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STRENGTH OF SOME HARDWOOD PULPS AND THEIR FIBER FRACTIONS

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AND THEIR FIBER FRACTIONS

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Summary

The strength, after beating, of some hardwood pulps and their fiber fractions were compared. These were kraft pulps of sweetgum, white oak, mixed red and white oak, and a cold soda pulp from mixed hardwoods. The effect of removing the fines, mainly parenchyma cells and short vessel elements, from beaten pulps was also determined.

Beating resulted in higher strength properties in the fiber fractions than in the corresponding whole pulps, except for the sweetgum pulp. For the oak pulps the beaten fiber fractions were markedly stronger than the beaten whole pulps that contained about 28 percent fines. The fiber fractions averaged 25 percent higher in bursting strength, 15 percent higher in tearing resistance and breaking length, 110 percent higher in folding endurance, but were substantially the same in density.

The fiber fractions obtained from the beaten whole oak pulps had strengths substantially the same as the fiber fraction taken from the unbeaten whole pulp and then beaten.

¹Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Handsheets made from the beaten fiber fraction of the sweetgum pulp that contained about 22 percent fines were not significantly stronger than those made from the beaten whole pulp at comparable freeness.

The cold soda pulp contained about 38 percent fines. The fiber fraction, beaten to the same freeness as that of the whole pulp (300 milliliters), had 200 percent higher bursting strength, 74 percent higher tearing resistance, 170 percent higher breaking length, and 30 percent higher density.

Introduction

The amount of hardwood pulps now used in various papers and paperboards could be increased and new uses created if higher strength properties could be developed in these papers without sacrifice of other desirable properties characteristic of hardwood pulps.

Paper strength depends considerably upon fiber length. Hardwood pulps have much shorter fibers than softwood pulps and also higher proportions of "fines." Usually, fines are defined arbitrarily as the amount of the pulp that will pass through a screen of specified fine mesh during the operation of a standardized fiber-classifying screen. This specification may range from 100 to 200 mesh.

With this criterion, fines of hardwood pulps will consist of fiber fragments, parenchyma cells, and vessel elements when screens are used having meshes of 100 to near 150. According to Adams,² the length of hardwood parenchyma cells is approximately 0.1 millimeter and the width is 0.02 millimeter. He defined the fines as the parenchyma cells. Haywood³ considered the portions of various softwood and hardwood pulps passing the 150-mesh screen of the Bauer-McNett fiber classifier to consist of ray cells. His screen-classification data showed that from 4 to 7 percent of softwood pulps and 7 to 29 percent of hardwood pulps passed the 150-mesh screen. The length of vessel elements was shown by Bergman⁴ to range from 0.15 millimeter for maples to 1.16 millimeters for gums.

² Adams D. O. Contribution to a panel discussion at the Third International Fundamental Research Symposium. Montreal, Sept. 15-17, 1958.

³ Haywood, Gerald. Effect of variations in size and shape of fibers on papermaking properties. Tappi 33(8):370-383, 1950.

⁴ Bergman, Stuart I. Lengths of hardwood fibers and vessel segments. Tappi 32(11):494-398, 1949.

Removal of the fines from a hardwood pulp would leave a residue of cells (fibers) averaging in length from 0.7 to 2.0 millimeters, depending on the species, or 7 to 20 times the length of the parenchyma taken out.⁴—With the fines removed, it would be reasonable to expect an increase in paper strength such as tearing resistance and folding endurance.

In a study made at the Forest Products Laboratory in 1947 by R. M. Kingsbury and Charles N. Betts, post oak kraft and neutral sulfite semichemical pulps were found to contain about 35 percent by weight of fines. These were the portions of the pulps passing through a 115-mesh flat, vibratory screen. Microscopical examination of these fines revealed the presence of small amounts of fibers and vessel elements, in addition to essentially all of the parenchyma cells of the original pulps. After beating the fiber fractions of these pulps to a freeness of 750 milliliters, Schopper-Riegler, the bursting strength and tearing resistance of handsheets were about twice those of the whole pulps.

Similarly, the fiber fraction of a kraft pulp made from a mixture of Philippine hardwoods was 15 percent higher than the whole pulp in bursting strength, 20 percent higher in tearing resistance, and 30 percent higher in folding endurance at a freeness of 500 milliliters, Schopper-Riegler. This was determined from a study made in 1952 by J. N. McGovern and his associates at the Forest Products Laboratory.

Haywood³ reported the strength of the fiber fraction of an oak kraft pulp was about 10 percent higher than that of the whole pulp after beating 77 minutes for the whole pulp and 92 minutes for the fiber. He concluded “Since deciduous wood pulps are especially deficient in tear value in the low-freeness range, the increase in tear does not justify the expense of or loss of yield due to fractionation.”

Adams² discussed effects of adding the parenchyma cells of hardwood pulps to unbeaten and beaten fiber fractions. Adding these cells to unbeaten fiber and testing the mixtures in the unbeaten condition showed higher centrifugal water retention, density, bursting strength, and air resistance, depending on the proportions added. There was essentially no effect on tearing resistance, scattering, and absorption coefficients of the handsheets. However, the addition of the parenchyma cells to beaten fiber fractions decreased bursting strength and tearing resistance.

The present report covers the study of variations in strength properties of some hardwood pulps and their fiber fraction upon mechanical processing. These included kraft pulps of sweetgum, white oak, mixed red and white oak, and a mixed hardwood cold soda pulp. The oak mixture was equal proportions of each species.

Both the pulps and their fiber fractions were beaten in the standard test beater and the strength properties of the handsheets were determined. The fiber fraction of the cold soda pulp was refined with a conical refiner also.

Experimental Procedures

Fractionation

A sidehill screen was used to separate the hardwood pulps into the two fractions, fiber and fines. This device was patented 30 years ago by Hatch⁵ to remove the color-containing parenchyma cells from western hemlock chemical pulp. The screen specified was about 25 mesh and the angle of inclination was 45° from the horizontal. The strength of the fiber fraction was a little higher than that of the whole pulp.

In the present study, a 70-mesh Fourdrinier wire screen was used and inclined at an angle of about 37°. A 0.2 percent suspension of the pulp, while agitated in a stock chest, was flowed onto the screen. A spray of water was directed onto the screen to assist in washing the fines through the screen and in moving the fiber fraction down the screen.

Fractionation by this method gave reasonably good removal of the fine material. The effectiveness of the separation was determined qualitatively by microscopical examination. The fiber fraction was rescreened whenever necessary. A small amount of long fiber and vessel elements usually passes through the screen along with the parenchyma cells.

In the use of the Bauer-McNett fiber classifier, the pulp fraction that passed through a 100-mesh screen was termed the fines, and the fraction retained on this and coarser screens was termed the fiber fraction.

Processing

Both the pulps and their fiber fractions were beaten in the beater according to TAPPI Standard T 200. The handsheets prepared from the pulps were tested according to TAPPI Standard T 220. In one instance, whole sweetgum kraft pulp

⁵Hatch, H. S. Method of treating chemical pulp. (U.S. Patent No. 1,951,017.) U.S. Pat. Off.. Off. Gaz. 440:481, 1934.

and also its fiber fraction were bleached by a three-stage process, comprising prehypochlorite chlorination, caustic soda extraction, and chlorine dioxide. The bleached whole pulp was screened to compare the strength properties of the resulting fiber fraction with the fiber fraction which had been bleached after its separation from the whole pulp.

Discussion of Results

Screen Classification Tests and Strength Comparisons

Results of fiber fractionation by the sidehill screen and by the Bauer-McNett fiber classifier are given in table 1. It was concluded from these results and the microscopical examinations that sidehill screening is suitable for separating hardwood pulps into their fiber and fine fractions when relatively large amounts of these materials are required.

Sweetgum Kraft Pulps

The results of beater tests on the unbleached and bleached sweetgum kraft pulps and their fiber fractions are given in table 2.

In the unbeaten condition, there was no significant difference in the strength properties or freeness of the whole pulp and fiber fraction, whether unbleached or bleached. As shown in table 1, the amount of "fines" removed from the unbleached whole pulp by sidehill screening was 22 percent, as compared to 14 percent by the Bauer-McNett classifier. Microscopical examination, however, indicated that a substantial amount of vessel elements and fiber had been washed through the sidehill screen. Hence, 14 percent is accepted as the preferred value for the amount of fines in this pulp. The fiber fraction contained a considerable amount of vessel elements and some parenchyma cells.

Upon beating, the time required to lower the freeness to an interpolated value of 350 milliliters was the same for the whole pulp and the fiber, whether unbleached or bleached. Also, there were no essential differences in strength properties. The fiber fraction obtained from the bleached whole pulp was as strong as the fiber fraction obtained from the unbleached whole pulp.

It is thus apparent that the 14 percent of fines in this pulp did not affect pulp strength adversely.

Red and White Oak Kraft Pulp

Fractionation Before Beating.--The amount of fines removed from the unbeaten red and white oak kraft pulp with the sidehill screen was 19 percent as compared to the accepted value of 14 percent removed from the sweetgum pulp with the Bauer-McNett classifier screen (table 1). However, the Bauer screen removed 28 percent of material from the oak kraft pulp. Although this difference remains unexplained, the values for the sidehill screen are possibly incorrect due to experimental errors in determining the amount of the fiber fraction recovered. The results for the white oak pulp and the Bauer-McNett classification data reported by Haywood³ for several oak kraft pulps tend to confirm this conclusion.

The strengths upon beating the red and white oak kraft pulp and its fiber fraction are given in table 3.

The data show that removal of fines from this pulp resulted in a substantial increase in all strength properties, but there was no consistent trend in sheet density. A comparison of the strength properties of the whole pulp with those of the fraction at a freeness of 350 milliliters, Canadian Standard, showed the fiber fraction was higher by about 17 percent in bursting strength and in tearing resistance, 9 percent in breaking length, and 100 percent in folding endurance. The beating required to lower the freeness to the 350 value was 5 minutes longer (23 percent) for the fiber fraction.

The amount of fines present in this pulp (27.7 percent) was sufficient to affect strength adversely.

Fractionation of Beaten Pulp.--Samples of the pulp were beaten to freeness values of 345 and 195 milliliters. The fiber fractions were separated from the beaten pulps with the sidehill screen, formed into handsheets, and tested for strength (table 3). The percentages of fines removed were 29 at 345 milliliters and 36 at 195 milliliters, which are considered reasonable on the basis of the other data in table 1 and those of Haywood.³

The freeness of the fiber fraction from the first of the beaten samples was 580 milliliters, as compared to 345 for the whole pulp. Accordingly, sheet density for the fiber fraction was lowered 11 percent, as were bursting strength 15 percent, breaking length 12 percent, and folding endurance 73 percent. Tearing resistance, however, was 40 percent higher. The strength properties of this fraction were essentially the same as those of the fiber fraction beaten after screen classification when compared at the 580 freeness level. Beating the fiber fraction alone to 580 freeness required but 10 minutes, as compared to 27 minutes for the whole pulp.

The freeness of the fiber fraction from the second of the beaten samples was 505 milliliters, compared to 195 milliliters for the whole pulp. Sheet density of the fiber fraction was 7 percent lower and tearing resistance 23 percent higher, but there were no other important differences. As with the preceding sample, this fraction was essentially the same in strength as the fiber fraction beaten after fractionation, and an equally longer beating time was required.

Fractionation after beating would be more costly, due to the higher power requirement.

White Oak Kraft Pulp

The amount of fines removed from the white oak kraft pulp by both the sidehill and the Bauer-McNett screens was the same--about 29 percent (table 1).

The strength properties of the pulp and its fiber fraction are given in table 4.

A comparison of the fiber fraction with the whole pulp at a freeness of 350 milliliters showed sheet density to be about the same, but the fiber fraction was uniformly stronger--14 percent in bursting strength, 20 percent in tearing resistance, 12 percent in breaking length, and 38 percent in folding endurance.

Like the other pulps in this study, the freeness of the unbeaten fiber fraction was only slightly higher than that of the unbeaten whole pulp. The fiber fraction required about 20 percent more beating than the whole pulp to lower the freeness to the same levels.

Hardwood Cold Soda Pulp

The cold soda pulp, prepared from a mixture of southern hardwoods, contained about 40 percent fines. The values for both the sidehill and Bauer-McNett screens were in satisfactory agreement (table 1). Similar amounts of fines have been found in other hardwood cold soda pulps produced at the Forest Products Laboratory. This type of pulp is consistently higher in fines than hardwood chemical pulps, due to the action of the disk refiners used in its production.

The strength properties of the cold soda pulp and its fiber fraction before and after mechanical processing are given in table 5. The fiber fraction samples were processed in the standardbeater and also with a laboratory-size conical refiner.

The freeness of the fiber fraction was 700 milliliters compared to 300 milliliters for the whole pulp, which agrees with the relatively high percentage of fines in this pulp (table 5).

The data presented in table 6 show that, in contrast to the three chemical pulps, the unbeaten fiber fraction of the cold soda pulp was considerably lower in tearing resistance than the whole pulp. This is attributed to a combination of fiber stiffness and of lignin blocking off hydrogen bonding between carbohydrate molecules to an extent that the influence of fiber strength on tearing resistance was minimized.

Upon beating, however, the tearing resistance of the cold soda fiber at 350 milliliters freeness was almost 80 percent of that of the chemical pulps.

Microscopical examination of the beaten fiber revealed the presence of considerable free fibrils and lamellae that appeared to have come mainly from fiber tracheids. There was but little fibrillation of the libriform fibers. The relatively mild mechanical action during beating would not be expected to remove lignin. Hence, the increased tearing resistance was attributed to increased bonding to such an extent that the fiber strength became a contributing factor. The increased bonding was a result of an increase in fibrous surface area (fibrils and lamellae) in conjunction with an increased flexibility of the fibers. Similar results and concepts for a 20-mesh fraction of a chip groundwood made from spruce were published recently.^{6,7}

It would be desirable to find out why the tearing resistance of the cold soda fiber was lower than that of the kraft pulps. It seems unlikely that there was an important difference in their fiber length. The density of sheets made from the cold soda fiber was from 26 to 38 percent lower than those of the other pulps. If density is accepted as an index of fiber bonding, it is plausible to conclude, in order to account for the difference in tearing resistance, that both types of fiber were essentially equal in fiber strength. Presumably, this conclusion could be tested by determining the tensile strength of single fibers from pulps made by different processes. Another fact for consideration is that the cold soda pulp contained only about 45 percent as many fibers per unit weight as the kraft pulps owing to the difference in pulp yields. This was discussed recently by Giertz⁸ with reference to softwood chemical pulps in the yield range of 55 to 70 percent. He concluded that the low tear strength of high-yield pulps is primarily an effect of the limited number of fibers per unit weight.

⁶ Marton, Renata, and Alexander, S. D. Properties of fiber fractions from chemical and mechanical pulps. I. Softwood pulps. Tappi 46(2):65-70, 1963.

⁷ Marton, Renata, Supka, K. A., and Bernhard, S. P. Properties of fiber fractions from chemical and mechanical pulps. II. Refining of the long fibers of softwood pulps. Tappi 46(9):534-538, 1963.

⁸ Siertz, Hans W. Some consequences of high yield on paper properties. Svensk Papperstidning 66(18):691- 695, 1963.

Conclusions

The fiber fractions of hardwood kraft and cold soda pulps are somewhat higher in handsheet strength than the whole pulp, depending on the proportion of other cells present in the pulp. This proportion was about 25 percent. The average strength of the kraft pulps in burst, tear, and breaking length approaches 87 percent of that of the fiber fraction and, for cold soda pulps, 59 percent.

Unless a now unforeseen profitable use for the fines or a market premium for the fiber fraction arises, pulp producers could not afford to discard 25 to 30 percent of their product.

Table 1.--Screen classification of some hardwood pulps

Pulp	Pulp No.	Sidehill screen ¹ :		Bauer-McNett fiber-classifier ² :	
		Fiber	Fines	Fiber	Fines
		<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>
Sweetgum kraft	I-4243	77.6	22.4	86.2	13.8
Unbleached					
Bleached				87.1	12.9
Unbleached	I-4382	85.2	14.8		
Red and white oak kraft ³	4167-8X				
Unbeaten		80.6	19.4	72.3	27.7
Beaten to 345 ml.		70.8	29.2		
Beaten to 195 ml.		64.0	36.0		
White oak kraft	4221-2-3X	71.0	29.0	71.2	28.8
Mixed southern hardwood cold soda ⁴	I-4361	62.0	38.0	58.0	42.0

¹Pulp suspension at 0.2 percent consistency was flowed over a 70-mesh screen inclined at an angle of 37° to horizontal.

²The fraction retained on 100-mesh and coarser screens is the fiber fraction and that passing the 100-mesh and finer screens is the fine fraction.

³Equal amounts of each species.

⁴Pulp was made from a mixture of 50 percent red and white oak and 50 percent of "soft" hardwoods, the composition of which was 50 percent sweetgum and yellow-poplar and 50 percent of soft maple, sycamore, river birch, and elm. Tests were made according to TAPPI Standards T 200, T 227, and T 205. Test values other than for unbeaten samples are interpolated.

Table 2.--Strength of a sweetgum kraft pulp and the fiber fraction¹

Sample	Beating time	Freeness (Canadian Standard)	Burst factor	Tear factor	Breaking length	Folding endurance (MIT)	Density
	Min.	Ml.			M.	Double folds	G. per cc.
Unbleached, whole pulp ²	0	750	6	51	1,910	2	0.33
	14	550	33	119	6,900	45	.53
	18	450	40	117	7,780	100	.59
	22	350	45	110	8,300	185	.62
Fiber fraction	0	750	5	44	1,715	2	.31
	17	550	39	122	6,900	85	.53
	21	450	46	112	8,100	140	.59
	25	350	50	110	8,800	180	.62
Bleached, whole pulp	0	730	8	56	2,085	2	.34
	15	550	38	130	6,900	20	.52
	20	450	45	108	7,900	45	.56
	22	350	48	100	8,450	100	.60
Fiber fraction ³	0	750	4	48	1,460	1	.31
	15	550	38	141	6,950	70	.54
	18	450	43	123	7,950	150	.58
	21	350	48	110	8,750	260	.62
Fiber fraction ⁴	0	750	4	49	1,365	.....	.28
	14	550	35	130	6,800	45	.51
	18	450	44	127	7,000	90	.56
	22	350	48	119	8,300	165	.60

¹Tests were made according to TAPPI Standards T 200, T 227, and T 205.

²Digestion I-4243. Yield about 49 percent.

³Whole pulp was bleached and then the fines were removed by sidehill screening. Bleaches 5091 and 5093.

⁴The unbleached pulp was fractionated, and the fiber fraction was then bleached. Bleach 5092.

Table 3.--Strength of a kraft pulp of red and white oak and its fiber fraction separated before and after beating the whole pulp¹

Sample	Beating time ²	Freeness (Canadian Standard)	Burst factor	Tear factor	Breaking length	Folding endurance (MIT)	Density
	Min.	Max.			Max.	Double folds	G. per cc.
1. Whole pulp	0	660	15	77	4,080	5	0.53
	5	550	36	108	6,900	80	.65
	9	450	49	101	8,300	300	.72
	22	350	59	88	9,000	670	.78
2. Fiber fraction from unbeaten pulp	0	695	11	74	3,610	4	.53
	10	580	44	108	7,700	120	.66
	12	550	50	114	8,400	200	.69
	17	505	59	115	9,000	370	.71
	20	450	65	112	9,400	600	.72
	27	350	69	103	9,800	1,100	.75
3. Whole pulp							
	A. 7	580	34	90	6,300	50	.60
B.	27	345	58	78	8,920	366	.72
4. Fiber fraction from 3B ³	.....	580	49	110	7,830	98	.64
5. Whole pulp							
	A. 11	505	48	90	8,000	90	.65
B.	36	195	60	70	9,160	486	.76
6. Fiber fraction from 5B ⁴	.....	505	60	96	8,420	.....	.71

¹Equal proportions of red and white oaks. Pulp 4167-68X. Tests were made according to TAPPI Standards T 200, T 227, and T 205.

²All values for time and tests are interpolated except those in lines 1, 5, 12 and 14.

³This fraction was 71 percent by weight.

⁴This fraction was 64 percent by weight.

Table 4.--Strength of whole white oak kraft pulp
and its fiber fraction¹

Sample	Beating time ²	Freeness (Canadian Standard)	Burst factor	Tear factor	Breaking length	Folding endurance (MIT)	Density
	Min.	Ml.			M.	Double folds	G. per cc.
Whole pulp,	0	700	13.5	82.8	3,740	4	0.49
4221-2-3X	12	550	39.0	102	7,000	60	.63
Yield 48 percent:	19	450	50.5	98	7,800	220	.70
	25	350	56.0	91	8,300	400	.74
	29	250	58.0	88	8,450	600	.76
Fiber fraction	0	715	14.5	90.4	3,890	4	.49
	16	550	50	126	8,000	125	.63
	22	450	60	120	8,800	310	.67
	28	350	64	110	9,300	550	.72
	35	250	65	100	9,440	760	.77

¹Freeness and other test values for beaten samples are interpolated, except for unbeaten materials. Tests were made according to TAPPI Standards T 200, T 227. and T 205.

Table 5.--Strength of a cold soda pulp and
its processed fiber fraction¹

Sample	Beating time	Freeness (Canadian Standard)	Burst factor	Tear factor	Breaking length	Folding endurance (MIT)	Density
	<u>Min.</u>	<u>Max.</u>			<u>M.</u>	<u>Double folds</u>	<u>G. per cc.</u>
Whole pulp, I-4361 ²	0	300	8.5	46.5	1,980	.....	0.37
Yield about 90 percent	5	235	10.9	49.5	2,555	.....	.40
Fiber fraction ²	0	700	3.3	28.3	1,125	.....	.29
	.....	350	23.5	80.5	5,100	13	.46
	43	300	26.0	81.0	5,400	17	.48
	49	235	29.0	77.0	5,800	23	.50
Fiber fraction ³	.....	300	12.0	47.0	3,130	4	.50
	.....	235	13.0	43.0	3,300	4	.52

¹Pulp was made from a mixture of 50 percent red and white oak and 50 percent of "soft" hardwoods, the composition of which was 50 percent sweetgum and yellow-poplar and 50 percent of soft maple, sycamore, river birch, and elm. Tests were made according to TAPPI Standards T 200, T 227, and T 205. Test values other than for unbeaten samples are interpolated.

²Beaten in TAPPI standard test beater.

³Refined in a laboratory-size conical refiner fitted with abrasive linings.

Table 6.--Density and tear factor values for whole pulps and their fiber fractions¹

Pulp	Whole pulp				Fiber fraction			
	Unbeaten		Beaten		Unbeaten		Beaten	
	Density	Tear factor	Density	Tear factor	Density	Tear factor	Density	Tear factor
	<u>G. per</u> <u>cm.³</u>		<u>G. per</u> <u>cm.³</u>		<u>G. per</u> <u>cm.³</u>		<u>G. per</u> <u>cm.³</u>	
<u>Kraft</u>								
Sweetgum	0.33	51.0	0.62	110	0.34	56.0	0.62	110
Red and white oak	.53	77.0	.78	88	.53	74.0	.75	103
White oak	.49	82.8	.74	91	.49	90.4	.72	110
<u>Cold Soda</u>								
Mixed hardwoods	.37	46.5	.40	49.5	.29	28.8	.46	81

¹Test values interpolated at a freeness of 350 ml., Canadian Standard, except the beaten whole cold soda pulp at 235 ml. Tests were made according to TAPPI Standards T 200 and T 205.

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