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An Evaluation of Wood Pulp Paper Durability

E. L. Graminski and E. E. Toth

Stability and Standards Section
Polymers Division

February 15, 1977

Progress Report Covering the Period
October 1, 1976 to September 30, 1977

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1. SUMMARY

Currency has been printed customarily on high grade rag paper owing to its superior durability. During the past several years the cost of raw material for rag pulps has risen tremendously and the thought of using high quality wood pulp papers as a means of lowering the cost of currency manufacture has been advanced. However, it would not be cost effective to use a wood pulp paper unless its durability was only slightly lower than regular rag currency paper. Otherwise the cost of replacing worn out currency would soon exceed the savings realized by using a less expensive paper.

During the past several years extensive work had been done on rag currency paper to resolve the origin of its superior durability. In addition, many chemical modifications of currency paper were evaluated as means for further increasing the durability of the paper. It was decided to develop similar fundamental information on wood pulp paper and to evaluate the chemical modifications which appeared promising for rag currency paper.

An estimate of fiber length distribution of untreated and mechanically treated wood pulps was determined. Wood pulp was fractionated by fiber length and handsheets were made from the various fractions. The mechanical and physical properties of these handsheets were determined. The possibility of further reducing the cost of durable wood pulp papers was investigated by using less expensive hardwood pulp, mechanically treated separately, then blended with softwood pulps to incorporate certain structural elements believed to be essential for good durability. Finally wood pulp handsheets were treated with acrylic resins by the beater addition and saturation techniques and the durability of the modified paper was evaluated.

Fiber length distribution was assessed by the classification technique according to Tappi method T233-os-75. Handsheets were prepared from the various fractions by the standard procedure. Standard Tappi methods were used to determine the physical properties of the papers. Durability of the papers was estimated with the aid of the NBS paper flexing apparatus. The extent of decline in physical properties as a function of flexing was used as a measure of durability. Modification of handsheets with acrylic resins was done by beater addition prior to sheet formation while modification by saturation technique was done with the aid of a laboratory size press.

Considerably more long fiber was contained in wood pulp stock than in rag currency paper stock. The differences in physical and mechanical properties of handsheets made from the various fiber length fractions of wood pulp were small in comparison to that observed in handsheets made from fractionated rag currency stock. Apparently large differences in fiber morphology exist between the various rag currency paper fractions but not between the wood pulp fractions.

The durability of wood pulp handsheets was affected by the addition of hardwood pulps to softwood pulps. Hardwood pulp had to be mechanically treated extensively in order for handsheets to have an acceptable level of durability. The results of this study indicated that it might be possible to produce an even less expensive wood pulp paper suitable for currency by a judicious choice of hardwood and softwood pulps. A critical factor is the mechanical treatment rendered to each pulp prior to blending.

Apparently many of the commonly accepted notions, such as the necessity for a large amount of long fibers for durable papers, are without foundation. The real factors contributing to high durability have not yet been adequately identified. The present rag currency paper should be investigated thoroughly in order to identify the factors which contribute prominently to the durability of paper. The importance of fiber morphology in paper durability must be established in the immediate future. Success in making a wood pulp paper having an optimum durability largely depends on identifying the factors important for durable papers.

2. INTRODUCTION

The durability of paper made from rag pulps is generally greater than that of paper made from wood pulps. The durability of rag papers is not immediately assured since the fiber source and mechanical processing of the pulps in advance of paper making are critical variables. Nevertheless, it is generally felt that greater durability can be developed with cotton and linen pulps than with wood pulps. The expense of rag papers relative to wood pulp papers cannot be ignored, however, and there is always the notion that for some applications it might be more cost effective to use a less expensive wood pulp paper having only a modicum of lower durability than a high quality rag paper.

The probability of making high durability wood papers would be greatly enhanced by a knowledge of the reasons for the high durability of rag papers. It is generally assumed that the main reasons for rag paper durability are the mechanical properties of the fibers and the morphological changes which the fibers undergo during the mechanical treatment prior to paper making. There are no good data for the mechanical properties of single fibers of cotton and linen in the literature (1). Some information on fiber length distribution of currency stock was developed (2) but there is essentially no information on the slenderness, curl and coarseness of currency paper fibers.

Although currency paper is quite durable there has been a desire to enhance its durability further. During the past several years extensive work was done determining the factors important to currency paper durability and on modifying the paper to improve its durability. The effect of beating and wet pressing, fiber length distribution and the addition of synthetic latexes to rag paper were investigated. Since a similar investigation was not done on wood pulp paper it was decided to conduct these experiments on handsheets made from wood pulp and to compare the results with those obtained with rag papers.

3. EXPERIMENTAL DETAILS

3.1 Beating

Beating was done similarly to that specified in the Canadian Pulp and Paper Association Test Method C7 except that 40g of pulp was soaked in 360 cm^3 of water for at least one hour prior to beating. The wet pulp was distributed evenly over the bedplate prior to beating. There was no clearance between bedplate and roll. The beating was done at 33.3N (3.4 kgf) and a relative velocity of roll to bedplate of 6 m/sec for either 5, 10, or 20 thousand revolutions.

3.2 Density

Handsheets were cut to 10x10 cm and the thickness of each sheet was determined at 10 different locations according to TAPPI Method T411os-76. The average of the 10 thickness measurements was considered to be the sheet thickness. From the measurement of length, width and thickness the volume in cm^3 was calculated. The weight of each sheet, previously conditioned according to TAPPI Standard T402os-70, was measured to the nearest milligram on an analytical balance. The density was calculated by dividing the weight by the volume of the sheet.

3.3 Durability

Specimens 15x30 cm were flexed 1000 times over 3.18 mm rollers while constrained by a 700g free hanging weight on the NBS paper flexer. Only that portion which passed over both rollers was used for subsequent testing. The air permeability of each specimen was determined at six different locations with a commercial tester prior to cutting into small testspecimens as described in a previous NBS report (9). The extent of decline in physical properties as a consequence of flexing was considered to be a measure of paper durability.

3.4 Fiber Length Distribution

The fiber length of pulp was determined according to TAPPI Method T233-0s-75.

3.5 Handsheet Preparation

Aliquots of beaten pulp sufficient to make a 30x30 cm handsheet of desired g/m^2 were diluted with approximately one dm^3 of water and disintegrated for 7,500 revolutions in a commercial disintegrator. The suspension was added to the deckle box of the handsheet machine and a sheet was formed. The wire containing the formed sheet was placed on a blotter, covered with a felt, and consolidated by pressing the sheet with a 30 cm long roller weighing 22.5 kg. The sheet was removed from the wire, placed between felts, and passed through the roll press of the handsheet machine at the maximum pressure possible. After pressing, the sheet was placed on a drum drier at 95°C for approximately four minutes.

3.6 Modification of Paper with Acrylic Resins

There are two methods for modifying paper with polymer latexes. One is the so-called beater addition method which actually does not take place in a beater but in a mixing chest where the beaten pulp can be agitated gently in the presence of a latex. The second method is called paper saturation which involves saturating dry paper with a latex, squeezing out the excess, followed by drying.

A. Beater Addition Technique

An aliquot of the beaten pulp, sufficient to make a 30x30 cm handsheet of 70 g/m^2, was diluted with 600 cm^3 distilled water and disintegrated for 7,500 revolutions in a British disintegrator. The pH was adjusted to 9 using 1N NaOH. A cationic retention aid was added to the slurry in the amount of four percent based on latex solids to be deposited on the fibers. The retention aid was added from a sufficient quantity of a one percent solution diluted with 30 cm^3 distilled water. Only two thirds of the retention aid was added at the start. The mixture of pulp suspension and retention aid was stirred five minutes prior to latex addition to allow the retention aid to be exhausted from solution. The pH of the mixture was then decreased to 4.0 with 0.5N H_2SO_4.

4. FIBER LENGTH DISTRIBUTION OF WOOD PULPS

4.1 Background

The average fiber length is greater for unbeaten rag pulps than for unbeaten wood pulps. However, pulp fibers are not suitable for paper manufacture as produced and it is necessary to subject the fibers to mechanical action before good paper can be made. During the beating or refining process the fibers imbibe water and swell, fibrils form and extend from the fiber wall, fibers are cut, surface area increases, the outer walls of the fiber are removed and internal bonds are broken. The morphological characteristics of pulp fibers are changed considerably, and it is these morphological changes which affect the fiber network structure of paper. One of the most apparent changes which occurs during the mechanical treatment of rag pulps is a change in the fiber length distribution.

In a previous study on fiber length distribution (2), it was shown that currency paper stock contained a surprisingly small amount of long fibers. Only 16 percent of the total furnish consisted of fibers with a length approximately 1.17 mm or longer. Perhaps the most surprising fact was that 32 percent of the furnish consisted of fibers 0.2 mm or shorter. Currency paper consists of a high percentage of short fibers and yet is has excellent durability.

Several wood pulps were fractionated in order to obtain an estimate of their fiber length distribution relative to currency paper stock. Three softwood and one hardwood bleached kraft pulps were chosen. In addition, the effect of the beating on fiber length distribution was determined for one of the softwood pulps.

4.2 Experimental

The procedure for determining fiber length of pulp by classification is described in section 3 of this report.

The pulps used in this investigation were as follows:

(a) Pulp "F" bleached softwood kraft consisting of 95% spruce and hemlock and 5% pine.

(b) Northern Softwood. Bleached softwood kraft consisting of 80% spruce and/or hemlock, 15% balsam fir and 5% douglas fir.

(c) Southern Softwood. Bleached softwood kraft containing 90% short leaf pine and 10% scotch pine.

(d) Hardwood. Bleached hardwood kraft containing 97% alder, poplar, maple, populus, birch, oak and/or chestnut and sweetgum and 3% short leaf pine.

4.3 Results and Discussion

All three softwood pulps beaten or unbeaten contained considerably more long fiber than currency beater stock while the hardwood pulp has considerably less long fibers (Table 1). It has been generally believed that a large portion of long fibers is essential for strong durable papers. It is apparent from the results of this study that factors in addition to fiber length are important for durable papers.

During beating, fibers are cut resulting in a shortening of long fibers and an increase in debris. Laboratory mechanical treatment is significantly different from that employed by industry and the results obtained in this study are not necessarily indicative of morphological changes which occur during commerical paper manufacturing. Nevertheless, the morphological changes in rag pulp fibers during mechanical treatment is considerably different from wood pulps regardless of the mechanical treatment equipment used. It is quite apparent from this study that much could be learned about paper durability by an indepth study of the changes in rag pulp fiber morphology as a function of mechanical refining.

5. THE PHYSICAL PROPERTIES OF HANDSHEETS MADE FROM CLASSIFIED WOOD PULP

5.1 Background

The various fiber length fractions which compose paper pulps affect distinct physical properties of paper in different ways. The long fibered fraction has a great effect on the tear strength and folding endurance of paper. The very short fiber fraction has a great effect on the density of paper which in turn affects the modulus and bending stiffness. But regardless of the importance of an individual fiber fraction on a distinct paper property each of the other fractions also has some influence on the property in question.

One means of demonstrating the importance of the various fiber fractions on physical properties is to make handsheets from each of the individual fractions and to determine the physical properties of these sheets. Such a study was done previously on currency paper stock (2). The results of that study indicated that each fiber fraction was characteristically different from each of the other fractions. The mechanical properties of handsheets made from the various fractions differed considerably. The handsheets made from the unfractionated pulp were superior in all respects and demonstrated the synergistic interaction between the various fiber fractions in whole pulp. It remained to be seen whether wood pulp possessed similar characteristics.

For this investigation pulp "F" was used since extensive work with this pulp showed it had excellent mechanical properties. The pulp was beaten to various degrees in a laboratory mill, fractionated, and sheets were prepared from the various fractions.

5.2 Experimental

The methods used for the classification of pulp by fiber length, pulp beating, handsheet preparation, measurement of paper density and assessment of paper durability are given in section 3 of this report. A total of 240g of type F beaten pulp was fractionated in 40g batches for each set of beater conditions. The various fractions collected on each screen were combined, diluted to one-half percent consistency with water and blended thoroughly and then dewatered by filtration.

handsheets were made only from the first and second fractions as there were insufficient quantities of fractions three and four to make a sufficient number of handsheets for testing. In addition, sheets were made from 95 percent of fraction one and approximately five percent of fraction three.

5.3 Results and Discussion

Significant differences were observed between rag (2) and wood pulp handsheets prepared from fractionated pulp (Tables 2-5). Handsheets prepared from fractionated currency stock exhibited larger differences in physical properties between the various fractions while the differences observed with the wood pulp handsheets were relatively small. One of the major differences between the rag and wood pulp handsheets was the variation in sheet density as a function of fiber fraction. Sheet density increased with decreasing fiber length to a much greater extent with currency stock than with wood pulp as shown in Fig. 1. Apparently the differences in fiber morphology between the various fractions are much greater in currency stock than in wood pulp stock. In fact the small differences in sheet density observed between the various wood pulp fractions might easily result from the difference in fiber length distributions. As the fiber length decreases the fibers can form a more compact fiber network.

The data suggest that the greatest morphological change which occure during the beating of wood pulp in a laboratory beater is fiber shortening. Apparently the morphological changes occurring during the beating of cotton are more numerous and considerably different from those occurring with wood pulp fibers. It is reasonable to assume that the changes in fiber morphology occurring during the beating of rag pulps contribute greatly to the superior durability of rag papers. An indepth study of the morphological changes in pulp fibers during beating of rag pulps for currency paper would be invaluable. The study would assist in explaining the reasons for the superior durability of rag paper and be extremely helpful in designing a durable wood pulp paper for currency.

The retention of bending stiffness after flexing varied from a low of 26 percent for the 14 mesh fraction beaten for 5000 revolutions in the laboratory mill to 57 percent for the unclassified pulp beaten for 20,000 revolutions. While the difference in stiffness retention was great, there was only a

29 percent difference between the final stiffness of these two papers. Although good stiffness retention is a desirable feature for currency paper it is not the only criterion for bending stiffness to be considered. Currency is redeemed when its stiffness falls below a certain value (3,4). Although the stiffness retention for a paper could be high, the paper might be considered unsuitable for currency if the bending stiffness of the unflexed paper was near the stiffness level of redeemed currency. In such an instance only a moderate amount of handling would result in a sufficient decline of bending stiffness to render currency unfit for recirculation. The net result would be a decrease in the circulation life of currency even though the paper would have a high retention of stiffness.

Little if any change in physical properties occurred as the result of adding five percent of the 65 mesh fraction to the 14 mesh fraction. Apparently the quantity of 65 mesh fraction used in this investigation was too small to have any significant effect on the physical properties of paper. This is somewhat surprising since this is precisely the amount of 65 mesh fraction normally found in this pulp (see Table 1). Additional work will be necessary before any conclusions can be made on the effect of specific pulp fractions on the mechanical properties of paper.

6. THE EFFECT OF PULP BLENDING ON THE DURABILITY OF WOOD PULP PAPERS

6.1 Background

The debris in currency furnish, which appears to be an important component in currency paper, is produced during the mechanical refining of the pulp. The production of the debris or fines involves a considerable consumption of energy, often results in considerable shortening of fiber length and results in extensive water imbibition by the fibers. Consequently, water removal by pressing and evaporation is escessive. It would be advantageous to use a less expensive short fibered pulp such as a hardwood pulp for the production of fines. These fines could then be blended with a more expensive softwood long fiber pulp mechanically treated separately to produce a durable paper at lower cost and with lower energy consumption. This investigation was designed to assess the feasibility of this hypothesis.

6.2 Experimental

The conditions for beating, handsheet formation and estimating paper durability were described in section 3 of this report.

6.3 Results and Discussion

As the proportion of hardwood pulp, beaten for 10,000 revolutions in the laboratory mill increased, the mechanical properties of the handsheets decreased for both softwood pulps. Hardwood pulp fibers are coarse and rigid and unless subjected to sufficient mechanical treatment in preparation for paper making will form porous, low density, weak paper. The fact that the density of the handsheets declined somewhat with increasing quantities of hardwood indicated insufficient mechanical treatment of the hardwood pulp.

When the hardwood pulp was beaten for 20,000 revolutions and blended with Northern softwood pulp beaten 10,000 revolutions in the laboratory mill the density of the paper increased somewhat with increasing hardwood content (Tables 6-9). In addition the air permeability decreased indicating a more compact fiber network has formed. Small increases in mechanical properties were observed with the exception of Elmendorf tear, folding endurance and cantilever stiffness.

The decrease in tear and folding endurance was probably the result of decreased fiber length while the decrease in cantilver stiffness was caused in part by the decline in paper thickness.

Retention of stiffness with flexing increased with hardwood content when beaten for 20,000 revolutions while little or no effect on stiffness retention was observed when the hardwood was beaten only 10,000 revolutions. These results indicate that it may be possible to manufacture a durable wood pulp paper by blending appropriate softwood and hardwood pulps mechanically treated separately. Additional work would be necessary in order to fully verify the utility of blending softwood and hardwood pulps for durable wood pulp papers.

Although the highest retention of stiffness after flexing occurred with handsheets containing 70 percent northern softwood and 30 percent hardwood beaten 20,000 revolutions the ultimate stiffness was slightly lower than that of some of the flexed handsheets made from southern softwood and hardwood pulps. However, the thickness of the southern softwood papers was approximately 20% greater than the Northern softwood-hardwood handsheets. Since the bending moment is related to the cube of the thickness the thicker paper would naturally be stiffer.

The results of this investigation indicate that blending of a wide range of pulps for specific paper properties may be a useful approach in designing a durable wood pulp currency paper. Once again a thorough study of the morphological characteristics of the various pulps would provide valuable information.

7. MODIFICATION OF WOOD PULP PAPERS WITH ACRYLIC LATEXES

7.1 Background

Previous investigations on the modification of paper with acrylic latexes resulted in a substantial improvement in stiffness retention. Improvements in stiffness retention occurred regardless of the modification procedure (6,7,8,9,10). Since the beater addition technique for modifying paper with acrylic resins distributes the resin uniformly throughout the paper and the saturation technique results in a more topical disbursement it appeared deterioration of bending stiffness might occur by at least two separate mechanisms.

The bending stiffness of paper is undoubtedly affected by the stiffness of the fibers and the structure of the fiber network. Conceivably the beater addition technique for modifying paper with acrylic resins enhances stiffness retention of the fibers and in turn the stiffness of paper while the saturation technique enhances stiffness retention brought about by the network structure.

At times the treatment of paper with acrylic resins by beater addition culminates in structural changes in the fiber network structure which has an adverse effect on stiffness retention (8). Acrylic latexes apparently have an effect on the functionality of the fibrillar component in the fiber network of paper which gives rise to a more porous network. Investigations have shown that this undesirable effect of acrylic resins on paper structure can be reversed by a post-treatment with a wet strength resin commonly used for wet strength paper. Paper so treated is less porous and does exhibit greater retention of bending stiffness with flexing.

If the bending stiffness of paper does deteriorate by more than one mechanism and ff the modification of paper with acrylic resins by beater addition and saturation affects different mechanism of deterioration it would be reasonable to assume paper modified with acrylic resin by both procedures would result in an optimum improvement in stiffness retention when flexed. This investigation was designed to determine whether wood pulp paper treated with acrylic resins by beater addition and saturation would exhibit superior stiffness retention.

7.2 Experimental

A Northeastern bleached kraft pulp, consisting of 95% spruce and hemlock and 5% pine, was used in this study. The procedures for beating the pulp, forming the handsheets, modifying the sheets with acrylic resins and estimating the durability of the various papers was described in section 3 of this report.

The regular controls in this investigation consisted of handsheets prepared in the regular manner with untreated beaten fibers. The water controls consisted of the regular controls, subjected to the beater addition procedure but without the addition of any of the additives. Finally the retention aid controls consisted of subjecting the beaten pulp to the beater addition procedure but only adding the retention aid. Durability was estimated according to the procedure described in section 3. Each sheet was cut in half, and one half, selected at random, was flexed.

7.3 Results and Discussion

The double treatment of wood pulp paper with acrylic resins by beater addition and saturation produces a paper having a stiffness and a high stiffness retention when flexed. This is an excellent property for a currency paper to have. Currency remains in circulation until it is torn, soiled excessively or its stiffness declines below a certain level. A previous study indicated that approximately 94 percent of currency is redeemed because it is limp (11). A more in-depth study indicated that currency is considered unacceptable for recirculation after its stiffness has declined to a cantilever stiffness in the neighborhood of 93 μN·m or lower (3). An ideal currency would therefore, have a cantilever stiffness substantially in excess of 93 μN·m and a high retention of stiffness when flexed. Such currency would be expected to have a substantially longer circulation life than the present currency.

Modification of paper with acrylic resins by beater addition produces some improvement in stiffness retention but not to the same extent as that produced by saturation. When the beater addition treatment is subsequently followed by treatment with wet strength resin a further improvement in stiffness retention results which is roughly equivalent to the improvement produced by saturation alone but the greatest improvement in stiffness retention occurs when the paper is modified with acrylic resins by both beater addition and saturation. There appears to be no advantage in using the wet strength resin post-treatment when the paper is subsequently treated with acrylic resins by saturation.

The double acrylic resin treatment appears to have more advantages than just improving stiffness retention. The strength, elongation to break, energy to break and folding endurance all exhibit appreciable improvements and are retained to a high degree when flexed. It would seem appropriate to conduct some mill trials with acrylic resin modification of the present currency paper as well as wood pulp papers under consideration for currency paper. Even though laboratory investigations provide useful information on the effect of modifications on paper durability it will be ultimately necessary to manufacture some currency type paper incorporating some of the more promising laboratory modifications. In this way the effect of paper machine variables can be evaluated on the performance of the paper.

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Figure 1. The density of handsheets made from classified currency stock and wood pulp stocks. (A unbeaten, B beaten 5000, C beaten 10,000, and D beaten 20,000 revolutions in a laboratory mill).

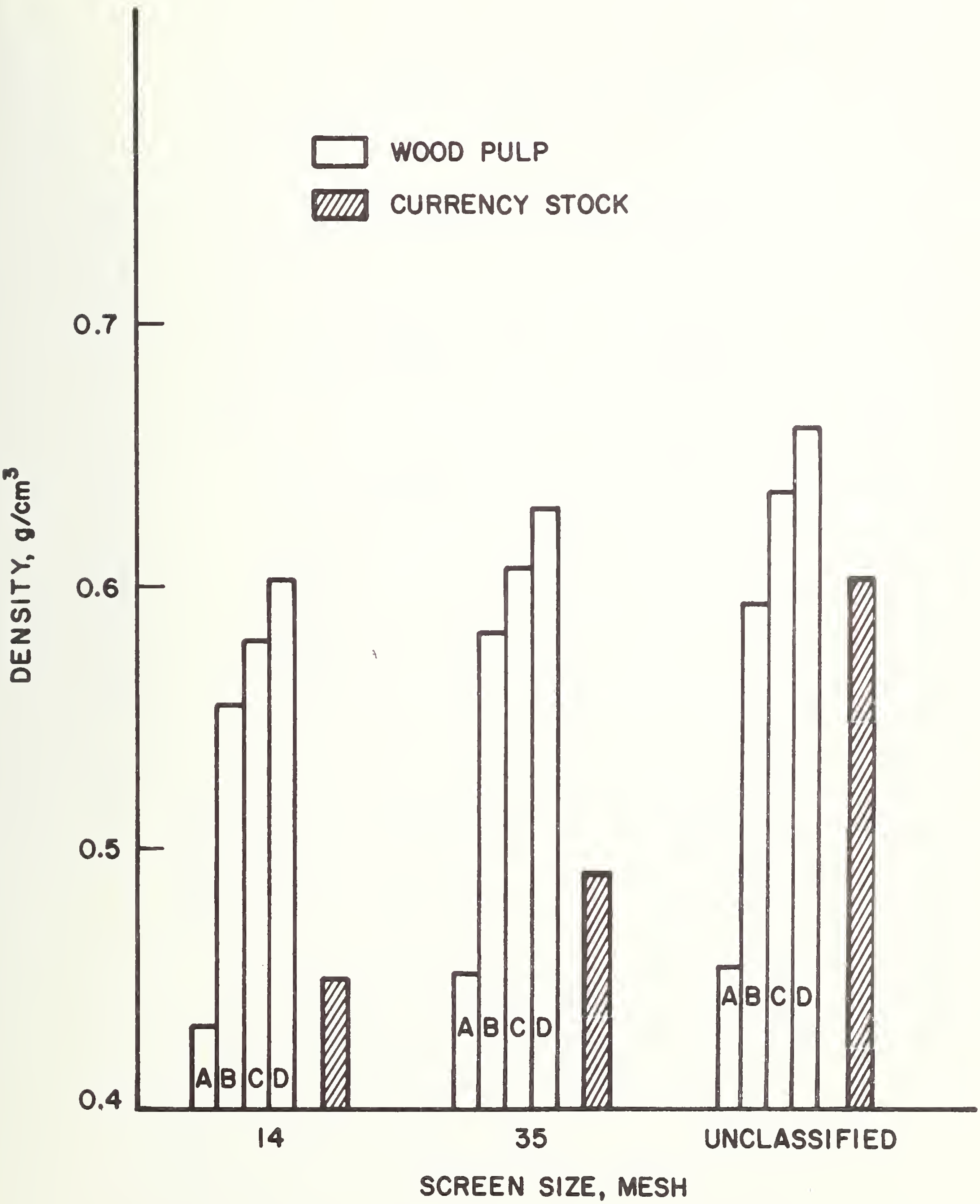

Table 1. Fiber Classification for Various Wood Pulps

Pulp	Revolutions PFI Mill 1,000		I	II	III	IV	V
		Fraction	I	II	III	IV	V
		Screen Mesh	+14	-14 +35	-35 +65	-65 +150	-150
"F"	0		60.7	27.5	5.5	1.0	5.3
	5		57.2	28.5	4.6	1.5	8.2
	10		55.5	31.1	4.8	1.7	6.9
	20		49.5	31.0	4.6	1.7	13.2
Northern Softwood	0		72.3	15.8	4.1	1.1	6.7
Southern Softwood	0		70.1	18.1	4.5	0.6	6.7
Hardwood	0		1.5	51.7	22.7	5.8	18.3
	5		1.0	49.4	18.5	6.0	25.1
	10		0.9	50.2	18.6	6.8	23.5
	20		0.5	45.1	17.7	(36.7)[2] (IV + V)	
Currency[1] Stock			15.7	36.8	14.5	(33.0)[2] (IV + V)	

[1]Currency stock sampled after final mechanical treatment and prior to dilution for the headbox.

[2]Plugging of 150 mesh screen necessitates removal. Figure represents total which passed 65 mesh screen.

Table 2. The Tensile Properties of Unflexed Handsheets Made From Fractionated and Unfractionated Type F Wood Pulp.

Fraction	No. of Specimens		Initial Modulus				Breaking Strength				Elongation To Break				Energy To Break				Elongation At Yield				Load At Yield				Plastic Modulus				Density	
Mesh Size[1]			GN/m²				kN/m				%				J/m²				%				kN/m				GN/m²				g/cm³	
	W	L[2]	W	s[3]	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s		s
Unbeaten Pulp																																
14	8	8	1.15	0.11	1.11	0.12	0.93	.06	0.98	.06	0.82	0.08	0.71	0.10	4.8	0.9	4.1	0.9	0.40	0.05	0.41	0.06	0.76	0.09	0.81	0.07	0.25	0.09	0.35	0.10	0.432	.004
35	7	7	1.30	0.14	1.38	0.17	1.07	.08	1.22	.10	1.03	0.17	0.98	0.11	7.2	1.2	7.2	1.3	0.49	0.09	0.48	0.06	0.90	0.10	0.96	0.10	0.23	0.06	0.35	0.05	0.453	.004
14 & 65	4	4	0.96	0.06	1.13	0.10	0.82	0.04	0.92	0.04	0.80	0.09	0.71	0.06	4.0	0.8	3.7	0.9	0.41	0.03	0.41	0.03	0.66	0.03	0.13	0.02	0.26	0.03	0.37	0.03	0.431	.005
unclassified	5	5	1.26	0.17	1.58	0.08	1.35	0.11	1.55	0.10	1.51	0.09	1.31	0.27	13.7	0.5	13.7	3.8	0.51	0.04	0.48	0.08	1.03	-	1.20	0.22	0.20	0.03	0.28	0.09	0.455	.007
Beaten 5,000 Rev. PFI Mill																																
14	10	10	3.23	0.15	3.53	0.38	4.63	0.35	5.18	0.50	2.97	0.33	2.71	0.30	90.9	14.4	91.5	17.7	0.61	0.03	0.67	0.04	2.62	0.18	3.14	0.25	0.62	0.06	0.72	0.10	0.557	.010
35	8	8	3.41	0.15	3.58	0.22	4.77	0.23	4.86	0.61	3.57	0.27	2.89	0.55	115.7	13.0	96.1	27.5	0.68	0.03	0.66	0.05	2.94	0.12	3.07	0.23	0.48	0.06	0.59	0.06	0.582	.005
14 & 65	5	5	3.27	0.23	3.49	0.12	4.72	0.55	4.99	0.59	3.08	0.58	2.70	0.46	96.8	25.5	88.3	22.9	0.69	0.10	0.73	0.05	2.80	0.31	3.16	0.28	0.61	0.05	0.70	0.10	0.558	.006
unclassified	5	5	3.73	0.14	3.99	0.09	5.04	0.33	5.62	0.16	4.06	0.24	3.85	0.03	108.6	16.3	144.5	4.1	0.55	0.04	0.53	0.06	2.58	0.17	2.79	0.18	0.56	0.03	0.64	0.01	0.593	.011
Beaten 10,000 Rev. PFI Mill																																
14	10	10	3.72	0.31	3.88	0.30	5.71	0.60	5.64	0.46	3.52	0.30	2.97	0.32	129.4	20.9	107.2	16.3	0.65	0.07	0.60	0.05	2.86	0.39	2.89	0.13	0.78	0.08	0.89	0.08	0.579	.006
35	8	8	3.94	0.29	4.03	0.25	5.70	0.25	5.55	0.38	4.10	0.31	3.29	0.22	155.6	16.7	121.6	15.0	0.64	0.06	0.62	0.03	2.92	0.14	3.02	0.10	0.68	0.02	0.76	0.05	0.607	.007
14 & 65	5	5	3.82	0.26	3.93	0.23	6.09	0.12	5.72	0.37	3.70	0.15	2.90	0.43	144.5	7.8	107.2	20.9	0.61	0.03	0.65	0.09	2.92	0.12	3.22	0.31	0.79	0.04	0.86	0.09	0.585	.003
unclassified	5	5	4.54	0.15	4.63	0.17	6.26	0.45	6.50	0.27	4.46	0.25	3.97	0.32	183.7	17.7	168.7	17.7	0.54	0.04	0.56	0.03	2.88	0.10	3.05	0.08	0.69	0.07	0.79	0.05	0.636	.004
Beaten 20,000 Rev PFI Mill																																
14	10	10	4.20	0.21	4.38	0.19	6.40	0.55	6.43	0.56	3.61	0.24	3.06	0.37	147.7	18.3	126.2	21.6	0.60	0.04	0.64	0.04	2.99	0.08	3.43	0.18	0.90	0.09	0.98	0.09	0.602	.006
35	8	8	4.32	0.15	4.42	0.25	6.54	0.20	6.41	0.41	4.27	0.17	3.56	0.32	182.4	7.2	149.1	17.0	0.64	0.04	0.65	0.03	3.16	0.13	3.34	0.13	0.78	0.05	0.87	0.09	0.629	.008
14 & 65	4	4	4.23	0.41	4.28	0.38	5.78	0.38	5.86	0.87	3.32	0.40	2.90	0.60	123.6	18.3	111.1	36.0	0.59	0.04	0.61	0.05	2.86	0.14	3.09	0.15	0.88	0.07	0.98	0.08	0.605	.005
unclassified	5	5	4.89	0.13	5.16	0.30	6.69	0.21	6.62	0.10	4.93	0.46	3.92	0.50	213.8	18.3	172.4	33.3	0.56	0.02	0.56	0.01	3.02	0.12	3.28	0.20	0.69	0.08	0.83	0.11	0.661	.004

[1]Indicates screen mesh size on which fibers were retained in fiber classification.

[2]W = width, L = length of 15X30 cm. flex specimens.

[3]

$$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{n(n-1)}}$$

Table 3. The Tensile Properties of Handsheets Made From Fractionated and Unfractionated Wood Pulp Type F After 1000 Flexes.

Fraction Mesh Size[1]	No. of Specimens		Initial Modulus GN/m²				Breaking Strength kN/m				Elongation To Break %				Energy To Break J/m²				Elongation At Yield %				Load At Yield kN/m				Plastic Modulus GN/m²			
	W	L[2]	W	s[3]	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s
Beaten 5000 Rev. PFl Mill																														
14	10	8	2.05	0.22	1.28	0.08	3.92	0.37	4.54	0.16	3.38	0.30	3.43	0.21	83.7	13.0	85.6	8.5	0.74	0.07	1.78	0.37	2.13	0.20	3.14	0.44	0.48	0.05	0.61	0.09
35	7	8	2.44	0.19	1.65	0.05	4.06	0.37	4.34	0.50	3.69	0.27	3.33	0.54	98.7	14.4	85.6	23.5	0.70	0.04	1.21	0.12	2.26	0.18	2.67	0.28	0.45	0.03	0.61	0.05
14 & 65	5	5	2.29	0.26	1.33	0.12	4.08	0.47	4.58	0.20	3.36	0.46	3.39	0.15	87.6	20.3	86.3	6.5	0.80	0.13	1.71	0.21	2.41	0.35	3.06	0.33	0.49	0.06	0.69	0.08
unclassified	5	5	3.00	0.27	2.43	0.36	4.53	0.39	5.16	0.18	3.82	0.29	3.51	0.18	114.4	16.3	109.8	9.2	0.64	0.09	1.02	0.21	2.35	0.13	2.96	0.24	0.56	0.04	0.74	0.04
Beaten 10,000 Rev. PFl Mill																														
14	10	10	2.86	0.24	2.02	0.12	5.20	0.33	5.66	0.53	3.77	0.25	3.60	0.33	121.6	13.0	115.1	20.3	0.68	0.14	1.18	0.19	2.46	0.47	2.99	0.41	0.68	0.08	0.88	0.08
35	8	8	3.21	0.21	2.59	0.21	5.29	0.46	5.41	0.29	4.36	0.36	3.78	0.29	148.4	21.6	123.6	13.7	0.71	0.08	1.05	0.10	2.67	0.19	3.20	0.19	0.59	0.06	0.68	0.06
14 & 65	5	5	2.77	0.28	2.01	0.11	5.22	0.75	5.85	0.28	2.69	0.44	3.63	0.21	119.6	28.8	119.0	11.1	0.72	0.05	1.27	0.09	2.47	0.18	3.28	0.15	0.69	0.05	0.85	0.08
unclassified	5	5	3.22	0.21	3.56	0.20	5.69	0.68	6.07	0.31	4.47	0.48	3.67	0.13	166.0	32.7	138.6	11.1	0.59	0.02	0.79	0.05	2.58	0.14	3.15	0.14	0.67	0.04	0.92	0.04
Beaten 20,000 Rev. PFI Mill																														
14	10	9	3.04	0.17	2.25	0.15	5.29	0.39	5.43	0.37	3.70	0.36	3.29	0.31	120.9	18.3	102.0	16.3	0.65	0.05	1.13	0.11	2.35	0.15	3.02	0.33	0.77	0.04	0.93	0.08
35	5	8	3.26	0.20	2.74	0.22	5.23	0.31	5.61	0.31	4.27	0.24	3.62	0.27	143.2	13.7	122.2	14.4	0.67	0.06	1.05	0.11	2.46	0.11	3.19	0.29	0.64	0.05	0.83	0.12
14 & 65	4	3	3.13	0.20	2.04	0.09	5.12	0.40	5.56	0.48	3.54	0.27	3.50	0.17	113.1	16.3	108.5	9.1	0.62	0.03	1.37	0.46	2.33	0.18	3.15	0.65	0.78	0.05	0.96	0.12
unclassified	3	4	4.31	0.20	3.97	0.24	5.32	0.10	5.30	0.20	5.28	0.24	3.81	0.14	214.4	11.1	151.7	7.8	0.56	0.04	0.75	0.04	2.68	0.06	3.11	0.05	0.66	0.02	0.98	0.04

[1]Indicates screen mesh size on which fibers were retained in fiber classification.
[2]W = width, L = length of 15X30 cm. flex specimens.
[3]

$$s \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{n(n-1)}}$$

Table 4. The Physical Properties of Unflexed Handsheets Made From Fractionated and Unfractionated Wood Pulp Type F.

Fraction	No. Of Specimens		Sonic Modulus[2]				Elmendorf Tear				MIT Fold Endurance 1000 g.				Cantilever Stiffness				Air Perme-ability		Thickness	Weight Per Unit Area
Mesh Size[1]			GN/m^2				mN				Double Folds				μN·m				cm^3/min (10cm)		μm	g/m^2
	W	L	W	s	L[3]	s[4]	W	s	L	s	W	s	L	s	W	s	L	s		s		
											Unbeaten Pulp											
14	8	8	1.66	0.12	2.11	0.19	343	30.4	354	71.6	1	0	1	0	229.4	22.6	236.3	24.5	>3000	-	177.4	76.6
35	7	7	2.00	0.30	2.35	0.27	327	45.1	346	39.2	2	0.5	2	0.7	195.1	19.6	207.9	31.4	>3000	-	159.9	72.5
14 & 65	4	4	1.61	0.09	1.99	0.14	390	54.9	371	38.2	1	0.5	1	0.5	212.8	24.5	254.0	13.7	>3000	-	176.6	76.1
unclassified	5	5	2.16	0.06	2.26	0.25	565	63.7	557	83.8	4	1.3	5	1.2	230.4	29.4	255.0	11.8	>3000	-	166.5	75.8
											Beaten 5000 Rev. PFI Mill											
14	10	10	5.05	0.22	5.29	0.22	1002	85.3	1060	99.0	2100	670	2280	507	286.3	26.4	271.6	24.5	1716	55	138.1	76.3
35	8	8	5.10	0.23	5.24	0.35	863	110.8	823	97.1	980	304	1250	540	254.0	14.7	244.2	20.6	659	26	134.6	78.3
14 & 65	5	5	5.11	0.15	5.41	0.20	992	103.9	951	99.0	1736	377	1540	346	248.1	10.8	255.9	21.6	1664	53	132.7	74.1
unclassified	5	5	5.41	0.31	5.29	0.54	869	109.8	916	129.4	1120	174	1370	291	227.5	9.8	246.1	10.8	216	11	125.6	74.5
											Beaten 10,000 Rev. PFI Mill											
14	10	10	5.91	0.40	6.27	0.89	1001	101.0	950	122.6	2580	397	2410	554	251.0	16.7	249.1	19.6	1060	60	129.3	74.9
35	8	8	7.02	0.67	6.37	0.61	739	98.1	734	74.5	2020	217	2030	268	219.7	13.7	209.8	12.7	348	14	122.3	74.3
14 & 65	5	5	7.29	0.59	7.29	0.76	977	118.6	857	117.7	2250	350	2130	393	283.4	20.6	284.4	30.4	861	47	131.5	77.0
unclassified	5	5	6.43	0.25	6.13	0.18	751	101.0	834	166.7	2080	193	2280	364	204.9	17.7	203.9	13.7	80	3	116.4	74.0
											Beaten 20,000 Rev. PFI Mill											
14	10	10	7.30	1.55	7.93	1.31	866	111.8	970	136.3	2790	602	2540	427	250.1	19.6	232.4	20.6	778	30	124.5	74.9
35	8	8	8.43	0.90	8.38	1.01	692	123.6	666	63.7	2090	462	2340	267	211.8	8.8	207.9	15.7	239	6	119.8	75.3
14 & 65	4	4	8.10	2.26	7.93	1.81	922	193.1	944	152.0	2630	156	2260	330	244.2	15.7	230.4	8.8	670	31	123.1	74.6
unclassified	5	5	7.20	0.84	6.43	0.46	602	20.6	620	38.2	3010	727	3220	552	168.7	13.7	172.6	19.6	16	1	110.5	73.0

[1]Indicates screen mesh size on which fibers were retained in fiber classification.
[2]Sonic modulus based on apparent density of paper.
[3]W = width L = length of 15X30 cm. flex specimens.
[4]

$$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{n(n-1)}}$$

Table 5. The Physical Properties of Handsheets Made From Fractionated and Unfractionated Wood Pulp Type F After 1000 Flexes.

Fraction	No. Of Specimens		Sonic Modulus[2]				Elmendorf Tear				MIT Fold Endurance 1000 g.				Cantilever Stiffness				Air Permeability		Thickness	
Mesh Size[1]			GN/m^2				mN				Double Folds				μN·m				cm^3/min (10cm)		μm	
	W	L	W[3]	s	L	s[4]	W	s	L	s	W	s	L	s	W	s	L	s		s		s
											Beaten 5000 Rev. PFI Mill											
14	10	10	3.27	0.26	2.55	0.23	888	88.3	994	48.0	1840	581	2470	537	122.6	15.7	70.6	6.9	1920	46	162.6	4.3
35	8	8	13.96	0.40	3.32	0.65	741	54.9	756	70.6	1200	213	1310	298	132.4	15.7	81.4	8.9	821	25	134.5	2.5
14 & 65	5	5	3.55	0.10	2.51	0.19	985	140.2	881	83.3	1880	375	2080	648	119.6	12.7	69.6	3.9	1862	52	134.0	3.9
unclassified	5	5	4.54	0.18	3.79	0.10	757	157.8	739	69.6	1660	289	1290	416	155.9	8.8	85.3	3.9	220	9.5	121.3	1.9
											Beaten 10,000 Rev. PFI Mill											
14	10	10	4.34	0.46	3.61	0.37	836	131.4	837	88.3	2784	580	2473	294	125.5	12.7	92.2	5.9	1199	49	127.8	2.7
35	8	8	4.93	0.58	4.42	0.65	655	101.0	716	75.5	1970	522	1890	532	99.1	10.8	90.2	7.8	384	18	119.9	2.3
14 & 65	5	5	4.53	0.20	3.80	0.30	724	77.5	837	113.7	2880	451	2320	414	145.1	21.6	94.1	7.8	989	33	130.3	2.3
unclassified	5	5	5.30	0.27	5.13	0.18	620	69.6	753	66.7	2270	407	2160	593	150.0	13.7	102.9	8.8	85	3.3	113.2	3.2
											Beaten 20,000 Rev. PFI Mill											
14	10	10	4.53	0.21	4.31	0.43	804	87.3	853	110.8	2970	452	2800	493	152.0	24.5	91.2	5.9	870	26	121.9	1.7
35	8	8	5.38	0.56	4.81	0.32	642	62.8	663	36.3	2430	523	1930	315	140.2	12.7	100.0	4.9	264	15	116.0	1.8
14 & 65	4	4	4.70	0.20	3.84	0.36	814	155.9	905	61.8	3160	187	2350	444	158.9	11.8	91.2	5.9	759	23	121.5	2.0
unclassified	5	5	5.86	0.37	5.82	0.23	575	53.0	632	37.3	3100	732	3150	1119	136.3	6.9	99.0	2.9	18	1.7	107.5	2.6

[1] Indicates screen mesh size on which fibers were retained in fiber classification.
[2] Sonic modulus based on apparent density of paper.
[3] W = width L = length of 15X30 cm. flex specimens.
[4] $s \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$

Table 6. Tensile Properties Of Unflexed Handsheets Made From Combinations Of Soft And Hardwood Pulps.

Composition Soft-wood %	Composition Hard-wood %	Number Specimens		Initial Modulus GN/m^2				Breaking Strength kN/m				Elongation To Break %				Energy To Break J/m^2				Elongation At Yield %				Load At Yield kN/m				Plastic Modulus GN/m^2			
		W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s
Northern												Both Pulps Beaten 10,000 Rev. PFI Mill																			
100	0	6	6	2.86	0.11	2.83	0.26	4.58	0.17	4.54	0.20	4.24	0.14	3.77	0.32	126.2	7.8	111.1	12.4	0.56	0.03	0.63	0.05	2.09	0.07	2.29	0.24	0.51	0.03	0.54	0.04
98	2	6	6	2.84	0.15	2.85	0.21	4.35	0.21	4.53	0.42	4.55	0.35	3.90	0.51	129.4	9.2	115.7	24.2	0.58	0.03	0.62	0.05	2.06	0.10	2.24	0.08	0.44	0.06	0.52	0.02
95	5	6	5	2.85	0.28	2.72	0.19	4.26	0.32	4.50	0.14	4.04	0.52	3.96	0.20	114.4	15.7	117.0	7.8	0.60	0.03	0.64	0.04	2.16	0.12	2.27	0.04	0.46	0.06	0.49	0.03
90	10	6	5	2.67	0.21	2.65	0.11	4.47	0.25	4.41	0.13	4.53	0.29	3.97	0.13	132.7	9.2	114.4	5.6	0.64	0.03	0.63	0.02	2.23	0.23	2.22	0.14	0.42	0.04	0.46	0.01
80	20	6	4	3.07	0.08	2.57	0.20	4.36	0.24	4.50	0.25	4.16	0.34	4.05	0.19	120.9	14.4	119.0	11.1	0.56	0.02	0.65	0.03	2.16	0.07	2.24	0.08	0.45	0.04	0.47	0.02
70	30	6	6	2.53	0.14	2.43	0.27	4.09	0.15	4.11	0.15	4.50	0.11	4.16	0.30	122.9	4.4	113.1	8.5	0.63	0.04	0.68	0.07	2.05	0.08	2.18	0.17	0.39	0.02	0.39	0.03
												Softwood 10,000 Rev. Hardwood 20,000 Rev. PFI Mill																			
90	10	6	5	3.29	0.22	3.36	0.17	4.63	0.17	4.73	0.29	3.88	0.04	3.41	0.13	120.9	4.8	107.2	10.5	0.65	0.05	0.70	0.07	2.47	0.05	2.64	0.16	0.59	0.26	0.64	0.03
80	20	5	6	3.18	0.19	3.52	0.32	4.64	0.14	4.88	0.33	4.00	0.11	3.58	0.11	125.5	5.8	116.4	1.3	0.71	0.01	0.71	0.05	2.54	0.06	2.71	0.13	0.57	0.04	0.64	0.06
70	30	6	6	3.29	0.18	3.64	0.13	4.67	0.33	4.90	0.20	4.17	0.21	3.75	0.16	132.1	12.4	123.6	7.8	0.73	0.03	0.70	0.02	2.56	0.10	2.73	0.11	0.54	0.05	0.61	0.05
Southern												Both Pulps Beaten 10,000 Rev. PFI Mill																			
100	0	4	6	2.35	0.12	2.50	0.11	4.11	0.03	4.36	0.21	4.42	0.43	4.11	0.22	120.3	12.4	118.3	10.5	0.68	0.04	0.69	0.04	2.11	0.09	2.30	0.14	0.37	0.04	0.41	0.03
98	2	5	6	2.45	0.11	2.47	0.10	4.12	0.08	4.20	0.35	4.27	0.13	3.92	0.40	116.4	4.9	109.8	18.3	0.69	0.07	0.68	0.04	2.18	0.15	2.24	0.18	0.39	0.03	0.42	0.02
95	5	6	6	2.42	0.18	2.44	0.08	4.04	0.16	4.16	0.15	4.39	0.18	4.04	0.21	118.3	7.8	112.4	9.2	0.67	0.07	0.68	0.05	2.12	0.10	2.26	0.11	0.36	0.02	0.40	0.01
90	10	6	5	2.39	0.11	2.46	0.20	4.14	0.13	4.24	0.31	4.51	0.36	4.09	0.13	124.9	11.1	115.7	10.5	0.66	0.03	0.66	0.06	2.11	0.07	2.20	0.10	0.36	0.04	0.41	0.02
80	20	6	6	2.31	0.14	2.49	0.15	3.92	0.18	4.18	0.20	4.43	0.37	4.13	0.24	115.4	13.1	115.1	9.8	0.69	0.06	0.65	0.04	2.08	0.08	2.15	0.07	0.34	0.03	0.40	0.03
70	30	6	5	2.16	0.20	2.38	0.18	3.45	0.16	3.64	0.21	4.23	0.45	3.58	0.29	100.0	11.8	88.9	11.1	0.67	0.04	0.67	0.04	1.93	0.08	2.12	0.08	0.30	0.03	0.37	0.03

[1] W = width L = length of 15X30 cm flex specimens.

[2] $s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$

Table 7. Tensile Properties Of Handsheets Made From Combinations Of Soft And Hardwood Pulps After 1,000 Flexes.

Composition Softwood %	Composition Hardwood %	Number Specimens W[1]	Number Specimens L	Initial Modulus GN/m² W	Initial Modulus s[2]	Initial Modulus L	Initial Modulus s	Breaking Strength kN/m W	Breaking Strength s	Breaking Strength L	Breaking Strength s	Elongation To Break % W	Elongation To Break s	Elongation To Break L	Elongation To Break s
Northern															
Both Pulps Beaten 10,000 Rev. PFI Mill															
100	0	4	6	2.30	0.16	1.92	0.12	4.28	0.12	4.50	0.24	4.47	0.28	3.96	0.28
98	2	3	6	2.07	0.21	1.94	0.13	3.97	0.15	4.41	0.23	4.71	0.35	3.84	0.37
95	5	2	6	2.05	-	1.89	0.11	3.95	-	4.24	0.25	4.52	-	3.82	0.24
90	10	3	6	2.07	0.15	1.91	0.16	3.99	0.35	4.45	0.16	4.79	0.20	4.01	0.32
80	20	4	6	2.13	0.26	1.94	0.21	3.76	0.39	4.14	0.30	4.49	0.35	3.93	0.29
70	30	3	6	1.98	0.18	1.76	0.10	3.60	0.35	4.01	0.19	4.53	0.23	3.98	0.25
Softwood 10,000 Rev. Hardwood 20,000 Rev. PFI Mill															
90	10	6	5	2.84	0.12	2.38	0.26	4.51	0.20	4.50	0.35	3.99	0.07	3.29	0.25
80	20	5	6	2.94	0.09	2.48	0.18	4.58	0.31	4.63	0.28	4.11	0.20	3.41	0.05
70	30	6	6	3.11	0.24	2.56	0.19	4.53	0.16	4.64	0.28	4.11	0.22	3.59	0.10
Both Pulps Beaten 10,000 Rev. PFI Mill															
100	0	5	6	2.03	0.15	1.94	0.19	3.57	0.07	3.94	0.14	4.56	0.53	3.79	0.15
98	2	6	6	2.00	0.31	1.86	0.11	3.71	0.35	3.78	0.12	4.44	0.12	3.76	0.30
95	5	5	4	1.95	0.15	1.78	0.10	3.69	0.23	4.10	0.15	4.56	0.22	3.99	0.29
90	10	6	6	1.88	0.15	1.80	0.11	3.53	0.30	3.78	0.22	4.71	0.53	3.91	0.18
80	20	5	5	2.00	0.22	1.86	0.28	3.52	0.28	3.87	0.12	4.60	0.17	4.02	0.26
70	30	5	5	1.87	0.13	1.92	0.15	3.32	0.18	3.67	0.27	4.47	0.31	3.62	0.28

Composition Softwood %	Composition Hardwood %	Energy To Break J/m² W	Energy To Break s	Energy To Break L	Energy To Break s	Elongation At Yield % W	Elongation At Yield s	Elongation At Yield L	Elongation At Yield s	Load At Yield kN/m W	Load At Yield s	Load At Yield L	Load At Yield s	Plastic Modulus GN/m² W	Plastic Modulus s	Plastic Modulus L	Plastic Modulus s
Northern																	
Both Pulps Beaten 10,000 Rev. PFI Mill																	
100	0	120.3	8.5	107.2	12.4	0.67	0.09	0.99	0.15	1.90	0.08	2.33	0.25	0.48	0.03	0.59	0.04
98	2	118.3	9.8	102.6	15.0	0.68	0.05	0.98	0.10	1.75	0.09	2.31	0.18	0.43	0.03	0.60	0.05
95	5	113.1	-	99.4	9.8	0.70	-	0.97	0.07	1.78	-	2.27	0.13	0.44	-	0.56	0.04
90	10	121.6	4.2	109.2	9.2	0.72	0.02	0.99	0.11	1.85	0.11	2.37	0.19	0.40	0.06	0.56	0.06
80	20	109.2	15.7	101.3	13.7	0.71	0.08	0.96	0.06	1.83	0.13	2.29	0.15	0.40	0.04	0.51	0.02
70	30	105.9	13.1	99.4	9.8	0.73	0.07	1.07	0.13	1.82	0.11	2.35	0.27	0.36	0.04	0.46	0.03
Softwood 10,000 Rev. Hardwood 20,000 Rev. PFI Mill																	
90	10	117.0	5.6	92.2	14.4	0.85	0.05	1.03	0.11	2.58	0.10	2.69	0.21	0.55	0.05	0.76	0.07
80	20	124.2	13.7	98.7	6.5	0.74	0.06	1.04	0.05	2.41	0.17	2.77	0.18	0.59	0.03	0.74	0.06
70	30	124.2	9.8	105.3	7.2	0.71	0.05	1.04	0.13	2.39	0.07	2.84	0.24	0.58	0.03	0.68	0.06
Both Pulps Beaten 10,000 Rev. PFI Mill																	
100	0	105.3	12.4	93.5	3.9	0.63	0.04	0.84	0.11	1.68	0.08	2.08	0.14	0.34	0.04	0.48	0.03
98	2	105.9	11.8	88.9	9.2	0.73	0.14	0.90	0.10	1.82	0.12	2.13	0.22	0.36	0.03	0.45	0.08
95	5	109.2	11.1	102.0	11.1	0.69	0.06	0.96	0.09	1.80	0.09	2.27	0.14	0.34	0.02	0.45	0.03
90	10	109.2	16.3	93.5	6.5	0.70	0.04	0.85	0.07	1.75	0.10	1.99	0.12	0.31	0.04	0.45	0.05
80	20	107.2	11.1	98.1	7.2	0.68	0.06	0.89	0.18	1.77	0.07	2.08	0.16	0.32	0.02	0.44	0.07
70	30	98.7	9.8	84.3	12.4	0.68	0.04	0.82	0.09	1.69	0.07	2.03	0.12	0.31	0.02	0.45	0.03

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[1] W = width L = length of 15X30 cm flex specimens.

[2] s $\sqrt{\frac{n\Sigma(X)^2 - (\Sigma X)^2}{N(n-1)}}$

Table 8. Physical Properties Of Unflexed Handsheets Made From Combinations Of Soft and Hardwood Pulps.

Composition Softwood %	Composition Hardwood %	Number Of Specimens		Elmendorf Tear mN				MITfold Endurance 1000 g. Double Folds				Cantilever Stiffness μN·m				Air Permeability cm^3/min (10 cm)		Weight Per Unit Area g/m^2		Thickness μm		Density g/cm^3	
		W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s		s		s		s		s
Northern								Both Pulps Beaten 10,000 Rev. PFI Mill															
100	0	6	6	698	61	858	78	1080	139	1280	211	183.4	22.6	168.7	20.6	289	16.3	67	1.1	132.0	2.3	0.510	.005
98	2	6	6	750	69	840	132	1170	167	1180	211	165.7	14.7	172.6	15.7	285	13.3	67	1.2	131.5	3.7	0.512	.008
95	5	6	6	821	117	858	74	956	229	1050	145	184.4	8.8	172.6	8.8	303	8.3	68	1.0	134.0	2.0	0.505	.009
90	10	6	6	845	113	837	98	1070	252	1250	182	181.4	4.9	186.3	15.7	310	12.2	68	1.0	134.5	2.3	0.503	.006
80	20	6	6	824	31	768	78	950	235	1000	272	180.4	24.5	161.8	13.7	301	19.0	67	1.5	133.3	1.3	0.505	.009
70	30	6	6	814	90	703	21	600	145	630	96	169.6	14.7	167.7	13.7	379	11.1	67	0.4	137.1	1.6	0.492	.005
								Softwood 10,000 Rev. Hardwood 20,000 Rev. PFI Mill															
90	10	6	6	796	105	662	61	870	257	920	134	179.5	26.5	168.7	14.7	187	12.8	67	1.5	114.4	2.4	0.584	0.008
80	20	6	6	649	73	738	102	880	274	1200	274	149.1	8.8	151.0	8.8	138	8.4	66	1.3	113.0	1.9	0.585	0.006
70	30	6	6	639	94	684	161	920	186	950	180	154.0	14.7	150.0	12.7	94	4.1	66	1.7	112.1	2.0	0.591	0.010
Southern								Both Pulps Beaten 10,000 Rev. PFI Mill															
100	0	6	6	832	70	912	76	790	146	860	102	196.1	28.4	189.3	16.7	356	44.7	68	1.5	141.5	2.5	0.479	0.007
98	2	6	6	811	96	831	93	870	128	870	356	183.4	14.7	170.6	15.7	417	35.5	67	1.1	140.7	1.7	0.474	0.004
95	5	6	6	915	87	863	127	690	97	840	109	173.6	13.7	180.4	17.7	456	29.1	67	0.6	141.9	1.5	0.475	0.003
90	10	6	6	868	75	846	50	770	283	770	101	193.2	20.6	179.5	14.7	246	8.5	67	0.9	139.5	2.9	0.478	0.006
80	20	6	6	821	80	816	65	620	65	650	121	197.1	19.6	176.5	21.6	332	35.0	67	1.3	139.8	2.8	0.478	0.007
70	30	6	6	735	31	775	63	440	119	440	101	178.5	11.8	177.5	18.6	380	21.0	66	0.5	138.5	2.8	0.475	0.009

[1] W = width L = length of flex specimens.

[2]
$$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$$

Table 9. Physical Properties Of Handsheets Made From Combinations of Soft and Hardwood Pulps After 1,000 Flexes.

Composition Softwood %	Composition Hardwood %	Number Of Specimens W[1]	Number Of Specimens L	Elmendorf Tear mN W	s[2]	L	s	Mit Fold Endurance 1000 g. Double Folds W	s	L	s	Cantilever Stiffness μN·m W	s	L	s	Air Permeability cm^3/min (10 cm)	s
Northern																	
Both Pulps Beaten 10,000 Rev. PFI Mill																	
100	0	6	6	762	122	806	35	1370	175	1120	369	111.8	6.9	73.5	4.9	320	19.7
98	2	6	6	794	137	827	80	1580	311	1220	257	104.9	11.8	77.5	6.9	304	12.0
95	5	6	6	731	77	716	69	1000	412	1020	141	80.4	6.9	66.7	4.9	319	8.9
90	10	6	6	626	56	737	78	1110	246	980	290	104.9	8.8	79.4	3.9	330	14.5
80	20	6	6	684	78	693	71	830	339	770	112	88.3	8.8	79.4	7.8	318	15.7
70	30	6	6	748	93	733	77	540	151	580	256	89.2	3.9	74.5	7.8	474	33.7
Softwood 10,000 Rev. Hardwood 20,000 Rev. PFI Mill																	
90	10	6	6	639	76	672	46	1080	169	1120	173	114.7	8.4	79.4	7.1	210	15.2
80	20	6	6	585	57	610	74	1130	206	1030	326	98.1	7.6	80.4	5.8	147	7.7
70	30	6	6	595	62	588	48	1240	260	810	152	111.8	13.7	83.4	3.6	106	5.3
Southern																	
Both Pulps Beaten 10,000 Rev. PFI Mill																	
100	0	6	6	787	73	858	41	790	141	740	204	121.6	11.8	88.3	6.9	422	52.3
98	2	6	6	738	66	870	97	720	253	680	124	120.6	13.7	87.3	6.9	506	32.2
95	5	6	6	748	105	851	94	680	203	690	135	123.6	12.7	86.3	6.9	529	57.2
90	10	6	6	772	119	806	82	790	264	630	130	115.7	10.8	79.4	9.8	262	17.3
80	20	6	6	763	61	780	49	510	141	540	80	127.5	12.7	78.4	5.9	354	29.6
70	30	6	6	703	46	728	133	530	99	460	114	111.8	5.9	80.4	5.9	477	40.3

[1] W = width L = length of 15X30 cm. flex specimens

[2] $$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$$

Table 10. Tensile Properties Of Unflexed Wood Pulp Handsheets Treated In Various Ways With Acrylic Resins.

Treatment	Number Of Specimens		Initial Modulus				Breaking Strength				Elongation To Break				Engery To Break				Elongation At Yield				Load At Yield				Plastic Modulus			
			GN/m^2				kN/m				%				J/m^2				%				kN/m				GN/m^2			
	W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s
(A) Standard[3]	5	5	4.42	0.17	4.22	0.22	5.65	0.37	5.58	0.16	4.18	0.34	3.71	0.20	155.6	19.0	136.0	10.4	0.52	0.03	0.54	0.03	2.63	0.06	2.70	0.03	0.70	0.04	0.75	0.03
(B) H_2O Control[4]	5	5	4.03	0.11	4.17	0.28	5.27	0.21	5.41	0.42	4.24	0.24	3.56	0.17	147.7	11.8	127.5	14.4	0.58	0.02	0.57	0.02	2.60	0.05	2.79	0.19	0.61	0.04	0.74	0.06
(C) Retention Aid Control[5]	6	5	4.03	0.21	4.21	0.33	5.51	0.39	5.75	0.50	4.30	0.25	3.89	0.60	157.5	18.3	149.7	31.4	0.61	0.04	0.60	0.05	2.74	0.08	2.94	0.14	0.62	0.04	0.70	0.05
(D) 3% Wet Strength Resin	5	5	4.13	0.32	4.07	0.24	6.59	0.22	6.73	0.52	4.61	0.50	4.05	0.27	196.1	21.6	175.2	20.3	0.67	0.04	0.67	0.04	3.16	0.24	3.27	0.17	0.72	0.06	0.81	0.08
(E) Beater Addition	6	4	4.03	0.23	4.20	0.26	6.56	0.25	6.67	0.37	4.37	0.12	3.88	0.19	182.4	8.5	166.0	15.7	0.60	0.03	0.59	0.03	2.91	0.07	3.05	0.05	0.77	0.04	0.86	0.02
(F) (D) + (E)	3	4	4.02	0.15	4.37	0.09	7.34	0.63	7.22	0.52	4.84	0.03	4.07	0.32	223.6	17.0	189.6	26.8	0.68	0.06	0.63	0.02	3.17	0.17	3.36	0.11	0.80	0.07	0.91	0.03
(G) Saturation	4	6	4.37	0.37	4.27	0.47	6.76	0.20	6.95	0.42	5.04	0.47	5.15	0.38	213.1	21.6	220.3	16.3	0.63	0.07	0.62	0.06	2.84	0.17	2.82	0.16	0.73	0.02	0.72	0.10
(H) (B) + (G)	3	6	4.31	0.28	4.20	0.48	7.16	0.31	6.91	0.40	4.94	0.50	4.84	0.40	221.6	25.5	209.8	14.4	0.65	0.03	0.63	0.04	3.11	0.10	2.94	0.25	0.76	0.10	0.78	0.09
(I) (C) + (G)	4	6	4.05	0.45	4.10	0.29	6.54	0.54	6.95	0.47	4.97	0.74	5.09	0.34	207.9	30.1	224.9	21.6	0.63	0.04	0.63	0.02	2.94	0.19	3.02	0.13	0.70	0.16	0.70	0.05
(J) (D) + (G)	3	4	4.00	0.72	4.02	0.28	7.22	0.48	7.60	0.11	5.35	0.60	5.37	0.41	241.2	16.3	253.6	19.0	0.66	0.09	0.67	0.02	3.03	0.16	3.14	0.14	0.72	0.18	0.74	0.06
(K) (E) + (G)	4	4	4.00	0.26	4.42	0.20	7.67	0.33	7.73	0.36	5.04	0.50	4.24	0.30	236.0	23.5	205.3	20.3	0.66	0.03	0.62	0.04	3.03	0.23	3.31	0.17	0.84	0.10	0.96	0.04
(L) (F) + (G)	5	5	4.42	0.71	4.12	0.24	7.90	0.65	8.06	0.34	4.78	0.32	5.01	0.34	234.0	15.0	251.0	24.8	0.63	0.04	0.68	0.06	3.28	0.16	3.33	0.12	0.86	0.19	0.85	0.06

1 W = width L = length of 15X30 cm flex specimens.

2 $s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$

3 Handsheets prepared in conventional manner.

4 Sheets made according to beater addition procedure but without the addition of retention aid or acrylic resin.

5 Sheets made according to beater addition procedure but with retention aid only.

Table 11. Tensile Properties of Wood Pulp Handsheets Treated In Various Ways With Acrylic Resins After 1,000 Flexes.

	Treatment	Number Of Specimens		Initial Modulus GN/m^2				Breaking Strength kN/m				Elongation To Break %			
		W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s
(A)	Standard[3]	5	6	3.26	0.24	2.84	0.32	5.13	0.26	5.44	0.32	4.28	0.27	3.37	0.26
(B)	H_2O Control[4]	5	6	3.16	0.19	2.85	0.18	5.10	0.34	5.16	0.42	4.39	0.39	3.32	0.39
(C)	Retention Aid Control[5]	5	6	3.22	0.09	2.85	0.25	5.23	0.24	5.43	0.16	4.56	0.31	3.67	0.18
(D)	3% Wet Strength Resin	3	5	3.28	0.05	3.22	0.17	5.92	0.59	6.03	0.54	4.75	0.53	3.62	0.25
(E)	Beater Addition	4	4	3.17	0.03	2.90	0.20	5.86	0.18	6.31	0.33	4.55	0.11	3.78	0.14
(F)	(D) + (E)	3	4	3.52	0.20	3.42	0.09	6.52	0.37	6.68	0.35	4.74	0.13	3.85	0.22
(G)	Saturation	4	6	3.85	0.41	3.43	0.52	6.75	0.24	6.58	0.52	5.15	0.74	4.59	0.43
(H)	(B) + (G)	4	5	3.58	0.42	3.39	0.20	6.86	0.04	6.65	0.34	5.49	0.61	4.52	0.31
(I)	(C) + (G)	5	4	3.60	0.11	3.66	0.34	6.62	0.17	6.84	0.30	5.21	0.35	4.46	0.44
(J)	(D) + (G)	3	5	3.70	0.36	3.57	0.36	6.97	0.37	6.85	0.40	5.29	0.83	4.52	0.30
(K)	(E) + (G)	5	5	3.77	0.03	3.58	0.25	7.61	0.36	7.05	0.44	5.22	0.33	4.22	0.57
(L)	(F) + (G)	2	3	3.79	-	4.00	0.10	7.01	-	7.63	0.05	4.86	-	4.49	0.28

	Treatment	Engery To Break J/m^2				Elongation At Yield %				Load At Yield kN/m				Plastic Modulus GN/m^2			
		W	s	L	s	W	s	L	s	W	s	L	s	W	s	L	s
(A)	Standard[3]	141.2	10.5	113.1	15.0	0.66	0.02	0.94	0.02	2.48	0.22	2.93	0.25	0.63	0.06	0.96	0.04
(B)	H_2O Control[4]	145.1	20.3	107.2	20.3	0.67	0.03	0.88	0.07	2.41	0.07	2.83	0.23	0.61	0.04	0.89	0.06
(C)	Retention Aid Control[5]	156.2	15.0	126.2	9.2	0.66	0.03	0.96	0.13	2.51	0.06	3.01	0.12	0.57	0.02	0.82	0.04
(D)	3% Wet Strength Resin	178.5	34.0	136.0	19.6	0.73	0.02	0.89	0.07	2.64	0.08	3.29	0.25	0.69	0.02	0.89	0.06
(E)	Beater Addition	170.0	9.15	146.4	11.1	0.73	0.06	1.06	0.15	2.84	0.28	3.61	0.38	0.63	0.06	0.86	0.04
(F)	(D) + (E)	193.5	11.1	160.2	17.0	0.72	0.02	0.98	0.13	2.84	0.15	3.82	0.42	0.76	0.03	0.88	0.10
(G)	Saturation	214.4	28.8	185.0	26.8	0.64	0.02	0.71	0.08	2.73	0.22	2.71	0.23	0.74	0.11	0.88	0.08
(H)	(B) + (G)	232.7	23.5	185.7	19.0	0.67	0.03	0.77	0.04	2.73	0.13	2.92	0.13	0.71	0.11	0.88	0.04
(I)	(C) + (G)	218.3	19.0	190.9	17.0	0.69	0.02	0.76	0.06	2.85	0.10	3.21	0.23	0.67	0.03	0.87	0.11
(J)	(D) + (G)	232.1	39.1	192.2	19.6	0.72	0.06	0.78	0.07	3.07	0.29	3.15	0.19	0.69	0.10	0.86	0.06
(K)	(E) + (G)	239.3	13.1	182.4	32.7	0.64	0.04	0.72	0.06	2.81	0.12	3.07	0.22	0.81	0.08	0.95	0.06
(L)	(F) + (G)	212.5	-	213.8	13.7	0.69	-	0.79	0.05	2.99	-	3.67	0.26	0.77	-	0.93	0.02

1 W = width L = length of 15X30 cm flex specimens.

2 $$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$$

3 Handsheets prepared in conventional manner.

4 Sheets made according to beater addition procedure but without the addition of retention aid or acrylic resin.

5 Sheets made according to beater addition procedure but with retention aid only.

Table 12. Physical Properties of Unflexed Wood Pulp Handsheets Treated in Various Ways With Acrylic Resins.

Treatment	Number of Specimens		Sonic Modulus GN/m^2				Elmendorf Tear mN				Mit Fold Endurance 1000 g. Double Folds				Cantilever Stiffness μN·M				Air Permeability cm^3/min (10 cm)		Weight Per Unit Area g/m^2		Thickness mm		Density g/cm^3	
	W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s	W	s	L	s		s		s		s		s
(A) Standard[3]	6	6	5.89	0.21	5.80	0.26	627.6	89.0	679.6	75.9	1830	578	2300	728	172.6	10.8	170.6	17.7	143	15	68.4	1.0	113.4	1.4	0.603	0.002
(B) H_2O Control[4]	6	6	5.80	0.18	5.59	0.16	645.2	85.1	728.6	113.7	1790	287	1950	339	159.8	7.8	162.8	12.7	134	18	67.5	1.5	113.8	2.4	0.573	0.049
(C) Retention Aid Control[5]	6	6	5.64	0.28	5.44	0.16	663.9	72.0	681.5	125.0	2110	440	2090	552	164.7	10.8	159.8	8.8	142	16	66.7	3.6	117.4	1.1	0.582	0.009
(D) 3% Wet Strength Resin	6	6	5.92	0.31	5.61	0.34	549.1	22.4	568.7	73.6	3560	675	3370	391	180.4	11.8	173.6	7.8	104	24	70.8	1.2	119.6	2.7	0.592	0.009
(E) Beater Addition	6	6	5.90	0.25	5.60	0.11	571.7	56.4	570.7	22.7	3660	620	3290	617	187.3	7.8	181.4	10.8	125	15	72.9	1.3	122.5	1.8	0.595	0.003
(F) (D) + (E)	6	6	5.17	0.29	5.89	0.18	529.5	79.6	565.8	74.8	4670	1266	4350	865	185.3	22.6	186.3	19.6	76	16	72.5	2.2	119.3	2.8	0.607	0.011
(G) Saturation	6	6	6.71	0.42	6.08	0.59	570.7	56.3	570.7	90.2	3270	991	3460	758	180.4	14.7	170.6	5.4	12	1.4	79.1	1.1	111.8	1.5	0.707	0.010
(H) (B) + (G)	6	6	6.42	0.48	6.30	0.52	542.3	28.8	580.5	35.3	3300	831	3240	1102	186.3	18.6	174.5	14.7	12	1.5	80.1	0.9	112.7	1.2	0.710	0.010
(I) (C) + (G)	6	6	6.28	0.34	6.08	0.56	546.2	24.7	605.0	57.9	3800	860	4030	1455	183.4	17.7	175.5	9.7	13	2.0	80.4	2.0	117.4	3.2	0.685	0.008
(J) (D) + (G)	6	6	6.11	0.51	6.30	0.45	551.1	67.7	532.5	80.4	5440	1378	5120	779	221.6	22.6	195.1	16.7	12	2.3	80.7	1.8	117.8	2.8	0.684	0.007
(K) (E) + (G)	6	5	6.09	0.37	6.34	0.38	554.0	13.7	556.8	41.2	4510	927	4180	952	213.8	34.3	255.9	23.5	11	2.1	84.7	0.6	122.1	2.1	0.694	0.012
(L) (F) + (G)	6	3	6.28	0.53	6.37	0.56	553.1	45.1	517.8	32.4	5150	486	4790	968	204.9	24.5	198.1	16.7	11	1.9	83.6	1.4	121.2	1.9	0.689	0.009

1 W = width L = length of 15x30 cm flex specimens.

2 $$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$$

3 Handsheets prepared in conventional manner.

4 Sheets made according to beater addition procedure but without the addition of retention aid or acrylic resin.

5 Sheets made according to beater addition procedure but with retention aid only.

Table 13. Physical Properties of Wood Pulp Handsheets Treated in Various Ways With Acrylic Resins After 1000 Flexes.

Treatment	Number of Specimens		Sonic Modulus GN/m^2				Elmendorf Tear mN				Mit Fold Endurance 1000 g. Double Folds				Cantilever Stiffness μN·M				Air Permeability cm^3/min (10 cm)		Weight Per Unit Area g/m^2		Thickness mm		Density g/cm^3	
	W[1]	L	W	s[2]	L	s	W	s	L	s	W	s	L	s	W	s	L	s		s		s		s		s
(A) Standard[3]	6	6	4.79	0.28	4.70	0.16	612.3	75.1	654.1	84.5	2290	44	1880	410	103.9	10.8	86.3	7.5	147	15	68.5	2.1	112.6	4.0	0.608	0.004
(B) H_2O Control[4]	6	6	4.76	0.20	4.67	0.31	600.1	89.3	645.2	104.9	2400	644	2060	460	105.9	10.8	84.3	3.2	130	22	67.7	0.7	112.7	2.2	0.601	0.009
(C) Retention Aid Control[5]	6	6	4.65	0.26	4.80	0.13	596.2	103.6	606.0	65.2	2310	303	1710	521	108.8	10.8	87.3	9.1	145	17	68.7	1.3	114.7	1.9	0.599	0.003
(D) 3% Wet Strength Resin	6	6	4.79	0.27	5.07	0.20	508.0	52.8	576.6	84.0	3050	424	3690	521	129.4	18.6	103.9	5.1	130	24	69.9	0.9	116.8	2.1	0.599	0.007
(E) Beater Addition	6	6	4.90	0.30	5.04	0.20	537.4	43.6	557.0	58.3	3090	848	2640	458	135.3	9.0	114.7	7.7	162	21	72.4	1.5	120.3	2.8	0.602	0.006
(F) (D) + (E)	6	6	5.18	0.20	5.39	0.22	463.8	59.4	537.4	53.5	3970	433	3910	565	137.3	17.7	133.4	11.8	97	11	72.5	1.9	117.6	1.5	0.617	0.010
(G) Saturation	6	6	6.60	0.75	5.90	0.47	566.8	78.4	544.2	65.7	2990	472	3220	496	157.9	11.8	134.3	5.3	10	1.9	78.4	0.2	109.4	1.7	0.717	0.012
(H) (B) + (G)	6	6	6.45	0.57	6.18	0.38	586.4	55.2	571.7	40.0	3110	389	3120	712	164.7	21.6	124.5	7.1	10	0.8	80.1	1.3	111.5	2.6	0.718	0.010
(I) (C) + (G)	6	6	6.18	0.18	6.11	0.57	547.2	34.3	554.0	61.8	3880	1131	3900	1053	174.5	27.5	138.3	10.8	11	2.1	80.1	2.2	114.7	2.1	0.700	0.010
(J) (D) + (G)	6	6	6.30	0.64	6.39	0.60	490.3	34.3	492.3	37.3	5230	881	4650	611	172.6	13.7	141.2	11.8	11	1.9	79.7	1.3	114.1	2.0	0.699	0.001
(K) (E) + (G)	6	6	6.36	0.37	6.10	0.15	498.1	43.1	524.1	26.5	4490	1165	3801	606	180.4	13.7	154.0	8.1	9	1.2	83.5	1.2	118.1	1.7	0.707	0.009
(L) (F) + (G)	6	5	6.28	0.44	5.81	0.28	451.1	17.6	500.0	64.7	4960	906	4510	1288	177.5	11.8	158.9	11.8	10	1.2	82.5	0.7	117.2	1.9	0.704	0.009

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1 W = width L = length of 15x30 cm flex specimens.

2 $$s = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{N(n-1)}}$$

3 Handsheets prepared in conventional manner.

4 Sheets made according to beater addition procedure but without the addition of retention aid or acrylic resin.

5 Sheets made according to beater addition procedure but with retention aid only.

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Currency has been printed customarily on high grade paper owing to its superior durability. During the past several years the cost of raw material for rag pulps has risen tremendously and the thought of using high quality wood pulp papers as a means of lowering the cost of currency manufacture has been advanced. While considerable work has been done on rag currency paper to resolve the origin of its superior durability and to further increase its already excellent durability essentially little if any information has been developed for wood pulp paper durability. This report describes the results of experiments performed with wood pulp paper which had previously been performed on rag currency paper and probable reasons for observed differences were postulated.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Acrylic latexes; currency paper; fiber morphology, fiber network structure; paper durability; pulp mechanical treatment; rag pulps; wood pulps

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