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# EFFECT OF PRESTRESSING ON MECHANICAL PROPERTIES OF DOUGLAS-FIR AND SOUTHERN YELLOW PINE

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EFFECT OF PRESTRESSING ON MECHANICAL PROPERTIES  
OF DOUGLAS-FIR AND SOUTHERN YELLOW PINE

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Introduction

Strength research techniques used by the Forest Products Laboratory and other wood research laboratories frequently involve the mechanical testing of a large specimen, followed by comparative tests of small units or portions of that specimen. Although the small units are generally cut from undamaged portions of the large specimen, it is recognized that such portions may have been lightly or heavily stressed in the major test. The question then is whether or not the prestressing has affected the mechanical properties of the small specimens.

In a broad sense, all wood is prestressed. Wind or other forces in the living tree, and loads or forces applied in milling and handling, make prestressing almost a certainty. And yet, since the tree is a living organism and since wood has properties of yield and relaxation under stress, it seems reasonable to assume that such early stressing is less important than stressing and restressing within the time limits of the usual research project.

Effects from prestressing of wood have already been studied. Kommers<sup>2</sup> subjected Sitka spruce to 10 repetitions of high stress in bending and compression, and concluded that strength values were little affected, while stiffness was reduced. The stress repetitions were in rapid succession, and

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<sup>1</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

<sup>2</sup>Kommers, W. J. Effect of Ten Repetitions of Stress on the Bending and Compressive Strengths of Sitka Spruce and Douglas-Fir. Forest Products Laboratory Report No. 1320, 1943

the apparent modulus of elasticity may have been influenced by elastic after-effects from the previous loading and unloading. Brokaw and Foster<sup>2</sup> made similar rapid repetitions of stress on Sitka spruce and reported a similar reduction of the modulus of elasticity. The Forest Products Laboratory of Canada at Ottawa reported<sup>4</sup> an apparent reduction of modulus of elasticity but a slight increase of strength in the prestressing of red pine.

Recent tests of structural columns at the U. S. Forest Products Laboratory afforded an opportunity for further study of the question. Short columns of structural size were tested to failure. Small clear specimens cut from the columns after test were compared with similar specimens cut from the ends of the large columns before test. This report presents and discusses those comparisons, as well as the results from a small reloading series in clear southern yellow pine.

### Prestressing in Douglas-Fir Structural Columns

Two 2- by 2-inch clear specimens for bending tests and two for tests in compression parallel to grain were cut from each of seven unstressed Douglas-fir structural columns and tested by standard methods<sup>5</sup> together with an equal number cut from the columns after test. The structural columns were nominal 12 by 12 inches in cross section and had been tested to failure in compression parallel to grain, with stresses ranging from 81 to 92 percent of the maximum crushing strength of the clear wood. All specimens were kept and tested in the green condition at room temperature. Prestressed specimens were tested about 9 months after the structural columns had been tested. The results are summarized in table 1.

The average of all Douglas-fir values in table 1 indicates some reduction of all properties. Reductions of ultimate strength were 14 and 11 percent and of stiffness were 10 and 4 percent, in bending and compression, respectively. In view of the small number of tests, these average values are considered to be only indicative of a trend.

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<sup>2</sup>Brokaw, M. P., and Foster, G. W. Effect of Rapid Loading and Duration of Stress on the Strength Properties of Wood Tested in Compression and Flexure. Forest Products Laboratory Report No. 1518, reaffirmed 1952.

<sup>4</sup>Correspondence, 1949.

<sup>5</sup>American Society for Testing Materials. Standard Methods of Testing Small Clear Specimens of Timber, ASTM Designation D143-52, 1952.

## Prestressing in Southern Yellow Pine Structural Columns

Two 2- by 2-inch clear specimens in bending and four in compression parallel to grain from each of 15 southern yellow pine 12- by 12-inch structural columns were tested about 2 months after the structural column tests; as were two 1- by 1-inch clear specimens in bending and four in compression parallel to grain from each of 15 southern yellow pine 4- by 12-inch structural columns. Tests were made on the same number of similar specimens cut from the structural columns before the structural tests. The structural columns had been tested to failure in compression parallel to grain, with an average stress of 94 percent of the maximum crushing strength of the clear wood. All specimens were kept and given standard tests in the green condition at room temperatures. The results are summarized in table 1.

Table 1 shows much the same comparison between unstressed and prestressed specimens in the two sizes of southern pine structural columns. Average percentages of prestressed to unstressed values in both column-size groups combined are as follows:

### Properties in transverse bending

Modulus of rupture	98 percent
Modulus of elasticity	98 percent

### Properties in compression parallel to grain

Maximum crushing strength	96 percent
Modulus of elasticity	97 percent

The unstressed and prestressed specimens of southern yellow pine were end-matched individually as well as groupwise. Thus they presented 180 pairs of values, which were examined statistically for the significance of the differences indicated in table 1. Differences of modulus of elasticity, both in bending and in compression, were not significant. The difference in modulus of rupture was not significant, whereas the difference in maximum crushing strength was significant, though small. Study of individual pairs showed rather consistent though small differences in both modulus of rupture and maximum crushing strength. The values of 98 percent and 96 percent are considered rather reliable for showing the small difference in strength between unstressed and prestressed southern yellow pine.

### Reloading of Small Southern Yellow Pine Columns

A few reloading tests of green southern yellow pine were made for further information on the effect of prestressing. Seven 2- by 2- by 8-inch columns

of clear wood were loaded to 85 to 95 percent of the maximum crushing strength of end-matched control columns. Six were loaded, unloaded, and immediately reloaded twice to the same load, while one was reloaded once after 6 days' recovery after the first loading and unloading. All loadings were by the standard ASTM method.<sup>2</sup> Final loadings were continued to failure. These loadings and their results are summarized in table 2.

Table 2 indicates an average reduction of 8 percent in maximum crushing strength after reloading. Compared with the 4 percent reduction of the same property in southern yellow pine specimens prestressed in structural column tests, it is doubtful if there is a significant difference of effect resulting from the difference in elapsed time after the first loading. The specimen that recovered for 6 days before reloading in this series of 7 tests showed about the same strength reduction as the specimens that were reloaded immediately (table 2).

### Proportional-Limit Values

Proportional-limit values are often hard to locate from stress-strain data in compression, and the tests showed that prestressing accentuates that difficulty. Figure 1, a load-compression curve for a prestressed southern pine small clear specimen, illustrates the difficulty. Close examination of the plotted points shows curvature throughout, and no true proportional limit. Attempts to approximate portions of the curve by straight lines lead to pseudo-proportional limits at points A, B, or C, covering a wide range of values. In these tests of pairs of end-matched compression specimens effort was made to locate proportional limits on the most consistent basis possible. These attempts led to ratios of proportional limits in prestressed to unstressed southern yellow pine specimens ranging from a minimum of 0.18 to a maximum of 3.40.

Figure 1 shows how modulus of elasticity can also be affected by the curvature of the load-compression line. However, the difference between possible tangent moduli of elasticity, or between them and a possible secant modulus, is much less than the differences in the proportional-limit values. For this reason, moduli of elasticity are given in table 1, while proportional limits are omitted.

Figure 2 illustrates how this condition was accentuated by repeated loadings. In the second and third loadings, not only were the proportional limits uncertain, but alternative choices of proportional limit made considerable differences in the moduli of elasticity. For this reason, and because of the limited number of tests, both properties were omitted from the comparisons in table 2.

A similar problem existed with proportional limit in bending, but to a lesser degree. Ratios of prestressed to unstressed values from these data on pairs of end-matched southern pine specimens ranged from a minimum of 0.51 to a maximum of 1.71. The difference between bending and compression is believed to result from the differing stress distributions in the two tests. In

compression, there is an essentially uniform distribution of stress throughout a nonhomogeneous specimen, so that proportional limit is reached in different parts of the specimen at different load levels. In bending, a more definite proportional limit is observed when the very limited zone of the outer fibers on the compression side near midspan reaches its proportional limit.

Ratios of observed proportional limits in prestressed to unstressed material based on the averages in the three groups shown in table 1 were as follows:

Proportional limits in bending		
Douglas-fir 12- by 12s		90 percent
Southern yellow pine 12- by 12s		89 percent
Southern yellow pine 4- by 12s		96 percent
Proportional limits in compression		
Douglas-fir 12- by 12s		101 percent
Southern yellow pine 12- by 12s		77 percent
Southern yellow pine 4- by 12s		71 percent

In view of the wide range of the ratios in compression and the doubt of existence of any proportional limit in many of the compression specimens, the ratios are not significant. Ratios in bending are more consistent, and therefore somewhat more significant.

#### General Discussion and Conclusions

In assessing the application of the test results reported here, it should be remembered that the prestressing in every instance was compression nearly to the maximum crushing stress. The stress was high in all parts of the test specimen; whereas in bending, the maximum stress is in only very limited zones. The lower levels of stress in the major portion of a specimen subjected to transverse bending may be expected to have less effect than these tests have shown.

While the reduction of strength from prestressing is generally small, it is significant. The inconsistent and often large reduction of proportional limit stress indicates an increase of plasticity, which makes both proportional limit and modulus of elasticity hard to identify by the usual methods.

This work was done on Douglas-fir and southern yellow pine, and indicated some difference between the two in the effects of prestressing. While these are important structural species in the United States, other species should be examined before any general conclusions can be reached.

Table 1.--Comparison of average<sup>1</sup> bending and compression properties in unstressed and prestressed small, clear, green specimens of Douglas-fir and southern yellow pine

Structural column number	Transverse bending				Compression parallel to grain			
	Modulus of rupture		Modulus of elasticity		Maximum crushing strength		Modulus of elasticity	
	Unstressed	Prestressed	Unstressed	Prestressed	Unstressed	Prestressed	Unstressed	Prestressed
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Pounds per square inch	Pounds per square inch	1,000 Pounds per square inch	1,000 Pounds per square inch	Pounds per square inch	Pounds per square inch	1,000 Pounds per square inch	1,000 Pounds per square inch
			inch	inch				
12- BY 12-INCH DOUGLAS-FIR								
2	6,160	5,580	1,645	1,412	3,060	2,810	1,648	1,752
3	7,740	5,340	1,404	1,131	3,830	2,780	1,686	1,459
11	7,100	5,600	1,602	1,510	3,290	2,790	1,678	1,412
15	8,260	6,780	1,964	1,790	4,260	3,660	2,201	1,818
16	6,510	5,920	1,413	1,465	3,360	3,260	1,696	1,608
19	6,000	6,810	1,360	1,588	3,340	3,610	1,638	1,974
20	7,570	6,350	1,868	1,390	3,880	3,240	1,910	1,901
Average	7,050	6,050	1,608	1,441	3,570	3,160	1,780	1,703
12- BY 12-INCH SOUTHERN YELLOW PINE								
1	8,730	8,550	1,404	1,852	4,390	4,430	1,562	1,754
2	8,160	7,980	1,944	1,773	3,960	3,980	2,085	1,805
3	8,780	9,010	1,475	1,642	4,080	4,010	1,658	1,710
5	9,500	9,260	1,697	1,709	4,710	4,430	1,958	2,152
6	7,900	7,480	1,642	1,717	4,130	3,850	1,728	1,851
7	6,900	6,520	1,232	1,273	3,400	3,090	1,681	1,452
8	5,880	5,640	1,214	1,131	2,610	2,620	1,631	1,487
9	6,460	6,580	1,143	1,203	2,860	2,810	1,429	1,555
10	6,130	6,020	1,260	1,148	2,960	2,620	1,520	1,306
11	6,010	6,250	1,199	1,202	2,540	2,660	1,418	1,443
12	5,980	6,000	1,097	1,155	2,930	3,010	1,468	1,462
13	6,550	6,500	1,258	1,221	3,760	3,900	1,589	1,617
14	8,360	7,760	1,196	1,336	3,450	3,270	1,166	1,111
15	7,000	7,050	1,277	1,384	3,290	3,130	1,589	1,265
16	7,450	7,430	1,320	1,252	3,690	3,390	1,904	1,577
Average	7,320	7,200	1,357	1,405	3,520	3,410	1,626	1,568
4- BY 12-INCH SOUTHERN YELLOW PINE								
25	8,030	8,630	1,370	1,581	4,130	4,170	1,649	1,888
27	7,950	8,530	1,481	1,409	4,020	3,820	1,602	1,510
28	8,580	8,210	1,802	1,488	4,210	3,990	1,628	1,742
29	7,590	8,770	1,267	1,347	3,600	3,450	1,535	1,515
30	10,590	10,180	1,777	1,405	4,940	4,410	1,847	1,896
31	6,850	6,570	1,154	1,248	2,940	3,210	1,418	1,440
32	4,090	4,010	531	413	1,940	1,950	543	605
33	6,880	5,820	1,170	922	3,510	2,880	1,441	1,393
34	4,360	3,860	738	564	2,040	2,100	787	792
35	8,490	7,150	1,373	1,166	4,030	3,200	1,597	1,373
36	6,520	6,760	1,400	1,186	3,210	3,220	1,558	1,482
37	6,120	5,920	1,003	927	2,900	2,890	1,181	1,225
38	7,340	7,350	1,188	1,149	4,030	3,590	1,547	1,452
39	5,640	5,120	904	772	2,720	2,420	1,076	954
40	9,410	9,590	1,750	1,660	4,010	4,250	1,791	1,560
Average	7,230	7,100	1,261	1,149	3,470	3,300	1,413	1,388

<sup>1</sup>Average of 4 values in compression tests of southern yellow pine. Average of 2 values in bending tests of southern yellow pine and all tests of Douglas-fir.

Table 2.--Effect of reloading on the compressive strength  
of small clear columns of green southern pine

Stick number	Maximum crushing strength of control columns	Stress applied to: test column:	Times loaded:	Elapsed time between loadings:	Maximum crushing strength in last loading	Ratio to controls (ratio, col. 6 to col. 2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	<u>Pounds per square inch</u>	<u>Pounds per square inch</u>		<u>Hours</u>	<u>Pounds per square inch</u>	<u>Percent</u>
25-1	4,090	3,890	3	0	3,770	92
25-2	3,800	3,230	3	0	3,450	91
27-1	3,760	3,580	3	0	3,610	96
27-2	3,920	3,330	3	0	3,780	96
28-1	4,340	4,120	3	0	3,240	75
28-2	4,410	3,750	3	0	4,320	98
30-1	5,100	4,720	2	144	4,790	94
Average:	4,200				3,850	92



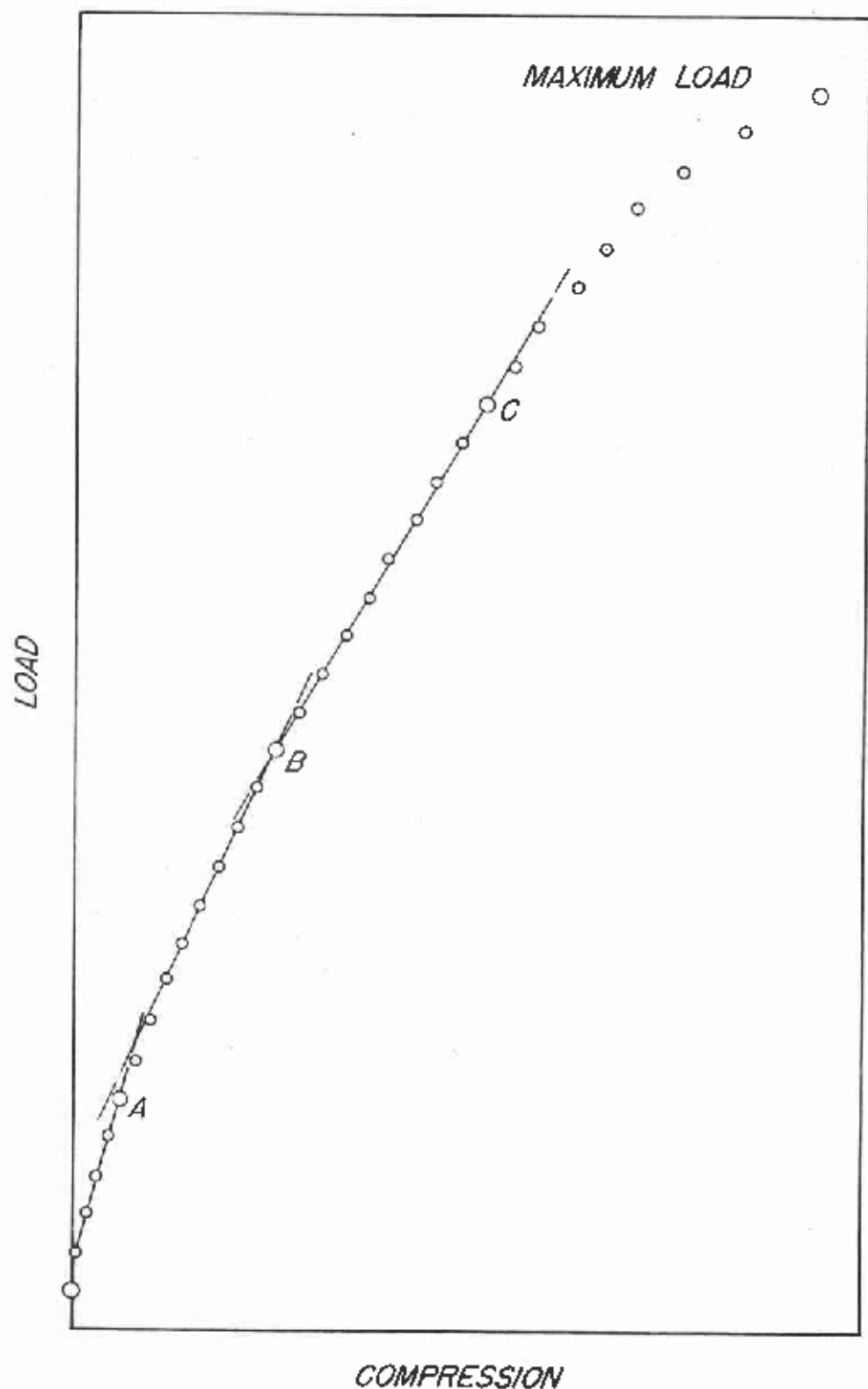


Figure 1. --Load-compression curve for a prestressed small clear specimen of southern yellow pine.

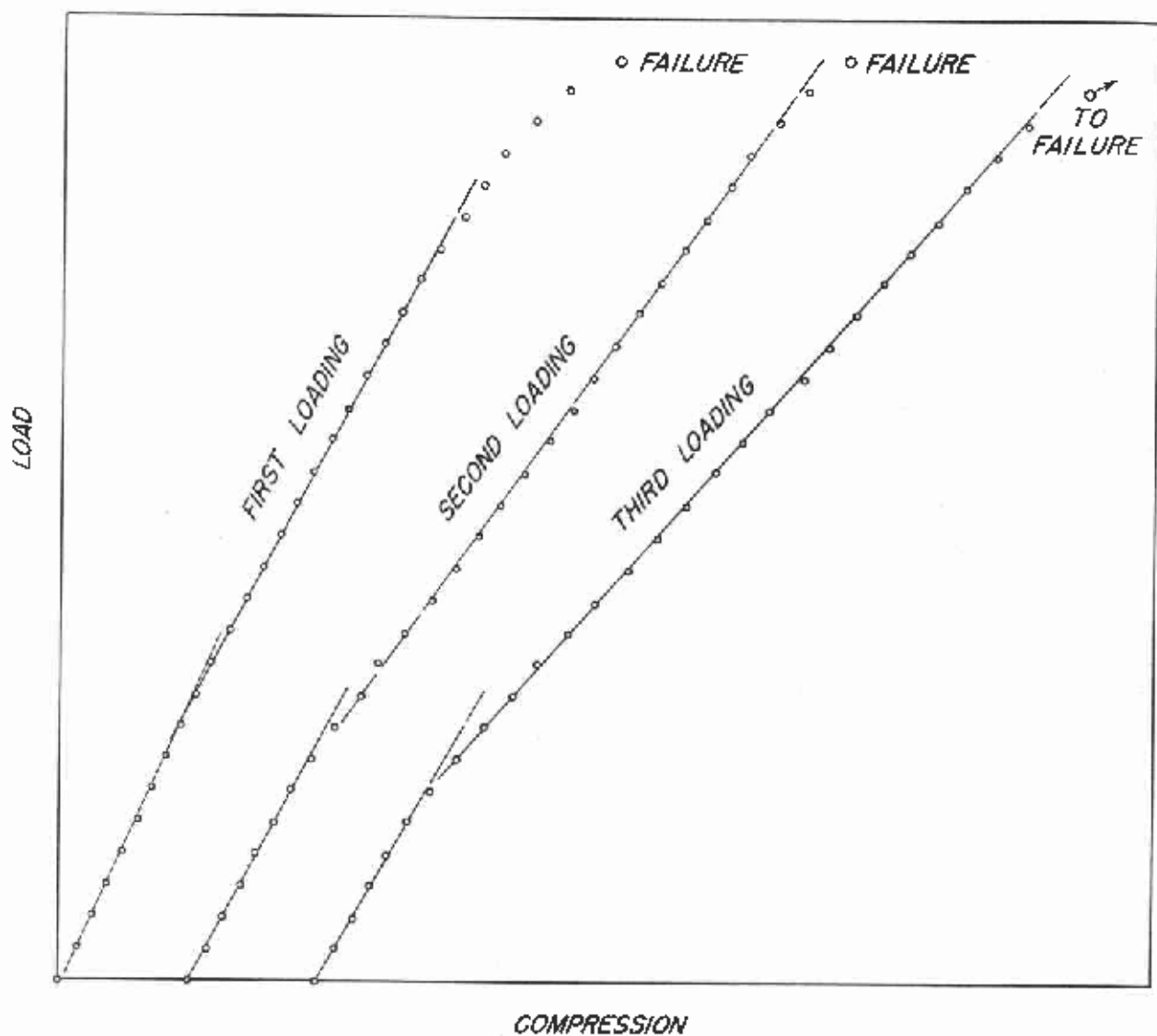


Figure 2. --Load-compression curves in reloading a small clear green specimen of southern yellow pine.