HOW KILN SCHEDULES AFFECT STRENGTH

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Estimates are that 90 percent of the southern pine dimension lumber manufactured today is kiln dried at high temperatures. Early research, especially by Peter Koch with the U.S. Forest Service, indicated that strength losses occurring during high temperature drying of pine were quite small, especially when compared to the rather large losses that have been noted with other species. Even though losses with pine are thought to be low, there are changes in the kiln schedules that can be made in order to assure these low levels of loss (and conversely, there are some kiln schedules that will encourage strength loss). The following discussion may be useful for all softwood lumber drying, but we feel that it will be especially useful for drying lam stock and other products (such as E-rated lumber) where strength is critical and affects the product's value.

WHAT AFFECTS WOOD'S STRENGTH?

In order to understand why and how a kiln schedule can influence the lumber's strength, let us look more closely at what happens to wood in the kiln that affects its strength. The first question that needs to be answered is "What affects the strength of wood?" There are four major factors that are affected in the kiln that in turn affect the strength of a piece of dimension stock:

1) First, there is the density of the wood. Although the basic density of wood is established by Mother Nature, the density after drying is affected by how much the wood shrinks during drying; a high shrinkage kiln schedule will increase the wood's density and therefore its strength. Of course, the more shrinkage there is, the larger the target size will have to be at the sawmill. The benefits of higher strength due to greater shrinkage must be large enough to offset the small loss in yield in the mill.

2) The strength of wood is affected by its temperature history. The hotter wood is (especially temperatures over 160°F), how long the wood is at these elevated temperatures, and how wet the wood is all determine how much permanent strength loss will occur. In general, the hotter, the longer, and the wetter wood is, the greater the loss. There is, of course, a trade off between drying temperature (and resultant strength loss) versus the increase speed of drying at hotter temperatures.

3) Kiln schedules also affect the amount of damage (such as checks and splits) that occurs in drying. The more severe the visible damage, the greater the overall strength loss, in most cases. Usually, faster drying and extremely low final moisture contents (under 10% MC) will result in the greatest damage.

4) Final moisture content is a major factor in the strength of clear wood. The effect of MC on the strength of full size members is not too well documented, but it appears that the strength of weakest pieces of southern pine lumber is not greatly affected by final MC's between 20 to 10 percent. However, the strength of the average and stronger pieces of lumber within a grade is greatly affected, the drier pieces being stronger. On the other hand, the drier that lumber is, the more likely it is that it will warp beyond the limits allowed for the grade. Likewise, the drier the wood is the more it shrinks, increasing its density. (Douglas-fir and many other softwoods are even more dramatically affected by final MC than pine.)

As a summary of these points, the ideal kiln schedule for maximizing strength is one that maximizes shrinkage, minimizes the temperature of the wood especially when the wood is at high MC's, minimizes drying splits, checks and so on, and achieves a moderately low MC without much warp.

THE STRENGTH OF FULL SIZE LUMBER

It is no surprise to anyone in the lumber business that wood is a variable material--no two pieces are alike. Therefore, when measuring the strength of a material such as lam stock, we will find a few very strong pieces, a few very weak pieces, and the rest somewhere in between. When calculating the strength that a building component such as beam or truss will require, designers use, for visually graded lumber (<u>vs.</u> machine graded or stress rated lumber), the strength of the 5 percent weakest piece. That is, 95 percent of the lumber will be stronger than the 5 percent weakest, and only 5 percent will be weaker. This is called the 5 percent exclusion limit. This is an important concept, because any kiln schedule we use must affect this 5 percent exclusion limit; gains in the 95 percent stronger pieces or gains in the average strength for <u>visually</u> graded lumber are typically of little value to a designer.

Having made the statement above, consider two cases where raising the strength of some or most of the pieces in a kiln load can be of value.

1) In this case, we attempt to find these weaker pieces and eliminate them from products where high strength is required. We can get a rough idea of which pieces will have the lowest strength by seeing how easily they bend--that is, measure their Modulus of Elasticity or "E" after drying. Unfortunately using E to predict strength is an imperfect relationship--some weak pieces can be fairly stiff, thereby giving us a high predicted strength when in fact the piece has a low strength. In addition, how this E <u>vs.</u> strength relationship changes with changing kiln schedules is <u>not</u> known. Nevertheless, for lumber sold with an E-rating where "the higher the E, the higher the price," there would be a benefit in raising the average E for a load.

2) Likewise, if we could use a better technique to predict strength, such as the acoustic methods that have been developed by J. Bodig in Ft. Collins, Colorado, we could then accurately exclude the weaker pieces from a load after drying, and very precisely predict the strength of the stronger pieces. Further, we could segregate the lumber into more uniform strength groups,

thereby reducing the variability.) We would use the actual estimated strength for design and for establishing the selling price rather than the 5 percent exclusion limit. In this case, we would be able to fully appreciate the strength gains made through drying, gains in both the strength of the average and the strength of the stronger pieces. That is, it is possible that our kiln schedule will raise the strength of the average pieces, but not the weakest; so then we'll identify and eliminate these weakest pieces.

THE KILN SCHEDULE

A. Control of Shrinkage

We know that shrinkage is affected by the temperature and speed of drying--fast drying with low temperatures and low relative humidities results in the least amount of shrinkage. As one example, a study by Temple-Eastex showed 4.3 percent shrinkage in pine dimension dried at 240°F and 4.0 percent at 202°F. Further, fast drying at low humidities results in less warp. On the other hand, the faster wood is dried and the lower the humidity, the greater the risk of checking and splitting, especially when compression wood is present. Therefore, the best drying would be accomplished at moderate wood temperatures. (I'd estimate around 170°F.) We would want to avoid high wood temperatures that result when drying at 240°F dry bulb and 210°F wet bulb. Further, I'd estimate that shrinkage would be well controlled if we could achieve a drying rate of approximately 10 percent MC loss per hour during the first 10 hours of the schedule.

B. Control of Wood's Temperature

The temperature of wood during drying, especially during the first 10 hours, greatly affects the ultimate strength of the wood, as well as its shrinkage. In an unpublished study, the average strength increased 5 percent when the dry-bulb was lowered from 220°F to 180°F. An important concept, however, is that the temperature of wood is not the dry-bulb temperature of the air in the kiln. Rather, the wood's temperature when drying first begins is the wet-bulb temperature (Figure 1). As the wood dries, the temperature gradually increases up to 212°F, the boiling point of water, and will not exceed 212°F until the MC in that region is below approximately 22 percent. Two simplified mathematical formulas have been developed to relate average wood surface temperature, T_s to the kiln conditions.

$$T_s = T(DB) - (A_1) \times (\text{Rate})$$

and

$$T_s = T(DB) - (A_2) \times (\text{Velocity}) \times (\text{Sticker Thickness}) \times (\text{TDAL})$$

where T(DB) = the kiln dry-bulb temperature

Rate = the MC loss per hour

A_1 and A_2 = numerical coefficients for air and heat transfer that can be obtained from a reference manual,

TDAL = the dry-bulb temperature drop across the load

Consider the implication of these formulas: in order to maximize strength, we require as low a wood temperature as possible, which means that the dry-bulb should not be too high and that the rate, velocity, sticker thickness, and TDAL should be as large as possible. The rate and TDAL are increased by lowering the wet-bulb.

In practical terms, this means that for a dry-bulb of 240°F, the wet-bulb temperature should be approximately 160°F, with velocities over 1200 feet per minute and sticker thickness of 7/8-inch. Higher wet-bulbs at the beginning of drying, lower velocities, or thinner stickers will all result in higher wood temperatures. These formulas also mean that if we find that kiln conditions result in too much splitting, we do not want to raise the wet-bulb if we also want to maintain the wood's strength. Rather we should lower the dry-bulb temperature.

C. Damage Control

The rate of drying and the final MC control the extent of damage in drying. The precise safe rate of drying (MC loss per hour) that pine can tolerate without developing excessive splitting is not well known. However, drying at under 8 percent appears to produce the best quality. Measuring the drying rate during drying can be accomplished by measuring the TDAL. The rate or TDAL is, as mentioned above, controlled by the wet-bulb temperature, dry-bulb temperature, velocity, and sticker thickness. The benefit of proper kiln loading to prevent gaps between the packages of lumber should not be underestimated.

D. Final MC

Avoiding over- or under-drying in high temperature pine kilns has been a tremendous problem. It has always been recognized that over-drying results in more degrade, more energy use, and longer drying times. Degrade alone is over $3 per MBF for each 1 percent MC the lumber is over-dried. Under-drying, of course, means that the lumber does not meet the MC standards. What is desired is that the entire load of lumber be dried to a uniform MC that is not much below the 15 percent MC limit. The only reliable technique to estimate the MC during high temperature drying of pine is to monitor the TDAL (Figure 2). With experience, an operator can estimate the average final MC to within 1 percent. (As an example, a TDAL of 5.9 degrees indicates in one particular kiln a final average MC of 12 percent.)

One other new kiln procedure to assure more uniform final MC throughout the kiln is zoning. Many new kilns (and even some retrofits for older units) are controlled with multiple dry-bulbs--as many as 48 sensors with 12 to 16 valves which control the temperatures very closely throughout the kiln. These controls permit the adding of heat where drying is slow or the wood is wet, and cooling areas where drying is too fast or the wood is drier. When used with exit air temperature control, rather than entering air temperature, the net result is very uniform drying throughout the kiln and uniform final MC's.

SUMMARY

The high temperature kiln schedule to maximize strength for southern pine dimension should use low wet-bulb temperatures (160°F), with the dry-bulb dropped as much below 240°F as needed to achieve rapid drying at acceptable quality levels. Where strength is not an overriding objective, higher wet-bulbs can be used to achieve less shrinkage and less splitting at very high drying rates. In either case, high velocities and thicker stickers would be suggested. In addition uniform drying achieved by zoning, temperature control using the exit air temperature, and use of TDAL should be considered as excellent ways to provide rapid drying with maximum quality.

I might add, in closing, that achieving extremely fast drying while maximizing strength and minimizing warp and splitting may not be possible in all cases, as these are opposite extremes as far as a kiln schedule goes. A compromise is often necessary--management must indicate which criteria are most important or how much compromising can be done. Perhaps a little more practical data collection is needed to define all the relationships between strength, warp, checks, and drying speed for pine, but we do know, in general, the trends.

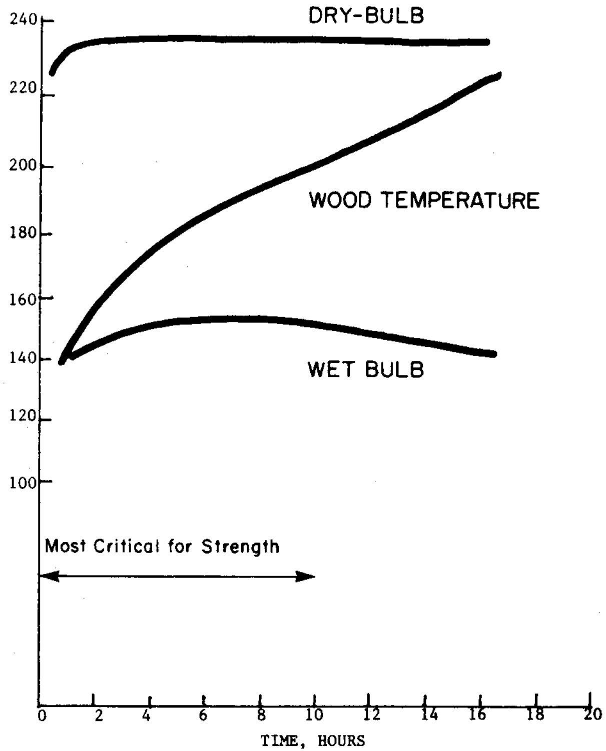

Figure 1 -- Temperature history for SYP 2 x 4's dried at high temperature.

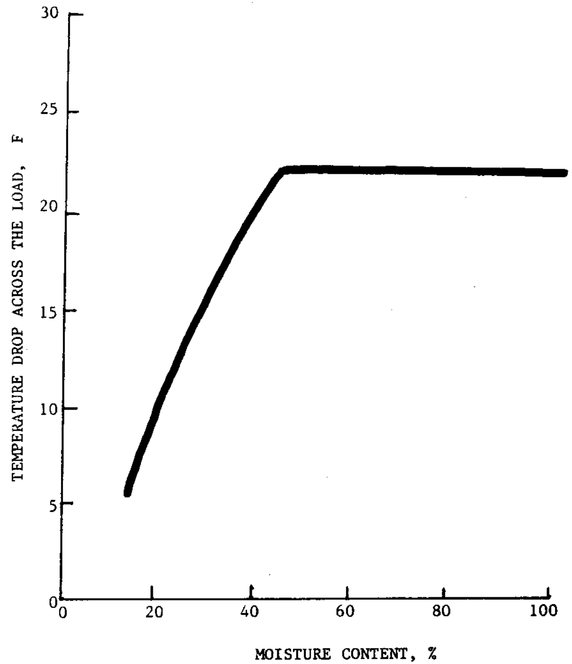

Figure 2 -- TDAL vs. MC in a Commercial Kiln Drying SYP 2 x 4's.