Effect of Kiln Temperatures on Strength of Douglas Fir and Western Hemlock Dimension Lumber

By Charles J. Kozlik

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Forest Research Laboratory
School of Forestry
OREGON STATE UNIVERSITY
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PROGRAM AND PURPOSE

The program of the Forest Research Laboratory is designed to provide information that will improve techniques of forest management and promote full utilization of forest products. Able specialists with well-equipped laboratories study Oregon's forest resources, supported by the forest industry and by state and federal funds.

Research in this field by wood scientists and technologists, chemists, and engineers includes studies of properties, processing, utilization, and marketing of wood and of timber by-products. Technical principles derived through this research can be applied to the operation of Oregon's forest industry.

The PROGRAM of research includes

- identifying and developing chemicals from wood,
- improving pulping of wood and wood residues,
- investigating and improving manufacturing techniques,
- extending life of wood by treating,
- developing better methods of seasoning wood for higher quality and reduced costs,
- cooperating with forest scientists to determine effects of growing conditions on wood properties, and
- evaluating engineering properties of wood and wood-based materials and structures.

The PURPOSE of research on forest products is to provide information that will enable the forest industry to expand markets, create new jobs, and bring more dollar returns by

>developing products from residues and timber now wasted, and

>improving treatment and design of present wood products.

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SUMMARY

To test the effects of kiln temperatures on the bending strength of 2- by 6-inch Douglas fir and western hemlock dimension lumber, temperatures applied included 70 (control), 170, 200, and 230 F.

Modulus of elasticity was affected least by increasing temperature. Modulus of rupture in Douglas fir was affected most. The higher the temperature, the greater the reduction in the modulus of rupture. Reduction as high as 23 percent took place on Douglas fir wood dried at 230 F. Modulus of rupture was reduced by 10 to 18 percent in western hemlock dried at 230 F.

Split and crook were the most common forms of seasoning degrade.

ACKNOWLEDGMENTS

Kenneth A. Birch and Louis W. Hamlin assisted greatly with collecting pieces studied, assigning strength ratios, and testing specimens.

EFFECT OF KILN TEMPERATURES ON STRENGTH OF DOUGLAS FIR AND WESTERN HEMLOCK DIMENSION LUMBER

Charles J. Kozlik

INTRODUCTION

Need for information on the effect of high temperatures in drying on the strength of dimension lumber prompted this study. Strength is important in lumber for structural purposes, and, although the effects of high temperatures are known for small, clear pieces of Douglas fir and western hemlock (5),[1] such information has not been available for full-size pieces that contain knots and other natural variations.

Previous studies have shown that increasing temperature adversely affects the strength properties of wood. Most investigations tested small clear specimens or clear specimens cut from timbers or dimension lumber. For example, Kozlik (5) and Salamon (9, 10) have reported reductions of 20 percent and higher in modulus of rupture in small clear specimens at drying temperatures of 230 F. Johnson (4) and Graham (3), however, used 12-foot-long dimension lumber, 2- by 6-inch, to study the effect on the strength of air or kiln-dried Douglas fir treated with fire retardants.

Graham's (3) and Lowery and Krier's (7) bibliographies included most of the published reports dealing with the effect of temperature on the strength of wood.

During the past five years, many producers have been drying wood with kiln temperatures ranging from 180 to above 212 F. To study the effect of temperature on strength properties, namely modulus of rupture and modulus of elasticity, commercial kiln schedules were followed to dry full-size members containing knots, distorted grain, and other defects. When drying lumber with natural strength-reducing characteristics, such as knots, this question remained: Does the reduction in strength properties remain within the same range as temperatures are raised?

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[1] Numbers in parentheses refer to literature cited.

PROCEDURE

After selecting an appropriate design for the experiment and de- termining lumber size and kiln temperatures, we collected and processed the material. "Matched" specimens of lumber were chosen so that the statistical analyses of the results would convey an understandin of the effect of temperature on the bending properties of the included species. The charges of seasoned lumber contained one piece of lumbe from each group of four pieces that had almost identical values for mod ulus of elasticity when tested nondestructively before seasoning.

Design of experiment

The experiment was designed to investigate effect of kiln temperatures on the bending properties of nominal 2- by 6-inch by 10-foot Douglas fir and western hemlock dimension lumber when dried to an average moisture content of 15 percent. Bending properties included modulus of elasticity (MOE) and modulus of rupture (MOR). Temperatures selected were 70 (basis for comparing other temperatures), 170, 200, and 230. F. Because it was desirable to duplicate commercial practice, total drying time and conditions for equilibrium moisture con tent (EMC) varied for each temperature.

Specimens were selected on the basis of the strength-ratio classes (40, 60, and 80 percent of the strength of defect-free wood) in accordance with ASTM Standards D245-64 T (1), with the critical knot in the middle third of the total span. Limits of each strength-ratio class were set for its mid-range; for example, the 40 percent class included pieces from 42 to 48 percent.

I studied the effect of temperature on bending properties of seasoned specimens by following a randomized block design with the replications based on values for MOE of unseasoned pieces within each of three chosen strength-ratio classes (40, 60, and 80 percent). The unseasoned specimens were tested nondestructively for MOE when placed on edge under approximate third-point loading (reaction and load points spaced 39, 36, and 39 inches). Critical knots were located on the tension side of specimens. The applied load was well below fiber stress a proportional limit. Values for MOE for unseasoned specimens were arranged in ascending order within each strength-ratio class for each species. The four "matched" unseasoned specimens with the lowest values for MOE were randomly assigned to the four test temperatures. Then the unseasoned specimens with the next four lowest values for MOE were assigned randomly, and so on. For each temperature, withi each strength-ratio class, I tested 44 specimens of Douglas fir and 50 specimens of western hemlock.

Collecting and processing of test material

Unseasoned and rough 2- by 6-inch dimension lumber 10, 12, and 14 feet long was collected from seven mills in the Willamette Valley in Oregon. I based selection on the following requirements:

1. Slope of grain not more than 1 inch in 16.
2. Freedom from shake, split, rot, and areas of concentrated pitch.
3. Assignment of strength-ratio class (40, 60, and 80 percent).

When the test material arrived at the laboratory, one surface and one edge of the boards were planed and strength ratios were rechecked. All boards were sawed to 10-foot lengths. Samples to measure moisture content were taken only from boards sawed from the original 12- or 14-foot lengths. We measured moisture contents for unseasoned pieces of both species (Figures 1 and 2). The mean moisture content of Douglas fir specimens was 42.3 percent and of western hemlock specimens was 85.6 percent, based on dry weight of the wood.

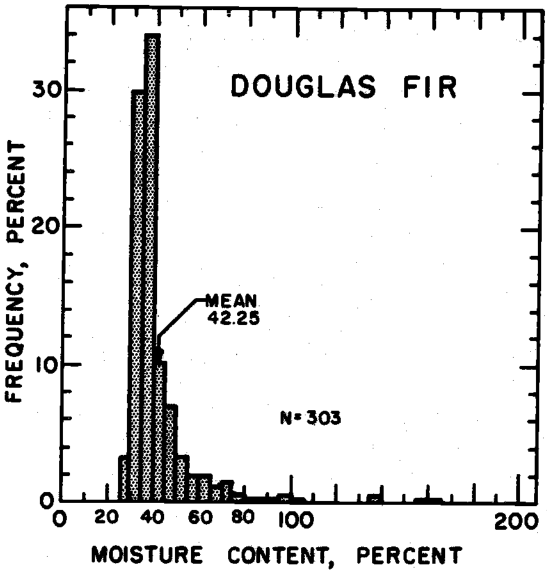
Drying test boards

Test charges were dried in the laboratory's experimental dry kilns. Temperatures were held constant, and conditions for EMC were varied to approximate commercial schedules. Kiln time was equivalent to commercial practice, so that the final moisture content would average 15 percent. The charges dried at 70 F were stickered and piled inside the laboratory for 7 months. The kiln schedules for both species are shown in Figures 3 and 4. Average and range of final moisture content after kiln drying of each species are in Table 1, except for the boards that were air dried at 70 F.

Table 1. Average and Range of Final Moisture Content After Kiln Drying Douglas Fir and Western Hemlock.

Temperature	Moisture content: Range	Moisture content: Average
Deg F	Percent	Percent
Douglas fir		
170	11-20	14.7
200	9-21	15.1
230	9-23	13.5
Western hemlock		
170	9-30	14.2
200	8-30+	14.4
230	8-30	12.5

Figure 1. Moisture contents of 303 unseasoned specimens of Douglas fir.



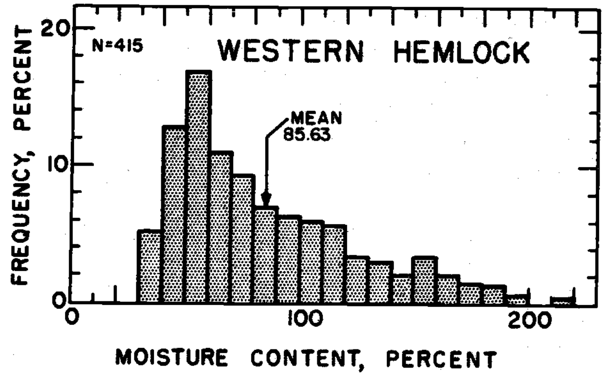


Figure 2. Moisture contents of 415 unseasoned specimens of western hemlock.

After the lumber was kiln dried, it was stickered and piled inside the laboratory for about 4 months. When the lumber had equalized, it was planed on all four sides at a commercial plant to 1 5/8 inches in thickness and 5 1/2 inches in width. The lumber was again checked for strength-ratio classification. Boards not maintaining the original strength-ratio classification were removed, as were the other specimens within the same replication. The final number of specimens in each of the four temperature classes for Douglas fir was as follows: 40 percent strength-ratio class, 35 specimens; 60 percent strength-ratio class, 40 specimens; and 80 percent strength-ratio class, 38 specimens. Western hemlock had specimens as follows: 40 percent strength-ratio class, 45 specimens; 60 percent strength-ratio class, 46 specimens; and 80 percent strength-ratio class, 46 specimens.

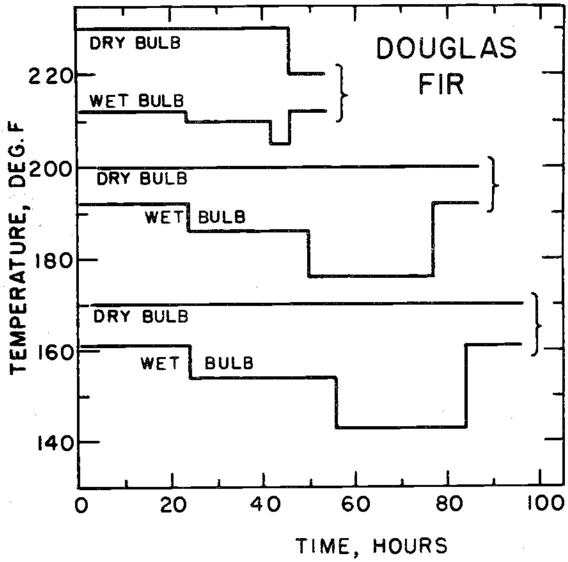


Figure 3. Kiln schedules for Douglas fir.

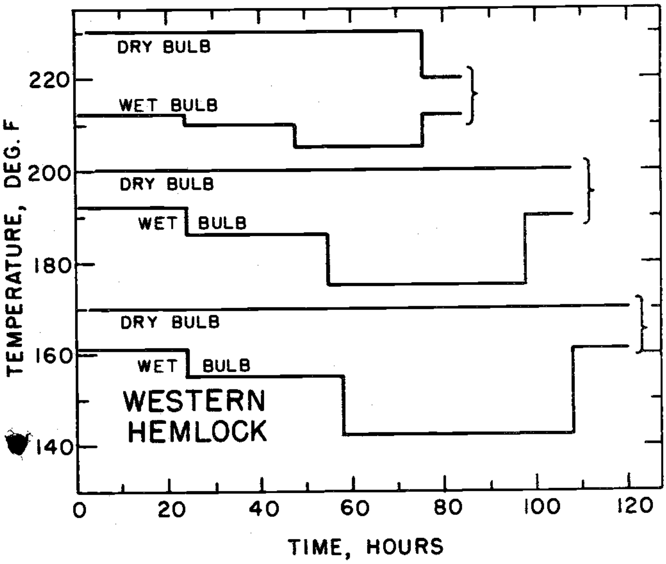


Figure 4. Kiln schedules for western hemlock.

Testing

The specimens were tested for static bending following the procedure set forth in ASTM Standards D 198-27 (1). Span length was 114 inches. Load-deflection curves were plotted by an electronic x-y recorder.

A wafer was cut from each tested specimen to determine moisture content and specific gravity. Specific gravity was based on weight when oven dry and volume of moisture content at time of test.

Analyzing

Calculations included moisture content, specific gravity, modulus of elasticity, and modulus of rupture. From these computations, means and coefficient of variation for each property were determined for the test temperatures. A randomized block analysis provided inferences about the effect of temperature on bending properties. Significant differences at the 5 percent level of probability were determined by Duncan's multiple-range test (6).

RESULTS AND DISCUSSION

Summaries of mean values increase from left to right in tables showing strength properties. Values not different at the 5 percent level of significance are underscored with a common line, and coefficients of variation are listed for each property.

Close agreement of mean for specific gravity is indicated by underlining values that did not test differently at the 5 percent level of significance (Table 2).

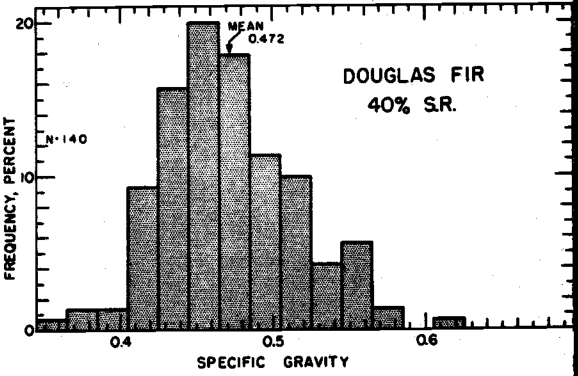
Table 2. Mean Values and Coefficients of Variation for Specific Gravity of Douglas Fir and Western Hemlock.

Units	Order[1]				Coefficient of variation	Ratio, low mean / high mean
	1	2	3	4		
					Percent	Percent
DOUGLAS FIR						
At 40 percent strength ratio						
Temp, Deg F	170	200	70	230		
Specific gravity	0.468	0.470	0.475	0.476	8	98.3
At 60 percent strength ratio						
Temp, Deg F	170	70	230	200	8	99.0
Specific gravity	0.473	0.474	0.475	0.478		
At 80 percent strength ratio						
Temp, Deg F	230	200	170	70	7	98.4
Specific gravity	0.505	0.511	0.512	0.513		
WESTERN HEMLOCK						
At 40 percent strength ratio						
Temp, Deg F	230	170	200	70	9	96.8
Specific gravity	0.427	0.432	0.438	0.441		
At 60 percent strength ratio						
Temp, Deg F	200	70	230	170	7	99.5
Specific gravity	0.441	0.442	0.443	0.443		
At 80 percent strength ratio						
Temp, Deg F	200	70	170	230	8	98.0
Specific gravity	0.445	0.448	0.448	0.454		

[1]Values are arranged in order of increasing magnitude; there were no differences at the 5 percent level of significance according to Duncan's multiple-range test (6), as indicated by common underlining.

The distribution of specific gravity is shown for all Douglas fir specimens (Figures 5-7), and western hemlock specimens (Figures 8-10) within each strength-ratio class. Mean specific gravity for each species tended to increase as the strength-ratio increased.

Figure 5. Distribution of specific gravity for 140 Douglas fir specimens in the 40 percent strength-ratio class.



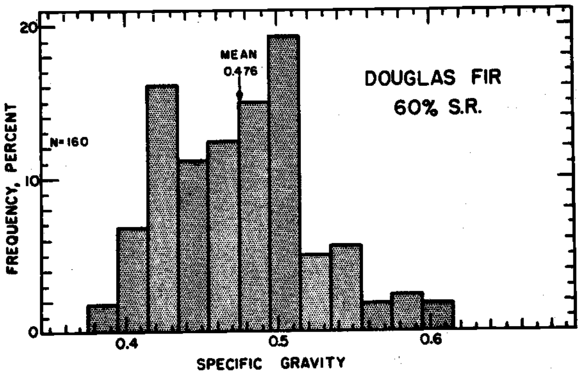


Figure 6. Distribution of specific gravity for 160 Douglas fir specimens in the 60 percent strength-ratio class.

Figure 7. Distribution of specific gravity for 152 Douglas fir specimens in the 80 percent strength-ratio class.

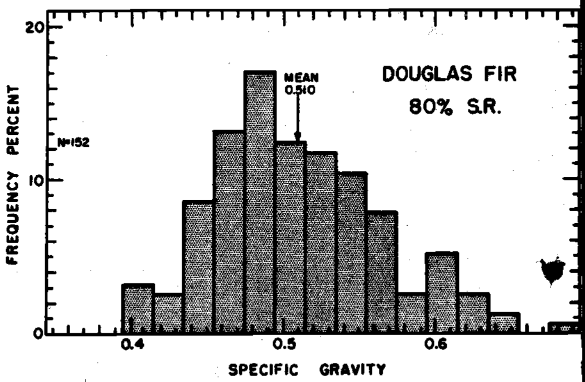
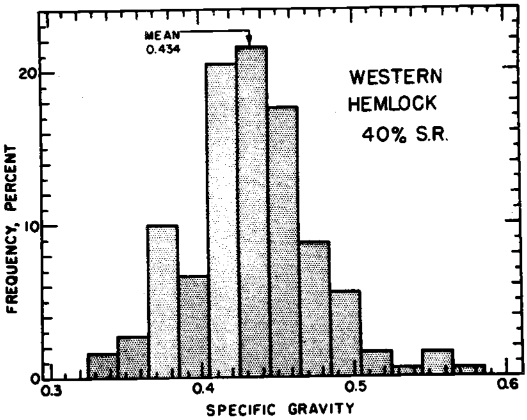


Figure 8. Distribution of specific gravity for 180 western hemlock specimens in the 40 percent strength-ratio class.



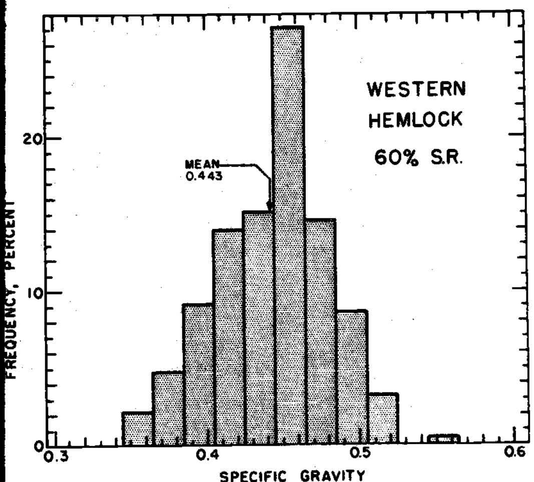
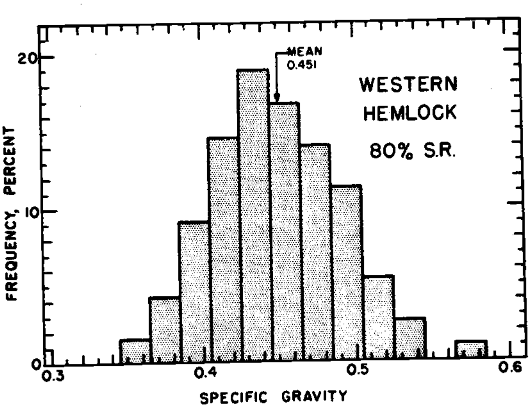


Figure 9. Distribution of specific gravity for 184 western hemlock specimens in the 60 percent strength-ratio class.

Figure 10. Distribution of specific gravity for 184 western hemlock specimens in the 80 percent strength-ratio class.



Moisture content

The average moisture content of the specimens at time of test in static bending showed significant differences at each temperature in each strength-ratio class of Douglas fir, but only in the 80 percent strength-ratio class of western hemlock (Table 3).

Although significant differences existed in Douglas fir specimens the greatest difference, 1.15 percentage points between the high and low means in the 60 percent strength-ratio class, could not be considered as a factor influencing strength properties of wood. Values for MOE and MOR were based on actual moisture content and were not adjusted to a base level. The low value for the coefficient of variation illustrated that values for moisture content were closely grouped around the mean.

Although significant differences did not exist in the western hemlock, except in the 80 percent strength-ratio class, a difference of 0.98 percentage point between the high and low mean moisture contents in the 60 percent strength-ratio class was similar to the Douglas fir. The coefficient of variation in the western hemlock was considerably higher than in Douglas fir (Table 3).

The greatest range in moisture content at a given temperature for all strength-ratio classes was in Douglas fir. The moisture content ranged from 6.41 to 9.36 percent for Douglas fir specimens dried at 230 F. Maximum range of moisture content was 7.70 to 9.62 percent for western hemlock specimens dried at 230 F. A plot of individual values for moisture content for both species revealed, however, that the bulk of the values for moisture content in Douglas fir were closely grouped near the mean value. In contrast, values for moisture content for the western hemlock were scattered; this explains the high values fo coefficients of variation.

Modulus of elasticity

In assigning unseasoned specimens to replications of the randomized block, nearly identical mean values for MOE were anticipated for each temperature within each strength-ratio class (Table 4). The small differences, which were compiled for only the boards included in the final static bending tests, illustrate that the specimens were very closely matched.

Effect of temperature on MOE showed no significant differences in any of the strength-ratio classes for either species (Table 5). Kozlik (5), MacLean (8), and Salamon (9) have shown that MOE was reduced from 5 to 7 percent as temperature increased while drying small clear Douglas fir specimens. Low temperatures in those studies ranged from 80 to 170 F, and the high temperatures ranged from 215 F to

230 F. This study, on full-size dimension lumber, showed a reduction of from 2 to 3 percent in MOE from low to high mean values, but the lowest mean was not necessarily associated with the highest temperature.

In testing small clear specimens of western hemlock for MOE, no significant difference, based on the 5 percent level of probability, was found in specimens dried at temperatures from 90 to 230 F. In one series of tests, Salamon (10) also found no significant change in MOE, at the 99 percent confidence level, in specimens dried at temperatures from 70 to 225 F. In a second series of tests, however, MOE was significantly influenced by the temperature of 225 F.

Table 3. Mean Values and Coefficients of Variation for Moisture Content of Douglas Fir and Western Hemlock at Test.

Units	Order[1]				Coefficient of variation
	1	2	3	4	Percent
DOUGLAS FIR					
At 40 percent strength ratio					
Temp, Deg F	230	200	170	70	4
Moisture content, %	7.76	8.11	8.54	8.86	
At 60 percent strength ratio					
Temp, Deg F	230	200	170	70	4
Moisture content, %	7.66	8.24	8.57	8.81	
At 80 percent strength ratio					
Temp, Deg F	230	200	170	70	5
Moisture content, %	7.68	8.16	8.44	8.75	
WESTERN HEMLOCK					
At 40 percent strength ratio					
Temp, Deg F	70	230	200	170	16
Moisture content, %	8.70	8.71	9.11	9.39	
At 60 percent strength ratio					
Temp, Deg F	70	230	170	200	22
Moisture content, %	8.35	8.70	8.82	9.33	
At 80 percent strength ratio					
Temp, Deg F	230	170	200	70	11
Moisture content, %	8.68	9.13	9.25	9.32	

[1]Values are arranged in order of increasing magnitude; those underscored by a common line were not different at the 5 percent level of significance according to Duncan's multiple-range test (6).

Table 4. Mean Values for Modulus of Elasticity for Each Temperature Within Each Strength-Ratio Class.

Strength-ratio class	Temperature	MOE	Ratio, low mean / high mean[1]
Percent	Deg F	M psi	Percent
Douglas fir			
40	70	1,232	99.9
	170	1,233	100.0
	200	1,231	99.8
	230	1,230	99.8
60	70	1,429	100.0
	170	1,424	99.6
	200	1,428	99.9
	230	1,421	99.4
80	70	1,707	99.7
	170	1,712	100.0
	200	1,708	99.8
	230	1,701	99.4
Western hemlock			
40	70	1,164	100.0
	170	1,164	100.0
	200	1,163	99.9
	230	1,164	100.0
60	70	1,292	99.8
	170	1,295	100.0
	200	1,294	99.9
	230	1,293	99.8
80	70	1,405	99.9
	170	1,406	100.0
	200	1,404	99.8
	230	1,402	99.7

[1] High mean value within each strength-ratio class for each species was the basis for comparison on the 100% level.

Modulus of rupture

Effect of temperature on MOR was significant in all strength-ratio classes of Douglas fir, but it was effective only in the 60 percent strength-ratio class of western hemlock (Table 6).

Modulus of rupture was reduced 22 to 23 percent when Douglas fir specimens were dried with temperatures increasing from 70 and 170

Table 5. Mean Values and Coefficients of Variation for Effect of Temperature on Modulus of Elasticity of Douglas Fir and Western Hemlock.

Units	Order[1]				Coefficient of variation
	1	2	3	4	Percent
		DOUGLAS FIR			
t 40 percent strength ratio					
'emp, Deg F	70	200	230	170	12
IOE, M psi	1399	1400	1411	1442	
t 60 percent strength ratio					
'emp, Deg F	70	200	170	230	7
IOE, M psi	1668	1674	1691	1721	
t 80 percent strength ratio					
'emp, Deg F	200	230	70	170	6
IOE, M psi	2076	2080	2098	2116	
		WESTERN HEMLOCK			
t 40 percent strength ratio					
emp, Deg F	200	170	70	230	10
IOE, M psi	1379	1385	1413	1431	
t 60 percent strength ratio					
emp, Deg F	230	170	70	200	10
IOE, M psi	1572	1584	1588	1630	
t 80 percent strength ratio					
emp, Deg F	170	200	230	70	8
IOE, M psi	1808	1826	1832	1858	

Values are arranged in order of increasing magnitude; those underscored by a common line show no significant difference according to Duncan's multiple-range test (6).

230 F. The significant ranges of temperature varied for each strength-atio class. In the 40 percent strength-ratio class, lumber dried at 0 F was significantly stronger than pieces dried at 200 and 230 F. In e 60 percent strength-ratio class, lumber dried at 70 and 170 F was ignificantly stronger than pieces seasoned at 200 and 230 F. In the 0 percent strength-ratio class, lumber dried at 230 F was significantly ifferent from the other three test temperatures. Observation of the eans for MOR at each temperature, within each strength-ratio class, evealed that the greatest decrease in MOR occurred at about 200 F 'igure 11).

I (5) made the same observation when small clear specimens o Douglas fir were dried at the test temperature of 195 F. Eddy (2) showed 20 percent reduction in MOR when 2-inch clear Douglas fir squares were dried in organic vapors at temperatures of 250 F. Salamon (9) showed that reductions in MOR ranged from 9 to 17 perce when 1-inch clear Douglas fir squares were dried at 212 to 240 F.

No significant difference occurred in modulus of rupture for western hemlock in the 40 and 80 percent strength-ratio classes; in th 60 percent strength-ratio class, MOR in wood dried at 230 F was sig-

Table 6. Mean Values and Coefficients of Variation for Effect of Temperature on Modulus of Rupture of Douglas Fir and Western Hemlock.

Units	Order[1]				Coefficient variation
	1	2	3	4	Percent
		DOUGLAS FIR			
At 40 percent strength ratio					
Temp, Deg F	230	200	170	70	33
MOR, Psi	2803	3060	3301	3613	
At 60 percent strength ratio					
Temp, Deg F	230	200	170	70	30
MOR, Psi	4076	4444	5171	5279	
At 80 percent strength ratio					
Temp, Deg F	230	200	70	170	25
MOR, Psi	7064	8360	8827	8994	
		WESTERN HEMLOCK			
At 40 percent strength ratio					
Temp, Deg F	230	200	70	170	34
MOR, Psi	3252	3346	3425	3610	
At 60 percent strength ratio					
Temp, Deg F	230	170	200	70	27
MOR, Psi	4454	5154	5208	5427	
At 80 percent strength ratio					
Temp, Deg F	230	200	70	170	23
MOR, Psi	7327	7669	7880	8158	

[1]Values are arranged in order of increasing magnitude; those underscored by a common line show no significant difference according to Duncan's multiple-range test (6).

nificantly different from the other test temperatures. Increasing temperature reduced MOR by 18 percent in the 60 percent strength-ratio class. The 40 and 80 percent strength-ratio classes had reductions of 10 percent in wood dried at temperatures from 170 F to 230 F. Plotting of the means revealed that the greatest reduction in MOR occurred in the specimens dried from 170 to 200 F (Figure 12).

In previous work, I (5) found reductions of 6 to 12 percent in MOR in 1 1/2-inch clear western hemlock squares when dried at 215-230 F, rather than 180 F. Salamon (10), drying 1/2-inch clear western hemlock squares, found significant differences at the 99 percent confidence level in wood dried at 70 and 225 F; the reduction averaged 29 percent. The disparity of results from the three studies cannot be explained and suggests a need for additional research.

Drying lumber at temperatures above 200 F reduced the values for MOR for both species, and this reduction cannot be visually determined. Johnson (4) suggested that mechanical stress grading could determine this reduction providing the appropriate relation for MOE-MOR was applied.

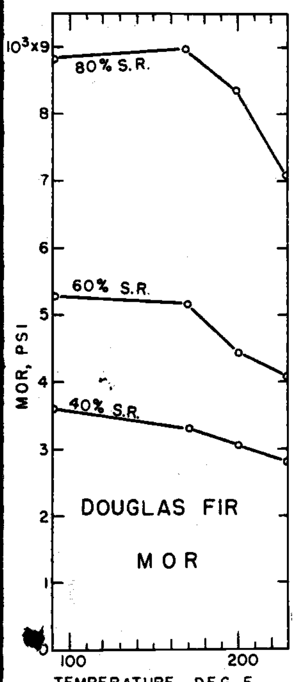


Figure 11. Douglas fir.

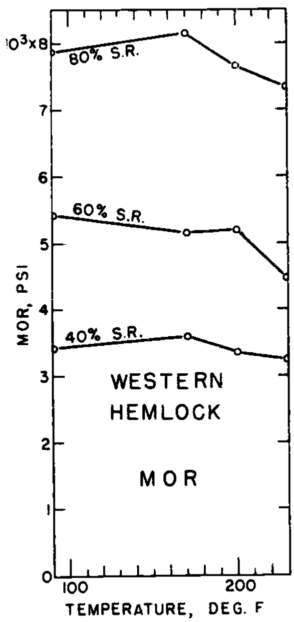


Figure 12. Western hemlock.

Effect of temperature on modulus of rupture within each strength-ratio class.

Degrade of seasoned specimens

In this study, I also considered seasoning degrade. Following planing, all specimens were graded in accordance with the standard grading rules of the Western Wood Products Association. Because all unseasoned lumber was free of splits, checks, and various forms of warp, I considered that these degrading factors occurred during drying; because shake is not generally visible in unseasoned lumber, I did not consider that shake was necessarily a drying defect, especially in western hemlock. All pieces degraded by splits and shake were removed from the sample before the strength tests. In all, five boards of Douglas fir and 12 boards of western hemlock were degraded (Table 7).

End split and crook were the most common forms of defects in both species. In the western hemlock, increasing temperature tended to increase the seasoning defects. The sample size, however, would be considered small for a degrade study and merely an indication of the effect of temperature on degrade.

Table 7. Seasoning Degrade in Douglas Fir and Western Hemlock.

Grade[1]		Defect	Kiln temperature
Undried	Dried		
			Degrees F
Douglas fir			
Select	Utility	Split	230
Select	Utility	Crook	200
Select	Utility	Crook	90
Construction	Standard	Bow	200
Standard	Utility	Split	90
Western hemlock			
Select	Construction	Twist	230
Select	Standard	Split	90
Select	Standard	Split	230
Select	Utility	Crook	200
Select	Economy	Crook	200
Construction	Standard	Crook	200
Construction	Standard	Split	170
Construction	Standard	Split	230
Construction	Utility	Split	230
Standard	Utility	Crook	170
Standard	Utility	Split	200
Standard	Utility	Split	230

[1] Each grade listed is that of an individual piece of lumber before and after drying.

CONCLUSIONS

. Effect of temperature on MOE of Douglas fir and western hemlock was not significant. No particular temperature necessarily produced the lowest mean value for MOE.

Mean values of MOR for Douglas fir dried at 230 F were significantly lower than values for specimens dried at 70 F or 170 F. Specimens dried at 230 F were only about 8/10 as strong in bending as were those dried at 70 F.
Mean values of MOR for western hemlock were not significantly different regardless of drying temperature for specimens in the 40 and 80 percent strength-ratio classes. In the 60 percent strength-ratio class, however, pieces dried at 230 F were somewhat less than 9/10 as strong in bending as were those dried at the other temperatures.

. Moisture content after storage of Douglas fir was significantly different at each test temperature; therefore, the equilibrium moisture content of the wood was lowered as temperature increased. Increasing temperature did not lower the equilibrium moisture content of western hemlock specimens.

. Split and crook were the most common forms of degrade in drying Douglas fir and western hemlock.

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