Wood Structure as Related to Drying Problems

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Successful utilization of any raw material is associated in no small measure with understanding the character of that material in relation to those operations performed to produce a finished article. Drying is an important phase in the chain of operations concerned with lumber processing. Not only must the operator be familiar with drying procedures and equipment employed, he should become acquainted with the characteristics of the lumber with which he is concerned in relation to process and equipment manipulation to obtain a quality product and at the same time maintain production. Equipment has been improved. It is fast and variable in control; the operator soon becomes familiar with its characteristics. How about the characteristics of wood? How well are they understood?

Various types of problems often arise in the drying of lumber, most of which can be associated with the complex structure of wood, and wood-moisture relations. The major problems may be grouped into two classes: (1) **variations in drying rates** for lumber of the same thickness as related to sapwood versus heartwood, inherent differences between species and variations within a given species; (2) **variations in shrinkage** which result in volume loss, checks, splits, warp, casehardening, collapse, honeycomb, cross breaks, shelling (grain separation), raised grain and others. These two classes of problems are related since both are associated with wood structure variations. Some can be combated and controlled, others may be traced to irregularities in wood over which little or no control can be exercised or which demand special attention.

Wood is a product of plant growth hence it is organic in nature, in contrast to some other resources such as minerals. Since wood is produced by plants, principally trees, it is a complex, cellular material involved in the functions required in support of plant life and growth. These functions require the services of several types of cells arranged in various ways dependent upon plant needs. Types of cells, their size, arrangement and wall thicknesses vary with individual tree species to affect the properties or behavior of wood. There are about 1200 species in the United States; however, only approximately 150 are of commercial importance. Added to species differences are those variations in structure associated with growing conditions such as soil, rainfall, temperature, topography, sunlight, timber stand density (crowded or open) and other factors. These conditions of growth contribute to variations which occur in lumber from a single given species, but cut from different trees from various locations. Further complications arise from knots, shake, cell alignment, juvenile and reaction wood, extractive content, decay and insects which influence behavior and utility of wood.

Examining the stem of a tree, the woody portion is found to consist primarily of long, slender cells oriented parallel to the tree axis, or with the length of a board. This group of cells comprises about 93 per cent of the total wood structure of a typical conifer. A second group of cells, notably wood rays, consist of short, brick-like elements oriented at right angles to the tree axis and extending through the inner bark towards the pith.

It is opportune at this time to mention the influence of wood rays upon drying. Wood rays are very narrow bands of cells in the conifers, but range up to considerable width in some hardwoods such as oak, beech and maple. Since they are at right angles to the longitudinal elements of wood and occur in large numbers, rays are points of weakness at which surface checks and end splits begin as a result of shrinkage stresses developed during drying.

Located between the bark and wood is a unicellular band of cells known as the 'cambium layer.' Through cell division, the cambium layer adds new wood

—vertical and horizontal cells—during each annual growing season to increase tree diameter. Cambium activity extends from early spring to some time in the fall depending upon climate. Since the cambium lies dormant over the winter months in the temperate zone, new wood generally is added in layers around the stem much the same as stacking megaphones in a pile. Each new, complete layer shows on the cross section of a log as a concentric ring, popularly referred to as an 'annual ring' of wood tissue.

In coniferous species, and some hardwoods, there are two distinct zones of longitudinal cells in each annual growth layer. Those cells cut off from the cambium early during the growing season have large diameters, thin walls and large cavities for rapid conduction of water from the roots to the crown. This early-formed zone is referred to as 'springwood' and is identified as being generally light in color, of light weight, porous and low in strength properties. Later during the growing season additioned cells become smaller with heavy, thick walls and small cavities for the purpose of strength to support the tree. This zone is referred to as the 'summerwood' zone and is identified by its darker color and higher strength due to the presence of considerable wood substance (cell wall material). Differences in shrinkage between these two zones may upon occasion become large enough to affect wood's behavior.

In some species (Douglas-fir, western larch; ponderosa, lodgepole and southern pines; redwood, some cedars and true firs) there normally is a sharp transition between the springwood and summerwood zones. On the other hand spruce, hemlock, white and sugar pines, other cedars and true fir species normally have a gradual transition, with no definite line of demarcation between the two zones.

The width of annual growth layers (ring width) together with the amount and character of summerwood material in each layer are variable among species; within a given species (i.e. Douglas-fir) both features often vary as a normal reaction to growing conditions. These two characteristics of growth—ring width and amount of summerwood—are related to the over-dry weight per unit volume (density), strength, shrinkage and swelling, drying rate and other general properties of wood. Because both features vary widely in lumber cut from different species and trees of the same species, they account for much of the normal variations encountered in the character of wood and its response to treatment or use. As an example, the time required to dry wood under a given set of conditions is related to its density—higher density woods require more time. Also, the type of schedule used to control defects is related to the density of wood as density affects shrinkage and drying stresses.

For a time, newly formed wood elements remain on the outside of the woody portion of the stem as 'sapwood.' While longitudinal cells and wood rays are a part of the sapwood, they are physiologically active in the conduction of water and foods that the tree requires. Wood from this region in the tree is light in color and a high moisture content is typical; it is permeable to liquid movement, hence water readily is removed during drying. As the tree continues to increase in diameter with the addition of annual growth layers, portions of the inner part of the sapwood region cease to function in conduction and slight structural changes develop together with the infiltration of extractives —resins, oils and tannins—which often cause the color to be dark. Such wood is designated as 'heartwood.' Although the green moisture content of heartwood usually is less than for sapwood in most species, lumber cut from this region usually is more resistant to moisture loss, hence requires a longer drying time. Some species are designated as being 'sapwood species' because of the lack of distinction between sapwood and heartwood as to color, possibly green moisture content and even to drying characteristics, i.e. western hemlock and cottonwood. Like many other properties of wood, moisture content is a variable item associated with the requirements of individual species and trees of the same or given species in response to environment (growing conditions).

The pith of a tree is of no major consequence other than to act as a region of specialized food storage tissue. However, the first few growth layers of wood in the vicinity of the pith are apt to be abnormal in structure as compared to succeeding growth. This region of early growth is referred to as 'juvenile wood.' Wood from the juvenile zone frequently exhibits high longitudinal shrinkage in drying causing crook, bow and twist.

Several confierous woods have scattered openings occurring among their longitudinal elements and within some wood rays. Because these openings are lined with specialized, resin secreting cells they are called 'resin canals' or 'resin ducts.' These canals are characteristic of Douglas-fir, pines, spruces and larches and are readily visible to the naked eye, or under a low power magnifier on the end grain of boards and logs. In ponderosa, white and sugar pines, resin canals are plainly visible as narrow, brown streaks on the surfaces of lumber. Occasionally, other species may produce localized bands of longitudinal resin canals in response to injury to the cambium, i.e. western hemlock and redwood. Kiln drying lumber from these species will tend to set resin and reduce later exudation when lumber is subjected to heat in the modern home.

The woody portion of a living tree constantly is fluxed with water which is present in two forms, 'free' water as confined to the cell cavities and 'bound' water which saturates the cell walls. The moisture content of wood is expressed as a per cent, i.e. 60%, which is a ratio value of the weight of water to the oven-dry weight of wood substance, represented by the formula:

$$\text{Per cent M.C.} = \frac{\text{Weight of water}}{\text{Oven-dry weight of wood}} \times 100$$

Some species usually have more wood substance per unit volume (density), i.e. comparing hickory with western redcedar. Consequently, at any given moisture content per cent figure wood from different species actually will contain variable amounts of water per unit volume (board foot or cubic foot). For example, at 60 per cent moisture content a board foot of hickory may contain approximately two pounds of water while a board foot of western redcedar may contain about one pound of water.

Of particular importance in drying wood is the presence of bound water confined to the cell walls (wood substance). When any part of the cell structure of a piece of wood has dried to the point that free water is removed and only bound water remains, those wood cells involved have reached their 'fiber saturation point' (a figure of about 30 per cent moisture content for most practical purposes). Further drying removes bound water from its close association with the chemical cell-wall components (principally cellulose) to cause the walls of those cells affected to shrink (or desire to shrink). The chemical components comprising the bulk of wood substance normally are oriented more or less parallel to the longitudinal axis of wood cells. With water loss from between these components, it is evident that most shrinkage occurs perpendicular to the axis of each wood cell. It has been noted that 93 per cent of the cell structure in conifers is comprised of long, slender cells paralleling the length of logs or lumber. Therefore, almost 100 per cent of the shrinkage normally developing in a board is in its width and thickness. Generally, the amount of shrinkage in a board may be related to the character and quantity of summerwood present since this material very largely controls density. Longitudinal shrinkage usually is exceedingly low, less than one-half of one per cent in wood of normal growth.

Wood is a product of nature exhibiting many inconsistencies.

1. Cross-sectional (transverse) shrinkage is not uniform. The amount of shrinkage occurring parallel with growth rings (tangential direction) ranges from one and one-half to two times as much as across, or at right angles to, the growth rings (radial direction). This difference in

directional shrinkage often causes deformation in shape (cup, diamonding and rectangular shapes from squares). A flat grain board will shrink more in width than a vertical grain board of the same initial size. A flat grain board from near the center of a log will cup more than one sawn farther out from the center. To further complicate matters, the amount of tangential and radial shrinkage (in per cent of green dimension per inch of dimension), varies with the density of wood; i.e. values recorded for western larch and Douglas-fir are higher than those for redwood, western redcedar and the western pines while they are lower than for oak, hard maple and hickory when all are dried to the same moisture content. Due to density variations within a tree and between trees (indicated by per cent summerwood), actual shrinkage developing often will vary widely from recorded values for the species. Published shrinkage values given for a species are averages; it would be helpful if data included the variation in shrinkage to be expected.

Heavy shrinking allowances when sawing lumber to compensate for variation in density and grain orientation result in a loss of footage. On the other hand, insufficient allowances result in degrade from failure to surface out to standard size. Learning something about variations peculiar to the timber sawn by a mill should be a valuable aid in reducing these losses, where practical.

2. Not all portions of a board reach the fiber saturation point at the same time. The outer surfaces of a board dry first and the tendency to shrink, like change in moisture content, progresses from the outside towards the center of a board (between opposite faces). This results in the familiar development of drying stresses within a board to cause casehardening, splits, checks, honeycomb and one form of collapse. Casehardening of lumber will result in abnormally low total shrinkage values while collapse will result in abnormally high values. Severity of stresses developed may be associated with the density of the wood in relation to the conditions of moisture removal during the drying operation. Adjusting drying conditions to lumber characteristics is essential; the same applies to segregation of lumber into groups with similar features prior to drying.

3. Undesirable longitudinal shrinkage often occurs in some lumber to cause twist, crook, bow and cross breaks.

Twist occurs where the longitudinal cells significantly vary in deviation from the axis of a board (such as spiral, wavy and diagonal grain). When such material dries, part of the normal transverse shrinkage is transmitted lengthwise of the piece in an irregular manner since grain distortion generally is not uniform throughout the width, thickness and length of lumber.

Crook and bow frequently are associated with juvenile wood (1), compression wood (2), or wood of abnormally low weight for the

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(1) Juvenile wood—is confined to the first few growth rings surrounding the pith of a tree. Lumber sawn from small timber often contains a significant amount of this material. It is identified in a piece by the sharp curvature of the growth rings.

(2) Compression wood—is most commonly formed by conifers growing on steep hillsides to counteract gravity and maintain an upright position. Log ends show the pith to be off-center with excentric, wide growth rings on one side (downhill side of the tree). It may occur in narrow to wide bands in lumber. The summerwood is abnormally high in percentage and differs in color from usual tissue. Although heavier than average wood of a species, compression wood is poor in most properties.

species (3). In all three, the cell wall components have a very large angle with the axis of the longitudinal cells; hence as bound water is removed, shrinkage tends to be abnormally high lengthwise of the piece with transverse shrinkage being lower than usual. Should an appreciable quantity of either of the three types of growth appear on one face, or edge of a board the piece will bow or crook. Bow may be reduced, if not eliminated, by proper piling practices. There is no way to stop a piece from crooking. Cross-breaks (tension failures) may occur when either juvenile wood or compression wood is bracketed on two sides in a piece by wood of normal growth. The excessive longitudinal shrinkage in the juvenile or compression wood zones is restrained by adjacent normal wood and failures may occur perpendicular to the grain in these zones.

4. Grain separation (slivering or shelling) may be a serious problem in some lumber from Douglas-fir, western larch and southern pines, showing up when dry lumber is planed, worked to pattern or after being put in place (flooring, trim, etc.). The intention here is to present a few of the possible causes for the occurrence of grain separation as the subject is open to debate. When occurring, this feature so far has been observed in lumber having a decided contrast in character between summerwood and springwood as regards density. The summerwood generally is clearly defined (abrupt transition), rather wide, and very hard and heavy while the springwood appears upon magnification to have but little cell wall material present. The bond between the summerwood of one growth ring with the springwood of the succeeding ring seems to be weak. High differences in shrinkage develop within these two areas upon drying to weaken the natural bond further since the dense summerwood is prone to shrink transversely considerably more than is springwood, with the latter inclined to exhibit more longitudinal shrinkage (especially in the first formed cells). When such stock is planed or matched, separation of growth rings may occur, particularly where pieces are run through the machine against the grain, where knives are dull, improperly ground, or where excessive pressures are applied. It appears probable that grain separation may be due to a combination of these factors - abnormal shrinkage and machining.

5. In raised grain either the summerwood or the springwood extends above the board's surfaces, usually some time after machining. The most prevalent type is where summerwood is raised because the surfaces have picked up moisture and since summerwood has greater density it will swell considerably more than the surrounding springwood. Generally, raised summerwood shows up when lumber is subjected to higher moisture conditions (humidity) than to what it was dried, i.e. during storage, shipping or at the building site. Should the reverse condition exist, the springwood is raised because the summerwood has shrunk from continued drying and indications are the lumber had not been dried sufficiently to meet conditions of use. Raised grain is more of a problem on flat grain surfaces than on vertical grain. Sometimes planer knives will pound very dense expansive areas of summerwood down into the soft springwood underneath. Later the springwood, if not crushed, expands to raise the summerwood. Where raised grain occurs prior to finishing, a great deal of sanding is required. If it develops after finishing, an unsightly appearance results, often with

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(3) Abnormally light weight wood has a higher per cent of springwood cells typical of exceedingly slow or fast growth for a species. Often wood appears normal but microscopic examination shows cell cavities to be unusually large in the summerwood and cell walls thinner than average for a species.

checks developing in the finish. In case the springwood is crushed and the summerwood picks up moisture to swell, localized grain separa- may develop. This generally occurs on the surface towards the pith.

6. Knots cause localized grain misalignment which will react with drying to produce bow, crook and bulges depending upon knot size, degree of grain distortion and whether lumber is flat or vertical grain. In addition to warp, torn grain often is heavy.

7. Longitudinal wood cells are about 100 times greater in length than in diameter. Therefore, water is removed more rapidly from the ends of boards during drying than from side surfaces as moisture has fewer cell walls to pass through on its way towards the ends. This condition holds only for five to seven inches from the ends, beyond that length drying primarily is from the side surfaces. However, due to rapid moisture loss from end grain, plus lateral loss from side surfaces within the five to seven inch length from the end, high shrinkage stresses are prone to develop early in drying to cause end check and split. Once checks or splits begin, they may run into the piece for considerable distances. Occurrence may be minimized by: end coating large sized or dense material; segregating lumber to length and placing stickers close to the ends of the boards; begin drying under the mildest conditions possible.

In summarizing it is desirable to emphasize that wood is not a uniform material but exhibits complex structural variations typical of different species and even within a species as a result of growing conditions. These structural variations are associated with such factors as density, moisture content and shrinkage; all are related. Drying conditions can be manipulated to compensate for some of these variations. Sacrificing quality for production can be a costly item at the prevailing prices paid for logs, and other costs.

This has been a brief introduction to the subject of Wood Structure As Related to Drying Problems. More complete information may be found in textbooks on wood technology, bulletins available from the United States Forest Service Laboratory, Madison, Wisconsin, and the Oregon Forest Products Laboratory in Corvallis. The Journal of the Forest Products Research Society contains many useful articles.