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Some Implications of the Properties of Wood

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Please note

Many of the applications and the practices in the use of wood have become established through long experience. This basis for predicting performance can be inadequate or even misleading when conditions of use are changed or new applications are involved, unless the reasons for satisfactory past performance can be identified and related to new situations. It is thus important with wood, as with other materials, to understand basic properties and their implications in use in order to be able to select and to design with confidence that the desired results will be obtained. Some basic characteristics of wood were described in **CBD 85**; the implications of these will now be discussed in more detail.

Strength Properties

It is well worth repeating that the outstanding characteristic of wood, apart from its general availability, workability and relatively low cost, is its ability to withstand both tensile and compressive stresses along the grain. It can thus withstand bending loads, and it is this capability that makes it unique among natural structural materials and has always contributed greatly to its value as a natural resource. As this superior strength in tension and compression is along the grain, the length of the structural members obtainable is limited only by the height of the tree or by the length of log that can be handled. The appropriateness of the diameter to length ratio, which often means that the whole trunk can be used as a structural member, is a reflection of the natural function of the trunk in supporting the tree.

The markedly reduced strength properties across the grain and in shear along it introduce some interesting features to the use of wood for general structural purposes. While these are well recognized and are taken into account in timber engineering practice, it is well to review some of them in the interests of understanding wood. Wood columns themselves present little problem since they can carry axial compression well. When high concentrated loads are transferred to wood sills, plates or beams, local crushing in the cross-grain direction becomes a possibility and must always be checked in view of the reduced compressive strength in this direction.

Short wood beams, which can because of their short span carry high transverse loads and consequently have high induced shear stresses, must be checked for horizontal shear failure in the long-grain direction. The proportionately low shear strength along the grain also makes it necessary to design carefully when exploiting the generally excellent tensile properties of wood in tension members because complications are introduced into the transfer of end loads. Splices in tension members and on the tension side of beams require similar attention. Long-scarf joints or finger joints or relatively long gusset or splice plates become necessary in order to provide the areas necessary for load transfer by shear. For the same reason bolts or nails used in such fastenings must always be located at adequate distances from the ends of the members. Joints made with patented devices such as ring connectors are designed to involve relatively large shear areas along the grain for load transfer. When large tension loads must be transferred at an angle to one member, it is usually necessary to use intermediate elements such as gusset plates to assist in distributing the load without exceeding the permissible stresses in tension across the grain.

It has already been indicated in the preceding Digest that the normal working stresses in structural applications must be substantially reduced from the basic values for the species obtained from clear, air-dried specimens, because of such defects as knots and checks in commercial sizes and grades of timber. It is often desirable to differentiate further through adjustments in the allowable stresses between long-time and short-time load applications. There can be appreciable deformation with time, and failure can occur at lower loads when these are to be resisted continuously over long periods. Correspondingly, higher loads can be carried over short periods. This tendency under stress for continuing deformation, or creep, which occurs under certain conditions with most materials, is not always a disadvantage. It can lead to some desirable relief of stresses such as are caused by changes in moisture content.

Dimensional Changes due to Moisture

The most significant effect of moisture content on wood is related to the dimensional changes that take place with changes in moisture content. The marked difference between small moisture-induced movements along the grain and those across the grain introduces some important considerations.

It may be recalled that shrinkage along the grain, upon drying from a fibre saturation level of about 30 per cent to oven-dry, may be only about 0.1 per cent, while that across the grain can be of the order of 5 per cent, the shrinkage in the tangential direction being greater than that in the radial direction. Such an extreme range in moisture content is not normally to be expected in service, but wood put in place at a relatively high moisture content of say 19 per cent could readily dry in place to a moisture content of 5 per cent or even less (depending on the average relative humidity to which it is exposed), thus shrinking as much as 2½ per cent or ¼ inch in the width of a 10-inch board.

Fortunately the corresponding change along the grain, that is, along the length of the board, will only be about 1/50 of this amount. If this were not so, all structures made of wood could vary in their principal dimensions owing to moisture content changes in service by unacceptably high amounts and it would be impossible to combine wood satisfactorily with other materials. Consider, for example, the situation if the length of framing members in a house changed by 1½ per cent, or 2 inches in 10 feet, with changes in moisture content from 15 to 5 per cent.

The fact that such changes occur in cross-grain directions is significant, however, and must always be kept in mind. The walls of the traditional log cabin provide one example, but there are also contemporary constructions of solid wood in which the cross-grain dimensional change may be a major consideration. Walls made by placing logs or planks horizontally so that they bear on one another in resisting vertical loads can change in height by one or more inches per storey as the wood expands and contracts across the grain with changes in moisture content. This may be of little consequence when the wall consists of only logs or planks and the structure is a simple one. When other members are attached to the wall, however, many complications can arise. Interior partitions fastened structurally to the outside wall may not change by similar amounts or at the same time as the exterior wall. The vertical members of window and door frames and any other vertical members built into the wall do not change in the same way and must be provided with suitable clearances to avoid having the logs or planks pried apart when shrinkage takes place. If this is not done all such members may be heavily loaded when shrinkage takes place. Vertical boarding applied as sheathing or cladding either inside or out is unlikely to shrink and expand exactly in accordance with the basic log structure; it must always be specially arranged to avoid the conflict from differential changes in dimension if potential difficulties are to be avoided.

It should be appreciated that every application of wood in its natural or unprocessed state is affected potentially by the tendency to relatively large cross-grain dimensional change whenever significant moisture content changes in service can be expected. Consider, for example, that every structural connection in wood, with the possible exception of a glued joint, can be affected in its performance by differential dimensional changes in the members. Even simple glued joints, including those in laminated wood members, show shrinkage or swelling stresses if the pieces being put together do not have identical moisture response properties.

Every dimension across grain in wood and every dimension of any wood structure that includes cross-grain wood is subject to change with variations in moisture content unless this is prevented by some form of restraint. Under such restraint stresses will always be produced, except that, with shrinkage, stresses may be relieved by splitting or the opening of joints. All successful applications of wood must implicitly or intentionally take into account the dimensional change characteristics of wood due to moisture.

Moisture Content Changes in Service

Clearly, it is desirable also to appreciate the influence of the conditions of service upon the moisture content. As the moisture content of wood tends to follow any changes in the relative humidity to which it is exposed, wood in heated buildings will generally lose moisture during the winter because of decreasing indoor humidity and regain it the following spring and summer as the humidity rises. The moisture content of wood in buildings that are heated but not air-conditioned can thus vary widely, from as little as 5 per cent in winter to 12 per cent or more in summer, depending on the climate of the location involved. The moisture content of wood in an air-conditioned building in which the relative humidity is held between 40 and 50 per cent the year round will be about 8 or 9 percent.

The relative humidity outdoors in winter, on the other hand, is usually quite high. Moisture contents of wood exposed outdoors but protected from rain and snow may therefore vary from a low of 10 per cent in early summer to as much as 18 per cent in mid-winter under climatic conditions characteristic of most areas in Canada. Direct wetting by rain or melting snow may lead to higher moisture contents at times, and some differences due to species are also to be expected.

Wood taken from outdoor storage to be used in the interior of occupied buildings will usually adjust to a lower moisture in service. If it is fastened in place at the outdoor moisture content there will be an initial shrinkage as well as a subsequent shrinkage and swelling owing to seasonal changes in service conditions. The influence of initial shrinkage may be avoided if the moisture content can be adjusted to the level it will subsequently have in service before the wood is put in place.

It is always preferable to use wood that is at least as dry as proper protected outdoor storage will provide. It is not always practical or necessary to require lower moisture contents; service conditions may not justify this, or the shrinkage that occurs may not be a serious problem. In some situations, particularly with furniture, flooring and other interior building applications where shrinkage must be minimized in the interests of good performance, wood may have to be kiln dried in order to achieve the desirable reduction in moisture content prior to manufacture or application. Moisture contents as low as 8 per cent, or even 6 per cent in some cases, as for fir flooring, are commonly provided through kiln drying. Such drying is of little benefit, however, if the wood is allowed to return to higher levels of moisture content before use. It may also be noted that swelling can also be a problem, as for wood flooring tightly laid at a low moisture content. It may, in extreme cases, buckle or shift with a rise in moisture content.

There are, then, some limitations but also some excellent possibilities for minimizing dimensional change problems by controlling the moisture content of wood at the time it is put into service. It may also be possible, within limits, to select species having relatively small dimensional change characteristics. Cedar, for example, is relatively stable dimensionally across the grain and thus may be a preferred material for solid wood exterior walls of the real log or simulated log type. Some improvement may be achieved also in some applications by selecting a preferred grain direction, as with quarter-cut or edge-grain flooring, which takes advantage of the lower dimensional change in the radial as compared to the tangential grain direction.

Such possibilities, including the use of coatings to reduce the rate of response to short-time changes in conditions of exposure, serve only to emphasize the need to recognize that dimensional changes will take place consistent with imposed conditions and the basic nature of wood. It is necessary to design realistically for them, in both engineering and architectural applications if consistently good performance is to be achieved.

Processed Forms of Wood

Some processed forms of wood are of interest in the context of these discussions. Wood can be broken down by pulping or chipping and reconstituted into sheets in numerous ways as represented by paper, fibreboards and chipboards of various kinds. The strength and the dimensional change properties in the different directions of the sheet or board are altered in ways that are generally quite consistent with the nature of the fibre reorientation achieved. When the fibres are laid in more or less random fashion in the plane of the finished board, some of the properties in the two principal directions of the board become more nearly equal at values between those for the long- and cross-grain directions of the original wood. Dimensional changes from the wet to dry condition in plywoods and most fibre and chipboards will normally be in the range of ¼ to ½ per cent in width and length directions. Changes in thickness may be much greater, approximating those in the original cross-grain direction.

Plywood is one of the more interesting forms of processed wood. As the geometry of the fibre orientation in the board is clearly defined -- alternating grain directions in successive veneers at right angles -- reasonably adequate calculations of the properties of the composite board can often be made. Plywood for general use must always be of balanced construction. Briefly, this means that each veneer on one side of a sheet must always be balanced by one of equal properties and equal orientation on the other side. unless this is done, serious warping will take place when the moisture content changes.

A three-ply board with three equal plies provides balanced construction, but it has unequal properties along and across it because there are two long-grain plies in one direction and only one in the other. This directional effect is progressively reduced as the number of plies is increased. The strength of the board in tension or compression is determined largely by the percentage of long grain in the cross-section being loaded and on the long-grain properties of the original wood. The situation in bending is somewhat more complex: not only the grain direction but also the position of the veneers in relation to the surface of the sheet becomes involved. Shear properties in the plane of the sheet are always greatly improved because of the reinforcement given by adjacent plies against tension failure across the grain. The improvement in dimensional stability is marked, since the superior stability and modulus of elasticity along the grain provide an enhanced restraint for the cross-grain dimensional change.

Durability

It is appropriate in concluding this discussion to refer briefly to the durability of wood. As wood is organic in nature it can be attacked and destroyed by micro-organisms of various kinds. The risk generally becomes serious only when wood is maintained at a high moisture content in excess of 20 per cent but less than saturated. Treatment with preservatives is usually desirable in order to extend its life under these conditions. Wood can have a very long life when continuously immersed in water. At the other end of the moisture scale, it can last almost indefinitely if protected from sunlight and from excessive moisture contents and rapid or large changes in moisture content. Sunlight slowly attacks and changes the exposed surface, but its main deteriorating effect is probably associated largely with the rapid large moisture changes and corresponding dimensional changes that can result in serious checking when exposed wood is wetted by rain and then dried by sun heat. Even under these conditions wood can function very well as long as it is always arranged in such a way that it can drain and dry freely and is not held at high moisture contents for prolonged periods of time.

Conclusion

This discussion has tended to emphasize some of the potentially challenging aspects of wood and its applications. This bas been done intentionally, not with any thought of being critical of wood as a material, but in order to promote a better understanding of its nature and of the ways in which it will perform in particular situations. It is only through such understanding that the best ways of using it can be devised and unsuitable performance avoided.

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