

SOME COMMENTS ON WARPING

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During the past twenty five years it has been my good fortune to have been continuously associated with the study of the fundamentals of lumber drying. The efforts of these studies have been rewarding since some of the findings of our drying team have resulted in substantial economic savings when they have been applied.

However, from a personal standpoint, the most significant result of the studies has been the ever-growing list of questions concerning drying mechanism and kinetics to which I do not know the answers. Two years ago before this group I recited an abbreviated list of these questions. The paper was presented with the frank admission that simply because I did not know the answers was no valid reason to assume that nobody else knew the answers. Despite considerable favorable comment concerning the presentation I have not been deluged with communications containing answers.

One of the topics in that presentation related to the mechanism of shrinkage during change in moisture content below the fiber saturation point. Today, I wish to pursue this point further as it relates to the warping of small log Western hemlock during kiln drying. Unfortunately the paper will provide no new answers---just more questions.

It is not news to those of you who process Western hemlock lumber that a major problem related to the economics of kiln drying this species is the tendency for degrading warp to occur. It is also not news that the warping problem is accentuated as more and more small log lumber is being processed. Neither is it news to consumers of kiln dried hemlock that the product has a tendency to warp further particularly under low EMC conditions and that this tendency too is accentuated in the case of small log product.

Warping is the change in geometrical configuration of a piece. Four types are generally recognized--crook, cup, bow and twist. Crook is deviation from linearity of the narrow face of the board. Cup is deviation from linearity across the wide face. Bow is deviation from linearity of the wide face along the length of the board and twist is the deviation from a flat plane resulting in one corner of the board not lying in the same plane as the other three.

Anyone who has spent time around a dry kiln or a planer is familiar with some of the more severe examples--the ski, the chair rocker and the cup which causes planer split during later processing.

Warping during kiln drying is of course, due to unbalanced stresses which are set up and which react to actually deform the entire gross structure of the piece. Warping which takes place after drying is due to the relief of stresses which are residual within the piece. Much excellent work has been done in the past

to identify the mechanism of stress build-up during drying. We are all familiar with the classical work performed by John McMillen, U. S. Forest Products Laboratory, relating compressive and tensile stress and stress reversal.

Wood structure is highly complex even in the relatively simple softwoods. Atoms are bound together chemically to form molecules. Molecules are bound together to form chains or polymeric structures which in turn combine to form micelles which are tied together to form the various components of the cell walls. The cells, in turn are bound to neighboring cells by some kind of bonds. The early wood is bound to the late wood and on and on. Any volume or shape change within the gross structure must take place by the modification of the bonds which hold the affected elements together. The point is that wood structure has structural integrity. The diagrams and models that we see frequently suggest that wood consists of fragmented particles and when water enters the structure these particles simply become farther apart--like adding water to solid sand particles in the bottom of a cup. The sand particles simply get farther apart when the cup is shaken. If the water is evaporated away the sand particles simply get closer and closer together until the water is all gone. I maintain that this picture, although it shows that gross volume increases when moisture is being added and that gross volume decreases when moisture is removed, is unrealistic and entirely too simplistic.

We have good evidence to back up the hypothesis that the major volume change which takes place during moisture content change below the fiber saturation point takes place in the secondary layers of the cell walls. In this structural element, the fibrils are aligned parallel to each other and the moisture that is bound in the structure is positioned between these fibrils with the result that the fibrils are pushed apart. In most softwoods the fibrils are aligned parallel to the bole of the tree so that if any change in spacing between the fibrils takes place it will result in a dimension change which is tangential or radial but not longitudinal. However growth conditions may result in the tree which result in laying down fibrils in the secondary wall which are much more perpendicular to the bole of the tree. The result of shrinking or swelling due to moisture change is therefore much more longitudinal than radial or tangential. Western hemlock is a notable example. These growth characteristics in Western hemlock are first the fact that small logs contain a high percentage of juvenile wood which is characterized by large fibril angles in the secondary wall and secondly, there is a substantial amount of compression wood produced by the tree as it fights continually to straighten up the bent-over leader which is characteristic of the species. The large proportion of juvenile wood and compression wood in small log boards provides ample opportunity for atypical dimensional changes during shrinking and swelling.

The general reaction of wood substance to stress during drying is to relieve the stress by readjustment of bonds. The mechanism of stress relief is postulated to be somewhat as follows. The first tendency during shrinkage of a wood element is to change the shape of the element due to the characteristics within the wood that produces differential shrinkage. However,

there are crystalline elements within the wood which are not affected by moisture content change because no moisture content change takes place within these regions which tend to maintain the geometric symmetry of the piece--that is to maintain the relative positions of the various component elements--which direct the stress relief principally toward bond breakage and reestablishment or, in the case of weak or insufficient bonds, toward internal or external checking of the piece. As a gross generalization it may be said that the greater the cross-sectional dimensions of the piece the greater is the tendency for stress relief to take place by means of bond rearrangement or by checking and that the smaller the cross-sectional area of the piece, the greater is the tendency for stress relief to take place by means of warping. I do not recall any timbers that I have seen which were significantly warped. However a piece of very thin veneer will react to stress relief by severe geometrical change.

Not only is mechanism of stress relief important but the kinetics of the reaction appears to be of prime importance. Complete stress relief does not take place immediately after the stress is established. Rather in some cases the piece is filled with residual stresses. These can be recognized by the immediate change in shape when stress samples are prepared. There is ample evidence that restraint during drying results in reduced warping. It is commonly noted that the incidence of severe warping is greatest in the top courses. Ken Bassett, Research and Development at Weyerhaeuser Company, among others has reported the advantages of mechanical restraint. Bruce Kuhnau, Research and Development at Weyerhaeuser Company, has been recently granted a patent for a restraining device.

However, there appear to be types of residual stresses in some pieces that are not immediately relieved by isolation such as by making stress samples. In these cases stress relief is definitely time-dependent and the time-dependency is undoubtedly a function of temperature and moisture conditions within the piece.

If the crystalline regions in the specimen are not "strong" enough to direct the stress relief into bond rearrangement without changing the shape of the piece aid can be provided by using externally applied restraints. These externally applied forces combine with the internal "Forces" to direct the mechanism of stress relief.

External restraint has been proven many times on many different species to have significant benefit in the reduction of degrade during drying. Even in kiln charges which have not been physically restrained the amount of warping and the severity of warping decreases from the top to the bottoms of the charges. It is also significant that the greatest amount of warpage degrade in restrained charges (both physically restrained top portions and weight restrained bottom portions is due to crook, with twist and bow being much less prevalent and less severe. This can be explained on the basis that bow and twist both represent vertical movement in the charge whereas crook represents horizontal movement. Restraint of either type is applied vertically and in sufficient number of places to counteract vertical movement in the boards. However the only restraint against horizontal movement is

the friction between the board surfaces and the surfaces of the contacting stickers.

Of course no restraint has value if the stock is mis-sawn such that there is no contact between boards and stickers.

It has been further noted that restraint has an added advantage beyond reducing the amount of warpage during the drying operation. The amount and severity of warp during subsequent drying under low EMC conditions is substantially less for boards restrained during kiln drying than for boards which were not restrained. This fact suggests that the addition of external restraint during drying when added to the resident internal restraint results in bond modification and realignment which produces less residual stress in the board when it leaves the kiln. There is therefore less stress to be relieved during subsequent drying.

It is further noted that warp-free kiln dry lumber when subjected to post-drying low EMC conditions develops substantially less warp if it is maintained in tightly banded packages before use than if the material is kept in unbanded packages. This is further evidence of the value of restraint during drying.

Thus far there have been no concrete suggestions concerning solutions to the problem of warpage during kiln drying which are not already well known. Nor will there be any solutions offered by this writer because he does not know any positive answers. Some additional questions can be raised, however. There is considerable evidence that stress relief is time dependent. How long does residual stress operate to produce warping? Most importantly, how can lumber be treated to reduce residual stresses which are normally produced during kiln drying.

When considering these questions this writer is continually reminded of the process of bending of lumber. Here the procedure is reversed. Warp is created without residual stresses. How are these bond modifications and realignments managed?

During the past year or so I have been toying with the problem of small log hemlock warping in an attempt to identify causes for the very significant economic downfall which is becoming increasingly important as the available logs become smaller in diameter.

One of the approaches has been to cut longitudinal stress samples as well as conventional stress samples from kiln dry boards and to observe the behavior of these longitudinally isolated strips. Some of the results have been rather dramatic.

The longitudinal stress sample technique results in the isolation of a different thin strip orientation and permits the demonstration of stresses other than those shown by the conventional technique.

Conventional stress samples isolate thin sections across the width of the board. They are invaluable for freeing up the resident stresses that tend to make the board cup. Upon standing in a low EMC atmosphere the isolated segments continue to dry and shrink and thus become excellent indicators of the moisture content gradient from shell to core which existed in the board when the stress samples were cut.

The conventional technique is an excellent means for demonstrating what is commonly called case hardening and reverse case

hardening. If the surface segments deform immediately after sawing it is evidence that the case hardening stresses are present.

It should be pointed out that the greatest value of any stress sample procedure results when very thin sections are isolated. In a large section of wood the complex bonding of structural elements resists the full action of resident stresses. When the wood sections are very thin the stresses have greater opportunity to act. I am not aware of having observed substantial bow, crook or twist in large timbers as they dry in use. Rather, these large pieces react to shrinkage stresses by checking instead of by changing geometric shape. A very thin strip of Douglas fir veneer sliced from a green cant and allowed to dry shows the effect of stresses which are not inhibited by three dimensional inter-element bonding.

This discussion is incomplete because it does not include any information concerning moisture content distribution within the piece when the samples were sawn. It is well known that it is characteristic of hemlock to contain wet streaks or pockets. A most probable cause of these wet areas is the result of micro-organism infestation as reported by Ward of the U.S. Forest Products Laboratory and confirmed by studies by Kozlik at the Oregon Forest Products Laboratory. I am not aware of a definitive conclusion concerning the effects of these wet streaks on product performance in the field.

The wet streaks show an unpredictable meandering through a hemlock board after kiln drying.

It is my hope to have the opportunity to study the relationship between strip moisture content and strip reaction in various stress samples.

The obvious question in the minds of all of us is "So What?" What can the kiln operator do to reduce the costly downfall in quality in small log hemlock due to warping during drying? Perhaps someone knows the whole answer. I do not!

It is obvious that the ultimate solution to the problem lies in the application of the drying procedure which results in the rearrangement of inter-element bonds in the wood structure in such a manner and at such a rate that the overall structure is at equilibrium at the lower moisture content or in use. Can this be done economically in the kiln--and if so, how?

Certainly the reverse of the situation is well known. Straight, stress-free boards are routinely bent into permanently warped structures which are completely stable. This can result only by controlled bond rearrangement. If permanent warping can be produced in unwarped boards, perhaps the same concept of programmed bond rearrangement can be applied to produce straight, stable stress-free boards from those with the tendency to warp during drying.

So where are we?

Warping is a serious economic problem in kiln dry small log hemlock.

More and more small log hemlock is coming to the mills for processing.

Warping takes place as the lumber is dried.

The kiln operator dries the lumber.

What can the kiln operator do to eliminate or to substantially reduce the occurrence of warping economically?

The challenge is great and the solution will be rewarding.