NBSIR 74-431 (R)

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E. L. Graminski and E. E. Toth

Paper Evaluation Section
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January 2, 1974

Progress Report covering the period
July 1 – December 31, 1973

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Bureau of Engraving and Printing
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

CONTENTS

1. SUMMARY

As part of a continuing study for the Bureau of Engraving and Printing of the U.S. Department of the Treasury, the effect of acrylic resins on the structure of handsheets and the possibility of improving stiffness retention with acrylic resins was studied. In addition, the effect of wet pressing on the structure of handsheets was investigated.

When wood pulp handsheets are modified with certain acrylic resins by beater addition, there is a decline in tensile modulus and strength of the paper which could be attributed to the rheological properties of the resin. However, the resin modification also leads to an increase in air permeability which cannot be explained by the rheology of the resin and is likely caused by structural changes of the paper.

Scanning electron photomicrographs of handsheets treated with certain acrylic resins indicate a marked decrease in fibrillar content. This decrease in fibrillar content results in a decrease in the formation of film-like material (matrix) in the interstices of the fibers. The matrix appears to affect a multitude of paper properties one of which is air permeability. Apparently, the acrylic latex causes the fibrils and cell wall debris to precipitate onto the fiber surface making them unavailable for matrix formation. The decrease in matrix permits stress to dissipate in the direction of least resistance when paper is strained, as in the lateral movement and/or twisting of fibers, which could account in part for the reduced modulus and strength. In essence, the changes in the properties of paper are not only due to the rheology of the resin but also to the structural changes of the resulting handsheets. Investigations show that these same acrylic resins not only affect the structure of wood pulp handsheets but also currency type (linen-cotton) handsheets.

Some acrylic resins improve retention of stiffness best when introduced into handsheets by beater addition, while others perform best when applied to paper by the saturation technique. If the improvement in stiffness retention by the two different modification techniques were additive, then a greatly improved stiffness retention could result if the paper were modified first with one acrylic resin by beater addition, then followed by a second treatment with another resin by the saturation technique.

Once handsheets have been modified with acrylic resins by beater addition and dried, there is a significant resistance to wetting, and only small quantities of the second resin were introduced into the sheet by saturation. Even though only small weight gains resulted with saturation, the improvement in stiffness retention was encouraging. In an effort to increase the weight gain of acrylic resin with saturation, the handsheets were saturated immediately following wet pressing to overcome the resistance to impregnation of the dry sheets. This resulted in further improvements in stiffness retention.

The second wet pressing caused the properties of the control handsheets to change significantly. In a separate experiment it was demonstrated that the pressing procedure affected the structure of handsheets. In order for the handsheets to be more uniform and for results to be reproducible, it appears that consolidation of the web on the forming wire be accomplished with minimum pressure, the sheet removed from the wire, and placed between felts and pressed at the desired pressure a second time.

2. STRUCTURAL CHANGES IN HANDSHEETS MODIFIED WITH ACRYLIC RESINS BY BEATER ADDITION

Work done previously on the modification of wood pulp handsheets with acrylic resins by beater addition [2] generated some interesting questions. The softest resins caused a decrease in modulus and breaking strength and an increase in elongation to break. It was easy to attribute these changes to the rheological properties of the acrylic resins, but as the strength properties were decreasing, air permeability was increasing, and this could not be attributed to the rheological properties of the resins. An increase in air permeability can be accounted for only by changes in paper structure.

Three handsheets were prepared consisting of a control and two sheets modified by beater addition of acrylic resins. One sheet contained resin AC-61, and the other sheet contained resin E-631. The sheets modified with AC-61 showed only a slight increase in air permeability, while those treated with E-631 exhibited a very large increase in air permeability. Scanning electron photomicrographs from these three sheets are shown in Figure 1. The photomicrographs indicate that the treatment with acrylic resins significantly affected the fibrillar component of the paper structure. Resin AC-61 appeared to cause a noticeable reduction in the fibrillar component compared with the control, but resin E-631 practically eliminated the fibrillar component as a visible structural entity. The result was a paper with large "holes" which apparently are responsible for the large increase in air permeability. Apparently, the acrylic latex causes the fibrils to redeposit on the fibers so they cannot function in the normal fashion in sheet formation. Although data on loss of fines among the three sheets were not obtained, significant differences in basis weight were not noted.

It is proposed that the decline in modulus and strength and increase in extensibility are at least partially a result of structural changes in the paper and are not entirely due to the rheological properties of the resins. The absence of material in the interstices between the fibers allows the fibers to move laterally and to twist when the sheet is strained. This permits stresses in the sheet to dissipate in the direction of least resistance and for elongation to occur without affecting fiber bonds or requiring fiber elongation at low stress levels. In the control handsheet, where the interstices contain fibrillar material, lateral movement and twisting of the fibers is restrained, requiring greater force to strain the paper a given amount. This results in higher modulus, higher strength, and lower elongation in comparison with the sheet ccntaining resin E-631.

This investigation indicates that the modification of paper by beater addition of acrylic resins is not entirely due to the rheological properties of the polymer but probably is due in part to structural changes of the paper.

3. MODIFICATION OF HANDSHEETS MADE FROM CURRENCY BEATER STOCK BY TREATMENT WITH ACRYLIC RESINS

3.1 Background

In earlier work [2] it was shown that treatment of wood pulp handsheets with acrylic resins produced better stiffness retention when the treatment was accomplished by a saturation technique rather than by beater addition. In the last NBS Report [1] to BEP, it was shown that the treatment of handsheets, made from currency beater stock, with acrylic resins by saturation produced changes in properties similar to those observed in wood pulp handsheets. It remained to be determined whether treatment of the currency-type handsheets with acrylic resins by beater addition, rather than by saturation, resulted in less improvement of stiffness retention as occurred with wood pulp handsheets. It was especially important to determine whether certain acrylic resins affected the structure of the currency-type handsheets similarly to that found in wood pulp handsheets (section 2 of this report).

3.2 Experimental

Sufficient amounts of currency beater stock to make a 12" x 12" handsheet of 70 g/m^2 basis weight was diluted with 1.5 liters distilled water and disintegrated for 7,500 revolutions in a British disintegrator. The pH was adjusted to 9 using 1 N NaOH. A retention aid was added to the pulp slurry in the amount of 2 percent based on latex solids to be deposited on the fibers. The retention aid was added from a sufficient quantity of a 1 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 5 minutes prior to latex addition to exhaust the retention aid from solution. The pH of the mixture was then decreased to 4.0 with 0.5 $\underline{N}$ H_2SO_4.

The acrylic emulsion was diluted with approximately 50 cm^3 distilled water and added to the pulp suspension in three equal portions with moderate stirring. Five minutes was allowed between each addition to exhaust the acrylic latex. Only moderate stirring was used in order not to remove any adsorbed polymer by shearing. After all of the latex was added, the remainder of retention aid was added and the mixture stirred for an additional 5 minutes. Handsheets were then prepared by placing the mixture in the deckle box of the handsheet machine and forming the sheet in the usual way using tap water. The sheets were dried at 95°C for approximately 3 minutes on a drum dryer.

The effect of the acrylics on the retention of cantilever stiffness was evaluated by determining the decline in cantilever stiffness after 1,000 double flexes over 1/8" rollers on the NBS paper flexer. All of the tensile properties and other physical properties were determined in addition to the cantilever stiffness. The results are given in Tables 1 and 2 and the standard deviation of the results are given in Tables 3 and 4. Six acrylic emulsions designated K-3, E-631, P-339, AC-61, HA-16, and AC-201 were evaluated. The acrylics covered a wide range of film stiffness.

3.3 Results and Discussion

There was good agreement between the results obtained on the currency stock handsheets and the wood pulp handsheets. The extensional stiffness declined below that of the controls for the three softest acrylics, K-3, E-631, and P-339, while the air permeability increased. It is believed that the decline in handsheet extensional stiffness was not entirely due to the low resin stiffness but primarily caused by a change in structure resulting from the treatment. This structural change can also account for the increase in air permeability over the two controls (section 2). The extensional stiffness increased steadily as the polymer stiffness increased with the remaining three latexes, AC-61, HA-16, and AC-201.

In addition to extensional stiffness, an increase in breaking strength, energy to break, load at yield, and plastic stiffness increased with increasing film stiffness. Little or no increase in elongation to break and elongation at yield with increasing film stiffness was observed. There was no adverse effect by any of the resins on Elmendorf tear and a varied effect on folding endurance. A decline in folding endurance was observed in the handsheets treated with K-3, while an improvement in fold was observed for all the other resins.

Of the six resins, HA-16 appeared to improve stiffness retention with flexing to a greater extent than any of the other resins. The improvement with HA-16 was almost as great as that observed with currency stock handsheets modified with acrylics by saturation. Apparently some of the acrylic resins produce better results when applied by beater addition, while others perform best when applied by the saturation technique.

The stiffest of the acrylic resins, AC-201, apparently cracks during flexing resulting in a greater decline of cantilever stiffness. This same behavior was observed when wood pulp as well as currency stock handsheets were treated with AC-201 by saturation. Apparently there is an optimum film stiffness beyond which no improvement in stiffness retention with flexing occurs.

4. MODIFICATION OF WOOD PULP HANDSHEETS WITH ACRYLIC RESINS BY BOTH BEATER ADDITION AND SATURATION TECHNIQUES

4.1 Background

The results of the investigation on modifying currency beater stock handsheets with acrylic resins by beater addition (section 3) and by saturation techniques [2] indicated that appreciable improvements in stiffness retention are possible by either technique providing the proper resin is employed in each treatment. Acrylic resin, HA-16, imparts greater improvement in stiffness retention with flexing by beater addition, while AC-61 performs best in the saturation technique. Since the distribution of the resin throughout the paper is different with the two techniques, it would appear that decline in stiffness with flexing occurs by at least two separate mechanisms.

It has been demonstrated previously [3, 4, 5, 6] that the deterioration of the film-like constituent or matrix of paper is probably most responsible for the decline in bending stiffness. Stabilization of the matrix by some modification results in an improvement in stiffness retention with flexing.

While the matrix contributes significantly to stiffness retention, the stiffness of paper must result from other factors as well. Wood pulp papers, having an apparent density equal to that of highly beaten rag paper but with little or no matrix, are as stiff as the rag papers. Apparently, the stiffness of the fibers must contribute greatly to the stiffness of the sheet. However, stiffness declines rapidly and extensively when the wood pulp paper is flexed.

In beating of pulp, the fibers become gelatinous. It has been proposed by Clark [7] that the surface of beaten fibers is covered with a colloidal suspension of water and cellulose which serves as the bonding material or adhesive. This colloidal material may contribute significantly to the stiffness of fibers in addition to serving as bonding material, especially in the areas where no interfiber bonding takes place. The colloidal material might be viewed as a substance similar to a starch suspension that forms a stiff film when it dries. Upon drying over the surface of the fiber, it imparts added stiffness to the fibers. Unfortunately, the film is brittle and cracks when bent.

In cases where little, if any, matrix is present in the paper, stiffness is mostly derived from fiber stiffness. When flexed, the paper stiffness declines sharply because the brittle film cracks and causes a sharp decline in paper stiffness.

Had this same paper contained a matrix which did not crack with flexing, the stiffness of the paper would not have declined as extensively even though fiber stiffness declined sharply. The matrix spans the areas between the fibers, causing a shortening of the effective fiber segment length, and also prevents fiber twisting and/or lateral movement of fibers when the paper is strained. The shortening of the fiber segments leads to an increase in bending stiffness, as the apparent fiber stiffness increases with decreasing fiber length. Consequently, a greater force will be necessary to bend or strain the paper when the matrix is present even if fiber stiffness is greatly reduced with flexing.

If the above hypothesis is correct, then maximum stiffness retention can be achieved by modifying the fiber surface as well as the matrix to prevent or retard breakdown of the film-like materials. Treatment of the pulp by beater addition with a suitable resin would modify the fiber surface making it more resistant to breakdown on flexing, and saturation of the resulting paper with a suitable resin would improve the cracking resistance of the matrix. The two treatments should result in a sheet of paper with very superior retention of stiffness with flexing.

4.2 Experimental

A bleached kraft wood pulp was beaten in a PFI laboratory mill at 10 percent consistency with no clearance between bedplate and roll for 5,000 revolutions at 3.4 kilograms-force and a relative velocity of roll to bedplate of 6 m/sec. The beating was done in distilled water. Forty grams of pulp were beaten for each of the seven variables investigated. Six aliquots were taken from each beater run sufficient to make a 12" x 12" handsheet of 70 g/m^2. Depositions of acrylic latex by beater addition was done exactly as described in section 3.2 of this report.

The sheets modified with acrylic resin by beater addition were then saturated with an acrylic resin as follows. The felts which are used in wet pressing of handsheets were saturated with a 10 percent emulsion of the acrylic resin. A handsheet was placed between the felts and passed through the calender rolls of the sheet machine. As the felt passed through the calender rolls, the excess latex was squeezed out of the felt saturating the paper with latex. As the felt and paper proceeded through the rolls, the excess latex in the paper was squeezed out. The wet sheet, saturated with acrylic, was lifted from the felt and dried on the drying drum at 95°C for approximately 3 minutes. The saturation controls were treated in the same manner, except the felts were saturated with water only.

Three resins were investigated, HA-16, which improves stiffness retention appreciably when applied by beater addition, AC-61, which has been found to be one of the best saturants for improving stiffness retention, and P-339, which does not improve stiffness retention appreciably by any method of application. The use of P-339 was for control purposes primarily.

Unfortunately, the sheets treated with acrylic resins by beater addition, especially with HA-16 and AC-61, resisted wetting resulting in a non-uniform treatment and low weight gains. Therefore, additional experiments were conducted in an effort to reduce the effect of water resistance of the handsheets treated with acrylic resins by beater addition.

The beater addition was performed as before, but the sheets were not dried immediately following wet pressing. Instead, the sheets were removed from the wire after wet pressing and couched between felts saturated with an acrylic resin and passed through the calender rolls of the sheet machine to effect saturation of the wet handsheet similar to that described for dry handsheets.

The effect of the acrylic treatments on the retention of cantilever stiffness was evaluated by determining the decline in cantilever stiffness after 1,000 double flexes over 1/8" rollers on the NBS paper flexer. Half of each handsheet was used for flexing, while the other half remained unflexed. All of the tensile properties and other physical properties were determined in addition to cantilever stiffness. The results of the experiment involving beater addition and saturation of the dried handsheets are given in Tables 5 and 6, with the standard deviation of the results in Tables 7 and 8. The results of the experiment involving beater addition and saturation of the wet handsheets are given in Tables 9 and 10, with the standard deviation of the results in Tables 11 and 12.

4.3 Results and Discussion

As mentioned above, the saturation of handsheets with acrylic resins which were previously treated with acrylic resins by beater addition was non-uniform because of their resistance to wetting. However, the results were encouraging as the handsheets which were treated with AC-61 by both techniques retained 75 percent of their initial stiffness after 1,000 flexes. This represents the highest stiffness retention ever realized with any paper evaluated so far. It appeared that modification of handsheets with acrylic resins by both techniques would result in a paper with extremely good stiffness retention if only the saturation treatment were more uniform and more resin could be deposited.

An attempt at obtaining a more uniform treatment and greater weight gains was made by saturating the handsheets immediately after wet pressing and before drying. Unfortunately, greater weight gains with saturation were not realized but the treatment was more uniform. In addition, the retention aid did not function properly, and the weight gain in beater addition were approximately half of that intended. Nevertheless, there was a marked improvement in the stiffness retention of the handsheets with flexing especially with the handsheets containing HA-16 by beater addition and AC-61 by saturation. The retention of stiffness after flexing was an impressive 82 percent.

A first glance at the stiffness retention data in Table 10 is not impressive when one considers the final stiffness values. However, the stiffness of the unflexed sheets are lower than usual so that even with an excellent stiffness retention, the final stiffness is not greater than has been realized with other handsheets having a high stiffness before flexing.

The reduced stiffness of the handsheets which were saturated immediately after wet pressing is due to a marked decrease in thickness of the handsheets as seen in Table 10. Apparently the second pressing off the forming wire in the saturation procedure led to the decline in thickness. A separate investigation, concerning the effect of wet pressing on the properties of handsheets, was conducted and is reported in section 5 of this report.

The various investigations involving modification of handsheets with acrylic resins by the saturation technique have led to the conclusion that the procedure used to saturate the handsheets is unacceptable because it is difficult to control and to reproduce results. As a consequence, specialized equipment is being obtained to improve this situation, and no further saturation work will be performed until the new equipment is operational.

5. EFFECT OF WET PRESSING ON THE PHYSICAL PROPERTIES OF HANDSHEETS

5.1 Background

The results of the investigation of saturating handsheets immediately after wet pressing on the forming wire with acrylic resins raised some interesting questions regarding handsheet preparation. The results obtained with the controls were most interesting. When the control handsheets were removed from the wire after pressing and pressed a second time between felts, there was a marked change in the properties of the handsheets. Most noticeable were the changes in modulus, breaking strength, elmendorf tear, cantilever stiffness, air permeability, and thickness. Modulus and breaking strength increased while the other properties decreased. Since considerable work on handsheets is being performed at NBS and BEP, it was decided to investigate variables in wet pressing the handsheets.

5.2 Experimental

A bleached kraft wood pulp was beaten in a PFI laboratory mill as described in section 4.2 of this report. Forty grams of pulp were beaten for each of the seven variables investigated. Six aliquots were taken from each beater run sufficient to make 12" x 12" handsheets of 70 g/m^2. Each aliquot was disintegrated for 7,500 revolutions in a standard disintegrator and transferred to the deckle box of the handsheet machine containing the appropriate amount of water, and the sheet was formed by the standard procedure. The sheets were then pressed in a variety of ways as given in Table 13.

One half of each handsheet was designated at random for flexing. The effect of pressing on the retention of cantilever stiffness was evaluated by determining the decline in cantilever stiffness after 1,000 double flexes over 1/8" rollers on the NBS paper flexer. The long direction of the flex samples was in the direction the handsheets were passed through the calender rolls. The results are given in Tables 13 and 14, and the standard deviation of the results are given in Tables 15 and 16.

5.3 Results and Discussion

The differences in the physical properties between handsheets which were wet pressed under high or low pressures would be due to the degree of consolidation of the web. More fiber bonding occurs when the sheet is wet pressed under high pressure resulting in greater strength and higher apparent density. The results in Table 13 indicate that this basically is the case.

A second pressing of the sheet between felts after removing the sheet from the forming wire following the first wet pressing produces further changes in the physical properties of the paper. This is true whether the first pressing was at low or high pressure. One might expect that two wet pressings at low pressure might result in better web consolidation than with just one wet pressing. However, it is difficult to imagine that an improvement in web consolidation would occur with a second wet pressing at low pressure when the first wet pressing was done at high pressure. Nevertheless, a significant increase in modulus and strength, and a significant decrease in thickness occurred when the handsheets which were wet pressed on the forming wire were pressed off the screen a second time at low pressure.

The second pressing at low pressures on the felt is accompanied by a large decrease in air permeability when the sheets were pressed on the wire at low pressure, and a smaller decrease when the first pressing was done at high pressure. These differences in air permeability must result from changes in the structure of the paper.

Apparently, wet pressing the web on the forming wire causes a heterogeneous web consolidation. The area of the sheet making contact with the wire of the forming screen consolidates satisfactorily while the area in the interstices of the wire are poorly consolidated because it is under little or no pressure even at high calender roll pressures.

This heterogeneous consolidation can explain the cause for the substantial decrease in thickness after two wet pressings at low pressure. The thickness of paper pressed on the forming wire is dominated by the areas which were located in the interstices of the forming wire. These areas have a lower density than the areas which were in contact with the wire. The second wet pressing off the screen produces a more homogeneous web consolidation resulting in a higher overall density and lower thickness. When the second wet pressing is done at high pressures, the consolidation is even greater and the thickness is further reduced.

Wet pressing has essentially no effect on the retention of stiffness with flexing. The stiffness of the handsheets subjected only to low pressure pressing declined more extensively than any of the other handsheets. This was due to the high initial stiffness caused by their greater thickness. Upon flexing, all of the handsheets declined to approximately the same level of stiffness.

While wet pressing has little, if any, effect on stiffness retention, it has a significant effect on paper structure. This is an important consideration in research work on paper involving handsheets. Surely, the results of an experiment will be affected by paper structure. Since wet pressing on a wire screen can affect the structure significantly, it appears that all handsheets should be prepared by using a minimum pressure in consolidating the sheet on the screen followed by a second pressing between felts at some desired pressure.

6. BIBLIOGRAPHY

1. Graminski, E. L. and Toth, E. E., Evaluation of Currency and Stamp Papers, NBSIR 73-274, August 15, 1973.

2. Graminski, E. L. and Toth, E. E., Evaluation of Currency and Stamp Papers, NBSIR 73-124, January 30, 1973.

3. Graminski, E. L. and Toth, E. E., Evaluation of Currency and Stamp Papers, NBS Report 10 336, September 17, 1970.

4. Graminski, E. L. and Toth, E. E., Evaluation of Currency and Stamp Papers, NBS Report 10 465, August 9, 1971.

5. Graminski, E. L., Toth, E. E., and Smith, M. A., Evaluation of Currency and Stamp Papers, NBS Report 10 802, February 15, 1972.

6. Graminski, E. L.,"The Effect of Flexing on the Mechanical Properties of Paper," The Fundamental Properties of Paper Related to Its Uses (Technical Section, BP&BMA, London) in press.

7. d'A Clark, J., Paper Ind., No. 5, 507-10, August 1943.

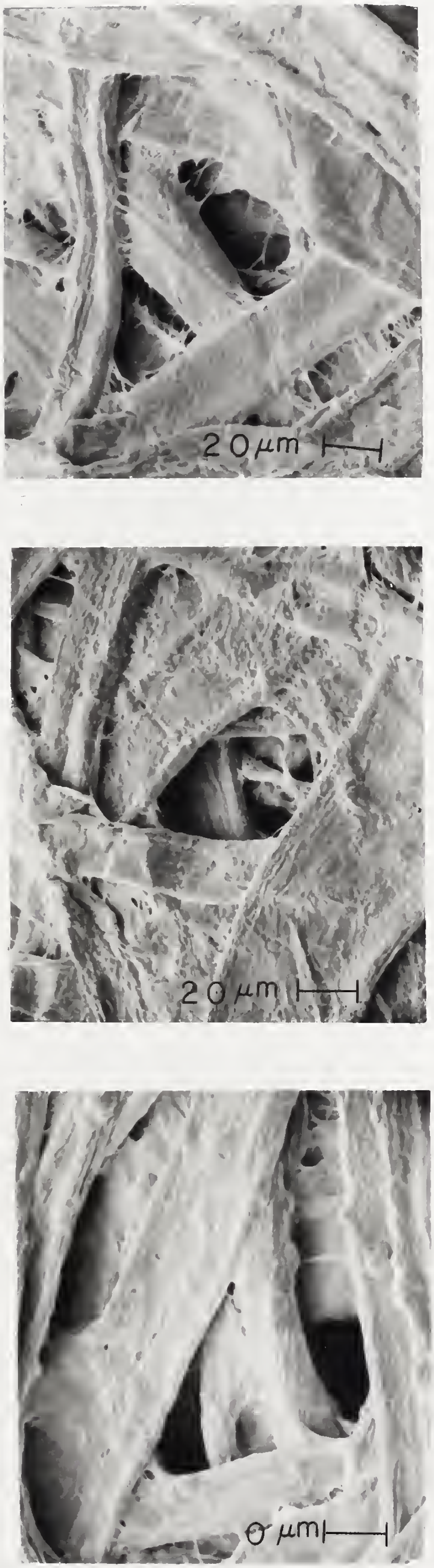

Figure 1. Scanning electron photomicrographs of handsheets containing acrylic resins. Top - waterleaf control; Center - 10% AC-61; Bottom - 10% E-631. Magnification approx. 400 X.

Table 1. Tensile properties of flexed and unflexed handsheets made from currency beater stock treated with various acrylic resins by beater addition.

Acrylic Resin Type	%	T_{300}[1]	Extensional[2] Stiffness		Breaking Strength		Elongation to Break		Energy to Break		Load at Yield		Elongation at Yield		Plastic Stiffness	
		°C	kg W[3]	kg L[3]	kg W	kg L	% W	% L	kg-cm W	kg-cm L	kg W	kg L	% W	% L	kg W	kg L
Unflexed																
K-3	10	-32	333	351	3.5	3.6	3.5	3.5	0.9	0.9	2.7	2.6	0.9	0.8	35	36
E-631	10	-11	369	369	4.0	3.9	4.2	4.4	1.2	1.3	2.9	2.8	0.8	0.8	35	34
P-339	10	3	425	410	5.9	5.4	4.5	4.4	1.8	1.6	4.1	3.7	1.0	1.0	53	52
AC-61	10	16	554	548	6.4	6.1	4.2	4.2	1.9	1.8	4.3	4.2	0.8	0.8	64	58
HA-16	10	33	567	576	6.7	6.4	4.4	4.1	2.1	1.8	4.5	4.2	0.9	0.8	65	69
AC-201	10	45	598	602	6.8	7.0	4.1	4.4	2.0	2.2	4.8	5.1	0.9	0.9	62	56
controls	retention aid[4]		534	535	4.4	4.4	2.9	3.0	0.9	0.9	3.4	3.4	0.7	0.7	50	47
	regular[5]		494	466	4.1	4.1	2.9	3.2	0.9	0.9	3.0	3.0	0.7	0.7	52	49
Flexed 1,000 times over 1/8" rollers																
K-3	10	-32	227	164	3.3	3.4	3.7	4.2	0.8	0.9	2.3	2.5	1.1	1.6	43	39
E-631	10	-11	246	166	3.7	3.7	4.5	4.9	1.2	1.2	2.7	2.8	1.2	1.7	31	35
P-339	10	3	308	230	5.4	5.5	4.7	4.8	1.7	1.6	3.6	3.9	1.2	1.7	53	53
AC-61	10	16	450	299	5.9	5.9	4.1	4.2	1.6	1.5	4.1	4.0	1.0	1.4	61	70
HA-16	10	33	486	340	6.4	6.7	4.5	4.7	1.9	2.0	4.2	4.6	0.9	1.4	60	66
AC-201	10	45	471	349	6.7	6.7	4.7	4.6	2.2	2.0	4.5	4.8	1.0	1.4	60	59
controls	retention aid[4]		352	242	3.7	4.0	2.7	3.2	0.7	0.8	2.7	2.9	0.9	1.3	55	65
	regular[5]		345	245	4.1	4.0	3.7	3.5	1.1	0.9	2.9	2.9	0.9	1.2	44	54

[1] Temperature at which the torsional modulus of an air dried film is 300 kg/cm^2.
[2] Initial slope of load-strain curve.
[3] W = width, L = length of flex samples.
[4] Sheets made according to beater addition procedure but with retention aid only
[5] Sheets made in conventional manner.

Table 2. Physical properties of flexed and unflexed handsheets made from currency beater stock treated with various acrylic resins by beater addition.

Acrylic Resin Type	%	T_{300}[1]	Sonic[2] Modulus W[3]	Sonic[2] Modulus L[3]	Elmendorf Tear W	Elmendorf Tear L	MIT Fold Endurance W	MIT Fold Endurance L	Cantilever Stiffness W	Cantilever Stiffness L	Air Permeability	Weight per Unit Area
			$kg/cm^2 x 10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(10cm^2)$	g/m^2
Unflexed												
K-3	10	-32	7.8	7.8	148	149	260	260	2.2	1.9	294	81
E-631	10	-11	8.3	8.2	147	145	620	640	2.1	1.8	322	80
P-339	10	3	9.8	9.5	132	139	2750	2650	2.4	2.3	322	82
AC-61	10	16	11.0	10.6	153	143	2000	2010	2.9	2.7	170	81
HA-16	10	33	11.0	10.7	132	132	2790	2400	3.0	2.7	167	80
AC-201	10	45	11.0	11.3	132	135	2520	3310	2.9	2.5	160	77
controls	retention aid[4]		10.6	10.4	142	123	380	330	2.5	2.6	234	75
	regular[5]		10.6	9.8	131	137	380	420	2.2	1.9	191	72
Flexed 1000 times over 1/8" rollers												
K-3	10	-32	5.8	4.4	147	136	230	230	1.0	0.6	334	--
E-631	10	-11	6.6	5.0	132	126	460	460	0.9	0.6	372	--
P-339	10	3	7.6	6.0	141	129	2560	2540	1.4	0.8	346	--
AC-61	10	16	9.2	6.7	126	131	1840	1650	2.0	1.2	197	--
HA-16	10	33	9.0	6.9	125	127	2340	2210	2.3	1.4	177	--
AC-201	10	45	9.0	7.1	125	121	2200	2160	1.8	1.1	167	--
controls	retention aid[4]		6.9	5.1	147	134	220	300	1.0	0.8	286	--
	regular[5]		6.8	5.9	145	122	290	320	1.1	0.7	226	--

[1]Temperature at which torsional modulus of an air dried film is 300 kg/cm^2.
[2]Sonic modulus is based on cellulose density of 1.54.
[3]W = width, L = length of flexed samples.
[4]Sheets made according to beater addition procedure but with retention aid only.
[5]Sheets made in conventional manner.

Table 3. Standard deviation[1] for tensile property data in Table 1 for flexed and unflexed handsheets made from currency beater stock treated with various acrylic resins by beater addition.

Resin Type	No. of Specimens		Extensional Stiffness kg		Breaking Strength kg		Elongation to Break %		Energy to Break kg-cm		Load at Yield kg		Elongation at Yield %		Plastic Stiffness kg	
	W	L	W^2	L^2	W	L	W	L	W	L	W	L	W	L	W	L
Unflexed																
K-3	6	6	31.4	19.4	0.1	0.3	0.4	0.06	0.1	0.09	0.2	0.3	0.1	0.06	7.4	3.8
E-631	6	6	17.3	33.5	0.2	0.3	0.4	0.3	0.2	0.1	0.2	0.3	0.04	0.05	4.7	5.7
P-339	6	6	38.7	10.6	0.4	0.5	0.5	0.9	0.2	0.5	0.3	0.5	0.2	0.1	7.5	11.2
AC-61	6	6	36.9	28.2	0.3	0.2	0.5	0.3	0.3	0.1	0.2	0.2	0.09	0.04	5.1	6.3
HA-16	6	6	39.7	35.3	0.3	0.3	0.4	0.3	0.3	0.1	0.2	0.3	0.1	0.06	6.9	5.2
AC-201	6	6	25.0	19.5	0.3	0.4	0.5	0.5	0.3	0.4	0.2	0.3	0.06	0.05	8.9	11.5
Control[3]	6	6	56.1	27.0	0.5	0.3	0.6	0.5	0.3	0.2	0.4	0.2	0.08	0.05	10.7	6.7
Control[4]	6	6	40.5	29.5	0.3	0.3	0.5	0.7	0.2	0.3	0.3	0.2	0.02	0.1	8.0	13.7
Flexed 1000 times over 1/8" rollers																
K-3	5	6	31.6	.8.9	0.2	0.07	0.3	0.2	0.1	0.05	0.1	0.2	0.1	0.1	3.1	4.1
E-631	6	6	10.3	12.6	0.1	0.2	0.6	0.6	0.2	0.2	0.1	0.3	0.08	0.2	6.4	6.5
P-339	6	6	48.5	13.8	0.5	0.3	0.6	0.6	0.3	0.3	0.2	0.3	0.2	0.2	6.4	9.5
AC-61	6	6	14.9	25.9	0.4	0.3	0.4	0.5	0.3	0.3	0.3	0.4	0.05	0.2	6.8	14.3
HA-16	6	6	19.6	34.9	0.4	0.4	0.6	0.4	0.4	0.3	0.1	0.5	0.06	0.3	3.1	9.2
AC-201	6	5	24.1	22.5	0.2	0.3	0.3	0.4	0.2	0.3	0.2	0.2	0.1	0.1	6.1	3.8
Control[3]	5	6	37.2	17.8	0.3	0.3	0.6	0.5	0.2	0.2	0.2	0.4	0.09	0.2	11.2	15.3
Control[4]	6	6	28.9	6.7	0.3	0.2	0.5	0.3	0.2	0.1	0.2	0.2	0.1	0.07	4.0	9.1

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

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

[3] Sheets made according to beater addition procedure but with retention aid only.

[4] Sheets made in conventional manner.

Table 4. Standard deviation[1] for physical property data in Table 2 for flexed and unflexed handsheets made from currency beater stock treated with various acrylic resins by beater addition.

Resin Type	No. of Specimens		Sonic Modulus		Elmendorf Tear		MIT Fold Endurance		Cantilever Stiffness		Air Permeability
			$kg/cm^2 x 10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(10cm^2)$
	W[2]	L[2]	W	L	W	L	W	L	W	L	
Unflexed											
K-3	6	6	0.3	0.6	8.9	18.7	84	63	0.2	0.2	9.9
E-631	6	6	0.5	0.4	15.9	8.6	134	124	0.3	0.8	13.1
P-339	6	6	0.3	0.4	13.5	15.4	577	576	0.2	0.3	20.9
AC-61	6	6	0.3	0.4	28.4	8.0	516	360	0.2	0.2	11.8
HA-16	6	6	0.2	0.6	14.8	9.7	409	389	0.1	0.2	12.6
AC-201	6	6	0.3	0.5	14.7	20.2	448	304	0.2	0.2	12.3
Control[3]	6	6	0.3	0.2	16.9	9.1	141	270	0.2	0.5	11.8
Control[4]	6	6	0.6	0.3	4.1	11.4	80	104	0.2	0.2	3.0
Flexed 1000 times over 1/8" rollers											
K-3	5	6	0.5	0.2	3.3	8.6	55	39	0.09	0.03	15.6
E-631	6	6	0.4	0.2	9.7	9.2	110	146	0.2	0.05	23.8
P-339	6	6	0.7	0.09	8.7	15.1	211	568	0.1	0.1	24.0
AC-61	6	6	0.4	0.2	14.8	21.1	392	495	0.3	0.1	15.6
HA-16	6	6	0.3	0.3	8.5	15.2	471	332	0.06	0.2	6.1
AC-201	6	6	0.4	0.4	12.4	18.8	601	972	0.05	0.1	8.4
Control[3]	6	6	0.4	0.3	4.2	10.3	68	105	0.2	0.06	20.8
Control[4]	6	6	0.4	0.9	10.1	14.4	163	164	0.1	0.07	2.9

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

[2] W = width, L = length of flex specimens.
[3] Sheets made according to beater addition procedure but with retention aid only.
[4] Sheets made in conventional manner.

Table 5. Tensile properties of flexed and unflexed wood pulp handsheets modified with acrylic resins by beater addition followed by saturation with acrylic resins.

Acrylic Resin: Type	Beater Addition %	Saturation %	Extensional[1] Stiffness kg W^2	Extensional[1] Stiffness kg L^2	Breaking Strength kg W	Breaking Strength kg L	Elongation to Break % W	Elongation to Break % L	Energy to Break kg-cm W	Energy to Break kg-cm L	Load at Yield kg W	Load at Yield kg L	Elongation at Yield % W	Elongation at Yield % L	Plastic Stiffness kg W	Plastic Stiffness kg L
Unflexed																
HA-16	9.4	5.6	700	694	10.4	10.3	4.6	4.5	3.0	2.9	4.4	4.5	0.7	0.7	144	147
HA-16 } AC-61 }	10.0 --	- 2.9	633	569	10.0	10.2	5.2	5.2	3.1	3.1	3.9	4.1	0.7	0.8	129	132
HA-16 } P-339 }	9.5 --	- 4.2	614	568	9.3	9.7	4.5	4.8	2.6	2.8	4.0	3.9	0.7	0.8	136	140
AC-61	7.3	3.4	531	594	9.0	9.5	5.0	4.7	2.7	2.7	3.5	4.0	0.8	0.7	122	135
P-339 } AC-61 }	10.0 --	- 5.0	479	475	8.6	8.9	5.2	5.1	2.7	2.7	3.3	3.7	0.8	0.9	119	122
Control[3]	Retention aid		615	715	7.7	8.1	4.1	3.2	2.0	1.7	3.8	4.8	0.7	0.8	116	131
Control[4]	--	-	543	609	7.0	6.9	4.1	3.8	1.9	1.8	3.8	4.2	0.8	0.8	98	89
Flexed 1000 times over 1/8" rollers																
HA-16	9.4	5.6	653	529	10.2	9.7	4.6	4.2	2.9	2.4	4.3	4.9	0.7	1.0	149	153
HA-16 } AC-61 }	10.0 --	- 2.9	595	425	9.7	9.5	4.8	5.0	2.8	2.8	3.8	4.1	0.7	1.0	138	137
HA-16 } P-339 }	9.5 --	- 4.2	611	459	9.6	9.1	4.5	4.4	2.7	2.3	4.2	4.3	0.7	1.0	142	142
AC-61	7.3	3.4	538	447	9.0	8.7	4.8	4.7	2.6	2.4	3.5	3.7	0.7	0.9	127	133
P-339 } AC-61 }	10.0 --	- 5.0	427	304	8.6	8.5	5.2	5.3	2.6	2.6	3.3	4.5	0.8	1.6	120	112
Control[3]	Retention aid		512	384	7.0	7.6	4.2	3.3	1.9	1.4	3.5	4.9	0.7	1.4	105	140
Control[4]	--	-	430	379	6.4	6.6	4.1	3.8	1.6	1.5	3.3	3.9	0.8	1.1	95	99

[1] Initial slope of load-strain curve.
[2] W = width, L = length of flex specimens.
[3] Sheets made according to beater addition procedure but with retention aid only.
[4] Sheets made in conventional manner.

Table 6. Physical properties of flexed and unflexed wood pulp handsheets modified with acrylic resins by beater addition followed by saturation with acrylic resins.

Acrylic Resin			Sonic[1] Modulus		Elmendorf Tear		MIT Fold Endurance		Cantilever Stiffness		Air Permeability	Weight per Unit Area
Type	Beater Addition	Saturation										
	%	%	$kg/cm^2 x 10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(10cm^2)$	g/m^2
			W[2]	L[2]	W	L	W	L	W	L		
Unflexed												
HA-16	9.4	5.6	14.2	13.3	64	67	2820	3340	2.3	2.3	205	77
HA-16 } AC-61	10.0 / --	-- / 2.9	12.2	12.5	71	66	2300	2920	2.3	2.1	275	77
HA-16 } P-339	9.5 / --	-- / 4.2	12.9	12.3	68	67	3070	3424	2.0	2.0	276	77
AC-61	7.3	3.4	11.2	12.6	70	72	1740	2050	2.1	2.0	280	77
P-339 } AC-61	10.0 / --	-- / 5.0	11.2	11.4	67	73	2680	2850	2.2	2.0	631	81
Control[3]	Retention aid		13.6	15.0	84	74	1550	1470	1.8	1.8	643	69
Control[4]	--	--	12.5	13.2	89	88	1130	1230	1.9	2.0	623	70
Flexed 1000 times over 1/8" rollers												
HA-16	9.4	5.6	13.0	11.6	65	66	2850	2700	2.1	1.5	239	--
HA-16 } AC-61	10.0 / --	-- / 2.9	11.6	9.8	68	69	2200	2030	1.9	1.4	327	--
HA-16 } P-339	9.5 / --	-- / 4.2	12.4	10.7	67	69	3440	2980	1.6	1.3	312	--
AC-61	7.3	3.4	11.3	9.7	73	68	1830	1510	1.9	1.5	300	--
P-339 } AC-61	10.0 / --	-- / 5.0	10.8	9.4	64	67	2790	2170	1.7	1.2	625	--
Control[3]	Retention aid		10.7	9.2	77	71	1530	1180	1.1	0.8	660	--
Control[4]	--	--	9.9	8.4	93	75	1260	980	1.2	0.8	678	--

[1]Sonic modulus is based on cellulose density of 1.54.
[2]W = width, L = length of flex specimens.
[3]Sheets made according to beater addition procedure but with retention aid only.
[4]Sheets made in conventional manner.

Table 7. Standard deviation[1] for data in Table 5 on the tensile properties of flexed and unflexed handsheets modified with acrylic resins by beater addition followed by saturation with acrylic resins.

Acrylic Resin: Type	Acrylic Resin: Beater Addition	Acrylic Resin: Saturation	No. of Specimens		Extensional Stiffness		Breaking Strength		Elongation to Break		Energy to Break		Load at Yield		Elongation at Yield		Plastic Stiffness	
	%	%			kg		kg		%		kg-cm		kg		%		kg	
			W[2]	L[2]	W	L	W	L	W	L	W	L	W	L	W	L	W	L
Unflexed																		
HA-16	9.4	5.6	5	6	36	62	0.7	0.5	0.2	0.3	0.1	0.2	0.4	0.4	0.05	0.06	16.6	15.9
HA-16 } AC-61 }	10.0 / --	-- / 2.9	6	6	29	71	0.3	0.3	0.1	0.3	0.1	0.3	0.2	0.6	0.07	0.2	4.7	12.9
HA-16 } P-339 }	9.5 / --	-- / 4.2	6	6	27	25	0.4	0.5	0.4	0.2	0.3	0.2	0.2	0.5	0.05	0.1	7.4	12.2
AC-61	7.3	3.4	6	6	47	44	0.3	0.4	0.4	0.3	0.3	0.2	0.2	0.3	0.1	0.1	3.3	8.4
P-339 } AC-61 }	10.0 / --	-- / 5.0	6	6	34	60	0.5	0.7	0.4	0.2	0.3	0.3	0.4	0.9	0.1	0.2	8.2	15.6
Control[3]	Retention aid		6	6	51	46	0.4	0.9	0.3	0.3	0.2	0.3	0.3	0.2	0.1	0.1	8.4	20.2
Control[4]	--	--	5	6	83	97	0.4	0.4	0.3	0.4	0.2	0.3	0.3	0.4	0.2	0.2	6.5	10.2
Flexed 1000 times over 1/8" rollers																		
HA-16	9.4	5.6	6	6	58	61	0.8	1.0	0.3	0.4	0.2	0.4	0.5	0.7	0.05	0.1	17.3	20.7
HA-16 } AC-61 }	10.0 / --	-- / 2.9	6	6	32	51	0.5	0.4	0.2	0.2	0.2	0.2	0.3	0.6	0.1	0.1	4.4	8.0
HA-16 } P-339 }	9.5 / --	-- / 4.2	6	6	33	66	0.4	0.2	0.3	0.3	0.2	0.1	0.3	0.3	0.4	0.1	7.1	11.8
AC-61	7.3	3.4	6	6	63	40	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.3	0.1	0.2	7.8	6.5
P-339 } AC-61 }	10.0 / --	-- / 5.0	6	6	31	32	0.4	0.2	0.2	0.2	0.2	0.1	0.7	0.5	0.2	0.3	10.9	8.2
Control[3]	Retention aid		6	6	32	48	0.2	0.4	0.2	0.1	0.1	0.1	0.2	0.5	0.1	0.3	3.6	17.6
Control[4]	--	--	6	6	48	34	0.5	0.6	0.4	0.4	0.2	0.3	0.5	0.3	0.1	0.2	5.8	8.1

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

[2] W = width, L = length of flex specimens

[3] Sheets made according to beater addition procedure but with retention aid only.

[4] Sheets made in conventional manner.

Table 8. Standard deviation[1] for data in Table 6 on the physical properties of flexed and unflexed wood pulp handsheets modified with acrylic resins by beater addition followed by saturation with acrylic resins.

Type	Acrylic Resin: Beater Addition	Acrylic Resin: Saturation	No. of Specimens		Sonic Modulus		Elmendorf Tear		MIT Fold Endurance		Cantilever Stiffness		Air Permeability
	%	%			$kg/cm^2 x 10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(10cm^2)$
			W[2]	L[2]	W	L	W	L	W	L	W	L	
Unflexed													
HA-16	9.4	5.6	6	6	0.7	0.7	2.7	5.1	909	826	0.3	0.3	40
HA-16 / AC-61	10.0 / --	-- / 2.9	6	6	0.3	0.7	9.3	6.4	370	758	0.2	0.2	26
HA-16 / P-339	9.5 / --	-- / 4.2	6	6	0.4	0.5	6.9	6.5	874	798	0.3	0.2	30
AC-61	7.3	3.4	6	6	0.7	1.1	4.0	12.6	337	323	0.2	0.2	25
P-339 / AC-61	10.0 / --	-- / 5.0	6	6	0.5	0.6	3.7	5.7	748	655	0.2	0.04	58
Control[3]	Retention aid		6	6	0.4	0.6	12.8	3.7	251	287	0.2	0.2	46
Control[4]	--	--	6	6	0.6	0.3	8.8	3.7	81	176	0.1	0.3	47
Flexed 1000 times over 1/8" rollers													
HA-16	9.4	5.6	6	6	0.9	0.9	8.0	4.3	572	573	0.3	0.2	51
HA-16 / AC-61	10.0 / --	-- / 2.9	6	6	0.4	0.3	4.1	5.2	415	217	0.1	0.1	23
HA-16 / P-339	9.5 / --	-- / 4.2	6	6	0.3	0.4	13.6	6.5	561	604	0.2	0.2	20
AC-61	7.3	3.4	6	6	0.2	0.4	11.1	7.8	288	415	0.3	0.1	20
P-339 / AC-61	10.0 / --	-- / 5.0	6	6	0.5	0.4	5.1	5.3	661	396	0.2	0.1	70
Control[3]	Retention aid		6	6	0.3	0.5	10.1	3.6	232	297	0.1	0.05	42
Control[4]	--	--	6	6	0.5	0.2	8.6	4.4	358	258	0.1	0.04	24

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

[2] W = width, L = length of flex specimens.
[3] Sheets made according to beater addition procedure but with retention aid only.
[4] Sheets made in conventional manner.

Table 9. Tensile properties of flexed and unflexed wood pulp handsheets treated with various acrylic resins by (1) beater addition and (2) beater addition followed by saturation of wet handsheets.

Acrylic Resin		Extensional[1] Stiffness		Breaking Strength		Elongation to Break		Energy to Break		Load at Yield		Elongation at Yield		Plastic Stiffness	
Beater Addition	Saturation	kg		kg		%		kg-cm		kg		%		kg	
		W[2]	L[2]	W	L	W	L	W	L	W	L	W	L	W	L
						Unflexed									
HA-16	--	608	629	8.9	9.3	4.5	4.6	2.5	2.7	4.5	4.4	0.8	0.8	114	126
HA-16	AC-61	678	706	10.5	10.8	4.4	3.9	2.9	2.6	4.8	4.6	0.8	0.7	156	189
HA-16	water	705	770	9.0	9.8	3.9	3.6	2.3	2.2	4.4	4.8	0.7	0.7	140	174
AC-61	--	589	602	7.5	8.0	4.0	4.1	1.9	2.1	3.6	4.0	0.7	0.7	116	120
AC-61	AC-61	652	664	9.8	9.9	4.1	3.6	2.5	2.2	4.7	4.8	0.8	0.8	152	183
AC-61	water	686	728	9.0	9.7	4.0	3.4	2.3	2.0	4.5	4.9	0.7	0.8	137	183
Retention aid	--	541	596	6.6	7.0	3.9	3.8	1.7	1.7	3.7	4.0	0.8	0.7	91	98
Retention aid	AC-61	697	723	9.6	9.8	4.1	3.6	2.5	2.2	4.7	4.8	0.7	0.8	144	177
Retention aid	water	673	712	7.9	8.5	3.8	3.4	2.0	1.9	4.4	4.8	0.7	0.8	111	140
None	none[3]	573	622	6.8	6.9	4.1	3.6	1.8	1.6	3.7	4.0	0.7	0.7	92	100
						Flexed 1000 times over 1/8" rollers									
HA-16	--	509	418	8.8	8.4	5.1	4.4	2.7	2.2	3.6	4.0	0.7	1.0	117	133
HA-16	AC-61	646	571	10.4	9.8	4.5	3.6	2.8	2.0	4.3	5.1	0.8	1.0	159	185
HA-16	water	615	539	8.9	9.1	4.2	3.5	2.4	1.8	4.2	4.8	0.8	1.0	136	172
AC-61	--	477	377	7.7	7.8	4.4	4.4	2.1	2.0	3.6	3.5	0.8	1.0	115	125
AC-61	AC-61	620	540	9.5	9.6	4.4	3.6	2.6	2.0	4.5	5.1	0.8	1.0	137	170
AC-61	water	611	529	8.2	9.0	4.0	3.3	2.1	1.7	4.1	4.9	0.7	1.0	129	177
Retention aid	--	479	290	6.5	6.3	3.9	4.1	1.6	1.5	3.5	3.5	0.8	1.3	99	101
Retention aid	AC-61	602	527	8.9	9.3	4.1	3.6	2.3	2.0	4.3	4.8	0.8	1.0	138	177
Retention aid	water	551	475	7.2	8.4	4.0	3.4	1.9	1.7	4.0	4.4	0.8	1.0	100	168
None	none[3]	453	319	6.7	6.5	3.8	4.0	1.6	1.5	3.6	3.7	0.9	1.2	103	100

[1] Initial slope of load-strain curve.
[2] W = width, L = length of flex samples.
[3] Sheets made in conventional manner.

Table 10. Physical properties of flexed and unflexed wood pulp handsheets treated with various acrylic resins by (1) beater addition and (2) beater addition followed by saturation of wet handsheets.

Acrylic Resin: Beater Addition	Acrylic Resin: Saturation	Sonic[1] Modulus kg/cm²x10⁻³ W[2]	Sonic[1] Modulus L[2]	Elmendorf Tear g W	Elmendorf Tear g L	MIT fold Endurance 1000 g double folds W	MIT fold Endurance L	Cantilever Stiffness g-cm W	Cantilever Stiffness L	Air Permeability cm³/min(10cm²)	Thickness mils	Weight per Unit Area g/m²	Weight[4] Gain %
Unflexed													
HA-16	--	12.9	13.2	77	78	2610	2190	2.1	2.2	544	5.14	74	5.7
HA-16	AC-61	14.8	15.5	62	59	3120	3110	1.8	1.9	125	4.57	76	11.5
HA-16	water	14.3	15.2	63	66	2570	2380	1.8	2.0	283	4.56	72	5.8
AC-61	--	12.4	12.8	84	83	1660	1770	2.1	2.0	631	5.05	74	6.4
AC-61	AC-61	14.3	14.3	67	66	2630	2450	1.8	2.0	220	4.75	78	12.9
AC-61	water	15.0	15.5	68	84	2260	2070	1.8	2.1	250	4.49	72	6.3
Retention aid	--	12.4	12.8	91	92	950	1250	2.0	1.8	875	4.94	69	--
Retention aid	AC-61	15.1	15.3	66	69	2220	2310	1.5	1.8	153	4.55	73	6.1
Retention aid	water	14.2	15.6	71	74	1640	1440	1.6	1.7	277	4.39	68	--
None	none[3]	12.6	13.1	89	90	1080	1150	2.1	1.7	631	4.96	70	--
Flexed 1000 times over 1/8" rollers													
HA-16	--	11.1	9.9	68	70	2420	2180	1.6	1.2	567	5.07	--	--
HA-16	AC-61	13.7	13.2	56	56	3160	2710	1.6	1.6	140	4.52	--	--
HA-16	water	13.1	12.3	57	70	2440	2040	1.5	1.2	268	4.50	--	--
AC-61	--	10.9	8.9	72	76	1470	1720	1.7	1.1	644	5.05	--	--
AC-61	AC-61	13.0	13.1	61	62	1970	2340	1.7	1.4	290	4.60	--	--
AC-61	water	12.5	12.2	64	63	1740	1730	1.5	1.1	295	4.42	--	--
Retention aid	--	10.4	7.7	90	86	990	1070	1.4	0.8	926	5.00	--	--
Retention aid	AC-61	13.3	13.2	58	63	2040	1760	1.5	1.3	172	4.35	--	--
Retention aid	water	12.0	11.9	75	77	1300	1290	1.3	0.9	321	4.31	--	--
None	none[3]	10.7	7.7	87	86	1170	1010	1.4	0.7	720	4.92	--	--

[1]Sonic modulus is based on cellulose density of 1.54.
[2]W = width, L = length of flex samples.
[3]Sheets made in conventional manner.
[4]Weight gains are based on handsheets containing retention aid only.

Table 11. Standard deviation[1] for tensile property data in Table 9 for flexed and unflexed wood pulp handsheets treated with various acrylic resins by (1) beater addition and (2) beater addition followed by saturation of wet handsheets.

Acrylic Resin: Beater Addition	Acrylic Resin: Saturation	No. of Specimens W[2]	No. of Specimens L[2]	Extensional Stiffness kg W	Extensional Stiffness kg L	Breaking Strength kg W	Breaking Strength kg L	Elongation to Break % W	Elongation to Break % L	Energy to Break kg-cm W	Energy to Break kg-cm L	Load at Yield kg W	Load at Yield kg L	Elongation at Yield % W	Elongation at Yield % L	Plastic Stiffness kg W	Plastic Stiffness kg L
Unflexed																	
HA-16	--	6	5	74.6	62.6	0.7	1.1	0.6	0.3	0.4	0.4	0.6	0.8	0.2	0.08	15.1	6.4
HA-16	AC-61	6	6	39.5	83.8	0.5	0.7	0.3	0.1	0.3	0.1	0.6	0.3	0.08	0.09	9.2	18.6
HA-16	water	6	6	41.8	35.9	0.8	0.5	0.5	0.06	0.4	0.1	0.2	0.2	0.08	0.2	4.5	10.7
AC-61	--	6	6	27.6	33.8	0.4	0.3	0.3	0.1	0.2	0.1	0.1	0.2	0.02	0.03	8.1	5.6
AC-61	AC-61	6	6	40.8	38.4	0.3	0.5	0.3	0.3	0.2	0.3	0.4	0.3	0.1	0.1	6.9	7.2
AC-61	water	6	6	43.6	50.8	0.3	0.7	0.2	0.1	0.1	0.2	0.4	0.5	0.1	0.07	11.5	10.0
Retention aid	--	6	6	18.6	33.3	0.3	0.2	0.2	0.3	0.1	0.1	0.2	0.3	0.05	0.06	7.3	8.0
Retention aid	AC-61	6	6	43.3	38.6	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.4	0.07	0.1	8.4	10.7
Retention aid	water	6	6	27.8	62.8	0.6	0.8	0.4	0.4	0.3	0.3	0.2	0.3	0.06	0.06	15.3	13.5
None	none[3]	5	5	29.5	51.5	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.2	0.05	0.06	6.3	6.3
Flexed 1000 times over 1/8" rollers																	
HA-16	--	5	6	53.3	46.4	0.1	0.4	0.3	0.3	0.1	0.2	0.5	0.3	0.2	0.2	9.3	13.9
HA-16	AC-61	6	6	38.8	49.0	0.3	0.7	0.2	0.3	0.2	0.3	0.3	0.5	0.09	0.2	4.0	11.3
HA-16	water	5	6	18.6	33.1	0.4	0.6	0.1	0.3	0.2	0.3	0.3	0.4	0.05	0.1	8.4	11.9
AC-61	--	6	6	48.3	26.4	0.4	0.5	0.1	0.3	0.1	0.3	0.2	0.4	0.09	0.1	11.3	16.8
AC-61	AC-61	6	6	35.8	66.8	0.2	0.4	0.2	0.2	0.1	0.2	0.4	0.5	0.08	0.2	12.6	19.8
AC-61	water	6	6	67.1	65.0	0.7	0.3	0.4	0.2	0.4	0.2	0.3	0.4	0.03	0.2	5.3	27.0
Retention aid	--	6	6	25.1	36.9	0.3	0.5	0.2	0.5	0.1	0.3	0.3	0.3	0.07	0.2	11.5	10.0
Retention aid	AC-61	6	6	43.2	43.1	0.6	0.2	0.3	0.2	0.3	0.2	0.3	0.3	0.1	0.1	15.6	12.1
Retention aid	water	5	6	65.6	72.8	0.9	0.4	0.3	0.3	0.4	0.2	0.5	0.5	0.5	0.3	11.2	10.0
None	none[3]	6	6	38.6	29.8	0.3	0.5	0.2	0.3	0.1	0.2	0.2	0.2	0.06	0.1	9.5	4.8

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

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

[3] Sheets made in conventional manner.

Table 12. Standard deviation[1] for physical property data in Table 10 for flexed and unflexed wood pulp handsheets treated with various acrylic resins by (1) beater addition and (2) beater addition followed by saturation of wet handsheets.

Acrylic Resin: Beater Addition	Acrylic Resin: Saturation	No. of Specimens W[2]	No. of Specimens L[2]	Sonic Modulus $kg/cm^2 x10^{-3}$ W	Sonic Modulus L	Elmendorf Tear g W	Elmendorf Tear g L	MIT Fold Endurance 1000 g double folds W	MIT Fold Endurance L	Cantilever Stiffness g-cm W	Cantilever Stiffness L	Air Permeability $cm^3/min(10cm^2)$	Thickness mils	Total Weight Gain %
Unflexed														
HA-16	--	6	6	0.5	0.9	8.4	7.8	523	322	0.2	0.05	57.3	0.10	1.4
HA-16	AC-61	6	6	0.5	1.2	3.1	4.8	635	414	0.1	0.2	14.7	0.13	3.0
HA-16	water	6	6	0.4	0.5	4.2	6.7	577	380	0.1	0.2	38.3	0.12	2.7
AC-61	--	6	6	0.6	0.5	10.3	12.6	269	228	0.1	0.1	46.9	0.12	1.3
AC-61	AC-61	6	6	0.3	0.6	7.0	11.3	435	378	0.2	0.1	23.7	0.06	1.6
AC-61	water	6	6	0.7	0.6	6.7	21.1	149	321	0.1	0.1	31.0	0.10	1.6
Retention aid	--	6	6	0.4	0.4	13.2	13.3	213	88	0.1	0.2	26.4	0.07	--
Retention aid	AC-61	6	6	0.5	0.7	7.2	10.5	228	263	0.2	0.1	23.9	0.11	2.8
Retention aid	water	6	6	0.8	0.6	8.4	12.4	217	389	0.2	0.2	33.0	0.10	--
None	none[3]	6	6	0.7	0.3	9.6	6.1	264	189	0.1	0.2	38.9	0.11	--
Flexed 1000 times over 1/8" rollers														
HA-16	--	6	6	0.3	0.4	4.3	7.1	431	223	0.2	0.09	60.9	--	--
HA-16	AC-61	6	6	0.4	0.6	12.1	6.6	448	415	0.2	0.1	15.0	--	--
HA-16	water	6	6	0.7	0.4	2.5	10.2	743	639	0.2	0.08	12.9	--	--
AC-61	--	6	6	0.3	0.2	7.6	9.5	232	397	0.3	0.08	45.0	--	--
AC-61	AC-61	6	6	0.5	0.6	3.8	4.6	317	628	0.2	0.08	43.2	--	--
AC-61	water	6	6	0.3	0.6	4.5	9.5	231	379	0.2	0.10	33.0	--	--
Retention aid	--	6	6	0.4	0.4	9.9	14.4	227	303	0.09	0.06	28.2	--	--
Retention aid	AC-61	6	6	0.7	0.6	3.7	4.6	242	300	0.09	0.1	18.4	--	--
Retention aid	water	6	6	0.6	0.5	5.1	13.7	253	221	0.2	0.06	48.4	--	--
None	none[3]	6	6	0.7	0.2	10.4	9.4	282	254	0.1	0.08	40.0	--	--

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

[2] W = width, L = length of flex specimens.
[3] Sheets made in conventional manner.

Table 13. The effect of wet pressing on the tensile properties of wood pulp handsheets.

Pressing Pressure		Extensional Stiffness[1]		Initial Modulus		Breaking Strength		Elongation to Break		Energy to Break		Yield Load		Elongation at Yield		Plastic Stiffness	
Wire	Felt	kg		$kg/cm^2 x10^{-3}$		kg		%		kg-cm		kg		%		kg	
		W[2]	L[2]	W	L	W	L	W	L	W	L	W	L	W	L	W	L
Unflexed																	
Low[3]	--	563	547	25.4	24.4	6.1	6.2	3.2	3.2	1.3	1.3	4.2	4.1	0.8	0.9	79	92
Low	Low	658	665	34.9	33.9	7.1	7.1	3.3	3.1	1.6	1.5	4.4	4.4	0.8	0.8	107	115
Low	High[4]	685	693	39.6	38.7	7.9	8.1	3.8	3.3	2.0	1.7	4.4	4.6	0.7	0.8	114	134
High	--	653	659	34.0	34.0	7.2	7.3	3.2	3.3	1.6	1.6	4.3	4.3	0.7	0.7	117	114
High	Low	654	700	37.5	38.6	7.6	7.6	3.7	3.4	1.9	1.7	4.1	4.4	0.7	0.7	114	123
High	High	696	724	41.1	42.0	7.7	8.2	3.6	3.4	1.8	1.8	4.2	4.7	0.7	0.8	118	129
Flexed 1000 times over 1/8" rollers																	
Low	--	468	205	21.6	9.2	5.7	5.5	3.2	3.9	1.2	1.9	3.7	3.9	0.9	2.1	91	88
Low	Low	494	288	25.8	14.8	6.2	6.3	3.3	3.7	1.3	1.4	3.8	4.2	0.8	1.5	97	96
Low	High	540	376	30.6	21.6	6.7	7.3	3.9	3.7	1.7	1.6	3.7	4.7	0.8	1.3	96	109
High	--	518	319	27.5	16.7	6.7	6.5	3.4	3.7	1.5	1.4	4.1	4.2	0.8	1.4	103	100
High	Low	526	365	29.6	20.5	6.6	6.8	3.7	3.5	1.6	1.4	3.7	4.4	0.8	1.3	98	109
High	High	570	396	33.0	23.3	7.0	7.4	3.9	3.5	1.8	1.5	3.5	4.4	0.7	1.2	108	134

[1]Initial slope of load-strain curve.
[2]W = width, L = length of flex specimens.
[3]Minimum force possible on calender rolls.
[4]Maximum force possible on calender rolls.

Table 14. The effect of wet pressing on the physical properties of wood pulp handsheets

Pressing Pressure		Sonic[1] Modulus		Elmendorf Tear		MIT Fold Endurance		Cantilever Stiffness		Air Permeability	Weight per Unit Area	Thickness
Wire	Felt	$kg/cm^2 x10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(10cm^2)$	g/m^2	mils
		W[2]	L[2]	W	L	W	L	W	L			
Unflexed												
Low[3]	--	12.2	12.6	99	102	1000	900	2.9	2.8	1887	69	5.84
Low	Low	14.3	14.2	94	90	960	1160	2.6	2.4	1045	69	5.04
Low	High[4]	14.6	15.4	80	82	1410	1220	1.9	2.0	451	69	4.62
High	--	14.0	13.8	88	86	1210	1550	2.2	2.1	644	70	5.06
High	Low	14.1	14.9	96	85	1080	1250	2.1	2.1	604	69	4.70
High	High	14.4	15.8	90	80	1450	1530	1.8	1.8	304	69	4.50
Flexed 1000 times over 1/8" rollers												
Low	--	10.4	5.3	97	82	980	590	1.8	0.7	1915	--	5.74
Low	Low	11.3	6.8	87	84	930	930	1.7	0.7	1124	--	5.07
Low	High	11.2	9.0	70	77	1120	890	1.3	0.8	548	--	4.60
High	--	11.6	7.7	77	74	1080	1210	1.4	0.8	732	--	4.97
High	Low	11.4	8.6	79	77	1100	1090	1.3	0.8	677	--	4.67
High	High	11.7	10.1	71	78	1520	1250	1.3	0.9	342	--	4.49

[1]Sonic modulus based on cellulose density of 1.54.
[2]W = width, L - length of flex specimens.
[3]Minimum force possible on calender rolls.
[4]Maximum force possible on calender rolls.

Table 15. Standard deviation[1] of data in Table 13 on the tensile properties of wood pulp handsheets.

Pressing Pressure		Extensional Stiffness		Initial Modulus		Breaking Strength		Elongation to Break		Energy to Break		Yield Load		Elongation at Yield		Plastic Stiffness	
Wire	Felt	kg		$kg/cm^2 x10^{-3}$		kg		%		kg-cm		kg		%		kg	
		W[2]	L[2]	W	L	W	L	W	L	W	L	W	L	W	L	W	L
Unflexed																	
Low	--	57.9	29.0	2.8	1.5	0.4	0.5	0.2	0.2	0.1	0.2	0.5	0.4	0.1	0.1	17.3	7.1
Low	Low	31.8	30.8	1.7	2.3	0.2	0.5	0.3	0.3	0.2	0.2	0.2	0.2	0.04	0.03	8.1	18.6
Low	High	35.7	31.0	2.5	1.9	0.5	0.4	0.3	0.2	0.3	0.1	0.1	0.2	0.1	0.1	8.7	12.6
High	--	48.3	44.9	2.4	2.0	0.3	0.5	0.4	0.4	0.2	0.2	0.3	0.1	0.1	0.1	9.5	10.2
High	Low	38.4	27.6	2.4	1.7	0.2	0.3	0.1	0.2	0.1	0.1	0.2	0.3	0.1	0.1	4.9	4.2
High	High	57.5	22.3	3.5	2.4	0.7	0.5	0.3	0.3	0.3	0.2	0.3	0.4	0.1	0.1	6.5	7.5
Flexed 1000 times over 1/8" rollers																	
Low	--	23.8	20.3	1.7	0.9	0.4	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.04	0.4	11.3	16.0
Low	Low	32.8	24.9	1.9	1.4	0.4	0.4	0.3	0.2	0.2	0.1	0.5	0.4	0.1	0.2	11.9	12.6
Low	High	43.4	34.5	1.9	2.1	0.5	0.3	0.3	0.1	0.2	0.1	0.3	0.5	0.1	0.2	10.1	11.7
High	--	45.0	35.7	2.1	2.0	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.6	0.1	0.4	13.7	8.2
High	Low	41.9	18.3	2.0	1.0	0.3	0.4	0.2	0.2	0.1	0.1	0.4	0.4	0.1	0.1	9.8	11.9
High	High	69.0	32.6	3.8	2.0	0.7	0.3	0.3	0.1	0.3	0.1	0.3	0.4	0.1	0.2	9.3	12.2

[1] $s = \sqrt{\frac{n\Sigma(X)^2 - (\Sigma X)^2}{n(n-1)}}$ where n = 6

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

Table 16. Standard deviation[1] of data in Table 14 on the physical properties of wood pulp handsheets.

Pressing Pressure		Sonic Modulus		Elmendorf Tear		MIT Fold Endurance		Cantilever Stiffness		Air Permeability	Thickness
Wire	Felt	$kg/cm^2 x 10^{-3}$		g		1000 g double folds		g-cm		$cm^3/min(cm^2)$	mils
		W[2]	L[2]	W	L	W	L	W	L		
						Unflexed					
Low	--	0.4	0.9	9.2	11.2	319	128	0.2	0.3	117	0.18
Low	Low	0.4	0.6	3.9	11.8	152	187	0.1	0.2	47	0.12
Low	High	0.6	0.6	8.2	8.6	263	304	0.1	0.1	42	0.10
High	--	0.4	0.9	10.5	10.0	333	318	0.2	0.1	82	0.10
High	Low	0.5	0.4	8.9	4.0	197	285	0.2	0.2	34	0.05
High	High	0.4	0.8	17.3	10.6	406	401	0.1	0.2	17	0.12
				Flexed 1000 times over 1/8" rollers							
Low	--	0.3	0.3	13.6	4.3	288	200	0.1	0.02	127	0.16
Low	Low	0.4	0.3	7.2	9.3	253	234	0.2	0.05	43	0.11
Low	High	0.6	0.3	8.0	6.9	255	283	0.2	0.1	38	0.09
High	--	0.9	0.3	8.2	5.3	568	305	0.2	0.06	63	0.09
High	Low	0.3	0.4	7.3	7.7	195	337	0.2	0.06	30	0.10
High	High	0.5	0.5	7.5	4.6	396	500	0.1	0.1	15	0.11

[1] $s = \sqrt{\frac{n\Sigma(X)^2 - (\Sigma X)^2}{n(n-1)}}$ where n = 6.

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

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM.
BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO.
NBSIR 74-431

2. Gov't Accession No.

3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Evaluation of Currency and Stamp Papers
July 1 - December 31, 1973

5. Publication Date
2/7/74

6. Performing Organization Code

7. AUTHOR(S)
E. L. Graminski and E. E. Toth

8. Performing Organ. Report No.
NBSIR 74-431

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.
3000443

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Bureau of Engraving and Printing
U.S. Department of the Treasury
Washington, D.C. 20401

13. Type of Report & Period Covered
Progress, 7/1 - 12/31/73

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

As part of a continuing study for the Bureau of Engraving and Printing of the U.S. Department of the Treasury, the effect of acrylic resins on the structure of handsheets and the possibility of improving the stiffness retention of paper with acrylic resins was studied. It was shown that certain acrylic resins affect the structure of paper, apparently by causing the fibrils and cell wall debris to precipitate onto the fiber shafts, resulting in a marked decrease in the material which normally is found in the interstices of the fiber network of paper. It appears that superior stiffness retention of paper can be effected by treating papermaking fibers, while still suspended in water, with acrylics, forming the sheet, and then treating the dry formed sheet by a saturation technique with a second acrylic resin. Finally, the structure of paper is significantly affected by the technique used in pressing the wet sheet. It appears that consolidation of the sheet on the forming screen should be done at minimum pressure, removed from the wire, and pressed a second time between felts.

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 resins; paper; paper durability; paper structure; stiffness retention.

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19. SECURITY CLASS (THIS REPORT)
UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE)
UNCLASSIFIED

21. NO. OF PAGES
36

22. Price