples are cited and illustrated. Attention is paid to the recognition of the causes of brashness in the field and in the laboratory.

INTRODUCTION

In engineering, as distinct from the aesthetic and other physical considerations, a material must be strong, stiff and tough. Clear, straight-grained timber, in possessing good strength properties (especially so when expressed in terms of its density) moderate stiffness, and excellent toughness across the grain, is therefore characterised by a rare combination of properties which is emulated among all other materials only by the other natural composite, namely bone.

Although lower than that of the ductile metals, the toughness of timber has a value similar to that of the man-made composites. Toughness is a measure of a material's inherent resistance to the propagation of cracks during stressing by absorbing large quantities of energy. In timber this ability can be explained in part by the arrest of horizontally running cracks by the presence of 'weak' interfaces within the cell wall (Cook & Gordon, 1964) and in part by the delamination, buckling and subsequent large extension of parts of the cell wall as described briefly by Gordon & Jeronimidis (1974) and more fully by Jeronimidis in this issue.

The occurrence of knots in timber reduces its toughness, by an amount dependent upon their size, type and distribution. In structural calculations, therefore, it is common practice to regard timber as lacking toughness, a state which is usually described as brittle: this is a necessary, though nonetheless a conservative approach. Brittle behaviour is also present when the crack runs longitudinally parallel to the fibre axis, a feature which is exploited when splitting wood for burning or cleaving it for fencing.

Given both of these important exceptions, it is still true to say that clear, straight-grained timber is very tough in a direction perpendicular to the grain. However, under exceptional conditions the natural toughness of timber is reduced appreciably and the item fails abruptly absorbing little energy. Under these conditions the timber is said to be 'brash' indicative of the abnormal state of the timber. As such, the term should not be confused with 'brittleness' which is a normal behaviour of many materials such as glass and ceramics. Some brittle materials possess very high strength properties; brash wood, on the other hand, is never strong. Occasionally the term 'brittle' is applied to wood, but it should be used to describe only the actual fracture surface and not the general condition of the wood (Koehler, 1933).

Brash wood, when stressed, breaks suddenly and completely with brittleness in fracture. The failing load, amount of deflection, work to maximum load, and the amount of energy absorbed are low in comparison to the corresponding values for normal wood. Such values are indicative of the very poor resistance to shock that brash wood possesses.

Another characteristic of brash wood is its low ratio of tensile to compression strength along the grain. In normal wood the ratio is about four to one and failure occurs slowly on the compression side of a beam stressed in bending. In brash wood, however, there is a lower differential between tensile and compressive strengths because failure in tension occurs at a lower level of stress. Complete failure of the beam will be associated with lower deflection and energy absorption.

It should be noted, however, that the appearance of a fracture is influenced by the span over which the timber is stressed. On short spans, fractures are frequently brittle in appearance and timber can be deemed to be brash quite erroneously. Similarly high rates of stressing can also induce brittle-type failure, though the timber is not inherently brash. As indicated previously, the term brash is permissible only where the various strength properties have been markedly reduced.

THE CAUSES OF BRASHNESS

The most common factors influencing the development of brashness in timber are:

(1) Reduction in density
 a below average proportion of fibres in hardwoods
 b reduced thickness of the cell walls
 c inclusion of 'core' or 'juvenile' wood
 d presence of fungal decay

(2) Changes in moisture content and temperature

(3) Ultrastructural changes
 a effect of fibril angle
 b inclusion of compression wood

(4) Changes in chemical composition
 a prolonged elevated temperature

b chemical degradation by strong acids and alkalis
c elevated temperature and fire-retardants
d gamma irradiation

(5) Presence of compression damage
A damage originating in the tree
a brittleheart
b compression failures
B damage originating in converted timber
a overloading in compression
b fatigue.

Brashness *per se* cannot be measured directly but many techniques are available for quantifying the reciprocal factor, toughness. Both the Charpy and Izod instruments are used, especially in continental Europe, but in the UK toughness is usually determined using a modified Hatt-Turner instrument. In this technique a shaped metal plunger of mass 1.5 kg is allowed to fall onto a suspended timber beam, the height of drop being increased progressively until failure occurs. Whilst the technique provides only relative data on toughness, it does eliminate difficulties arising from notching composite materials of variable structure. Toughness may also be calculated from the area under the stress-strain curve which is a measure of the work done to fracture.

Reduction in density

Density of the timber exerts a considerable influence on the occurrence of brashness. In Fig. 1 toughness is plotted against density for a wide range of both hardwoods and softwoods (Lavers, 1969): a similar relationship is known to exist within a species (Kollman & Côté, 1968).

Within their normal range of density all timbers are tough or fairly tough unless there is some defect or degrade. In any one species, however, the incidence of brashness increases as density decreases for any one of the following four reasons.

Fibre content

The density and consequently the toughness of ring-porous hardwoods is markedly influenced by the percentage of thick-walled fibres present in the growth ring. Conversely, the higher the percentage of the thin-walled parenchyma and vessels, the greater is the tendency to brashness.

The percentage distribution of the different cells present in the growth ring in ring-porous hardwoods is influenced by the rate of growth of the tree when the wood was formed. A decrease in growth rate (i.e. narrower growth rings) results in a higher

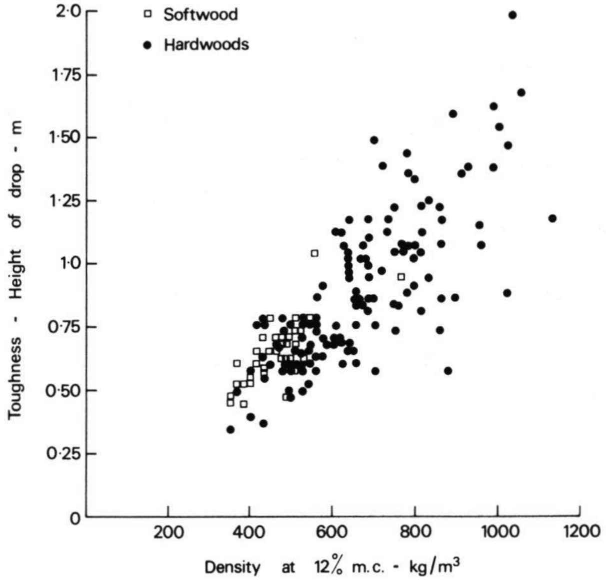

Fig. 1. The influence of density on toughness for a wide range of softwoods and hardwoods (data from Lavers, 1969).

percentage of large-diameter pores and a reduction in fibre content. This influence of growth rate on wood structure is illustrated in Plate 1 and its significance in controlling both density and toughness is apparent from the data presented in the caption to the figure.

Cell-wall thickness

In all hardwood timbers in which very high rates of cell production have occurred (about two to three rings per inch), there is frequently a reduction in the thickness of the cell walls due to the inability of the tree to cope with the excessive demands for cell-wall material. This reduction in wall thickness is reflected in decreased density and toughness. It is necessary, therefore, to exclude not only slowly grown, but also very fast grown hardwood as both conditions can result in a lower density. Rates of growth between 4 and 16 rings per inch (ring width between 1.5 and 6.5 mm) have been recommended in the selection of ash where toughness is important (P.R.L., 1972).

In softwoods, increased growth rate is accompanied by a higher proportion of early wood comprising thin-walled cells. Since late wood has been shown to be four times tougher than early wood (Raczkowski, 1963) the toughness of softwood decreases as growth rate increases.

'Juvenile' or 'core' wood

Another form of low density timber which is found in both soft and hardwoods is 'core' or 'juvenile' wood. The technical properties of this central zone are quite different from those of the surrounding area, reflecting differences not only in density but also in cell length, microfibrillar angle and straightness of grain. A common pattern is for the density of the wood to increase outwards from the centre of the tree to about the fifteenth ring, after which it remains fairly constant. The average density of the wood contained within this corewood zone is about three-quarters of that of the wood outside it, but it should be realised that extreme differences in density of 100% can exist between the first two or three rings from the pith and the rings near the outside of the trunk. Timber containing core wood, therefore, commonly has a lower than normal density and is often brash.

Fungal decay

The attack of wood by wood-destroying fungi results in the removal of cell wall material by enzymatic dissolution. In the initial stages of fungal infection significant losses in strength have been recorded before there is any appreciable loss in density.

With further attack there is a marked reduction in cell wall material, and, consequently, density; this is accompanied by a further decline in all strength properties including toughness, leading to a brittle failure as illustrated in Plate 2A.

Changes in moisture content and temperature

Below the fibre saturation point the effect of moisture content on toughness, or lack of brashness, appears to be slight and to vary considerably from species to species. Thus it has been shown for beech wood that toughness is independent of moisture content (Krech, 1960) while for other timbers, toughness has been found to decrease slightly as the moisture content is lowered (Sulzberger, 1946) or raised (F.P.L., 1955).

The effect of moisture content appears to be interrelated with that of temperature. Both Thunell (1941) and Sulzberger (1946) have demonstrated that at low moisture contents toughness remains constant or increases slightly with a reduction in temperature from ambient to sub-zero. At moisture contents of 16% and above, however, the relationship is reversed and the marked reduction in toughness at sub-zero temperatures is obviously related to the formation of ice crystals within the cell wall.

The relationship for low moisture contents has been confirmed for Douglas fir and balsa by Comben (1962) who found, however, that the toughness of ash, by contrast, decreased with reduction in temperature.

Although timber is used only infrequently under conditions combining low temperature and moderate to high moisture content, it is usually in situations where shock resistance is extremely important as, for example, in high-altitude gliding or in ice-axe shafts in high-altitude mountaineering.

Ultrastructural changes

Effect of fibril angle

Over the last decade attempts have been made to relate various strength properties to the angle at which the microfibrils are orientated in the secondary cell wall (e.g. Cowdrey & Preston, 1966; Mark, 1967). Most of these investigations relate to tensile stressing and stiffness, but recently Kollman & Côté (1968) have echoed views first expressed by Koehler in 1933 that toughness is inversely proportional to the size of this angle.

It is difficult to set out the reasons why one should expect a direct relationship between microfibrillar angle and toughness, especially those elements of toughness concerned with pliability and energy absorption. Since microfibrillar angle is inversely proportional to fibre length (Preston, 1947), it may be that toughness is related to the amount of fibre overlap, since it has been shown that the length of overlap is proportional to the length of fibre (Ahlborn, 1964). On the other hand it is possible that microfibrillar angle is influencing the capacity of the composite structure to arrest horizontally running cracks.

Presence of compression wood

One of the most frequent causes of brashness in softwood is the inclusion of compression wood (Koehler, 1933). The brashness of this abnormal reaction wood is due, at least in part, to the increased percentage of lignin and reduced percentage of cellulose compared with normal wood. However, since the microfibrillar angle is larger and the fibre shorter in compression wood compared with normal wood, the brashness of the former could be explained in terms of microfibrillar angle or fibre overlap as in the preceding section.

Differences in fracture topography and brashness in hemlock ladder stiles are illustrated in Plate 2B where the toughness of the sample containing compression wood was 77% that of the normal wood stile.

Modification of chemical composition

As mentioned previously, the initial stages of fungal attack can result in significant reductions in toughness, without any loss in density; the development of brashness in this case is due to chemical changes in the cell wall (Cartwright *et al*, 1931).

Significant changes in the relative proportions of cellulose, hemicellulose and lignin occur with the development of compression wood. Even more important is the marked reduction in the degree of polymerisation of the cellulose (Dinwoodie, 1965); such a marked change in the length of the molecule has a most significant effect in reducing both tensile strength and toughness.

Several other factors influence the chemical composition of the timber and affect toughness; these are:

Elevated temperature

Thermal decomposition of wood resulting from prolonged exposure to temperature above 66°C results in a marked deterioration in all strength properties especially toughness (F.P.L., 1955). The higher the temperature the greater is the degree of brashness irrespective of whether or not the temperature is subsequently reduced. An example of brittle failure of timber subjected to prolonged heating is presented in Plate 2C.

Hardwoods are usually affected to a greater degree than softwoods. It has been shown that after eight days' exposure to 140°C, the toughness of Sitka spruce was 51% and white ash 27% that of matched control specimens (Koehler, 1933).

Chemical degrade

Wood is generally highly resistant to a large number of chemicals. Compared with iron it is superior in resistance to corrosion from weak acids, but inferior in its resistance to alkaline attack. However, under prolonged very acidic conditions and alkaline conditions permanent weakening of the timber results; strong acids hydrolyse the cellulose and hemiculluloses while strong alkalis delignify the wood and also dissolve the hemicelluloses.

The toughness of wood appears to be particularly sensitive to chemical degrade; even the small concentration of zinc chloride used formerly in some wood preservatives can cause a reduction in toughness (F.P.L., 1955).

Elevated temperature and fire retardants

Considerable caution has to be exercised in determining the level of heating to be used in drying timber following impregnation by aqueous solutions of fire-retardant chemicals. The salts most commonly used in the United Kingdom are mono-ammonium phosphate, diammonium phosphate, ammonium sulphate, boric acid, and borax: most of the proprietary solutions are mixtures of these chemicals.

On heating, the ammonium phosphates and sulphate tend to break down giving off ammonia and leaving an acidic residue which can result in degradation of the wood: reductions in toughness of up to 35% have been recorded for timber kiln-dried at 65°C, while at 90°C the loss can be as high as 60%. The brittle failure associated with this cause of brashness is illustrated in Plate 2D: it will be noted that although the gross failure is brittle and very similar to that for prolonged heat, failure at the micro level appears to be sawtoothed, quite unlike that due to elevated temperature (Plate 2C).

Gamma irradiation

It is well established that the irradiation of timber by gamma rays at moderate to high dosages results in a marked reduction in the degree of polymerisation of the cellulose molecule (Ifju, 1964). As in the case of compression wood, such a reduction is reflected in losses in both tensile strength and toughness.

Compression damage in timber

DAMAGE ORIGINATING IN THE TREE

Brittleheart

Brittleheart is an abnormal condition of timber formed in the core of many tropical hardwoods and is a major cause of brashness in many of these timbers.

The trunk of a tree is highly stressed with the outside layers in tension and the centre of the tree under longitudinal compression. As the tree increases in diameter, the compression stressing intensifies and in low density tropical hardwoods this longitudinal compression stress in the core is greater than the natural compression strength of the wood (Dinwoodie, 1966). Failure in compression occurs with the formation of slip planes in the cell walls (Dinwoodie, 1970). Frequently these are aligned in a horizontal plane forming a compression crease as illustrated in Plate 3A.

The crease represents a line of weakness; when brittleheart is stressed in tension or subjected to impact, separation occurs along the crease at loads considerably lower than those for normal wood and with brittleness in fracture. Whilst most strength properties are lowered to some extent in brittleheart, toughness is affected appreciably and this abnormal form of timber must be excluded where the timber will be subjected to impact loading.

Natural compression failure (other than brittleheart)

Compression damage may result in any tree from localised over-stressing. This may occur on the leeward side of the trunk when the crown is buffeted by gale-force winds (Mergen, 1954; Phillips & Patterson, 1965) or on the underside of logs felled across

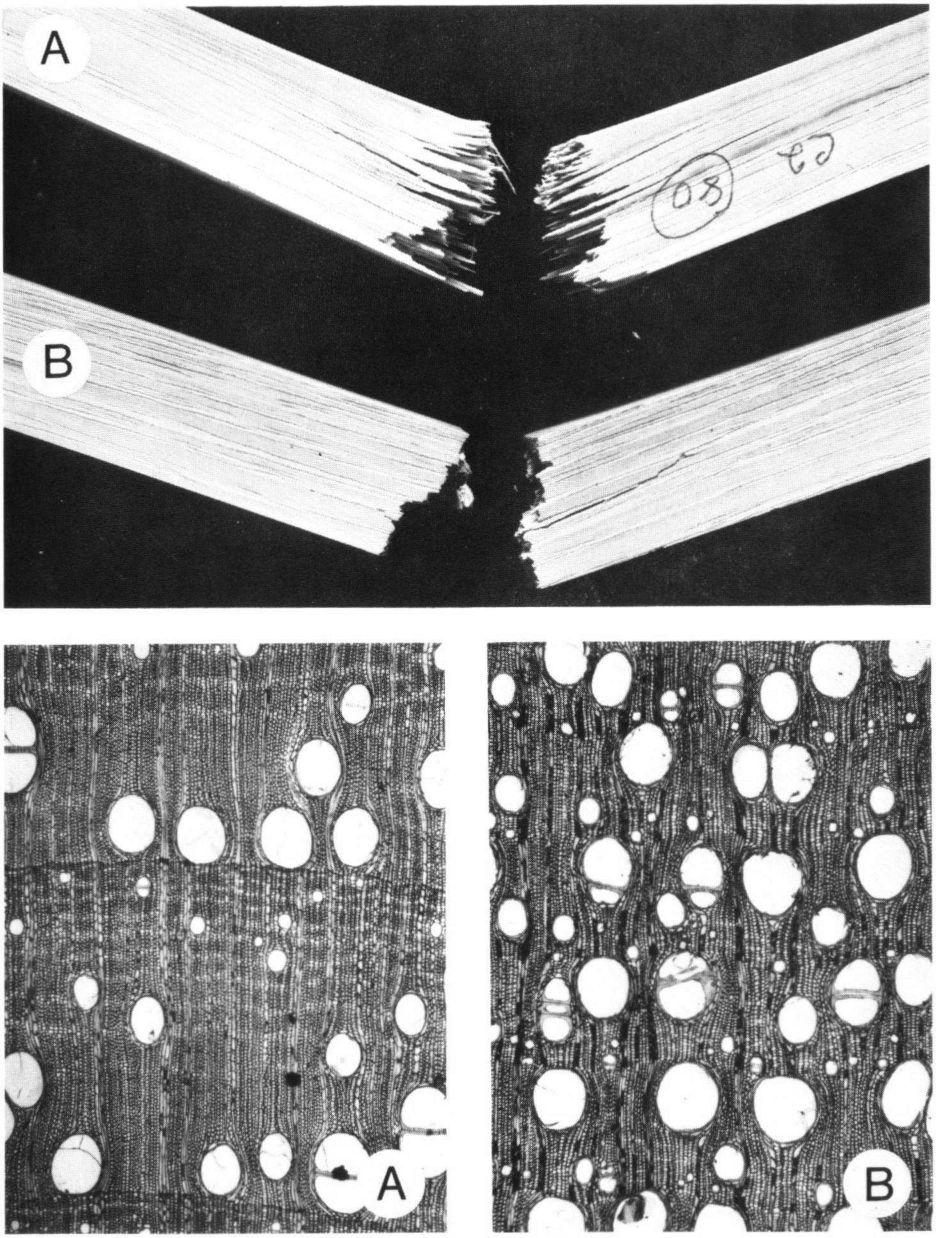

Plate 1. The influence of rate of growth on fracture morphology and toughness of hickory. Sample A had a growth rate of 14 rings per 25 mm, a density of 780 kg/m^3 and in the Hatt-Turner toughness test the height of drop was 2 m. The corresponding values for sample B were 30 rings per 25 mm, 630 kg/m^3 and only 0.70 m.

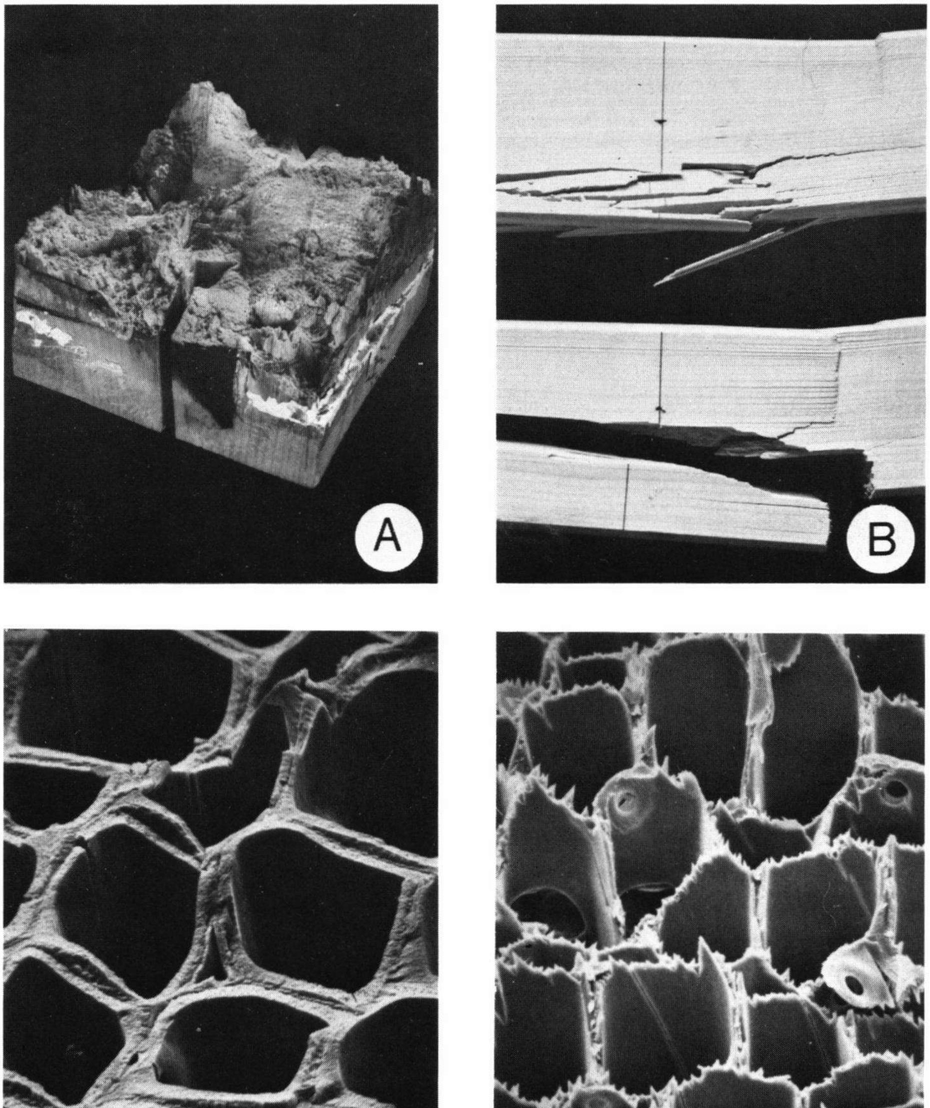

Plate 2.—A. Brash fracture of Ash beam due to fungal attack.—B. The influence of compression wood on toughness. The upper ladder stile is made from normal hemlock timber and has failed in bending with an interlocked fracture. The lower stile, however, contains compression wood. It has failed with a brittle fracture and has a toughness value only 77% that of the upper stile. — C. The effect of prolonged heating on toughness; sample of Scots pine removed from the warm air ducting in the House of Lords (×650).— D. Brash fracture in Scots pine timber following impregnation by fire retardants and kilning at high temperatures (×360).

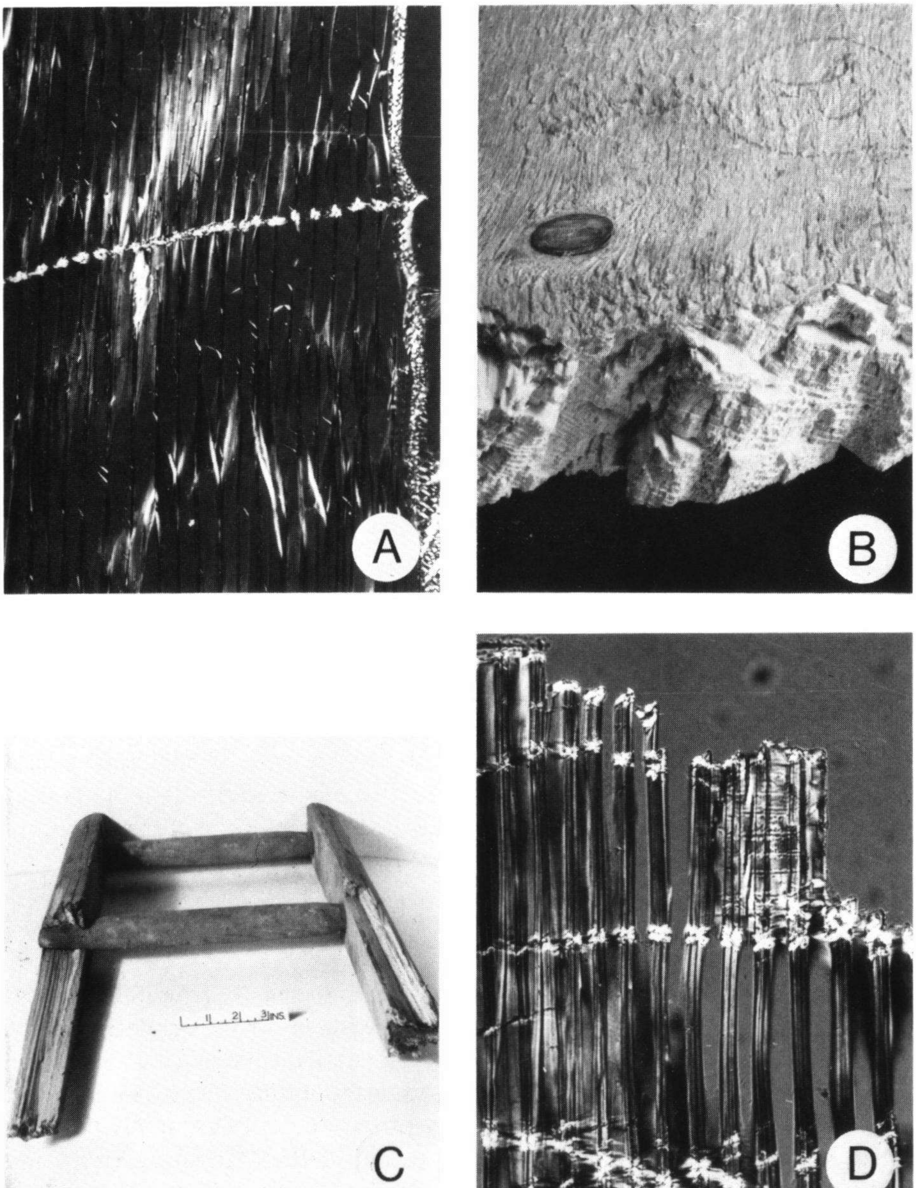

Plate 3. — A. The lateral development of slip planes to form a compression crease in brittleheart of *Shorea* sp. (Photographed under polarized light, ×60). — B. Brittle fracture of a scaffold board manufactured from spruce timber containing a natural compression failure. — C. Brash fractures occurring in both stiles of a spruce ladder resulting from previous overstressing in use. Separation has occurred along the line of prior compression damage when the ladder has been turned over and the damaged area put into tension. — D. Slip planes and creases in a glider wing subjected to cyclic loading. The fracture face follows lines of creases frequently jumping from one crease to the next. (Photographed under polarized light, × 100).

some obstacle on the ground. Slip planes and compression creases similar to those in brittleheart (Plate 3A) develop in the outer growth rings reducing the strength of timber, especially its toughness. These creases are frequently referred to as thunder-shakes and, although they can be recognised in planed wood, they are extremely difficult to detect in sawn timber.

Plate 3B illustrates the brittle fracture of a new Norway spruce scaffold board manufactured from a tree containing natural compression failures and subsequently dropped when delivered to a building site.

DAMAGE OCCURING IN CONVERTED TIMBER

Overloading

When wood is compressed along the grain it yields slowly and progressively with the formation of slip planes and creases (Dinwoodie, 1968). Research at P.R.L. on the significance of compression damage has demonstrated that timber of low moisture content compressed to failure is about 10% less strong in tension and up to 50% weaker in toughness than normal wood (Hudson, 1961; Dinwoodie, 1976).

An example of brashness due to overloading is illustrated in Plate 3C. The failure of the ladder at lower than design load is due to the presence of compression damage on the upper side resulting from its misuse. When the ladder was turned over and loaded, tension failure on the lower side developed along the line of the existing compression damage giving rise to the brittle fracture.

Fatigue

The alternation of tension and compression loading over a long period of time produces slip planes and compression creases at the points of stress concentration. These micro-fractures intensify with duration of stressing until on a tension cycle the timber breaks with a brittle fracture. Loads well below the ultimate strength of wood, as determined in short-term loading, are sufficient to initiate failure in fatigue. Timber used in wooden gliders and diving boards is subjected to fatigue stressing and an example of crease development in the wing of a glider is illustrated in Plate 3D.

RECOGNITION OF THE CAUSES OF BRASHNESS

It is apparent from preceding sections that the factors responsible for brashness are extremely variable covering not only the structure of wood but also its physical, chemical and mechanical degrade. Consequently it is frequently difficult, and at times impossible, to determine for certain the cause or causes of brashness.

Above average density for the timber may be an indication of compression wood, while lower-than-average density is a feature common to a number of factors causing brashness. The number of rings per inch must be taken into consideration as both very fast and very slow rates of growth can result in brashness.

Visual examination of the surface of the timber should indicate whether the wood has been attacked by fungi. Attack by wood-destroying fungi is often indicated by localised changes in colour and texture of the surface of the wood, sometimes with dark zone-lines delineating the zone of attack, and, in advanced stages of decay, marked softening of the wood and the presence of transverse cracks of fibrous bundles on the longitudinal surfaces.

A careful examination of a planed surface should show whether or not compression creases are present, although good illumination at a low angle to the surface of the timber is often necessary for the purpose.

The colour of the wood may also yield useful information. An overall and even darkening of a particular timber is usually indicative of chemical degrade due either to prolonged exposure to high temperature or to acid attack.

While the above examinations may be carried out in the field, detailed examination of the material is possible only in the laboratory where various types of microscopy can be employed to examine sections of the timber.

The reasons determining the reduction in density can be deduced from an examination of the cross-section. Information on the percentage distribution of fibres in the growth rings and the thickness of the cell wall should be compared with that from sections cut from reference timbers.

The presence and extent of compression wood are readily determined from transverse and longitudinal sections, but the assessment of the degree and origin of compression damage is considerably more difficult. If only a small piece of wood is available, it is impossible to state whether the compression damage within it developed in the living tree, in the wood after conversion as a result of overloading or fatigue, or as part of the failing process in bending. However, equipped with the entire structural member, areas of high stressing can be identified and the tensile and compression faces of the fracture determined. From this information it is sometimes possible to deduce the development of the fracture and the origin of the compression damage.

CONCLUSION

It should be emphasised that brashness in timber is an abnormal condition. Although it may arise as a result of one or more factors it is nevertheless infrequent in occurrence when expressed in terms of the total volume of wood used annually. Any tendency to lessen the significance of brashness because of its numerical occurrence, however, must be condemned when consideration is given to the severity of the accidents that occur when brash timber is used.

The significance of this defect will intensify in future years as a result of the increasing utilisation of small-diameter softwoods. Such timber contains a large percentage of weak core wood and, quite frequently, some compression wood, two factors which result in pronounced brashness.

The range of factors responsible for the development of brashness in timber is extensive, varying from particular combinations of anatomical tissues to the physical, chemical and mechanical degrade of wood. Whatever the cause, or causes, the end result is similar; brashness results not only in the production of a brittle fracture, but also in reducing the various strength properties, in particular the toughness or impact resistance.

Brashness in timber, with the associated danger of human injury, can be avoided only by the careful and systematic selection of timber by trained personnel conversant with the causes and significance of this defect.

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