Shrinkage of Douglas Fir, Western Hemlock, and Red Alder as Affected by Drying Conditions

By Leif D. Espenas

drying of wood

Report D-12
June 1971

Forest Research Laboratory
School of Forestry
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SUMMARY

Moisture content and shrinkage were determined on specimens equilibrated at two conditions for equilibrium moisture content (EMC) at room temperature after the specimens had been dried under a variety of constant temperatures with constant EMC's. Moisture content at room temperature equilibrium was less for specimens dried at high temperature than for those dried at low temperature, and the effect was about the same on the three species. Shrinkage was greater on specimens dried at high temperature, more than can be accounted for by lower moisture content. Douglas-fir was least and red alder most affected, sometimes doubled. Effect of temperature on both moisture content and shrinkage was more pronounced above 150 F.

ACKNOWLEDGMENTS

I wish to express my sincere thanks to Charles Kozlik and Louis Hamlin for valued assistance in the conduct of this study.

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

Leif D. Espenas

INTRODUCTION

THE STUDY reported here was undertaken not just because of the lack of information on the effect of drying conditions on shrinkage but also because of the recent and current interest in high-temperature drying, that is, drying at 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 (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were chosen for study because of their importance in the Northwest. Red alder (*Alnus rubra* Bong.) was chosen because of its importance as a local hardwood and because, in a study of drying this species, we suspected that material dried at temperatures approaching 200 F would be difficult to machine because of excess shrinkage.

For many years, recognition has been given to the fact that, in lumber drying, shrinkage is influenced by drying conditions. The earliest reference I have found to this phenomenon is by Tiemann (5), "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, information on the subject is extremely scarce. I have been unable to find reference to a systematic study of the relations between drying conditions and shrinkage. McMillen (2), however, in a study of drying stresses, did describe an increase in board shrinkage for northern red oak as the constant drying temperature increased from 80 to 140 F with the same equilibrium moisture content (EMC) for comparable stages of dryness. He related this to the amount of compression set that developed; his article presents a good discussion on the subject. In a later study of stresses in ponderosa pine (3), he showed that more compression set and shrinkage develop in this species when it is dried at 170 F than when it is dried at 140 F or less. Stamm (4) also discussed this phenomenon, but not so extensively as McMillen did.

Briefly, in the early stage of drying, the surface layers of lumber are subjected to a tensile stress, usually sufficient to cause tension set. Creep also can 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.

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 ovendried. Suitable weights and measurements were determined for calculation of moisture content and shrinkage.

Preparation of Specimens and Groups

Material collected on the green sorting chain at local sawmills was processed into clear, straight-grained, square specimens with the annual rings parallel to two opposite faces, so that essentially true tangential and radial shrinkage could be determined. No shake, pitch streaks, or red heart were permitted in the specimens, and slope of grain could be no steeper than 1 inch in 20. Final surfaced size of the specimens was 1½ inches square by 15 inches long for Douglas fir and western hemlock, and 1 inch square by 15 inches long for red alder.

Specific gravity is known to influence shrinkage. To minimize the influence of this property, far more specimens were prepared than were needed so that selection could be made of specimens in the midrange of the specific gravity distribution.

Specific gravity based on green volume and ovendry weight was determined for each specimen from a 1-inch wafer cut adjacent to the specimen along the grain. Specimens were sorted into specific gravity classes of 0.005. Then, starting at the average class, specimens were assigned randomly to one of 18 groups, proceeding to the next higher class, then the next lower class and so on. Although only 16 groups of 20 specimens each were needed, 18 were prepared to provide against malfunction of equipment during the drying process. Groups also were assigned randomly to a particular drying condition.

Specimens were weighed, end coated, and stored under sprinklers until they could be measured. Tangential and radial measurements to the nearest 0.001 inch were made at a marked spot at the midwidth of the face and somewhere near the midlength. Care was taken to choose the straightest possible grain. Specimens again were stored under sprinklers until they could be dried.

Drying and Equilibrating

Specimens were dried under constant conditions. Temperatures 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 conditions for EMC of 6 percent. The higher EMC's cannot be obtained at this temperature.

Drying was started immediately on groups to be dried at 90 F. The groups to be dried to 9 percent moisture content were dried in a humidity cabinet. The other groups were dried in controlled temperature-humidity rooms with conditions for nominal EMC's of 6 and 12 percent.

All other groups were dried in a small, experimental dry kiln. For a given drying condition, all three species were placed in the kiln at the same time, but their removal depended on their drying rates. To determine time for removal for each species, selected specimens were weighed daily; when daily weight loss was less than about 1 or 2 percent moisture content, the species group was removed. After the specimens cooled, the end coating was removed on a wire buffing wheel and the specimens were weighed and measured.

After drying, the groups were placed in a humidity room or cabinet with about the same EMC conditions as those under which it was dried and allowed to reach equilibrium. Then they were weighed and measured.

Groups at 9 and 12 percent EMC were then placed with the groups in the humidity room having a nominal 6 percent EMC, again allowed to equilibrate, and again weighed and measured.

Finally, the groups were ovendried to a constant weight. The specimens were 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 Analyses

All calculations for moisture content and shrinkage were made by an electronic computer, which also calculated means, standard deviation, sum of the squares, and mean squares for analysis of variance. Significant ranges were determined by Duncan's multiple range test at the 1 percent level of probability. Data obtained when all specimens had equilibrated in the conditions for nominal 6 percent EMC provided a randomized block with five treatments and three replications so that tests could be made for effect of temperature and effect of EMC. Data obtained on the ovendry specimens were analyzed similarly. Data for specimens dried at 230 F were not included in the analyses.

RESULTS AND DISCUSSION

Within each of the three species, no significant differences were found in specific gravity and green moisture content. Therefore, these factors are not considered variables in the study. Table 1 presents the average, maximum, and minimum values found for the three species.

Moisture content attained after drying and equilibrating at room temperature to the EMC used in drying is shown in Table 2 and Figure 1. In Table 2, the groups are ranked in ascending order of moisture content from the left. Coefficient of variation (CV) also is shown.

As shown in Table 2 and Figure l, the EMC attained was less with higher than with lower drying temperatures. The trend appears consistent for the three species and three conditions for equilibrium moisture content, although the significant differences vary, and data for groups dried at 150 F seemed somewhat inconsistent. Controls for the cabinet in which specimens were to be equilibrated to 9 percent EMC actually maintained conditions for an EMC closer to 7 percent, but, for convenience, the conditions will still be referred to as 9 percent EMC.

Table 1. Specific Gravity, Based on Green Volume and Ovendry Weight, and Moisture Content of Groups of Specimens.

Species	Specific gravity			Moisture content		
	Average	Maximum	Minimum	Average	Maximum	Minimum
				%	%	%
Douglas fir	0.459	0.467	0.454	64.0	72.8	59.6
Western hemlock	0.391	0.387	0.395	121.6	138.9	108.2
Red alder	0.393	0.396	0.390	157.9	147.7	167.5

That the three species were affected about the same can be shown if the moisture content attained by specimens dried at 215 F is expressed as a percentage of the moisture content attained by specimens dried at 90 F, as in Table 3.

Moisture contents attained by specimens dried at 230 F and relative humidity for 6 percent EMC were 5.24, 5.83, and 4.94 percent for the Douglas fir, western hemlock, and red alder, respectively. For all species, the values are significantly less than the moisture contents attained by specimens dried at 215 F.

Table 2 shows more significant differences at higher than at lower temperatures, and, as shown in Figure 1, the effect of temperature increases above about 150 to 180 degrees. Kozlik

Table 2. Moisture Content at Equilibrium with EMC of Drying Conditions. Common Underlining Indicates That Values Did Not Differ Significantly at the 1 Percent Level of Probability.

Item	Rank by moisture content				
	1	2	3	4	5
			DOUGLAS FIR		
6 % EMC conditions					
Temp, *F*	215	200	180	90	150
Means, %	5.46	5.74	6.03	6.05	6.18
CV, %	5.0	4.3	3.1	3.1	2.9
9 % EMC conditions					
Temp, *F*	215	200	180	90	150
Means, %	6.57	6.85	7.25	7.30	7.86
CV, %	4.1	4.4	7.8	2.1	3.7
12 % EMC conditions					
Temp, *F*	215	200	180	150	90
Means, %	10.61	11.22	11.58	12.35	12.49
CV, %	3.8	3.0	4.2	3.8	3.8
			WESTERN HEMLOCK		
6 % EMC conditions					
Temp, *F*	215	200	180	90	150
Means, %	6.10	6.29	6.58	6.61	6.75
CV, %	2.9	2.9	2.4	2.2	2.1
9 % EMC conditions					
Temp, *F*	215	200	180	90	150
Means, %	7.55	7.85	8.03	8.10	8.62
CV, %	3.1	3.4	2.4	2.2	2.4
12 % EMC conditions					
Temp, *F*	215	200	180	150	90
Means, %	11.46	12.00	12.93	13.64	13.95
CV, %	2.4	1.3	2.6	2.6	1.9

Table 2. (Continued)

Item	Rank by moisture content				
	1	2	3	4	5
			RED ALDER		
6 % EMC conditions					
Temp, *F*	215	200	150	180	90
Means, %	5.21	5.49	5.59	5.60	5.72
CV, %	0.9	1.5	1.4	1.5	1.7
9 % EMC conditions					
Temp, *F*	215	200	180	90	150
Means, %	6.58	6.96	7.05	7.28	7.67
CV, %	0.8	3.3	1.9	1.0	2.3
12 % EMC conditions					
Temp, *F*	215	200	180	150	90
Means, %	10.46	10.87	11.99	12.75	12.81
CV, %	15	1.3	0.8	0.9	0.7

(1) noted a somewhat parallel decrease in some strength properties with drying temperatures over about 180 F.

Tables 4 and 5 and Figures 2 and 3 present tangential and radial shrinkage to the moisture contents given in Table 2. With one exception, both radial and tangential shrinkage are shown to be influenced significantly by temperature—the higher the temperature, the greater the shrinkage. The exception is tangential shrinkage of Douglas fir dried with conditions for 9 percent EMC. Even here, however, the trend seems apparent in Figure 2.

The question arises as to whether the increased shrinkage with increased temperatures occurred because lower moisture contents were attained than with low temperatures. This is not true, although it can account for some of the difference. In red alder that was dried with conditions for 12 percent EMC, the shrinkage at 215 F was more than double that at 90 F, yet the difference in moisture content was only 2.35 percent. The least difference shown is tangential shrinkage of Douglas fir dried with conditions for 9 percent EMC. Here, the difference in shrinkage was 6.27 - 5.52 = 0.75 percent, and the difference in moisture content was 7.86 - 6.57 = 1.29 percent. Roughly speaking, a loss of moisture content of 3 or 4 percent is needed to increase tangential shrinkage by about 1 percent.

Table 3. Moisture Content at 215 F as a Percentage of Moisture Content at 90 F.

Species	Conditions for EMC of:		
	6 %	9 %	12 %
	%	%	%
Douglas-fir	90	90	85
Western hemlock	92	93	82
Red alder	91	90	82

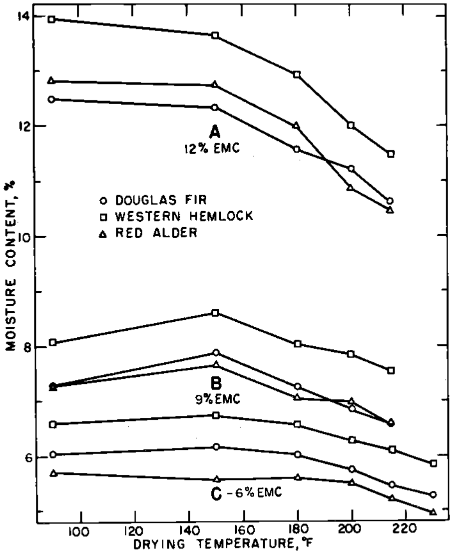


Figure 1. Moisture content at equilibrium.

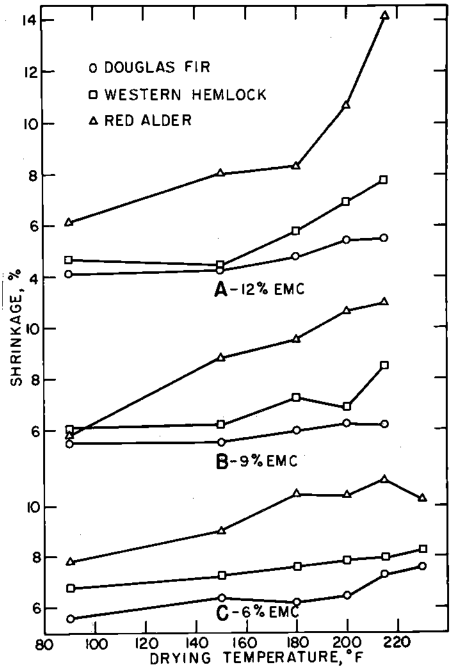


Figure 2. Tangential shrinkage to equilibrium.

Table 4. Tangential Shrinkage to Equilibrium with EMC of Drying Conditions. Common Underlining Indicates That Values Did Not Differ Significantly at the 1 Percent Level of Probability.

Item	Rank by tangential shrinkage					
	1	2	3	4	5	6
			DOUGLAS FIR			
6 % EMC conditions						
Temp, *F*	90	180	150	200	215	230
Means, %	5.61	6.18	6.39	6.44	7.30	7.57
CV, %	21	17	24	20	14	18
9 % EMC conditions						
Temp, *F*	90	150	180	215	200	
Means, %	5.52	5.52	5.97	6.21	6.27	
CV, %	27	21	18	22	23	
12 % EMC conditions						
Temp, *F*	90	150	180	200	215	
Means, %	4.11	4.29	4.78	5.43	5.49	
CV, %	24	22	21	15	16	

Table 4. (Continued)

Item	Rank by tangential shrinkage					
	1	2	3	4	5	6
			WESTERN HEMLOCK			
6 % EMC conditions						
Temp, *F*	90	150	180	200	215	230
Means, %	6.80	7.22	7.59	7.84	7.96	8.24
CV, %	19	15	12	13	21	12
9 % EMC conditions						
Temp, *F*	90	150	200	180	215	
Means, %	6.10	6.22	6.88	7.27	8.50	
CV, %	17	16	17	12	9	
12 % EMC conditions						
Temp, *F*	150	90	180	200	215	
Means, %	4.48	4.71	5.80	6.92	7.79	
CV, %	15	18	13	15	16	
			RED ALDER			
6 % EMC conditions						
Temp, *F*	90	150	230	200	180	215
Means, %	7.85	9.03	10.28	10.39	10.46	11.03
CV, %	9	8	9	8	9	11
9 % EMC conditions						
Temp, *F*	90	150	180	200	215	
Means, %	5.85	8.83	9.56	10.67	10.99	
CV, %	6	10	8	13	13	
12 % EMC conditions						
Temp, *F*	90	150	180	200	215	
Means, %	6.15	8.05	8.31	10.70	14.13	
CV, %	12	9	15	18	16	

The foregoing partially explains why significant differences in moisture content (Table 2) are not necessarily reflected by significant differences in shrinkage (Tables 4 and 5). Another contributing factor is that the coefficient of variation is smaller for moisture content than it is for shrinkage.

Figures 2 and 3 show that shrinkage was affected more by temperature in western hemlock than in Douglas fir, and that red alder was affected most of all when the EMC was 9 or 12 percent. When the EMC was 6 percent, however, hemlock was affected least. The data also tend to show that the effect of temperature increased as EMC increased, with an increasing effect above about 150 F, as with moisture content. Table 6, which expresses shrinkage at 215 F as a percentage of shrinkage at 90 F, emphasizes most of these points and also shows agreement in the effect of temperature on tangential and radial shrinkage.

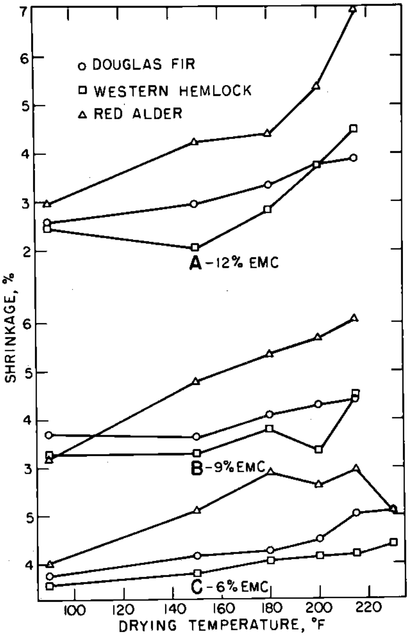


Figure 3. Radial shrinkage to equilibrium.

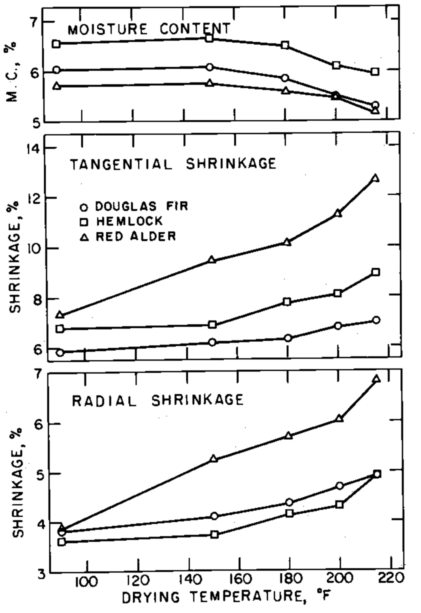


Figure 4. Moisture content and shrinkage when dried at conditions for 6 percent EMC.

Table 5. Radial Shrinkage to Equilibrium with EMC of Drying Conditions. Common Underlining Indicates That Values Did Not Differ Significantly at the 1 Percent Level of Probability.

Item	Rank by radial shrinkage					
	1	2	3	4	5	6
			DOUGLAS FIR			
6 % EMC condition						
Temp, *F*	90	150	180	200	215	230
Means, %	3.77	4.15	4.25	4.49	5.03	5.11
CV, %	23	20	17	16	12	13
9 % EMC condition						
Temp, *F*	150	90	180	200	215	
Means, %	3.63	3.71	4.08	4.29	4.41	
CV, %	15	26	14	19	24	
12 % EMC condition						
Temp, *F*	90	150	180	200	215	
Means, %	2.58	2.97	3.35	3.78	3.89	
CV, %	27	18	17	13	16	

Table 5. (Continued)

Item	Rank by radial shrinkage					
	1	2	3	4	5	6
			WESTERN HEMLOCK			
6 % EMC condition						
Temp, *F*	90	150	180	200	215	230
Means, %	3.55	3.78	4.05	4.13	4.18	4.40
CV, %	21	22	12	15	21	16
9 % EMC condition						
Temp, *F*	150	90	200	180	215	
Means, %	3.28	3.29	3.36	3.78	4.50	
CV, %	19	19	12	16	14	
12 % EMC condition						
Temp, *F*	150	90	180	200	215	
Means, %	2.06	2.47	2.84	3.76	4.50	
CV, %	30	17	15	22	41	
			RED ALDER			
6 % EMC condition						
Temp, *F*	90	230	150	200	180	215
Means, %	4.01	5.07	5.09	5.61	5.87	5.97
CV, %	15	10	7	14	12	11
9 % EMC condition						
Temp, *F*	90	150	180	200	215	
Means, %	3.18	4.79	5.35	5.67	6.18	
CV, %	13	10	12	15	11	
12 % EMC condition						
Temp, *F*	90	150	180	200	215	
Means, %	2.94	4.27	4.42	5.38	6.96	
CV, %	15	10	13	11	18	

Table 6. Shrinkage at 215 F as a Percentage of Shrinkage at 90 F.

Conditions for EMC of:	Douglas fir		Western hemlock		Red alder	
	Tangential	Radial	Tangential	Radial	Tangential	Radial
	%	%	%	%	%	%
6 %	130	133	117	118	141	149
9 %	112	119	139	137	188	194
12 %	132	151	165	182	230	237

Collapse did not occur in any of the Douglas fir specimens. Six western hemlock and four red alder specimens exhibited typical sunken or wrinkled surfaces of collapsed material, but only among specimens dried at 215 F with conditions for 12 percent EMC. Increased collapse might be expected in red alder because of the increased effect of temperature. In fact, some specimens did shrink as much or more than the specimens exhibiting collapse, but the pieces were not distorted. Two hemlock specimens, one of which had collapse, had small honeycomb checks, but no honeycombing was found in the alder.

Tables 7 and 8 show the average moisture content and shrinkage after all specimens had equilibrated in conditions for nominal 6 percent EMC. As mentioned earlier in the report, the experiment provided a randomized block design with five treatments and three replications. Results should not be confused with those presented previously, because here, for each species, each temperature is represented by 60 specimens and each set of EMC conditions is represented by 100 specimens. The shrinkage data of Table 7 are also shown graphically in Figure 4.

Table 7. Moisture Content and Shrinkage Data after Equilibration at Room Temperature with a Nominal 6 Percent EMC; Analysis for Effect of Temperatures. Common Underlining Indicates That Values Did Not Differ Significantly at the 1 Percent Level of Probability.

Item	Rank				
	1	2	3	4	5
			MOISTURE CONTENT		
Douglas fir					
Temp, *F*	215	200	180	90	150
Means, %	5.28	5.50	5.85	6.05	6.09
Western hemlock					
Temp, *F*	215	200	180	150	90
Means, %	5.94	6.19	6.50	6.65	6.66
Red alder					
Temp, *F*	215	200	180	90	150
Means, %	5.17	5.45	5.61	5.73	5.76
			TANGENTIAL SHRINKAGE		
Douglas fir					
Temp, *F*	90	150	180	200	215
Means, %	5.82	6.15	6.30	6.74	7.00
Western hemlock					
Temp, *F*	90	150	180	200	215
Means, %	6.80	6.88	7.74	8.04	8.88
Red alder					
Temp, *F*	90	150	180	200	215
Means, %	7.34	9.43	10.15	11.29	12.67

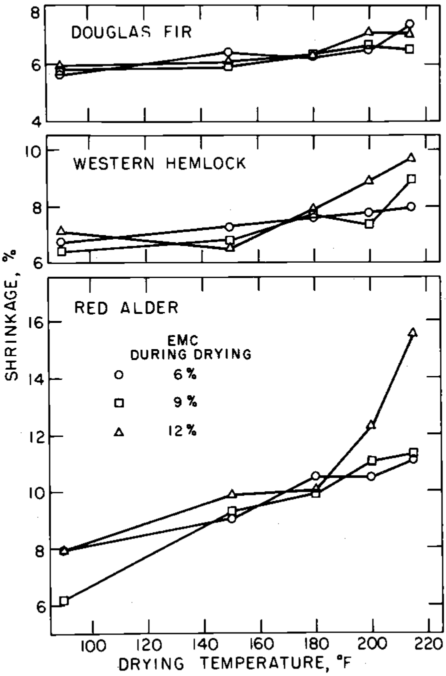
Table 7. (Continued)

Item	Rank				
	1	2	3	4	5
		RADIAL SHRINKAGE			
Douglas fir					
Temp, *F*	90	150	180	200	215
Means, %	3.83	4.08	4.34	4.68	4.89
Western hemlock					
Temp, *F*	150	90	180	200	215
Means, %	3.62	3.72	4.11	4.30	4.92
Red alder					
Temp, *F*	90	150	180	200	215
Means, %	3.90	5.26	5.70	6.03	6.81

With respect to the effect of temperature, the analysis does not lead to additional conclusions beyond those brought out in the previous analysis, but it does provide for an evaluation of the effect of EMC during drying on attained moisture content and shrinkage. As shown in Table 8, attained moisture content of Douglas fir and hemlock was significantly less when drying was done in conditions for EMC of 6 percent, and greatest for Douglas fir and red alder when drying conditions were set for EMC of 9 percent. To me, the results do not seem logical or consistent, despite the fact that statistical differences are shown.

The effect on shrinkage of EMC conditions during drying seems reasonably clear. Shrinkage was greater when EMC conditions during drying were 12 percent than it was when EMC conditions were set for 6 or 9 percent, though significantly greater in only three of six instances, and only slightly so with Douglas fir. A similar analysis of the data obtained on ovendry specimens shows the same results, except that radial shrinkage of red alder tested significantly greater for specimens dried in conditions for 12 percent EMC than for the lower EMC's. A statement that shrinkage is greater when drying is done at conditions for 12 percent EMC would be erroneous without some qualification, however, as examination of Figures 5 and 6 will show. In these figures, tangential and radial shrinkage to the nominal 6 percent EMC are plotted against temperature for each set of conditions for drying. The figures show that the greater shrinkage of western hemlock and red alder for specimens dried in conditions for 12 percent EMC occurs primarily at temperatures above 180 F. For Douglas fir, this trend, if any, is slight.

Interaction of the two drying variables, temperature and EMC, was shown by the analysis of variance to have no effect on attained moisture content or shrinkage of Douglas fir at the 1 percent level of probability. At the 5 percent level of probability, however, the interaction had a significant effect on moisture content. With both western hemlock and red alder, the effect was significant (1 percent level) on moisture content and tangential and radial shrinkage. This is illustrated only for attained moisture content of western hemlock at a nominal 6 percent EMC, Figure 7, and tangential shrinkage of red alder to the ovendry condition, Figure 8. Although not pronounced, the slope of the plane in Figure 7 can be seen to rise gently from the near right corner–high temperature, low EMC–to the far left corner–low temperature,



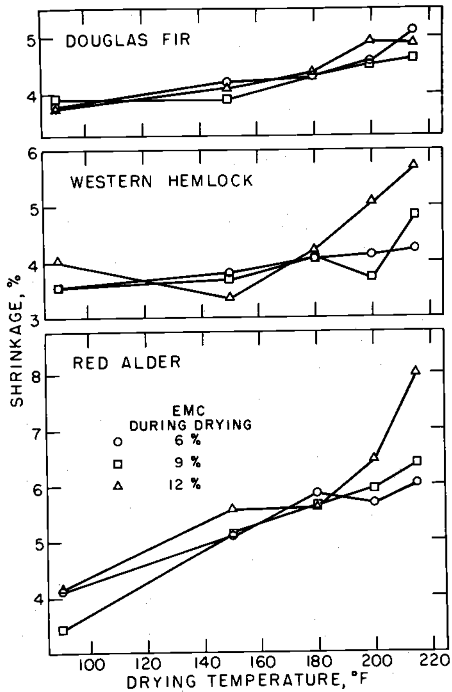


Figure 5. Tangential shrinkage when dried at conditions for 6 percent EMC.

Figure 6. Radial shrinkage when dried at conditions for 6 percent EMC.

Table 8. Moisture Content and Shrinkage Data after Equilibration at Room Temperature with a Nominal 6 Percent EMC; Analysis for Effect of EMC During Drying. Common Underlining Indicates That Values Did Not Differ Significantly at the 1 Percent Level of Probability.

Item	Rank 1	Rank 2	Rank 3
MOISTURE CONTENT			
Douglas fir			
EMC, %	6	12	9
Means, %	5.53	5.81	5.93
Western hemlock			
EMC, %	6	12	9
Means, %	6.24	6.43	6.49
Red alder			
EMC, %	12	6	9
Means, %	5.47	5.51	5.66

Table 8. (Continued)

Item	Rank		
	1	2	3
TANGENTIAL SHRINKAGE			
Douglas fir			
EMC, %	9	6	12
Means, %	6.25	6.44	6.51
Western hemlock			
EMC, %	9	6	12
Means, %	7.48	7.50	8.03
Red alder			
EMC, %	9	6	12
Means, %	9.56	9.82	11.16
RADIAL SHRINKAGE			
Douglas fir			
EMC, %	9	6	12
Means, %	4.26	4.41	4.42
Western hemlock			
EMC, %	6	9	12
Means, %	3.96	3.98	4.47
Red alder			
EMC, %	9	6	12
Means, %	5.30	5.35	5.96

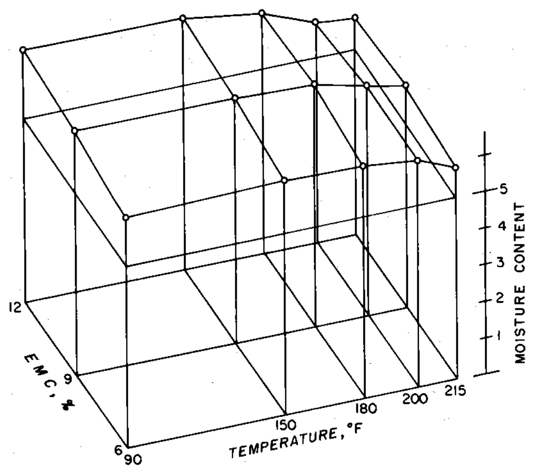


Figure 7. Relation of moisture content at nominal 6 percent EMC to temperature and EMC of drying conditions for western hemlock.

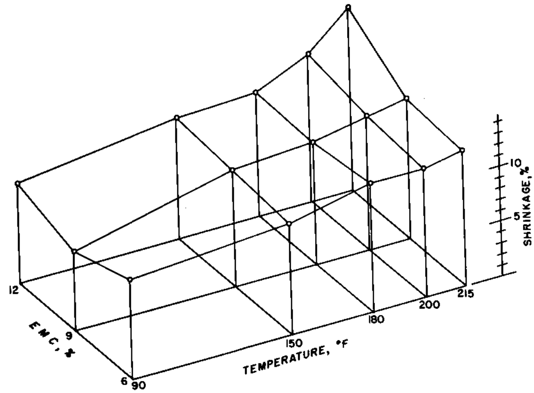


Figure 8. Relation of tangential shrinkage to ovendry condition with temperature and EMC of drying conditions for red alder.

high EMC. The effect of interaction is more clearly seen in Figure 8. Here, the plane slopes upward from the low-temperature, low-EMC coordinate to the high-temperature, high-EMC coordinate, with the slope becoming steeper with increase of temperature and EMC.

Because specimens dried with conditions for 12 percent EMC exhibited the greatest effect of temperature on shrinkage, it is of interest to consider subsequent shrinkage to the ovendry condition after equilibration at conditions for 12 percent moisture content. Such data are shown for tangential shrinkage in Figure 9. Within each species, curves of moisture content and shrinkage for specimens dried at the various temperatures are essentially parallel in the range from 12 to 0 percent moisture content. In other words, at this stage of drying, shrinkage for a given change of moisture content is virtually the same regardless of previous shrinkage. Obviously, this could not be true above 12 percent moisture content, which leads to speculation as to the stage of drying during which the excess shrinkage occurred. Collapse tends to develop rather early in drying. Collapse was not observed in specimens dried at temperatures less than 215 F, however.

Drying lumber at high temperature is reputed to impart some dimensional stability to the wood, although as pointed out above, shrinkage (or swelling) for a unit change in moisture content is essentially the same within the range of moisture content shown. Differences in shrinkage are simply a result of smaller changes in moisture content occurring between equilibrium conditions in specimens dried at high temperatures than in specimens dried at low temperatures. Average shrinkage for a 1 percent loss in moisture content between about 12 and 6 percent moisture content for the three species is shown in Table 9.

Table 9. Average Shrinkage for a 1 Percent Loss in Moisture Content.

Species	Shrinkage	
	Tangential	Radial
	%	%
Douglas fir	0.29	0.19
Western hemlock	.33	.21
Red alder	.27	.19

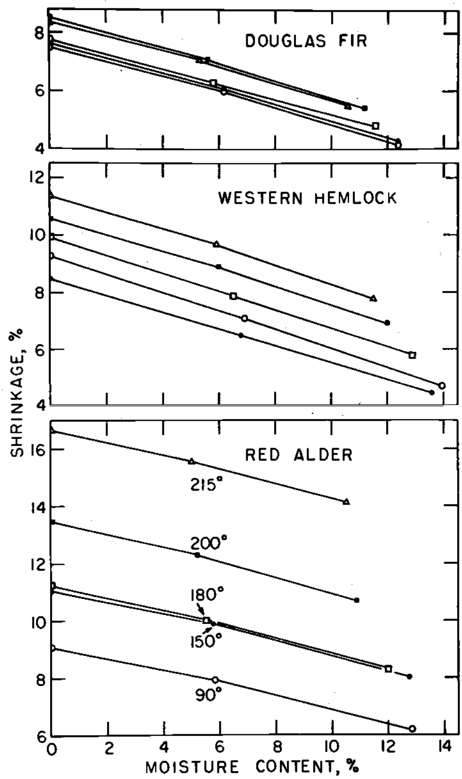


Figure 9. Shrinkage of specimens dried in conditions for 12 percent EMC.

CONCLUSIONS

Both temperature and relative humidity of the drying conditions influence moisture content attained at equilibrium conditions and shrinkage from the green state to equilibrium for the three species studied.

Specimens dried at high temperatures attained a lower moisture content at equilibrium than did specimens dried at low temperatures, as was anticipated. Temperatures in the study seemed to influence moisture content of the three species to about the same degree, though they did not attain the same moisture content under the same conditions. Differences in moisture content caused by temperature, though statistically significant, are rather small—about 1 percent moisture content at a nominal 6 percent EMC. Effect of temperature for a given temperature difference increases above about 150 F.

The influence of EMC conditions during drying on moisture content attained at equilibrium is obscure, because a general pattern was not established for the three species. At any rate, differences within the range of conditions studied were smaller than differences caused by temperature, and at most were less than 0.5 percent moisture content at a nominal 6 percent EMC.

All three species shrank more at high than at low temperatures, but the species were not affected to the same degree. Douglas fir was affected least, and red alder was affected, by far, the most. Depending on the EMC conditions during drying, shrinkage was increased in Douglas fir by a factor of up to 1.5, hemlock by up to 2.1, and alder by up to 2.3. All three species tended to show an increasing effect of temperature above 150 to 180 F.

EMC conditions during drying, within the range of this study, did not influence shrinkage of Douglas fir, but it did affect western hemlock and red alder. With these two species, shrinkage was greater with drying conditions for 12 percent EMC than it was when drying conditions were set for 6 or 9 percent.

Shrinkage for a unit change in moisture content in the range from about 12 percent to the ovendry condition is the same for material dried at high temperature as it is for material dried at low temperature, but total shrinkage from one equilibrium condition to another is less for the material dried at high temperature because of a smaller change in moisture content.

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

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