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Exploring Preferential Energy Absorption in Fiber Aggregates at Low Frequencies

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ABSTRACT

Previous research has shown that the earlywood portion of the annual growth ring appears to receive the majority of the energy in the early stages of chip refining. This study is attempting to determine if preferential energy absorption extends further into the refining process. Studies are being carried out on fiber aggregates, simulating a fiber floc in the coarse bars of a refiner. The fiber aggregates are cyclically compressed at 10 hertz on an MTS servo-hydraulic machine. Curl index, measured after various predetermined compression cycles, is used as an index of strain (an indirect measurement of energy applied to the fibers). The change in the curl indices of the earlywood and latewood fibers are then compared to determine if there is preferential energy absorption due to fiber type. Results of this study suggest there is a preferential energy absorption by the earlywood in the fiber aggregates compressed at low frequencies.

INTRODUCTION

Every tree that grows has inherent variation in local mechanical properties because of the presence of both earlywood and latewood within the annual growth ring. Earlywood fibers are generally shorter, thinner-walled, and larger diameter with a higher fibril angle compared to latewood fibers.¹ In wood, the strength, work to maximum load, elongation and modulus of elasticity differ greatly between the two growth regions, with earlywood having the smaller values.²⁻⁷ Tensile testing of microspecimens showed a difference in the mode of fracture of the specimens. Earlywood had a tendency to break across the cell walls while latewood fibers failed between the cells in the middle lamella. Strength of the latewood tracheid is superior.⁷

In the southern pines, earlywood and latewood fibers have a marked difference in anatomical dimensions. The latewood fibers have an average wall thickness approximately double the earlywood fibers. A histogram of the two fiber types and their wall thickness shows a bimodal distribution (Fig. 1). Tracheid diameter is larger for earlywood, due to a larger lumen. The larger diameter with less cell wall material leads

to a lower specific gravity for the earlywood. Compared to the northern softwoods, the southern pines have a much larger proportion of latewood in the annual ring. Latewood fibers are also slightly longer than earlywood fibers at all heights and ages.¹

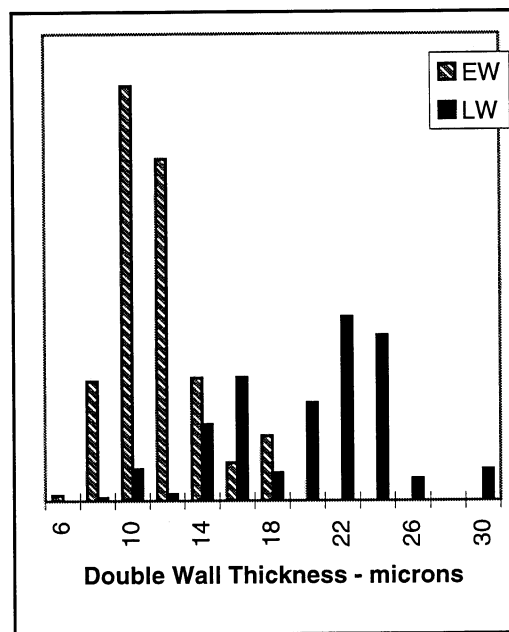


Figure 1. Bimodal distribution of fiber wall thickness in loblolly pine.⁸

The differences in mechanical properties also are present at the single fiber level. Defects such as kinks and curl lower the elastic modulus of the fiber and its capability of transmitting stress along the fiber length.⁹ It is felt that fibril angle, size and distribution of pits, degree of crystallinity and composition of the cell wall also influence fiber strength.¹⁰

TESTING METHODS

Wood Blocks

Studies of the fatigue of wood under conditions that simulate the cyclic compression of a refiner started with Salmén, Fellers, and Tigerström.¹¹⁻¹⁴ These researchers were trying to understand why the calculations of the energy required for fiber separation and flexibilization fell short of actual industry averages of energy required to achieve these processes. They used dumbbell-shaped pieces of wood with two configurations of grain direction. The pieces were tested at various frequencies, temperatures, amplitudes, and grain direction. They found that greater fatigue occurred with lower frequency, higher amplitude, and higher temperature.

Later work by Hickey and Rudie also focused on cyclic compression of wood blocks, but concentrated on differences in the earlywood and latewood sections of the wood.¹⁵ The blocks were videotaped during the compression sequence and the width of the zones of earlywood and latewood measured before compression and then at predetermined compressions. Miniature thermocouples (0.5 mm) also were inserted in the dumbbell body and in the earlywood and latewood sections within the necked down portion of the dumbbell.

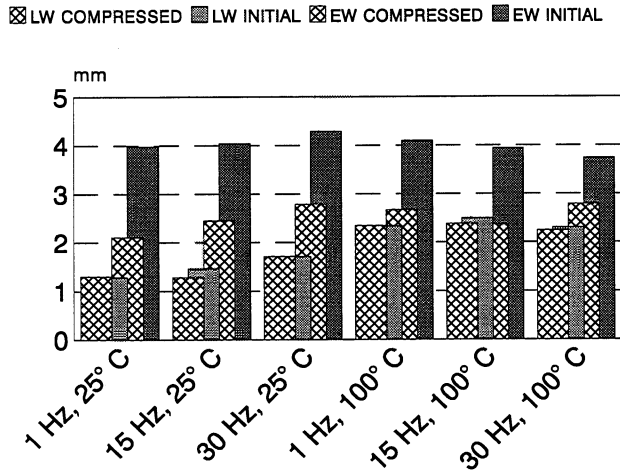


Figure 2. Response of Earlywood (EW) and Latewood (LW) to cyclic compression. Compressed width after 10,000 cycles.¹⁵

Figure 2 shows the thickness of the growth zones before and after 10,000 compression cycles.¹⁵ The earlywood portion is compressed to 63% of the initial width, but the latewood zone is only compressed to 97% of its initial width. Temperature and frequency had little effect upon this response. Figure 3 demonstrates how earlywood began absorbing energy and the temperature rose immediately as the compression sequence begins. The latewood temperature began to rise a short time later, but never reached the temperature level of the earlywood. This temperature difference at equilibrium and the time lag are dependent upon the latewood band width, indicating that the latewood heating may be due to the thermal conductivity of the wood (Figure 4).¹⁵

Wood Particles

If preferential energy absorption is occurring, then earlywood should break up earlier in the refining process, and the earlywood should be concentrated in the smaller size fractions of the pulp. To test this theory, wood chips were refined at low energy input (20kW-h/t) in an Asplund Defibrator D.¹⁶ After refining, the chips were fractionated on a Bauer-McNett apparatus with 4-, 8-, 20-, and 100-mesh wire screens. The

pulps captured by each screen were delignified using acidic sodium chlorite. The coarseness of each fraction was measured and compared to chlorite-pulped samples of pure earlywood and latewood fibers. The 4- and 8-mesh samples have coarseness values close to that of a whole

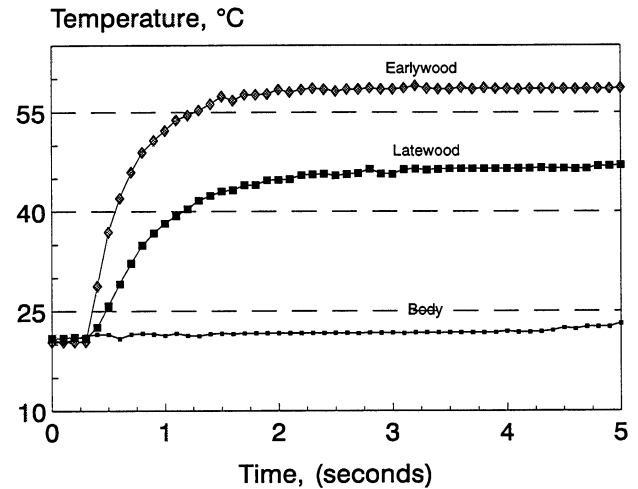


Figure 3. Temperature record of the sample tested at room temperature and 15 hertz. EW-LW-EW test piece.¹⁵

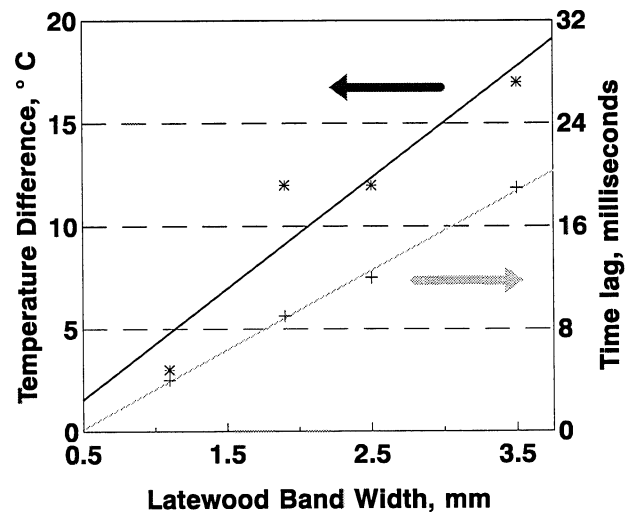


Figure 4. Equilibrium temperature difference between EW and LW growth zones (top line, $R^2=0.88$) and time delay for the latewood band to rise 50° C (bottom line, $R^2=0.99$).¹⁵

pulp, while the 20- and 100-mesh samples have a value close to pure earlywood (Table 1). This shows a slight enrichment of the small size fractions with earlywood as expected.

Table 1. Coarseness and fiber lengths for the various samples.⁸

Sample of Mesh	Coarseness (mg/m)	Fiber Length (mm)
EW	0.16	2.80
LW	0.38	3.26
4	0.22	3.21
8	0.21	2.94
20	0.17	2.62
100	0.18	1.21

Fiber Aggregates

The extent to which preferential energy absorption continues into the fiber stage is the subject of this report.

Experimental. A loblolly pine (*Pinus teada*) log was cut into approximately one inch discs, and the discs cut into wedges. The wedges were then chipped with a modified hand press fitted with a chisel blade. Wood from the 15th to the 35th annual rings was used in these experiments. Wood in each of the annual rings was separated into earlywood, transitional wood, and latewood using the hand press. Earlywood and latewood chips were refined at low energy input in an Asplund Defibrator D. Pulps were fractionated in a Bauer-McNett fiber classifier with 4-, 14-, 28-, and 48-mesh screens. The separated and fractionated pulps were bagged, flushed with nitrogen gas, sealed, and pasteurized.^{17,18} The bags were then placed into a cold room for storage.

The fiber aggregate sample size was determined by stopping a 12" Sprout Waldron refiner while under load. The refiner was opened and six fiber bundles extracted and measured for volume. They were then oven dried and weighed. This gave a density and, knowing the volume within the cuvet, a fiber mass was calculated.

The fibers in the aggregate are mixed in a 50/50 ratio by mass of earlywood and latewood, using fibers from the retained 28-mesh screen. Before mixing, 5% of either the earlywood or latewood was stained with a fluorescent dye. The fibers were mixed and brought to a 30% consistency.

The initial experimentation has been completed using a 10-hertz frequency, with a double amplitude of one millimeter (the MTS was controlled for stroke distance). Twelve earlywood and 13 latewood stained aggregates were videotaped. The video images were analyzed using an Optimas image analysis system. The curl index^{19,20} for each stained fiber in the microscope view is determined before starting and after 10, 10.5, 50, 100, 250, 500, 1000, 2500, 5000, and 10,000 cycles. The curl index is subtracted from the initial curl index for that fiber and the absolute value is calculated as the strain.

Discussion. The average values of the change in curl index are shown in Fig. 5. In this figure, the + symbols show the change in average curl index of the earlywood fibers, comparing the free expansion position through 10,000 compression cycles, to the fiber position in the starting aggregate. The * symbol shows the same data for the latewood fibers. This shows that latewood fibers have the greater change in curl index in the initial compression cycle. The diamond shows the average change in curl index of the earlywood fibers in the fully compressed position of the 10th compression cycle, relative to the initial state. The open box symbol is the same data for the latewood fibers. This shows that within a compression cycle, the earlywood fibers absorb the compression, and there is relatively little change in shape for the latewood fibers.

Figure 6 shows the cumulative percent versus curl index at 10 hertz for both earlywood and latewood at 10 and 10.5 cycles. In the freely expanded samples, earlywood and latewood appear to behave similarly relative to their initial state. There is no difference between the means of the absolute change in curl index for latewood between the 10 and 10.5 cycle samples. The difference in mean curl index for the earlywood samples at 10 and 10.5 cycles is significantly different at the 90% confidence interval as a one-sided t-test, but is not significant at the 95% confidence interval (Appendix).

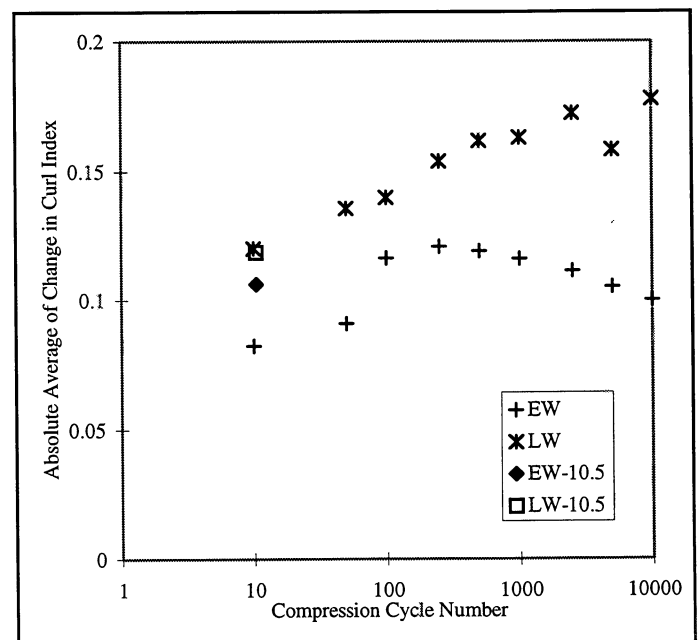


Figure 5. Average absolute values of change in curl index at 10 hertz.

CONCLUSION

Earlywood and latewood fiber aggregates appear to behave similarly in cyclic compression at a frequency of 10 hertz. While latewood has a high change in mean curl index relative to the initial uncompressed state, the change in curl index within a compression cycle is quite small. The earlywood fibers have a smaller change in curl index relative to the initial state, but show a greater change in curl index within each cycle. This flexing should increase the fatigue rate for the earlywood fibers.

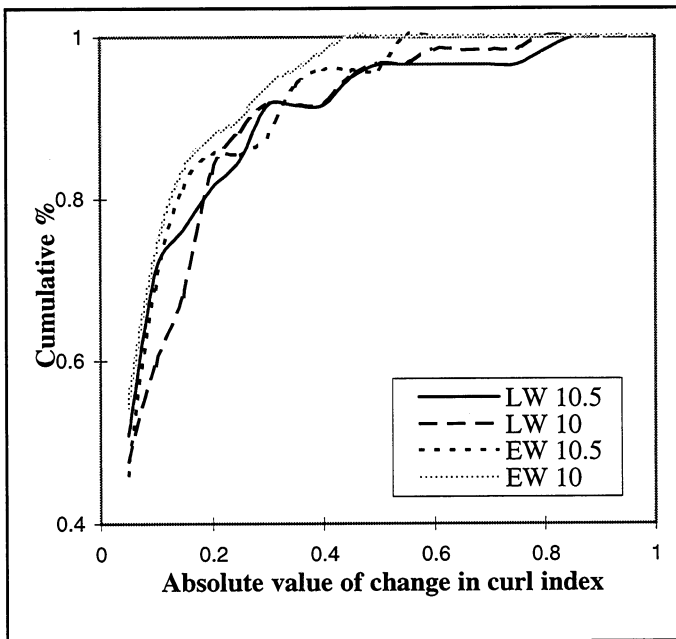


Figure 6. Comparison between 10 and 10.5 compression cycles of earlywood and latewood.

FUTURE WORK

Work is continuing with the addition of thermal imaging to detect the differences in energy absorption by the temperature differences within the sample. It is believed that the earlywood fibers should be much warmer than the latewood fibers. It also is expected that local "hot spots" will occur at defects in the fibers. In addition, higher frequencies will be explored.

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APPENDIX

t-Test: Paired Two Sample for Means		
Earlywood	10.5	10
Mean	0.1061	0.0822
Variance	0.0172	0.0108
Observations	48	48
Hypothesized Mean Difference	0	
df	47	
t Stat	1.3366	
P (T<=t) one tail	0.0938	
t Critical one tail	1.6779	
P (T<=t) two tail	0.1877	
t Critical two tail	2.0117	
t-Test: Paired Two Sample for Means		
Latewood		
Mean	0.1184	0.1199
Variance	0.0287	0.0225
Observations	59	59
Hypothesized Mean Difference	0	
df	58	
t Stat	-0.0907	
P (T<=t) one tail	0.4639	
t Critical one tail	1.6715	
P (T<=t) two tail	0.9279	
t Critical two tail	2.0017	

