

SHRINKAGE OF DOUGLAS-FIR, WESTERN HEMLOCK, AND
RED ALDER AS AFFECTED BY DRYING CONDITIONS*

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For many years, recognition has been given to the fact that drying shrinkage in lumber is influenced by the drying conditions. The earliest reference to this phenomenon that I have found is that of Tiemann (4) in which he states, "Thus when dried slowly at high temperature and high humidity, wood shrinks much more than when dried very quickly in dry air." He elaborates but little and cites no specific data. In fact, there seems to be a dearth of information on the subject. I have been unable to find reference to a systematic study of the relationships between drying conditions and shrinkage. McMillen (1) however, in a study of drying stresses, does show an increase in board shrinkage for northern red oak as the constant drying temperature increased from 80° F. to 140° F. using the same equilibrium moisture content (EMC) for comparable stages of dryness. He relates this to the amount of compression set that developed and his article presents a good discussion on the subject. In a later study of stresses in ponderosa pine (2), he shows more compression set and shrinkage developing in this species when dried at 170° F. than when dried at 140° F. or less. Stamm (3) also discusses the phenomenon, but not to the extent that McMillen does.

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In the early stage of drying, the surface layers of lumber are subjected to a tensile stress, usually of sufficient magnitude to cause tension set. Creep can also occur with duration of the stress. The central portion of the board is subjected to a compressive stress which may or may not be great enough to cause set in compression. If compression set occurs it can also be augmented by creep. Eventually, stresses reverse and in the final stages of drying, the surface layers are in compression and the central portion of the lumber is in tension. Board shrinkage is influenced by the relative amounts of tension and compression set and creep.

The magnitude of stress that develops is determined by the EMC conditions in the early stage of drying. The extent of tension and compression set, however, is influenced not only by the stress, but also by the relative strength of the wood in tension and compression perpendicular to the grain. Drying temperature is important because of its influence on strength. Thus, if drying conditions are such that tension set is large and little or no compression set occurs, shrinkage will be less than when tension set is at a minimum and appreciable compression set has developed.

The study reported here was undertaken not just because of the lack of information on the effect of drying conditions on shrinkage but because of the recent and current interest in high temperature drying, i. e., the use of temperatures above the usual high of around 180° F. to 190° F, and the possible application such information could have in this field. Douglas-fir, hemlock, and red alder were chosen for study.

Procedure

Groups of specimens were prepared and dried under assigned constant conditions. They were then equilibrated successively to two EMC conditions at room temperature and finally oven-dried. Suitable weights and measurements were determined for calculation of moisture content and shrinkage.

Preparation of Specimens and Groups

Material collected on the green chain at local sawmills was processed into clear, straight-grained, square specimens with the annual rings parallel with two opposite faces so that essentially true tangential and radial shrinkage could be determined. No shake, pitch streaks, or red heart was permitted in the specimens and slope of grain could be no steeper than one inch in twenty. Final surfaced size of the specimens was 1 1/2 inches square by 15 inches long for Douglas-fir and hemlock, and 1 inch square by 15 inches long for red alder.

Specific gravity is known to influence shrinkage. In order to minimize influence of this property, far more specimens were prepared than were used so that selection could be made of specimens in the mid-range of the specific gravity distribution. Specimens were, however, randomly assigned to the different groups, and the groups in turn were randomly assigned to the various drying conditions.

Specimens were weighed, measured, end-coated, and stored under sprinklers until they could be dried. Tangential and radial measurements were made at a marked spot at the mid-width of the face and somewhere near the mid-length, care being taken to choose the straightest possible grain. Measurements were made with micrometers to the nearest 0.001 inch.

Drying and Equilibrating

Temperatures used in the study were 90, 150, 180, 200, and 215° F. with relative humidities to give EMC's of 6, 9, and 12 percent at each temperature. An additional group was dried at 230° F. with the EMC at 6 percent. The higher EMC's cannot be attained at this temperature.

Specimens were dried in their assigned temperature and EMC condition until they were very nearly at equilibrium, at which time they were removed from the kiln. The groups were then placed in a humidity room or cabinet having approximately the same EMC condition as that under which they were dried, but at or near room temperature, and allowed to reach equilibrium. They were then weighed and measured and placed in a humidity room having a nominal 6 percent EMC where the procedure was repeated. Finally, the specimens were oven-dried to a constant weight, weighed immediately upon removal from the oven, and then cooled in plastic bags for several hours to permit them to contract thermally before measuring.

Calculations and Analysis

All calculations for moisture content and shrinkage were made by an electronic computer, which also calculated the means, standard deviation, sum of the squares, and the means squares for analysis of variance. A two-way analysis--effect of temperature and effect of EMC--was made on the data for equilibrium of all groups at 6 percent EMC and when oven-dry. Significant ranges were determined using Duncan's multiple range test at the 1 percent level of probability.

Results and Discussion¹

Within each of the three species, no significant difference was found in the specific gravity and green moisture content of the groups of specimens. Consequently, these factors should not have influenced the results.

As anticipated, moisture content attained at equilibrium was significantly less for groups of specimens dried at the higher temperatures than for groups dried at the lower temperatures. The effect is rather pronounced above 150° F. as shown in Figure 1. Differences between the high and low values were nearly the same for the three species, but values were somewhat higher for hemlock than for the other species.

Shrinkage was also influenced by temperature but the three species were not affected to the same degree. Figures 2 and 3 show tangential and radial shrinkage from the green condition to the moisture content shown in Figure 1. The figures show that when the EMC during drying was 12 percent, effect of temperature on shrinkage was greater on hemlock than on Douglas-fir and even greater on red alder. This was also true when the EMC was 9 percent. With conditions for 6 percent EMC, however, effect was least on hemlock but still greatest on red alder. Table 1 shows moisture content and shrinkage at 215° F. as a percentage of those at 90° F.

Table 1. Moisture Content and Shrinkage of Specimens Dried at 215° F. as a Percentage of Those Dried at 90° F.

Species	EMC during drying and equilibration	Moisture Content (%)	Shrinkage	
			Tangential (%)	Radial (%)
Douglas-fir	12	85	133	151
Hemlock	12	82	165	182
Red Alder	12	82	230	237
Douglas-fir	6	90	130	133
Hemlock	6	92	117	118
Red Alder	6	91	141	149

A natural question is whether the differences in shrinkage to a given equilibrium are a result of moisture content reached at that equilibrium. This is not the case although certainly it accounts for some of the difference. The most obvious case is with red alder dried with conditions for 12 percent EMC where shrinkage at 215° F. is more than double that at 90° F., yet the difference in attained moisture content was only about 2.3 percent. The least effect was found with hemlock dried with conditions for 6 percent EMC. In this case, tangential shrinkage was 1.16 percent greater at 215° F. than at 90° F. (7.96-6.80) and the moisture content difference was 0.51 percent (6.61-6.10). Roughly a 3 to 4 percent moisture content loss is required to increase tangential shrinkage by about 1 percent.

¹ For the purpose of this report, only some of the results will be presented. Detailed results are available in Oregon State University Forest Research Laboratory Report D-12, currently in press. The report is available from the Laboratory in Corvallis, Oregon.

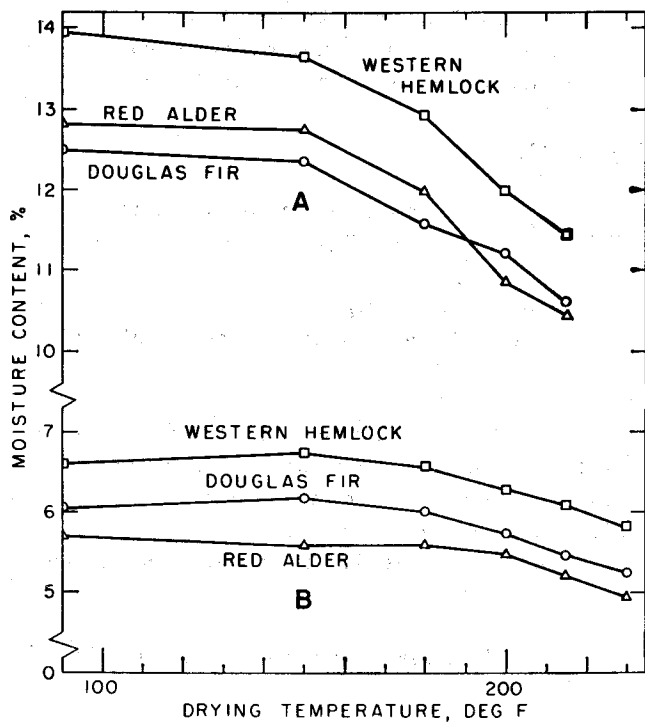


Figure 1. — Moisture content attained at equilibrium: (A) 12 percent EMC during drying; (B) 6 percent EMC during drying.

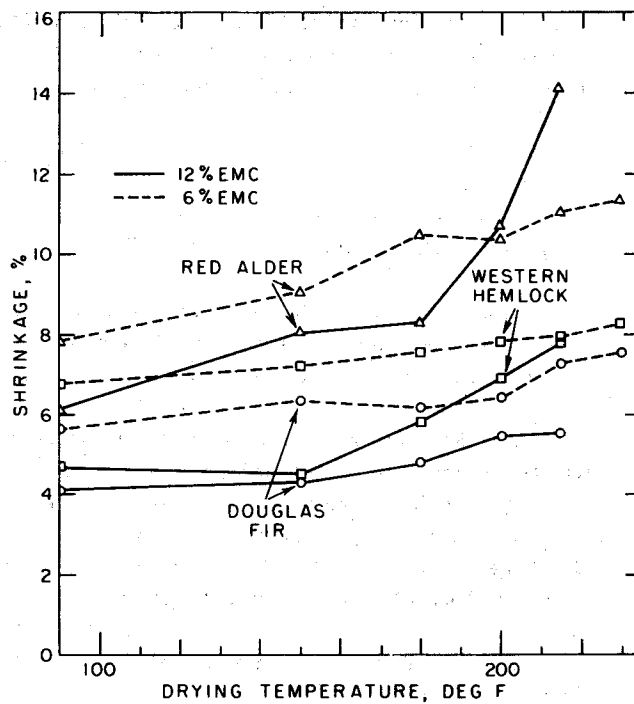


Figure 2. — Tangential shrinkage to EMC of drying conditions.

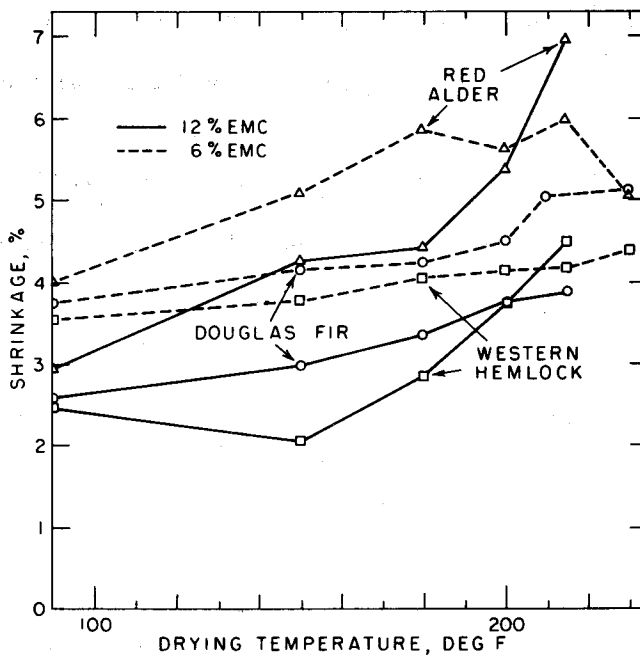


Figure 3. — Radial shrinkage to EMC of drying conditions.

The effect of EMC during drying on moisture content attained at equilibrium with a nominal 6 percent EMC is rather obscure since a consistent pattern was not found for the three species. With respect to its effect on shrinkage, all three species shrunk more when the EMC during drying was 12 percent than when it was 6 or 9 percent. However, the difference was not significant statistically in the case of Douglas-fir but it was with hemlock and red alder. Interaction between the two drying variables--temperature and EMC--was also significant for these two species.

Summary and Conclusions

Groups of specimens were kiln-dried under constant conditions and then brought to equilibrium at room temperature. Temperature ranged from 90° to 230° F. and EMC ranged from 6 to 12 percent except at 230° F.

Moisture content attained after equilibrating was less for specimens dried at high temperature than for those dried at the lower temperature. The three species were affected to about the same degree. Effect of EMC during drying or moisture content at equilibrium was not clear.

Shrinkage was greater as drying temperature increased, and it was also greater when the EMC during drying was 12 percent than when 6 or 9 percent. When the drying EMC was 12 percent, tangential and radial shrinkage of Douglas-fir increased by 33 and 51 percent, respectively, as drying temperature increased from 90 to 215° F. In the same comparison, tangential and radial shrinkage of hemlock increased by 65 and 82 percent, respectively, and shrinkage of red alder more than doubled. The increase in shrinkage with increase in temperature cannot be accounted for on the basis of moisture content differences.

The effect of temperature on both attained moisture content and shrinkage was greater above about 150° F. than it was below.

The results suggest the possibility that somewhat greater allowances for shrinkage may be necessary if these species, especially red alder, are to be dried at high temperature.

Literature Cited

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