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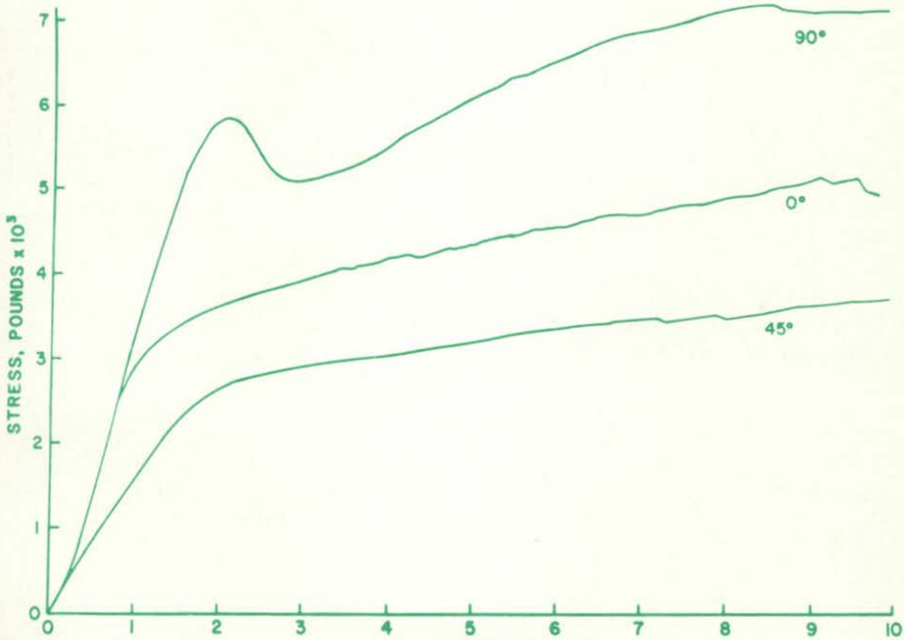
Transverse Compression Of Inland Douglas Fir



by

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Abstract

Twenty-five transverse compression specimens for each of seven growth ring orientations and for three moisture content levels were tested. Compression perpendicular to grain was influenced by moisture content and growth ring angle. Compression strength increased with decreased moisture content. Compression strength decreased from maximum at 0° and 90° to a minimum at 45°.

Modulus of elasticity decreased with an increase in number of growth rings-per-inch and increased with an increase in specific gravity.

TRANSVERSE COMPRESSION OF INLAND DOUGLAS FIR[1]

by

A. D. Hofstrand[2]

Although stress often is applied to wood at an angle perpendicular to the grain, we know little about the action of such stresses within wood. Knowledge of the reaction of wood to these stresses are of importance, not only in structural design, but also to manufacturers of pressed panel products including plywood, fiberboard, and particleboard.

Transverse compression can occur by a load being distributed over the entire surface or concentrated over a portion of the specimen surface. In the first instance, the true resistance to simple crushing is obtained. Examples of this type of load application are common to the manufacture of plywood and laminated beams. In the latter, a post resting on a sill plate or a rail on a cross-tie are examples of concentrated load. This latter condition also forms the basis for making standard transverse compression tests (ASTM 1949).

For softwoods (conifers), the stress above which permanent damage (proportional limit stress) occurs is about the same regardless of direction of transverse compression (Anon 1958). However, several investigators maintain there are differences between tangential and radial compression and that these differences are functions of anatomic structure (Bazhenov, et. al. 1943; Bodig 1963, 1965; Ivanov 1953; Kunesh 1961, 1968; and Perelvgin 1965). Non-uniformity of annual rings may cause conifers to have proportional limit stresses 50 percent greater in the tangential direction than in the radial direction (Perelvgin 1965). Bodig (1963) substantiated this generalization for Douglas fir, but not for western red cedar. Several investigators attribute failure to the crushing of fibers at the border for the annual ring (Bodig 1963, Ivanov 1953, and Vikhov 1953). The size and quantity of rays were found to increase both the proportional limit stress and elastic properties in radial compression of hardwoods (Bodig 1963, Kunesh 1961, and Schniewind 1959). Characteristics of the growth rings are critical in controlling transverse compression. The density contrast between earlywood and latewood and the intermediate orientation of growth rings between the radial and tangential positions influence the compression perpendicular to the grain strength (Kollmann 1959). Results of several investigations indicate that transverse compression is minimum at an annual ring orientation of 45^0 to the direction of stress (Alexander and Smith 1950, 1951; Kennedy 1968; and Kollmann 1959).

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I studied transverse compression stress at various levels and elastic properties under seven growth ring orientations ranging from pure radial to pure tangential loading and at three moisture content levels. Radial and tangential loading are defined as application of load perpendicular and parallel to the annual rings. I also studied how compressive stress was influenced by height in the tree bole.

Method

A single Douglas fir, *Pseudotsuga menziesii* (Mish.) Franco, was selected. The tree had a straight bole and nearly uniform circumference throughout the bole length. Two-foot lengths were cut along the bole to the base of the live crown. These two-foot lengths were end-coated to reduce moisture loss and tagged as to position in the bole. Each two-foot section was further subdivided into three 8-inch sections. From each section, seven specimens representing ring orientations (with respect to direction of load) of 0°, 15°, 30°, 45°, 60°, 75° and 90°, respectively, were prepared. No attempt was made to match specimens from each section as to specific gravity, rings-per-inch or position in the section's cross-section. Also, no attempt was made to cut specimens from the outer periphery of each section, although an attempt was made to reduce the degree of curvature of the growth rings to a minimum. Test specimens from a given two-foot section were randomly selected for testing at one of three moisture content levels (green, 12% and 6%).

Individual specimens, 2 inches by 2 inches in cross-section and 6 inches long, were compressed by a 2-inch wide plate placed on the central 2 inches of the specimen. The compression load was applied at a rate of 0.024 inch per minute resulting in a rate of strain of 0.012 inch per minute. Load-deformation curves were recorded continuously on an X-Y strip-chart recorder. Specimens were stressed until the maximum compression was 10 percent of the original uncompressed thickness. This test procedure conformed to ASTM Standard D-143-49 with the following exceptions: growth ring orientation varied, and compression was carried beyond the normal 0.1 inch compression.

Specific gravity (o.d. volume - o.d. weight), rings-per-inch and percent latewood were measured on a small section cut from each test specimen after the compression test was completed. Percentage latewood was measured on cross-sections using a microscope (Howe 1961). Mork's (1968) definition of latewood was used to estimate percentage latewood.

Stress at the proportional limit, stress at maximum compression (maximum stress), modulus of elasticity, rings-per-inch, percent latewood and specific gravity were analyzed statistically by analysis of variance. Regression and correlation analyses were made between the physical properties; rings-per-inch, percent latewood, specific gravity and the mechanical properties; proportional limit stress, maximum stress, modulus of elasticity.

Results and Discussion

Initially, I used two methods of measuring compression perpendicular to the grain. The first suggested by Ivanov (1953) estimates strain of plastic flow by a tangent line starting from the origin of the stress strain curve. I abandoned this approach when it became apparent that the point of tangency was extremely difficult to accurately pinpoint. Bodig (1963) found that he had the same difficulty in determining the point of tangency. The second approach utilized the standard ASTM method of finding the proportional limit strain (ASTM 1949). In this method, the strain at proportional limit is measured from the extended straight line section of the initial portion of the stress-strain curve.

The shape of the stress-strain curve in transverse compression is influenced by the characteristics and anatomy of the annual growth ring (Fig. 1). The slope or ascent of the elastic curve was generally greatest at ring orientations 0° and 90° and the least at ring orientation of 45° to the applied load. In general, the

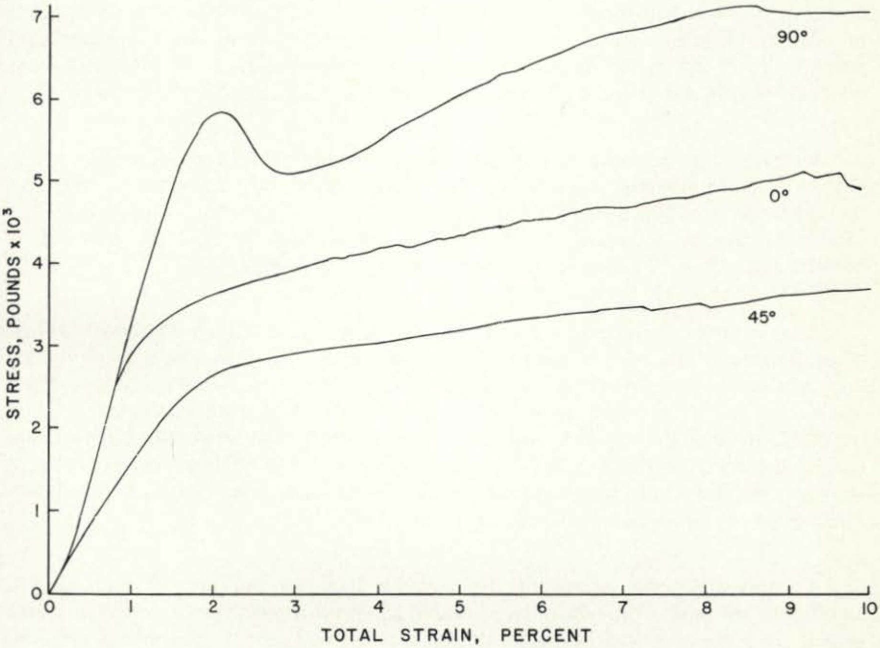

FIGURE 1—Typical transverse compression stress-strain curves for specimens tested at 0°, 45°, and 90° growth ring orientations.

average transverse compressive load was greatest at ring orientations approaching 90° (perpendicular to the growth rings). This agreed with results obtained by a number of investigators.

Analysis of variance indicated extreme variability existed between specimens for all properties measured (Table 1). Much of this variability was expected since the method of specimen selection and preparation precluded uniform test specimens. Also, within tree variations often are known to be significant. Variability might have been reduced by matching test specimens.

Moisture content also significantly influenced the ability of wood to resist transverse compression stresses (Table 1). Higher proportional limit stresses, moduli of elasticity, and maximum stress values were found, when present for any growth ring orientation, to be associated with lower moisture contents.

Moisture content level influenced modulus of elasticity in transverse compression (Figs. 2, 3). A family of curves was generated having about the same shape with the relative position of each curve related to a certain moisture content level.

As moisture content decreased from above fiber saturation (green) to 12 percent, the average modulus of elasticity increased approximately 85 percent and increased about 90 percent when moisture content level was decreased to 6 percent from the green condition. The increase in modulus of elasticity with decreasing moisture content holds true regardless of growth ring orientation.

Moisture content also influenced proportional limit load and maximum stress (Table 2). An increase of approximately 100 percent in proportional limit load resulted from conditioning test specimens to 12 and 6 percent, respectively. For maximum stress, increase in stress values averaged 87 and 91 percent at moisture levels of 12 percent and 6 percent, respectively.

Examination of the proportional limit loads in Table 2 showed the existence of an anomaly. The relationship between modulus of elasticity and proportional limit stress is linear, other factors being equal. In this case, modulus of elasticity showed a definite trend toward higher values when pressure was applied perpendicular to the growth ring (90°). The proportional limit load showed the opposite trend. Higher proportional limit stresses were realized when pressure was applied parallel to the growth rings (0°) regardless of moisture content level. Just why this anomalism occurred is not known.

As expected, the angle of the applied load to the growth ring had a significant influence on modulus of elasticity, proportional limit, and maximum stress. The average stress value decreased to a minimum when the applied pressure was at an angle of 45° to the growth ring (Fig. 2, Table 2). The percentage reduction in modulus of elasticity, based on the ultimate modulus of elasticity, was 44, 47 and 57 percent for green, 12 and 6 percent moisture, respectively. Average modulus of elasticity at the 90° ring position was about the

Table 1. Analysis of Variance for Various Physical Properties of Wood in Compression Perpendicular to the Grain

	Degrees of Freedom	Proportional Limit $\times 10^4$	Rings per Inch	Per cent Latewood	Specific Gravity $\times 10^{-4}$	Modulus of Elasticity $\times 10^8$	Maximum Stress $\times 10^4$
Moisture (M)	2	9326.7**	47.3	374.5**	105.8**	583.1**	2188 **
Angle (A)	6	2782.7**	8188.0**	7.5	1.5	172.1**	135.9**
Replication (R)	24	56.9**	4380.0**	44.9**	11.6**	3.5**	7.6**
(MR)	48	20.4	1153.5**	11.4	3.2	1.3	2.3*
Error	444	19.8	820.0	12.5	3.8	1.2	1.7

** Significant at the 1% probability level
* Significant at the 5% probability level

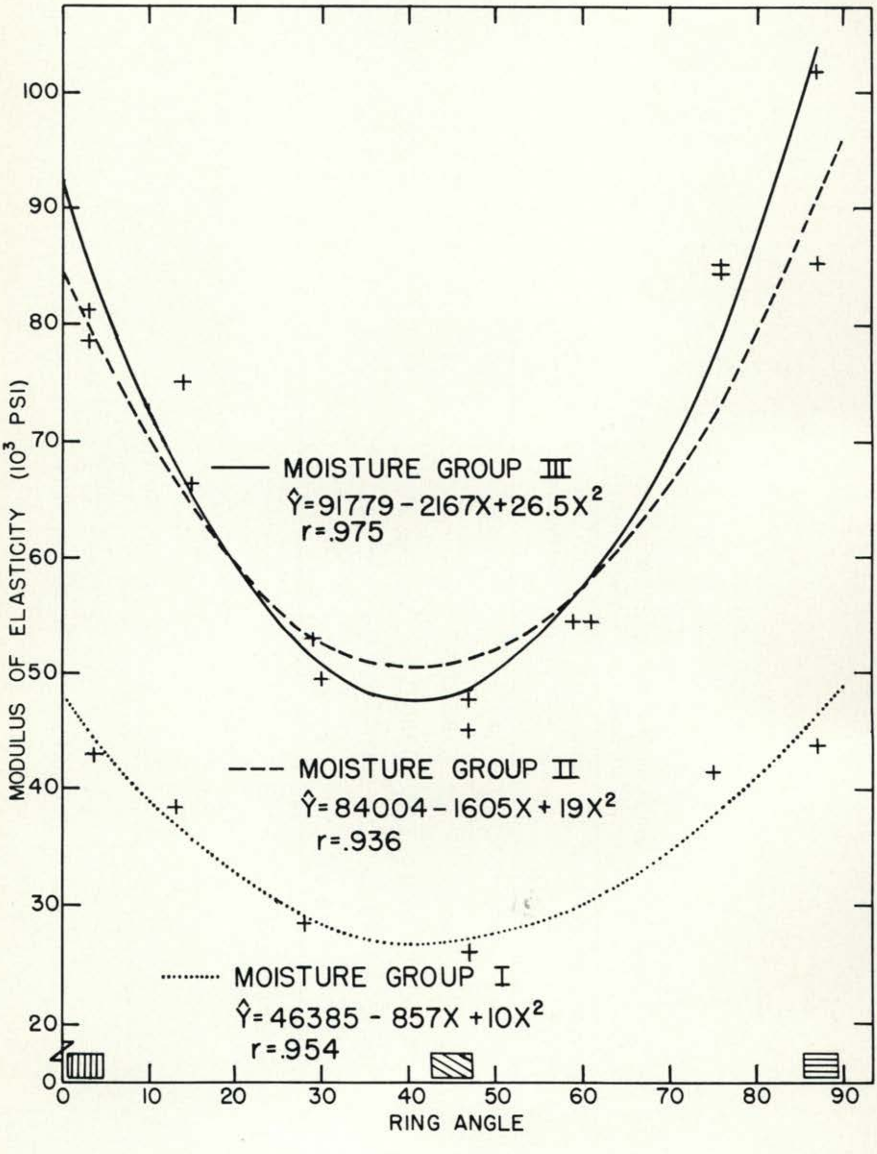

FIGURE 2—Relationship of modulus of elasticity and growth ring orientation for compression specimens tested green, at 12%, and at 6%.

same as that at the 0° ring position when test specimens were green and at 12 percent. However, when specimens were conditioned to 6 percent, the average modulus of elasticity at the 90° ring position was about 25 percent greater than that at the 0° ring position (Table 2).

The lowest stress at proportional limit was obtained when the growth rings were at an angle of 45° to the applied load,and was approximately one-half to two-thirds of the value obtained with growth rings at 0°, or parallel, to the

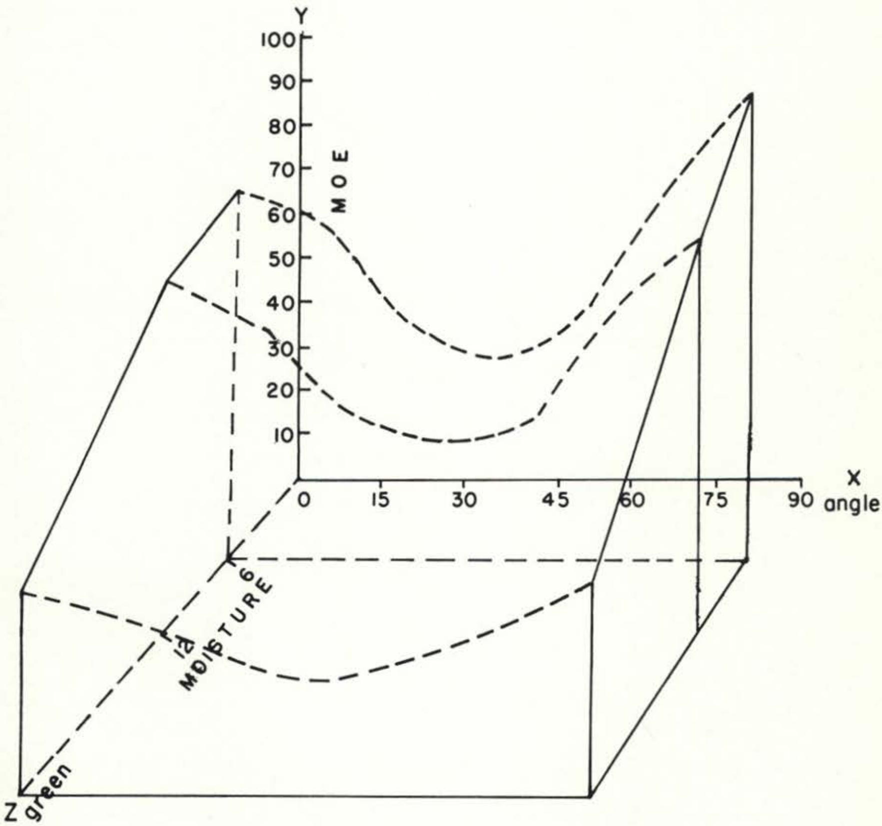

FIGURE 3—Graphic relationship between moisture content, growth ring orientation and modulus of elasticity for specimens tested in transverse compression.

direction of the applied load (Table 2).

Maximum stress followed the general trend — greatest at growth ring orientations of 0^0 and 90^0 to the applied load, and was reduced approximately 25 to 30 percent when the load was applied at a growth ring orientation of 45^0 (Table 2).

Transverse compression data were analyzed using a stepwise regression program. Specific gravity, percent latewood and rings-per-inch, respectively, were regressed against the strength properties, modulus of elasticity,

Table 2. Average Stress Values at Various Moisture Content Levels

Moisture Content Condition	Growth Ring Orientation	Property Measured		
		MOE	P.L.	Max. Stress
			Psi	
	0	43300	380	789
	15	38800	367	752
	30	28200	299	624
Green	45	26400	261	581
	60	29500	287	603
	75	37200	316	691
	90	47200	355	763
	0	80700	848	1433
	15	68200	751	1368
	30	51900	620	1238
12%	45	46300	566	1093
	60	52000	565	1121
	75	76000	682	1283
	90	88100	732	1448
	0	81300	871	1517
	15	75300	820	1500
	30	52200	643	1256
6%	45	44200	482	1048
	60	51600	545	1123
	75	79300	651	1323
	90	102100	751	1429

proportional limit stress, maximum stress, and the ratio of maximum stress to proportional limit stress. Analyses were made on test data from specimens tested in the green condition and at 6 percent moisture content. Correlation coefficients (Table 3) indicated no clear trend regarding the physical property contributing most toward the reduction of strength variability. For green specimens, specific gravity was entered first 12 times, rings-per-inch 9 times and percent latewood 7 times. While, for specimens at 6 percent, rings-per-inch was entered first 17 times and percent latewood 10 times. While a number of significant correlation coefficients were noted in Table 3, the degree of significance was too low in most instances to be of value for predictive purposes.

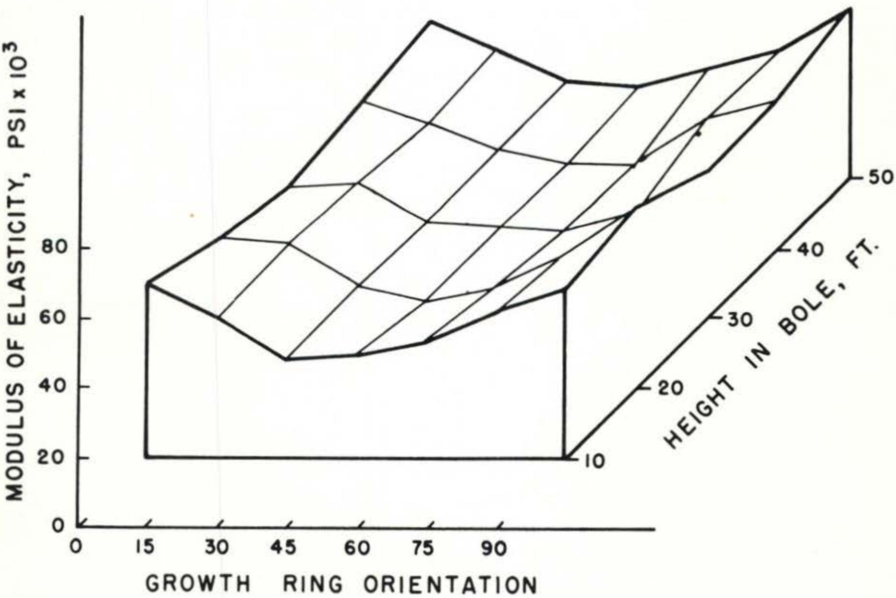

FIGURE 4—Inter-relationship between growth ring orientation, modulus of elasticity and height of specimen in the bole for transverse compression specimens tested in the green condition.

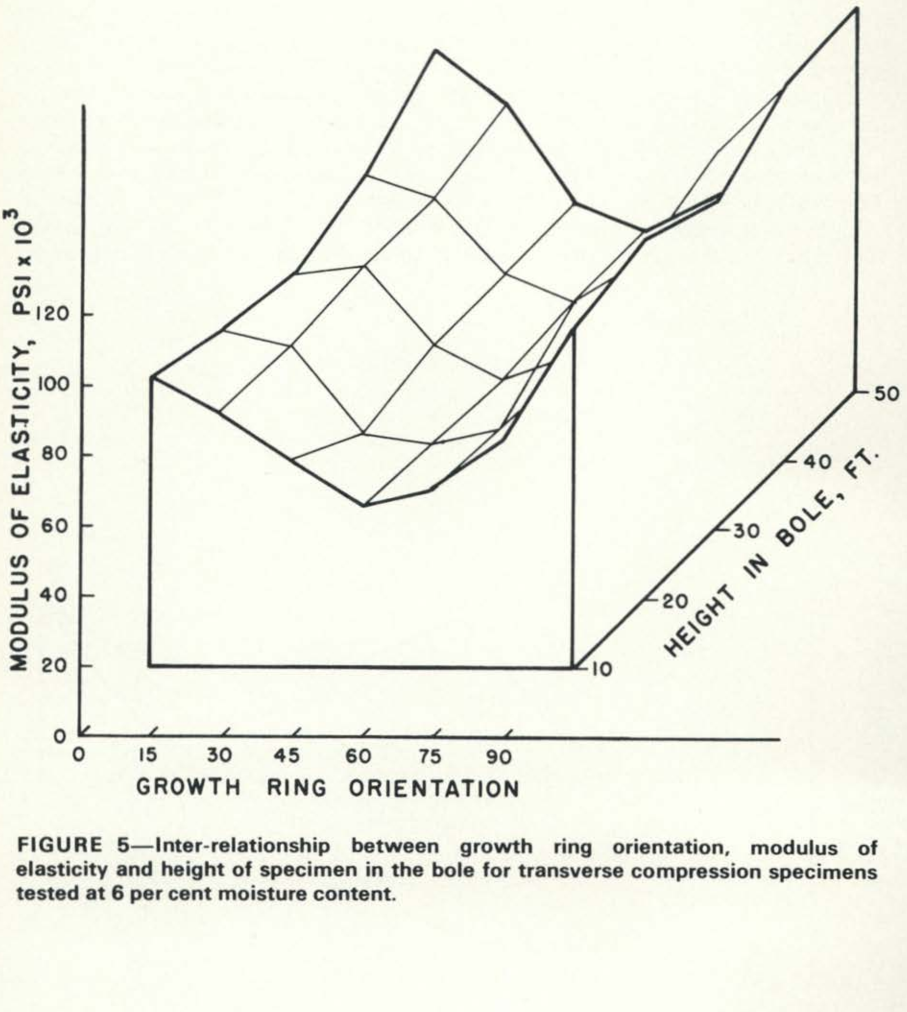

FIGURE 5—Inter-relationship between growth ring orientation, modulus of elasticity and height of specimen in the bole for transverse compression specimens tested at 6 per cent moisture content.

Transverse compression data were grouped within rings-per-inch, specific gravity, and percent latewood classes and then analyzed by regression-correlation techniques. Analysis of this data indicated the existence of several relationships:

1. As the number of rings-per-inch increased there was a general tendency for percent latewood, specific gravity, and the strength properties modulus of elasticity, proportional limit stress, and maximum stress to decrease.

2. As specific gravity increased there was a trend toward increased modulus of elasticity. However, this trend appeared to be influenced somewhat by moisture content level with specimens tested at 12 percent exhibiting a negative relationship between modulus of elasticity and specific gravity.

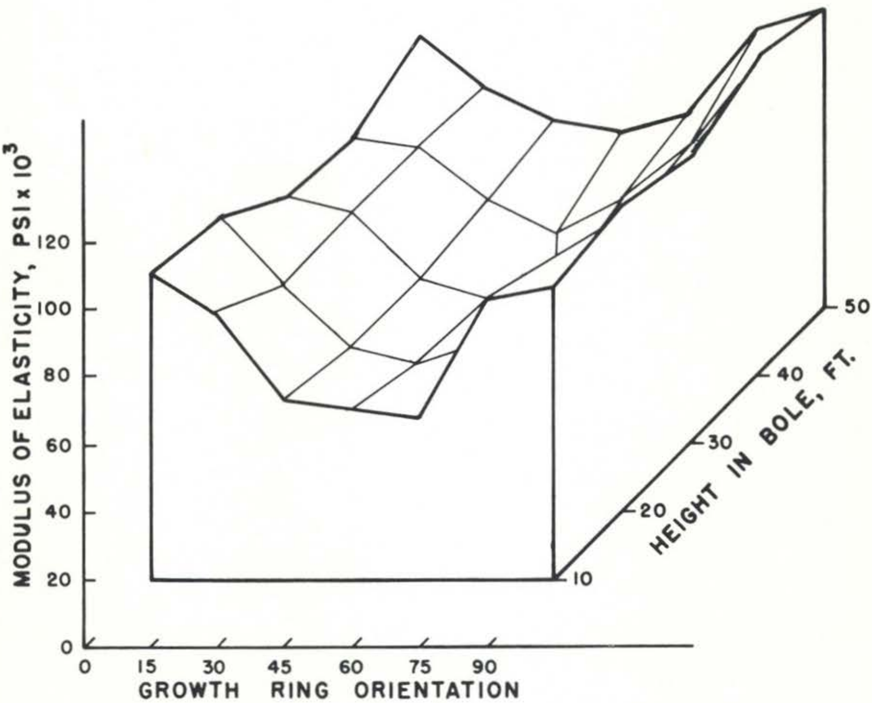

FIGURE 6—Inter-relationship between growth ring orientation, modulus of elasticity and height of specimen in the bole for transverse compression specimens tested at 12 per cent moisture content.

3. There was a relatively strong relationship between percent latewood and specific gravity which was expected because the amount of cell wall substance greatly influences specific gravity. Since the bulk of the cell wall substance is located in the latewood portion of the growth ring, it is only natural to expect a relationship to exist between specific gravity and latewood.

The relationship of modulus of elasticity to height in the bole is shown in Figs. 4, 5, and 6 respectively, for specimens tested green, at 12 percent and at 6 percent, respectively. There was a general trend of decreasing modulus of elasticity as height in the bole approached 20-30 feet and then increasing again up to the base of the live crown. Since the test specimens were not matched at time of preparation, this trend may be the result of coincidence and further compression data are needed to establish the reliability of this trend.

Table 3. Multiple Correlation Coefficients Obtained by BIOMED Stepwise Regression Analysis, N=25[a]

	Property Measured							
	Modulus of Elasticity		Stress Proportional Limit		Maximum Streess		Stress Proportional Limit Maximim Stress	
Moisture Condition	G	6%	G	6%	G	6%	G	6%
Grain Angle								
0°	SW = .453 RPI = .470	RPI = .146 SG = .204 SW = .205	SW = .452 RPI = .464 SG = .465	RPI = .160 SG = .212 SW = .215	SG = .654 SW = .675 RPI = .686	SW = .273 RPI = .289 SG = .290	SW = .202 SG = .231 RPI = .242	RPI = .252 SW = .253 SG = .259
15°	RPI = .458 SW = .527	SW = .308 RPI = .378 SG = .380	RPI = .456 SW = .520	SW = .307 RPI = .377 SG = .381	RPI = .534 SG = .560	SW = .433 SG = .445 RPI = .447	SW = .304 RPI = .330 SG = .346	RPI = .440 SG = .445 SW = .452
30°	SG = .976 RPI = .990 SW = .995	RPI = .597 SG = .621 SW = .637	SG = .938 RPI = .977 SW = .986	RPI = .603 SG = .632 SW = .649	SG = .970 SW = .989 RPI = .994	RPI = .608 SG = .682 SW = .683	SG = .916 SW = .938 RPI = .939	SW = .345 SG = .350 RPI = .353
45°	SG = .584 SW = .734 RPI = .750	RPI = .427 SW = .488 SG = .493	SW = .578 SG = .724 RPI = .739	RPI = .424 SW = .489 SG = .496	SG = .558 SW = .653 RPI = .667	SW = .165 RPI = .223 SG = .224	SW = .356 RPI = .394 SW = .485	RPI = .424 SG = .484 SW = .493
60°	RPI = .367 SW = .416 SG = .421	RPI = .390 SW = .404 SG = .452	RPI = .368 SW = .414 SG = .419	RPI = .385 SW = .401 SG = .446	RPI = .503 SG = .567 SW = .575	RPI = .559 SG = .573 SW = .642	SW = .109 RPI = .135 SG = .138	SW = .082 RPI = .091 SG = .095
75°	RPI = .098 SG = .126 SW = .137	RPI = .370 SG = .443 SW = .499	RPI = .115 SG = .142 SW = .148	RPI = .370 SG = .445 SW = .452	SG = .429 RPI = .472 SW = .526	SG = .313 SW = .347 RPI = .349	SG = .400 SW = .424 RPI = .432	RPI = .476
90°	SG = .173 SW = .244 RPI = .255	SW = .282 SG = .287 RPI = .289	SG = .176 SW = .240 RPI = .255	SW = .282 SG = .286 RPI = .290	SG = .194 RPI = .249 SW = .253	SW = .451 SG = .484 RPI = .499	RPI = .289 SG = .343 SW = .355	RPI = .085 SG = .112

[a]Level of significance for entered variable

	95%	99%
1	.388	.496
2	.470	.565

Summary and Conclusions

Twenty-five transverse compression specimens for each of seven growth ring orientations and for three moisture content levels were tested. Data were analyzed by analysis of variance, and regession and correlation techniques.

Compression perpendicular to grain bearing load was influenced by the moisture content, growth ring angle and the physical characteristics of the specimen.

Compression strength increased as the moisture content decreased. Approximately a two-fold increase in compression strength resulted in conditioning from the green condition to 12 and 6 percent, respectively.

Compression load values decreased from highs at 0^0 and 90^0 to a minimum at 45^0. This relationship held for the three levels of moisture used in this study.

Maximum modulus of elasticity was obtained when specimens were tested at a 90^0 growth ring orientation (perpendicular to the direction of applied stress).

There was a trend toward decreased modulus of elasticity, stress at proportional limit, maximum stress, specific gravity and percent latewood with increased number of rings-per-inch.

There was a strong linear relationship between percent latewood and specific gravity.

There was a trend toward increasing modulus of elasticity with increasing specific gravity. However, this trend appeared to be influenced by the moisture content.

There appeared to be a trend toward decreasing modulus of elasticity up to 20-30 feet and then an increasing trend up to the live crown of the bole.

Improved relationships between the physical and mechanical characteristics and their influence on the transverse compression strength of Douglas fir may be possible by using additional tree samples and by matching test specimens within a given tree.

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