Small-Diameter Ponderosa Pine Roundwood in Compression

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Summary

Two hundred and fifty roundwood full-size compression specimens were tested in late 2001 through the summer of 2002 at the College of Engineering and Technology at Northern Arizona University in Flagstaff, Arizona, US. These specimens were taken from 12.7 to 30.3-cm. DBH ponderosa pine *(pinus ponderosa)* trees cut from Unit 16 of the Fort Valley Ecosystem Restoration Project located in the wildland-urban interface of the Coconino National Forest. The specimens were sorted into two groups as a function of processing: hand-debarked logs known as tapered specimens and machine peeled logs known as uniform specimens. Each group of tapered and uniform specimens contained specimens taken from the butt, middle, and tip of the stem. The test results provided little statistical evidence of strength being influenced by processing, juvenile wood, specific gravity, or stem location. As a result, we concluded that compression strength was more likely influenced by the occurrence of stress risers such as knots and knot clusters than any other factor for these full-size round specimens taken from small diameter ponderosa pine.

1. Introduction

The creation of suitable markets to use small diameter material removed during forest restoration and fuels reduction projects in the southwestern United States is a complex problem. Currently the local market for small diameter material is limited to products such as firewood at $28.66/metric green ton [1] and pallet stock at $40.23/metric green ton [2]. These low-value products, however: barely pay for the cost to harvest and transport. They are not viable as a revenue source for funding forest treatment activities.

But, when small diameter material is used in structural round wood applications. its value and potential for funding forest intervention activities is enhanced. Small diameter logs in conventional pile, post. and pole applications are valued at around $242.51/metric green ton [3]. The market of using small diameter material as structural round wood, however, is an immature one that has languished for four reasons: (1) There are only a few suitable structural system designs that effectively use this material. (2) There is a lack of simple, cost-effective connectors for tying the roundwood members together. (3) Engineered systems will require precision manufacturing and tight product quality control; processes mostly unheard of in traditional roundwood markets. (4) And, very little is known about the engineering properties of small diameter roundwood.

Expanding markets for the structural use of small logs will require work and innovations in all four areas. This paper, however, is limited to item (4). Specifically, it reports on the results of testing small diameter ponderosa pine *(pinus ponderosa)* logs in compression.

2. Materials and Methodology

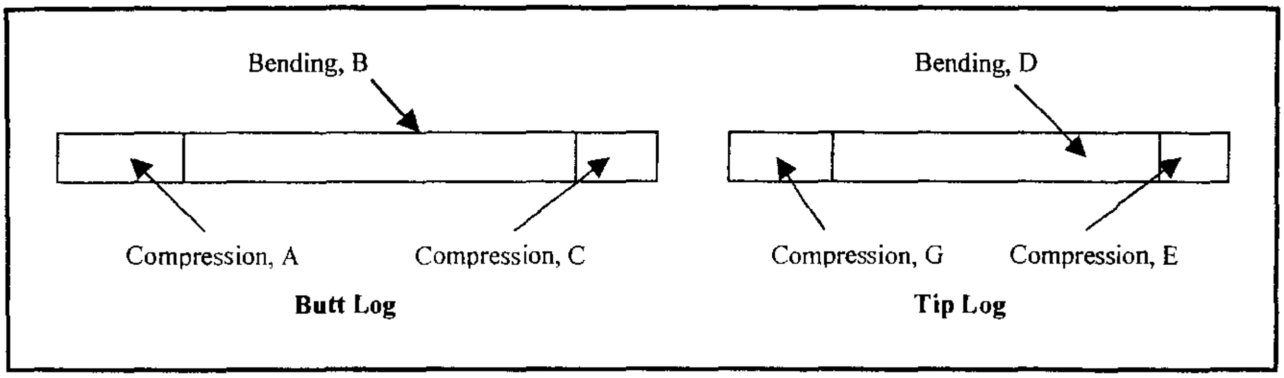
Test logs came from a forest ecosystem project in the Coconino National Forest located approximately 8-km northwest of Flagstaff, Arizona, U.S. Eighty ponderosa pine trees ranging in size from 12.7 to 30.5-cm diameter at breast height were selected for this study. The trees were hand felled on June 7, 2001, and delimbed and bucked into, whenever possible, 2 log sections - a butt log and a tip log.

Logs from trees 1 through 40 were debarked by hand with a drawknife. Debarked logs are referred to here as tapered specimens; whereby the specimens retained their natural white wood taper. Logs from trees 41 through 80 were machined processed to a constant diameter. Machined processed logs are referred to here as uniform. Each specimen was of a constant diameter along its entire length.

Prior to the cutting of compression specimens from the butt and tip logs, specific gravity plugs (12.7-mm in diameter by 38.1-mm in length) were taken from the butt, mid, and tip positions of the tapered logs. Ninety-four plugs were sent to the USDA Forest Service Forest Products Laboratory for moisture content and specific gravity evaluation.

Compression specimens were cut with a chain saw in a jig from the bottom and top of each tapered and uniform log. The length of each specimen was determined by multiplying specimen diameter by 4. The sampling scheme is shown in Figure 1. The beam specimens were also tested and these results documented in Larson, et al [4]. The number of compression specimens as suggested by Figure 1 combined with the above tree sampling scheme theoretically equals 320. Unfortunately, the number of recovered tapered and uniform specimens was 250, less than predicted because of two reasons. Some logs were too big for machine processing and were consequently removed from the testing program. Some logs were too small to produce compression specimens with a diameter greater than or equal to 10.2-cm, which was the lower dimensional limit for the compression test machine. These small specimens were removed from the testing program.

Figure 1. Specimen Location per Butt Log and Tip Log



Prior to compression testing, a variety of specimen measurements were taken, including: end diameter measurements, grain angle, specimen age, cross-sectional radius to the first 20 rings, and the average number of rings per inch after the first 20 rings. The first 20 ring radius data is used as an indicator of juvenile wood by expressing this in terms of the percentage of cross section juvenile wood, *%JW*. This indicator is based upon a study of 15.2 to 27.9-cm dib ponderosa pine logs. which suggests that the demarcation between juvenile and mature wood is at 20 rings from the pith [5].

Specimens were centered horizontally between the pump-driven hydraulic ram heads of the 2.22-MN mobile test machine. The specimens were slowly loaded in compression until maximum load was exceeded. During loading, displacement was measured with an electronic dial gauge situated between two nails located at a pre-determined gauge length. Load and deflection data were automatically recorded in real time. Each failure was located and described in some detail, noting possible stress risers. A total of 250 roundwood specimens were tested in either a dry or green state, beginning in late 2001 and extending through the summer of 2002 at the College of Engineering and Technology at Northern Arizona University in Flagstaff, Arizona, US. Dry specimens were air dried to moisture content less than 12%. Green specimens were tested at moisture content above 30%.

3. Test Results

Although a total of 250 specimens were tested, a smaller subset of data is presented here. This is because the focus of this presentation is comparative. Subsets of matched pairs of specimens coming from the same tree are analyzed to detect differences due processing, moisture content, and stem location. This comparative approach combined with the necessity of having a statistically sufficient number of specimens per matched set resulted in the presentation of data for 196 specimens vs. the full 250.

Only compression stress data is presented here. This is because the captured deflection data was noisy and led to unreliable stiffness results. We suspect that difficulties in making flat, plane cuts perpendicular to the specimen axis may have contribute to this noise.

3.1 Plug Specific Gravity

The specific gravity (SG) results are presented in Table 1. Mean specific gravity was statistically different for respectively butt vs. middle and middle vs. tip groupings. These results correspond to the expectation that specific gravity decreases with tree height.

Table 1. Specific Gravity and Moisture Content for Plugs of Small Diameter Ponderosa Pine

Stem Location	Number of Specimens	Moisture Content		Specific Gravity	
		Mean (%)	Stand. Dev. (%)	Mean	Stand. Dev.
Butt	33	41.2	30.3	.422	.043
Middle	29	32.2	26.1	.362	.040
Tip	32	36.2	21.9	.346	,038

It was possible to match 29 of the specific gravity plugs to corresponding green tapered compression specimens to investigate the possibility of relationships between compression strength (F_c) and *SG*. Regression analyses of these pairings, however. showed no discernable relationships.

3.2 Stem Location vs. Strength

It is believed that as the location of a structural specimen changes from the butt of the stem to its tip. there will be a corresponding decrease in strength. This decrease is theoretically attributed to an increase in the percent of the cross section composed of juvenile wood *(%/JW)*. Compression specimen matched pairs of tapered or uniform A vs. C and A vs. E were examined for the purpose of detecting any stem location phenomenon. The corresponding test results for three groups of specimen pairs are summarized in Table 2. The F_c results for the dry specimens have been adjusted to a moisture content of 12% [6].

A statistical analysis of the A and C strength results showed that compression strength did not vary between the bottom and the middle of the stems. A comparison of the A and E specimens, however, did reveal a statistically significant difference. The tapered specimens taken from the bottom of the butt log were approximately 15% stronger than comparable tapered specimens taken from the top of the tip log. A comparison of strength to *%JW* results did not reveal a discernable relationship, which suggests that F_c did not depend on the amount of juvenile wood in the cross-section for full-size ponderosa pine roundwood specimens.

3.3 Tapered vs. Uniform

To turn a tapered log into a uniform log necessitates the removal of mature outer wood. This loss of the stronger mature wood may impact the strength and stiffness characteristics of the uniform specimens in comparison to the tapered specimens. We examined the significance of processing for small diameter ponderosa pine specimens tested in compression by comparing tapered dry G specimens to uniform dry C specimens. These results are summarized in the second and third columns of Table 3.

Table 2. Ponderosa Pine Compression Test Results

	Green Tapered Pairs		Green Tapered Pairs		Dry Uniform Pairs	
	A	C	A	E	A	C
Number of Specimens	19	19	18	18	33	33
Average Diameter (cm)						
Mean	17.8	14.7	13.7	10.7	15.2	15.2
Standard Deviation	4.1	2.8	1.5	1.0	3.6	3.3
% of Cross Section Juvenile						
Mean	20.5	33.6	19.2	40.9	38.4	36.7
Standard Deviation	8.0	12.3	7.9	18.7	17.9	10.1
Ultimate F_c (MPa)						
Mean	16.1	16.2	14.9	12.9	32.3	31.9
95% Confidence Interval	14.7-17.5	14.6-17.9	13.9-15.9	11.9-13.9	30.2-34.4	30.1-33.7
Standard Deviation	2.8	3.4	2.5	2.0	6.0	5.1

Table 3. Ponderosa Pine Compression Test Results

	Dry Pain		Congregated A and C	
	G, Tapered	C, Uniform	Dry, Uniform	Green, Tapered
Number of Specimens	28	28	69	60
Average Specimen Diameter (cm)				
Mean	15.0	15.0	15.2	16.3
Standard Deviation	3.3	3.3	3.6	3.6
% of Cross Section Juvenile				
Mean	40.8	37.2	37.6	26.2
Standard Deviation	16.8	10.7	14.4	10.3
Ultimate F_c (MPa)				
Mean	31.1	31.8	32.1	16.4
95% Confidence Interval	29.8-32.4	29.8-33.9	30.8-33.4	15.6-17.2
Standard Deviation	3.5	5.3	5.4	3.1

This comparison between comparable tapered and uniform specimens showed no difference in strength that could be attributed to processing. The matched specimens realize the same range of F_c values.

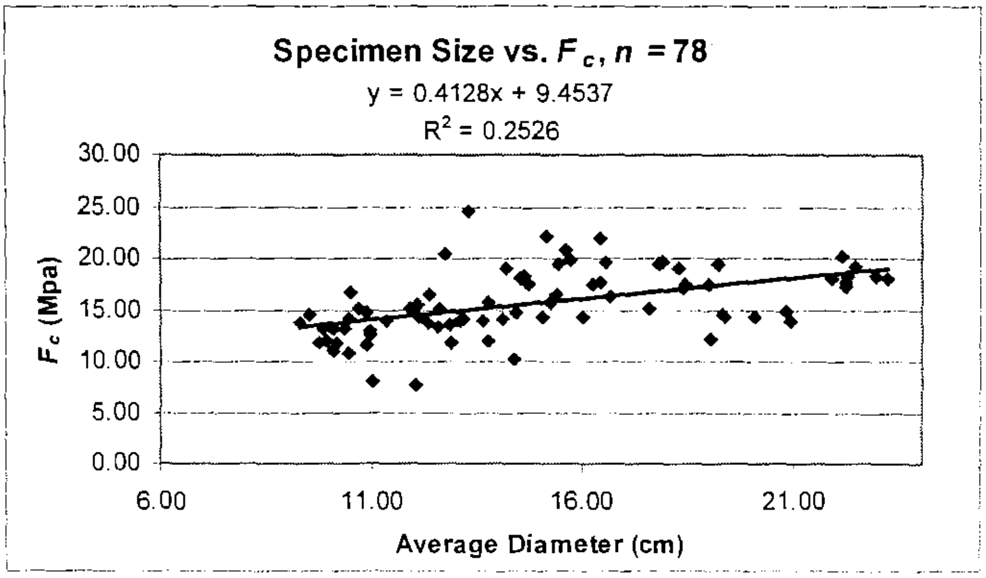
3.4 Congregated A and C Results

The results of the previous comparative work suggest that an analyses of aggregated A and C specimens would be appropriate, as these specimen sub-groupings did not differ statistically. In this section, we have analyzed the results of two butt-log samples: green tapered specimens and dry uniform specimens. These congregated results are provided in the fourth and fifth columns of Table 3.

The mean stress values between the dry, uniform butt log specimens and the green tapered butt log specimens groups are statistically different, with the dry specimens being, on the average, 1.95 times stronger than the green specimens. If indeed processing does not impact compression strength as previously suggested, then this ratio compares well to the ASTM ratio of 2.17 [7]. Both the dry uniform and green tapered specimen results were examined in attempts to detect. correlation between strength and juvenile wood. No correlations were found.

The stem location, specific gravity, processing, and juvenile wood analyses point to the hypothesis that the dominating factor in influencing compression strength is stress risers like knots. This hypothesis is supported by two observations. First, a large number of failures - 67% of the green tapered specimens and 82% of the dry uniform specimens - were attributed to the presence of a stress riser. Second, the discovery of a weak correlation between strength and size as shown in Figure 2 suggests that the smaller specimens with more knots and knot clusters are weaker. Figure 2 includes the matched data previously reported for the A,C, and E green tapered specimens.

Figure 2. Green Tapered A, C, and E Specimens



4. Conclusions

The compression test results suggest that specimens taken from the butt and middle of the stem do not differ in mean compression strength. In addition. there was no discernible difference in strength between tapered and uniform specimens leading to the conclusion that processing does not impact compression strength. The test data provided some indication, however, of strength variation between compression specimens taken from the top of the tip log vs. butt log specimens.

The dry-green compression strength ratio of 1.95 developed from this testing program compares well to 2.17 as given by ASTM D 2555.

The compression test data provided little evidence of strength being influenced by juvenile wood, specific gravity, or stem location. As a result, we conclude that compression strength was more likely influenced by the occurrence of stress risers such as knots and knot clusters than any other factor for these full-size round specimens taken from small diameter ponderosa pine. This conclusion is supported by the failure descriptions and the weak correlation between specimen size and strength. In a majority of the tested specimens, the failure mechanism was attributed to an occurrence of a stress riser. The smaller diameter specimens that generally contained more knots were found to be weaker.

5.0 References

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