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ABSTRACT—A three part study was conducted on a single quaking aspen tree (Populus tremuloides): (1) the strength and other physical properties of fiberboard made from the trunk, roots, and limbs using the cold soda pulping process, (2) the strength properies of paper made from the trunk, root, and limb sections using the Kraft pulping process, and (3) a chemical analysis of the trunk, roots, and limbs. Results of these studies indicate there are significant differences in many of the properties of the three parts of the tree, and that parts of the tree other than the trunk possess useful properties.

Conventional pulpwood cutting methods utilize only the trunk of pulp trees that in the aspen, comprises only about 60% of the total weight. Although there is presently a surplus of aspen pulpwood in our area, this situation may change in the future because of the development of new uses for wood. The limbs and roots normally left by the pulpcutters may also produce pulp with desirable properties. The present study was conducted to determine any differences that may exist in the properties of the trunk, roots, and limbs of a single aspen tree. The study was divided into three parts: (1) the strength and other physical properties of fiberboard made from the trunk, roots, and limbs using the cold soda pulping process, (2) the strength properties of paper made from the trunk, root, and limb sections using the Kraft pulping process, and (3) a chemical analysis of the trunk, root, and limb sections.

Procedures

The individual aspen tree used in this study was selected by Mando's Forestry Department in November 1964 from a company woodlot in Koochiching County, Minnesota. The tree was taken from the SE ¼ of the SW ¼ of Section 23, Township 67N, Range 23W. The soil was a light sandy loam. For the purpose of this study, the dividing line between trunk and roots was considered to be four inches above ground level. The parts of the tree above ground with a diameter of less than 4½ inches were considered limbs. The length of the trunk was 31¼ feet; the top and bottom diameters were 4½ and 10¼ inches, respectively. The weight distribution of the three parts of the tree was, trunk—493.5 lbs., limbs—162.5 lbs., roots—177.0 lbs.

Each section was separately run through a 15-blade chipper turning at 400 rpm. After chipping, two representative samples were taken from each section of the tree to determine moisture content. After being weighed, the samples were air dried for five days, then dried in an oven for 24½ hours at 240°F. and finally weighed again. From the initial and dry weight of the chips the moisture content of the wood from the three parts of the tree was calculated to be approximately 50%.

To make fiberboard samples, 50 pounds of chips from each part of the tree were pulped by the cold soda process. The chips were soaked in a caustic solution consisting of 11% sodium hydroxide. After one week, the chips were removed, washed, and refined in a Sprout-Waldron Refiner. When they were passed through the refiner the first time the plate clearance was set at .040 inch; for the second pass the plate clearance was set at .015 inch.

After refining, the pulps were washed, partially neutralized with hydrochloric acid, and dewatered in a screen box. They were stored in plastic bags at freezing temperatures until used.

An initial step in making fiberboard is to dilute the pulp stock to a desired consistency. The consistency of pulp stock is the percentage by weight of dry wood fiber in the pulp suspension. In the present study, the three pulp stocks were diluted to an approximate consistency of 2.7%. Consistency determinations were then conducted on two samples of each stock and the results were averaged to determine the final consistencies. The final consistencies of the root, limb, and trunk pulp stocks were 2.71%, 2.94%, and 2.68%, respectively. Each stock was partially neutralized with hydrochloric acid to a pH of 7.3.

The amount of dry fiber needed for making handsheets of 18 lbs./cu ft. density was calculated as follows:

$$w = \frac{18 \times 7.75 \times 7.75 \times 0.500}{1728}$$

Where w = weight of dry fiber in pounds
18 = standard density in lbs./cu. ft.
7.75 x 7.75 = area of handsheet in sq. in.
0.500 = desired thickness of handsheet in in.
1728 = factor for converting cu. in. to cu. ft.

The pounds of pulp stock that contained w, the required amount of dry fiber, was calculated by dividing w by the consistency fraction. The handsheets were formed by pouring the required amount of stock into the handsheet

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mold and dewatering the fibers by gravity and vacuum. The fiber mat was supported on a screen as it was removed from the mold and transferred to a cold press. The sheets were then pressed to a thickness of ¼ inch for 1 minute. After being pressed, the sheets were dried over night at 300°F and stored at 50% relative humidity and 72°F. Twenty-four handsheets were made from each of the three types of pulp.

Prior to selection of the handsheets to be tested all the handsheets were weighed and an average weight determined. Twelve handsheets from each type of pulp that came closest to the average weight of all the handsheets were selected as the test samples. Tests to determine the following properties were performed in accordance with the procedure of the American Society for Testing Materials (ASTM) (1961: modulus of rupture (MOR), modulus of elasticity (MOE), necked tensile, perpendicular tensile, water absorption, thickness, and density. The MOR and MOE values were corrected to a common density of 18 lbs./cu. ft. in a manner reported previously (Anderson, McLinn, Madison & Hyvarinen, 1964). The results of the tests appear in Table I. Unless stated otherwise the results are reported as the average of 6 determinations.

The second study consisted of comparing the strength of Kraft paper that was made from the three parts of the tree. The wood chips used for the process were the same as those described for making fiberboard. A representative sample of 3000 grams of chips from each part of the tree was pulped by the Kraft process.

Because the sections of the tree were chipped before being debarked (the fiberboard project required that the bark be left on), the bark was removed by hand for the Kraft cooks. The debarked chips were placed with the Kraft cooking solution in a 0.36 cubic-foot digester utilizing indirect heat and equipped with temperature and pressure gauges.

The Kraft cooking solution contained 51.6 grams of sodium hydroxide and 14.4 grams of sodium sulfide per liter. The liquid to wood ratio was about 4:1. A standard cooking curve was followed for each cook. A maximum temperature of 350°F, at 120 *psi* pressure was held for 75 minutes. The total cooking time was 4 hours.

After cooking, the pressure was released slowly and the cooked chips were emptied into a screen trough. The chips were washed, broken up into pulp, and the few large, uncooked knots were removed by hand. The washed pulp was placed in polyethylene bags and stored in a refrigerator until used.

The pulp was beaten to a freeness of 350 cc CSF according to a standard method.[2] To determine the extent of delignification that occurred during pulping a permanganate number [2] was taken on each of the beaten pulps. The beaten pulp was diluted and a total of 24 handsheets were made from each of the three pulps according to a standard method.[2]

The handsheets were conditioned at 72°F and 50% relative humidity. They were then weighed and their thickness was measured. The conditioned handsheets were tested for bursting strength, tensile strength, folding endurance, and tearing resistance.[2] The results of these tests appear in Table II.

Chemical analyses were performed on the chips that were used for making the paper and fiberboard samples. The air-dried chips were ground in a Sprout-Waldron Refiner until they passed through a 40-mesh screen.

This groundwood was used for the determination of the ash content, alcohol benzene extractives, holocellulose content, hot water solubles, and lignin content. The moisture content of groundwood, which was stored at 50% relative humidity and 72°F., was determined and used in subsequent calculations. The percent moisture is reported in Table III.

The ash content of three samples from each part of the tree was determined according to a standard method

[2] *Testing Methods Recommended Practices Specifications of the Technical Association of the Pulp and Paper Industry* (1965).

TABLE I. Properties of Fiberboard Made from Cold Soda Pulps from the Limbs, Trunk, and Roots of a Quaking Aspen Tree

	Limbs	Trunk	Roots
MOR (*psi*)			
Uncorrected for density	348 ± 34*	272 ± 29	372 ± 43
Corrected for density	400 ± 39	280 ± 30	330 ± 41
MOE (1000 *ppsi*)			
Uncorrected for density	24 ± 2	19 ± 3	26 ± 5
Corrected for density	28 ± 2	20 ± 3	23 ± 4
Necked tensile (*psi*)	189 ± 31	134 ± 9	213 ± 10
Perpendicular tensile (*psi*) (12)	7.2 ± 0.6	5.9 ± 0.8	8.4 ± 0.6
Thickness (inches)	0.534 ± 0.008	0.533 ± 0.009	0.510 ± 0.007
Weight per area (lbs/1000 sq. ft.)	745 ± 14	790 ± 19	816 ± 19
Density (lbs/cu. ft.)	16.8 ± 0.7	17.7 ± 0.6	19.1 ± 0.6
Water absorption			
% by Weight			
2 hr.	365 ± 12	368 ± 12	331 ± 20
24 hr.	368 ± 14	373 ± 13	329 ± 10
% by Volume			
2 hr.	101 ± 9	105 ± 3	101 ± 4
24 hr.	102 ± 11	106 ± 13	103 ± 3

* Limits of 95% confidence

TABLE II. Properties of Paper Made from Kraft Pulps from the Trunk, Roots, and Limbs of a Quaking Aspen Tree

	Trunk	Roots	Limbs
Weight (gms.)	1.19	1.21	1.16
Thickness (inches)	0.0032	.0030	.0032
Tear factor (4 sheets)	7.9 ± 0.5*	9.2 ± 0.3	7.2 ± 0.5
Tensile (lbs/15 mm.)	15.6 ± 0.3	14.9 ± 0.5	14.1 ± 0.4
Fold (Number)	102 ± 15	292 ± 43	46 ± 8
Burst (p.s.i.)	33.6 ± 0.7	36.0 ± 0.8	26.4 ± 0.9
Moisture %	7.53	7.27	7.60

* Limits of 95% confidence

TABLE III. Chemical Properties of Groundwood made from the Roots, Limbs, and Trunk of the Quaking Aspen.*

	Roots	Limbs	Trunk
Ash Content, %	1.61 ± 0.25**	1.45 ± 0.14	0.66 ± 0.12
Lignin Content, %	18.27 ± 0.67	24.11 ± 0.73	22.26 ± 0.12
Hotwater Solubles, %	1.64 ± 0.56	6.93 ± 2.69	2.49 ± 0.81
Holocellulose, %	77.36 ± 3.12	72.91 ± 2.40	81.79 ± 5.11
Alcohol—Benzene Extracts, %	5.84 ± 0.28	12.94 ± 1.61	3.62 ± 0.57
Moisture Content, %	7.73	7.77	7.47

* All the figures reported in this table are based on oven-dried weights.
** Limits of 95% confidence

(*Institute Methods*, 1952) using a muffle furnace. The average ash contents appear in Table III. The following qualitative analyses were performed on the ash samples: The ashed samples were dissolved in hydrochloric acid and flame test for calcium and potassium were performed on the resulting solutions. To determine if any iron was present, potassium thiocyanate was added to the test solution. The appearance of a red colored precipitate indicated the presence of iron.

The content of alcohol-benzene extractives in each part of the tree was determined by extracting six samples according to a standard method. (*Institute Methods*, 1952). The results appear in Table III.

The holocellulose determination was performed on three specimens according to a standard method (*Institute Methods*, 1952). The holocellulose contents are reported in Table III.

$$\% \text{ holocellulose} = \frac{\text{dry weight after chloriting x 100}}{\text{weight of dry fiber}}$$

The hot-water solubility test was performed on three samples from each part of the tree according to a standard method (*Institute Methods*, 1952).

The results are reported in Table III. A Benedict's test for reducing sugars was performed on the hot-water soluble materials. The final colors of the test solutions were as follows: control—bright orange; trunk—yellow; roots—very light yellow; and limbs—greenish yellow. The starch Iodine test was also performed on the hot-water solubles and the final colors of the solutions used in this test were as follows: control — dark blue; trunk — dark blue; roots—light blue; and limbs—no change.

The lignin content was determined on three samples from each part of the tree according to a standard method (*Institute Methods*, 1952). The percentage of lignin is reported in Table III.

The results of all tests were treated statistically by calculating the limits of 95% confidence according to ASTM (1951). The difference between two mean values was considered to be significant if it was equal to or larger than the sum of the 95% confidence limits of the two mean values.

Results and Discussion

As a result of this study, it was determined that there are significant differences among the limbs, trunk, and roots of the aspen tree, both in chemical composition and in the properties of paper and fiberboard made from these parts.

The tests performed on fiberboard made from the three parts of the tree indicated that the roots were significantly stronger in MOR, MOE, necked tensile, and perpendicular tensile than handsheets made from the trunk, while the limbs were of intermediate strength. The results of the water-absorption studies showed that the fiberboard made from the roots absorbed less water in a given time than did either the limbs or the trunk.

Studies on Kraft paper made from the three parts of the tree indicated that paper made from the roots was superior when judged by the results of the tear, burst, and fold tests. The results of tensile-strength tests indicated that paper made from the limbs was the weakest. No determination of density was made on the paper samples, therefore, these results are not corrected for density differences that may have existed.

From the analysis of the chemical constituents of the trunk, roots, and limbs, it was found that the ash contents of the limbs and roots were higher than those of the trunk. The results of the flame tests for calcium and potassium suggested that calcium was present in all three parts of the tree, whereas potassium was found only in

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