Institute of Paper Science and Technology
Atlanta, Georgia

IPST TECHNICAL PAPER SERIES

NUMBER 480

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K.L. HICKEY AND A.W. RUDIE

APRIL 1993

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Submitted to
International Mechanical Pulping Conference
Oslo, Norway
June 15–17, 1993

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Karen L. Hickey* and Alan W. Rudie

The Institute of Paper Science and Technology
500 10th Street, NW
Atlanta, GA. 30318.
* Now with Lake Superior Paper Industries
Duluth, MN.

Abstract:

As part of an effort to understand the critical features of the southern pines responsible for the high energy requirements in mechanical pulping, samples of southern pine have been subjected to cyclic compression to simulate the fatigue failure mechanisms in mechanical pulping. Analysis of high speed video images of these experiments indicates that most of the compression (strain) is absorbed by the earlywood portion of the wood. During several experiments, temperature measurements were collected from the wood by inserting small (0.5 mm) diameter thermocouples in the earlywood and latewood portions of the test piece. The temperature of blocks compressed at 15 and 30 Hz rose dramatically during the experiments. For room temperature experiments, the temperature of the earlywood increased significantly faster and higher than the temperature of the latewood growth zone. These results suggest that the majority of the energy applied in the early stages of disk refining is absorbed by the earlywood

INTRODUCTION:

Literature dating as far back as 1937 shows a strong correlation between wood density and the energy required to obtain desirable physical properties in mechanical pulping of softwoods (Figure 1).[1] Since then, there have been many papers on the influence of wood on mechanical pulping, but there is still not a clear understanding of how wood or wood fiber morphology affect mechanical pulping. Previous work attempted to establish a correlation between tensile index at a fixed specific energy application and the ratio of average fiber circumference divided by average fiber cross sectional area.[2] Although the relationship was supported by selected literature data, it was clearly violated by the superior performance of mature trees in mechanical pulping research on spruce[3,4], loblolly pine[5] and radiata pine.[6]

Previous research[7] has also shown that thicker walled fibers provide much of the long fiber fraction in TMP. Latewood fibers are known to be stiffer[8] and have higher tensile strength.[9] It is to be expected that more latewood than earlywood fibers will survive the mechanical pulping process intact. A large difference in elastic properties between earlywood and latewood has also been observed for whole wood sections.[10] This suggests that in mechanical pulping, energy might concentrate in the earlywood portion of the annual growth ring.

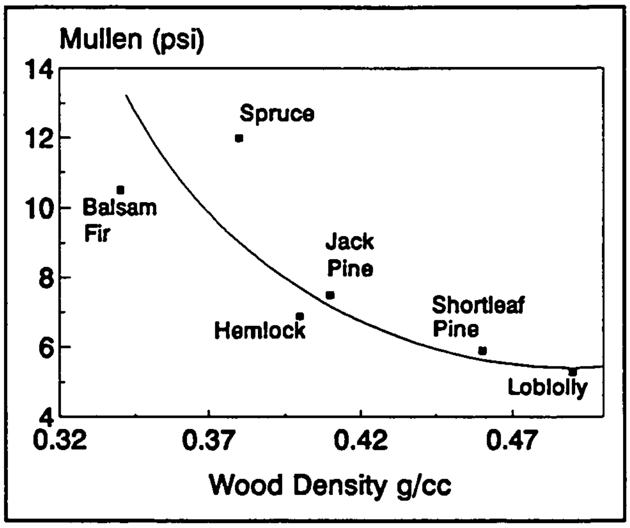

Figure 1. Mullen strength at 100 HPD/BDT plotted against wood specific gravity (dry weight over green volume) for various species. Data from Wynne-Roberts, 1937.

To test this hypothesis, an MTS machine was equipped with a plexiglas, atmospheric pressure, steam chamber. The apparatus was used to induce cyclic compression in radial cut wood samples, under conditions that simulate the early stages of disc refining.[11] High speed video records were made of each experiment, and the video images analyzed to determine strain distribution between the earlywood and latewood portions of the annual growth ring.

RESULTS and DISCUSSION:

The video strain measurements clearly show that under radial compression, the majority of the strain is absorbed by the earlywood portion of the annual growth ring. The data in Figure 2 shows the widths of the earlywood and latewood growth zones before compression, and the compressed width after 10,000 cycles. On average, the earlywood growth zone is reduced to 63% of original width, while the latewood region retains 97% of the original latewood width. Results at 10 cycles are not substantially different from the results at 10,000 cycles. After 10 cycles, the earlywood band was compressed to 67% of it's original width, while the latewood band retained 97% of it's original width. Neither frequency or temperature has a significant effect on the distribution of strain between the earlywood and latewood growth zones. Compression after 10,000 cycles ranges from 54% of original width to 75% of original

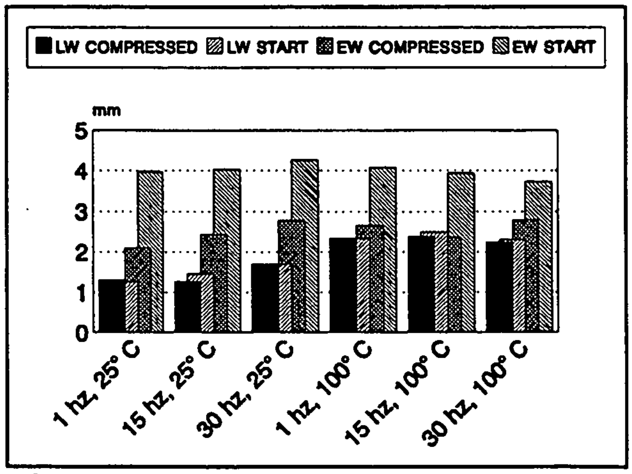

Figure 2. Response of Earlywood (EW) and Latewood (LW) to cyclic compression. Original width and compressed width after 10,000 cycles.

width in the earlywood growth zone, and 88% to 102% in the latewood growth zone. The maximum compression observed in latewood was a 12% loss in width (88% of original width) at 15 hz and 25° C. The other five conditions all produced latewood compressed widths between 95% and 102% of the original width.

A second set of samples was prepared with 0.5 mm Chromel Constantan thermocouples inserted in the latewood and earlywood growth zones and a control thermocouple placed in the body of the sample. The cyclic compression tests were then repeated with the thermocouples in place to measure temperature changes during the experiments. During the 15 and 30 hz room temperature tests, the earlywood temperature shows a dramatic rise immediately after starting the MTS machine. The temperature changes shown in Figure 3 are typical for these experiments. At 1 hz and room temperature, the temperature rise is much smaller, about 6° C. Since the steam chamber was not pressurized, evaporative cooling prevents observation of a temperature rise in the 100° C cases.

Four experiments were carried out at room temperature and 15 or 30 hz frequencies, one at each frequency using the normal test piece with earlywood/latewood/earlywood growth zones in the high stress area of the test piece, and one at each frequency with latewood/earlywood/latewood growth zones in the test area (see the experimental section). In all cases the latewood temperature rise was slower and equilibrated at a lower temperature than the earlywood band. The delay time in the temperature rise of the latewood band and the difference in the equilibrium between the earlywood and latewood bands are highly dependant on the width of the latewood growth zone (Figure 4). All of these effects are indicative of a substantial amount of convective heating of the latewood band.

CONCLUSIONS:

Although the radial orientation of the test piece is quite restrictive and is clearly not present in the majority of wood chips entering a chip refiner, these results show a strong preferential energy absorption by the earlywood portion of the annual growth rings in loblolly pine. The conditions of the study simulate conditions of chip compression in a plug screw feeder, and the initial compressive impacts of the chip breakers in the first stage refiner. If preferential energy absorption continues in the disk refining process, the

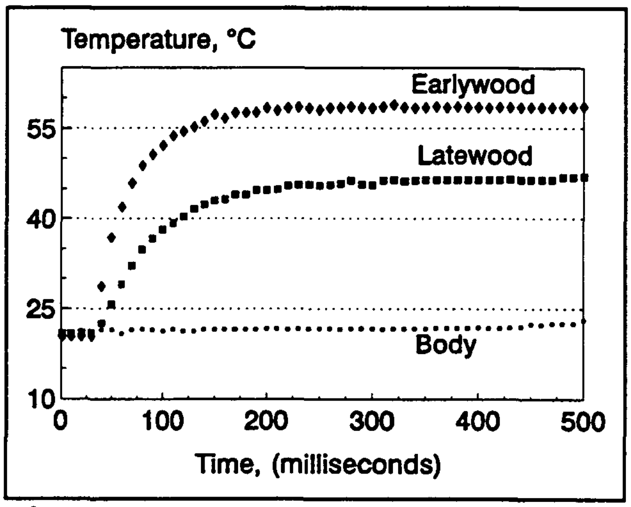

Figure 3. Temperature record of the sample tested at room temperature and 15 hz. EW-LW-EW test piece.

earlywood fibers will absorb the majority of the refiner energy leaving them overly refined. The latewood fibers will absorb comparatively little energy and will remain stiff, poorly developed and unable to bond well in the paper.

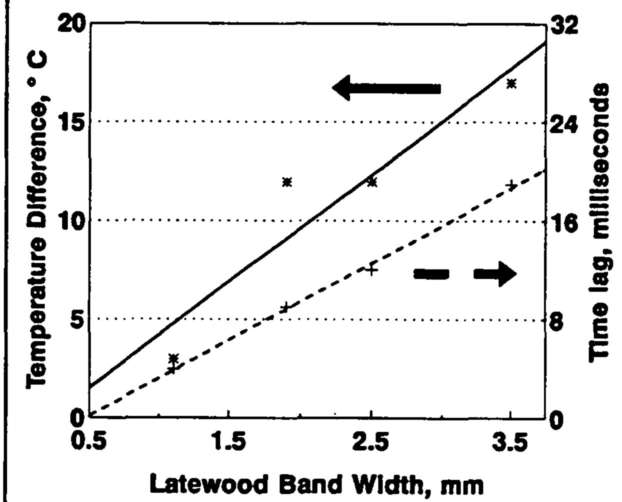

Figure 4. Equilibrium temperature difference between EW and LW growth zones (top line, R^2=0.88) and time delay for the latewood band to rise 5° C (bottom line, R^2=0.99).

EXPERIMENTAL:

A green, radial cut loblolly pine 2 X 12 was selected from a local lumber mill for the project. Half inch (13 mm) cross cut slices were cut from the board and trimmed to the dimensions indicated in Figure 5. For most of the test pieces, the tapered cuts were made to terminate in the latewood portion of an annual growth ring (based on the assumption that it would be less likely to collapse under compression and interfere with the test). This gave a typical test specimen with a 13 mm square test area consisting of two earlywood bands separated by a latewood band and a sample test length of 10.6 ± 0.6 mm. A 13 mm hole was drilled in the base of the test piece for attaching the sample to the MTS test machine.

Several test pieces were drilled with a # 76 (0.5 mm) drill bit to provide holes for the thermocouples used to measure temperature changes during the tests. Holes were drilled into an earlywood and a latewood band in the test area and in the body of the test piece for a base line thermal record of the sample. In several test pieces, the tapered cuts were made to terminate in earlywood portions of the wood to give a test area consisting of two latewood bands separated by an earlywood band. These samples were used to check for any effects from stress concentrations in the test piece. To avoid interference from the thermocouple holes, the video stain analysis and temperature record were carried out as separate tests and the samples used for the video strain analysis were not drilled for thermocouples. After cutting, the test pieces were stored in water to insure saturation and retard microbial degradation.

An MTS servohydraulic test machine was equipped with a plexiglass steam chamber for testing at temperatures up to 100° C in a saturated steam environment. The sample was placed in the standard test clamps, and then a 13 mm wooden dowel used to secure the sample to the bottom clamp of the MTS machine. The top of the test piece was left unattached so the sample could recover at the woods natural rate of expansion under the test conditions.

All tests were conducted at a constant strain amplitude of 3 mm. The video images were recorded using a Xybion video camera operating at 30 frames per second with 1 to 10 millisecond shutter speeds. Experiments without thermocouples were analyzed at 10, 10^2, 10^3, 10^4, $5X10^4$ and 10^5 cycles. Approximately 10 consecutive cycles were scanned and measured using a Noran TN-8500 image analyzer to locate the maximum (free expansion) condition, and the minimum (fully compressed) condition. Measurements were taken of all three bands in the test area.

Temperatures were recorded using 0.5 mm diameter Chromel Constantan thermocouples and a Trans-era® data acquisition system with a built-in reference junction. Thermocouples were calibrated by immersion in an ice bath and boiling distilled water. All four thermocouples used in the experiments were within ± 1° C of the reference temperatures.

ACKNOWLEDGEMENTS

Portions of this work were used by KLH as partial fulfillment of the requirements for the Masters of Science Degree at the Institute of Paper Science and Technology. The authors gratefully acknowledge the assistance of D. Samuels and W. Davis for technical support, J. Nadeau, J. Nunn and J. Welch for fabricating and installing the steam chamber and B. Burns for help with the data acquisition. KLH would like to thank M. Hickey for the long distance moral support.

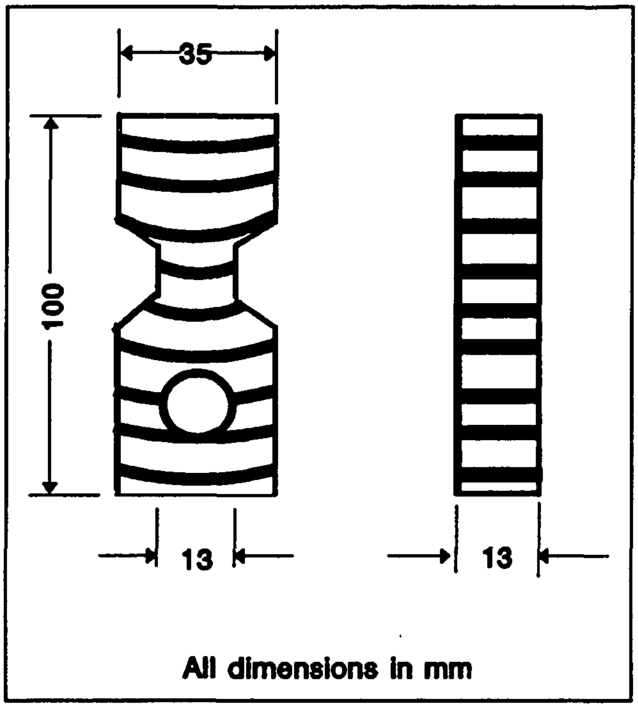

Figure 5. Shape and dimensions of test pieces.

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