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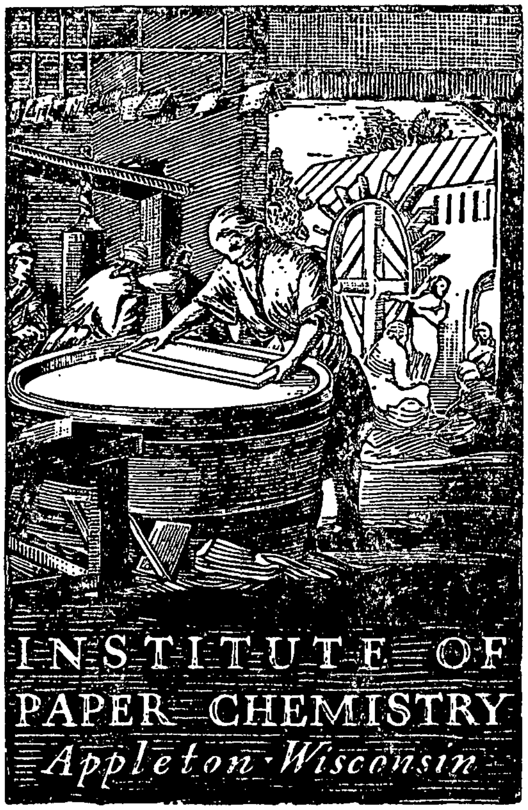

EFFECT OF CYCLIC EXPOSURE TO HIGH RELATIVE HUMIDITIES ON THE TENSILE PROPERTIES OF SACK PAPER

Project 2033

Report Seventeen

A Progress Report

to

MULTIWALL SHIPPING SACK PAPER MANUFACTURERS

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EFFECT OF CYCLIC EXPOSURE TO HIGH RELATIVE HUMIDITIES ON THE TENSILE PROPERTIES OF SACK PAPER

SUMMARY

During the drying of machine-made paper, its normal tendency to shrink as the moisture content decreases is often inhibited to a substantial degree by the tensions applied during drying. The net result is that the sheet emerging from the machine may possess "frozen" or "locked-in" strains. When substantial "locked-in" strains are present in a sheet, it has been demonstrated that such strains may be relieved in part if the sheet is rewet or exposed to high relative humidities and then redried under no tension. It was felt that the mechanical properties of the sheet--in particular the stretch and tensile energy absorption (TEA)--would also exhibit a similar response.

To determine the presence and magnitude of the effect, the tensile properties of ten samples of sack paper from the 1958 fabrication run were evaluated after

a. Normal preconditioning at less than 35% R.H. and conditioning at 50% R.H. and 73°F.

b. One cycle of exposure to 90-97% R.H. followed by normal preconditioning and conditioning.

In general, the following conclusions may be drawn from the work:

1. A single cycle of exposure to high humidity had little or no effect on the maximum tensile load in either direction.

2. A single cycle of exposure to high humidity caused appreciable increases in stretch and TEA for a number of the samples. On the average the

samples exhibited about a 20% increase in stretch or TEA in the machine direction. In the cross direction, the average increases were about 19% for stretch and 14% for TEA.

The above results indicate that in so far as energy absorption is concerned most of the sack papers are not utilizing fully the potential energy absorption capacity due to the varying degrees of locked-in stresses which decrease the available stretch. It may be that conditioning of the paper prior to sack manufacture will enhance its energy absorption capacity and, hence, the fatigue life of a sack made therefrom.

INTRODUCTION

In a drop test, the sack and contents possess kinetic energy due to their velocity at the moment of impact. During impact the system decelerates to zero velocity; as a consequence, the energy in the system is dissipated in several ways. Simply stated, the energy is dissipated in the form of heat and deformation of the contents and the strain energy associated with distention of the sack paper as a portion of the contents "explodes" outward against the sack walls. If the strain energy developed in the sack paper is greater than the paper can sustain, the paper would be expected to fail. Thus, in many respects the walls of a sack behave qualitatively like the walls of a balloon which suggests that the membrane tensile strains induced in the walls determine its performance.

The simplified concept expanded to include the effects of "fatigue" and the biaxial strain field which is presumed to exist at each point in the walls of the sack during impact underlies much past and current research work in the sack field. Qualitatively, the concept appears to explain the correlation which appears to exist between drop test performance and sack paper measurements of the energy absorption or fatigue types.

This latter fact has focussed much attention on the energy absorption characteristics of sack paper in its "virgin" state and as affected by cyclic loading, atmospheric conditions, etc. This interest also provided the motivation and justification for the study described herein.

The present study was prompted by the observation that in certain instances an increase in the tensile energy absorption characteristics may be obtained after paper has been exposed to high humidity for a period and then reconditioned to standard test conditions from the absorption side. For example, Wink (1), using a number of different types of papers, found that exposure to excursions of high relative humidity introduced irreversible effects which materially changed some of the properties of the paper. The effect is attributable to the swelling and shrinking of the fibers and with the relaxation of dried-in or built-in stresses; the major effect occurs on the first exposure of the paper to a high relative humidity. The properties which were found to be altered were gloss, smoothness, dimensions, tensile strength, stretch, tensile energy or tensile work, and zero-span tensile. The dimensional change appeared to be inversely proportional to the changes in stretch. In general, the tensile strength remains sensibly unchanged and the stretch and tensile work increased. The change in stretch and tensile work was irrespective of the principal direction, although, on the one kraft sample used, the change was greater in the machine direction.

Smith (2) has studied the development of strains during drying and terms as dried-in strain the difference between potential shrinkage (dried without tension) and the actual shrinkage that becomes apparent later in the form of shrinkage when the paper is dried tension free after moistening. Brecht (3) suggests that the tension during drying blocks shrinkage thus causing elastic deformations, which are retained in the finished paper by considerable forces. If the paper takes up moisture, it expands to an extent that corresponds to free (unlocked) shrinkage. If moistening and drying are repeated, the latter without tension, the elastic deformation diminishes in the sequence of cycles, and free shrinking increases so that the sheet shortens. Where this phenomenon occurs, it is apparently caused by the relaxation of strains which are "frozen" into the sheet during manufacture. Among the production factors which may contribute are high speed, high drier and winder tension, as well as overdrying.

During drying the wet paper web attempts to shrink; however, the tendency of machine-dried papers to shrink is inhibited to a large degree in the machine direction because of the tension applied to the sheet to draw it through the machine. In the cross direction, shrinkage restraint also occurs as the cross-direction properties of the paper web vary considerably from the edge to the center (4). A general summary of the several affects associated with drying may be found in Reference (5).

In general, the effects of the restraints during drying are to significantly affect the anisotropy of the sheet as measured by tensile or stretch or other tests. Rance (6) notes that the distortions during drying are "liable to manifest themselves if the paper is subjected to tension and this is the direct link between the hygroscopic and mechanical properties of the sheets." The cited reference develops the further argument that when a sheet originally dried under tension is rewetted and dried under no restraint, some part of the effect of the original tension may be undone. Thus, fibers originally deformed during drying should assume, after rewetting, a shape which approaches in part the shape they would have assumed had no tension been originally applied. This was borne out by hygroexpansivity measurements on sheets cycled between 5 and 95% R.H.

The above indicates that restraints during drying may be effective in producing a sheet with substantial locked in or "frozen" stresses. The action of rewetting or exposure to high humidity followed by subsequent unrestrained drying permits a redistribution of the stresses in the sheet and may be expected to affect not only the hygroexpansivity but also the mechanical properties--in particular, stretch or tensile energy absorption of the sheet.

Since stretch or tensile energy absorption appears to be important to sack performance, it was thought desirable to undertake a limited investigation for the purpose of determining the magnitude of the effect of high humidity cycling on the tensile energy absorption characteristics for currently manufactured sack papers. The results of such an investigation are summarized herein.

MATERIALS

For the study, pasted sacks from the fabrication run of 1958 were selected (7). The following runs were evaluated: C, F, H, I, J, K, M, O, P, and R. All specimens were cut from the outer ply.

PROCEDURES

PHASE I. EFFECT OF ONE CYCLE OF EXPOSURE TO HIGH HUMIDITY

To serve as a guard against the introduction of spurious effects the work was performed in two parts or trials. The procedure described below was used for each trial.

A. From each of four sacks per run, two tensile specimens were cut from the outer ply.

B. The specimens from each run were divided into two parts and half the specimens were conditioned as in (1) below and the other half as in (2) below.

   (1) 24 hours at less than 35% R.H. and 73°F. followed by at least 48 hours conditioning at 50% R.H. and 73°F.

   (2) At least 72 hours at 90-97% R.H. and 73°F. followed by the preconditioning and conditioning schedule noted in (1) above.

C. After both groups of specimens were conditioned to 50% R.H., tensile load elongation curves were obtained using the following test conditions: span, 10 inches; width, 1 inch; and test rate, 1 inch per minute. Specimens were tested alternatively from the (1) and (2) groups.

D. The results were reported in the following units: tensile, lb./in.; stretch, % and tensile energy absorption (TEA), ft. lb./sq. ft. of face area. Composite results for the two trials are described in the main body of the report. The results for the separate trials are tabulated in the appendix.

PHASE 2. EFFECT OF TWO CYCLES OF EXPOSURE TO HIGH HUMIDITY

As a limited check of the effect of additional cycles of exposure to high humidity, material from Run R was evaluated after

(a) normal conditioning (see B-1 above)

(b) after 1 cycle of high humidity exposure (see B-2 above)

(c) after 2 cycles of high humidity exposure--each cycle defined as in B-2 above.

The procedure described above for Phase 1 was used with the exception that (a) two trials were not performed, and (b) the number of specimens per condition was increased from 4 to 8 to correspond with the total number evaluated in Phase 1.

DISCUSSION OF RESULTS

The average results from the two trials are summarized in Tables I and II for the machine and cross-machine directions, respectively. (Note: the results obtained in each trial are tabulated in Appendix A.) When the machine-direction results in Table I are examined, it may be noted that the one cycle exposure to high humidity had little or no effect on the maximum tensile strength of any of the samples. This is in keeping with the results reported by Wink (1). In contrast, cyclic exposure to high humidity increased both the stretch and tensile energy absorption (TEA) by about 20% on the average. It may also be noted that equal effects were not exhibited by all samples. For example, in terms of TEA, Sample K exhibited the greatest increase (33.8%), Samples F, H, J, M, O, and R exhibited increases of from 19 to 26%, and Samples C, I, and P exhibited small increases of about 6 to 12%. Inasmuch as the samples were manufactured by different mills, it is quite likely that the different stock preparation and machine conditions would produce different degrees of shrinkage restraint during drying, etc. As a result, the effect of a cyclic exposure to high humidity would be expected to vary from sample to sample.

The cross-machine results tabulated in Table II show the same trends, i.e., no change in maximum load but increases in stretch or TEA. In the cross direction, however, fewer of the samples exhibited appreciable increases in stretch or TEA; in fact, the differences for Samples C, J, K, M, O, and P are probably not statistically significant. This may not be unexpected as the degree of shrinkage restraint during drying would be expected to be less in the cross direction for the paper machines employed.

TABLE I

EFFECT OF MOISTURE CYCLING ON MACHINE DIRECTION TENSILE PROPERTIES

Run	Load, lb./in.			Stretch, %			Tensile Energy Absorption, ft. lb./ft.^{2}		
	Control	Cycled to 90-97% R.H.	Diff., %[a]	Control	Cycled to 90-97% R.H.	Diff., %[a]	Control	Cycled to 90-97% R.H.	Diff., %[a]
C	37.6	36.8	-2.1	1.7	2.0	+17.6	4.80	5.38	+12.1
F	31.4	31.8	+1.3	1.6	2.0	+25.0	3.94	4.68	+18.8
H	28.1	28.4	+1.1	1.6	1.9	+18.8	3.40	4.23	+24.4
I	28.0	27.4	-2.1	1.2	1.4	+16.7	2.57	2.84	+10.5
J	30.6	31.6	+3.3	1.2	1.5	+25.0	2.78	3.40	+22.3
K	33.9	35.6	+5.0	1.6	2.0	+25.0	4.08	5.46	+33.8
M	31.6	31.8	+0.6	1.6	2.0	+25.0	3.96	4.84	+22.2
O	33.0	33.6	+1.8	1.6	1.9	+18.8	3.96	4.79	+21.0
P	33.6	32.4	-3.6	1.4	1.6	+14.3	3.65	3.89	+ 6.6
R	32.8	34.0	+3.7	1.6	2.0	+25.0	4.04	5.07	+25.5
Average	32.1	32.3	+0.6	1.5	1.8	+20.0	3.72	4.46	+19.9

[a] Based on Control as reference.

TABLE II

EFFECT OF MOISTURE CYCLING ON CROSS DIRECTION TENSILE PROPERTIES

	Load, lb./in.			Stretch, %			Tensile Energy Absorption, ft. lb./ft.^{2}		
Run	Control	Cycled to 90-97% R.H.	Diff., %[a]	Control	Cycled to 90-97% R.H.	Diff., %[a]	Control	Cycled to 90-97% R.H.	Diff., %[a]
C	19.0	18.4	-3.2	3.6	4.2	+16.7	6.12	6.84	+11.8
F	18.5	18.0	-2.7	3.0	3.6	+20.0	4.94	5.75	+16.4
H	17.1	18.4	+7.6	4.0	5.2	+30.0	6.03	8.20	+36.0
I	21.8	22.5	+3.2	2.2	2.8	+27.3	3.92	5.15	+31.4
J	21.4	23.0	+7.5	3.2	3.6	+12.5	6.04	6.72	+11.3
K	19.7	19.2	-2.5	3.8	4.0	+ 5.3	6.43	6.58	+ 2.3
M	21.6	21.1	-2.3	3.6	4.0	+11.1	6.75	6.98	+ 3.4
O	17.2	16.5	-4.1	2.0	2.3	+15.0	2.88	3.05	+ 5.9
P	16.4	16.2	-1.2	3.6	4.0	+11.1	5.26	5.54	+ 5.3
R	19.6	19.6	0.0	2.4	2.9	+20.8	4.06	4.83	+19.0
Average	19.2	19.3	-0.5	3.1	3.7	+19.4	5.24	5.96	+13.7

[a]Based on Control as reference.

The samples showing the greater increases in TEA for the machine and cross directions are summarized below:

Machine Direction	Cross Direction
F	F
H	H
J	I
K	R
M	
O	
R	

While duplications exist, it is evident that equal percentage effects of cyclic exposure to high humidity are not necessarily obtained in the two principal directions.

The above measurements relate to the "virgin" strength of the samples employed. It would be anticipated, however, that their "fatigue" performances in cyclic tensile tests or sack drop tests would follow the same trends.

As mentioned previously, a limited series of tests were performed with one of the samples to determine if an additional cycle of high humidity performance would produce any further significant change. The results obtained are tabulated in Table III and appear to indicate that a single exposure to high humidity produces the major change.

To summarize briefly, the results of the study indicate that just as a sheet may exhibit hygroinstability due to frozen or locked in stresses during manufacture, its mechanical properties such as stretch and TEA are similarly affected. In particular, significant increases in the stretch or TEA of sack paper may be obtained by exposing the sheet to high humidity followed by reconditioning.

TABLE III

EFFECT OF TWO CYCLE EXPOSURES TO HIGH HUMIDITY ON TENSILE PROPERTIES

	Control	One Cycle to 90-97% R.H.	Diff., %[a]	Two Cycles to 90-97% R.H.	Diff., %[a]
Machine Direction					
Tensile, lb./in.	33.8	32.9	- 2.7	31.8	- 5.9
Stretch, %	1.6	1.9	+18.8	2.0	+25.0
Tensile energy absorption, ft. lb./ft.^{2}	4.28	4.81	+12.4	4.88	+14.0
Cross Machine Direction					
Tensile, lb./in.	19.0	19.2	+ 1.1	18.5	- 2.6
Stretch, %	2.3	3.0	+30.4	2.7	+17.4
Tensile energy absorption, ft. lb./ft.^{2}	3.83	4.87	+27.2	4.44	+15.9

[a]Based on Control as reference.

It is evident that this phenomena must be considered in intralaboratory comparisons of stretch or TEA measurements. More importantly, the phenomena directs attention to

a. the effect of paper machine and other variables which may affect the state of stress in the sheet as it is manufactured, and

b. the possibility of utilizing the effect by modifications in present manufacturing operations to gain increases in sack performance.

LITERATURE CITED

1. Wink, W. A. The effect of relative humidity and temperature on paper properties. Paper presented at the 11th TAPPI Testing Conference, Grand Rapids, Mich., Sept., 27-29, 1960.

2. Smith, S. F., Paper Maker 119, no. 3:185(1950).

3. Brecht, W. Beating and hygrostability of paper. In Fundamentals of papermaking fibres. Surrey, England, Technical Section of the British Paper and Board Makers Association, 1958.

4. Steenberg, B. Paper as a viscoelastic body. I. General survey. Svensk Papperstidn. 40: no. 6:127-40 (March 31, 1947).

5. Meridith, R. Mechanical properties of wood and paper. Amsterdam, North Holland Publishing Co., 1953.

6. Rance, H. F. Effect of water removal on sheet properties. Tappi 37, no. 12:640-53(Dec., 1954).

7. The Institute of Paper Chemistry. A study of multiwall sack performance. Part 1: Relationship between sack performance and sack paper properties. Project 2033, Progress Report 12 to Multiwall Shipping Sack Paper Manufacturers. Feb. 8, 1960.

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APPENDIX A

TENSILE RESULTS FOR INDIVIDUAL TRIALS

TABLE A-1

EFFECT OF MOISTURE CYCLING ON MACHINE DIRECTION TENSILE

Code	Control			Cycled to 90-97% R.H.			Diff., %[a]
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	
C	37.2	38.0	37.6	35.1	38.5	36.8	-2.1
F	30.4	32.4	31.4	32.0	31.6	31.8	+1.3
H	28.2	28.0	28.1	29.5	27.4	28.4	+1.1
I	27.8	28.1	28.0	26.3	28.4	27.4	-2.1
J	29.9	31.2	30.6	31.4	31.7	31.6	+3.3
K	32.8	35.0	33.9	34.0	37.2	35.6	+5.0
M	32.2	31.0	31.6	31.0	32.6	31.8	+0.6
O	32.3	33.8	33.0	33.4	33.8	33.6	+1.8
P	32.5	34.8	33.6	32.5	32.2	32.4	-3.6
R	33.2	32.3	32.8	35.2	32.7	34.0	+3.7
Composite			32.1			32.3	+0.6

[a]Based on Control as reference.

TABLE A-2

EFFECT OF MOISTURE CYCLING ON MACHINE DIRECTION STRETCH

Code	Control			Cycled to 90-97% R.H.			Diff., %[a]
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	
C	1.8	1.6	1.7	1.9	2.1	2.0	+17.6
F	1.7	1.6	1.6	1.9	2.0	2.0	+25.0
H	1.5	1.6	1.6	2.0	1.8	1.9	+18.8
I	1.2	1.2	1.2	1.4	1.4	1.4	+16.7
J	1.2	1.2	1.2	1.4	1.6	1.5	+25.0
K	1.6	1.6	1.6	2.0	2.0	2.0	+25.0
M	1.7	1.5	1.6	2.0	2.0	2.0	+25.0
O	1.5	1.6	1.6	1.9	1.9	1.9	+18.8
P	1.4	1.3	1.4	1.6	1.7	1.6	+14.3
R	1.6	1.6	1.6	2.0	2.0	2.0	+25.0
Composite			1.5			1.8	+20.0

[a]Based on Control as reference.

TABLE A-3

EFFECT OF MOISTURE CYCLING ON MACHINE DIRECTION TENSILE ENERGY ABSORPTION

Code	Control			Cycled to 90-97% R.H.			Diff., %[a]
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	
C	5.04	4.56	4.80	4.70	6.05	5.38	+12.1
F	3.88	4.00	3.94	4.68	4.69	4.68	+18.8
H	3.34	3.46	3.40	4.48	3.98	4.23	+24.4
I	2.52	2.62	2.57	2.63	3.06	2.84	+10.5
J	2.80	2.77	2.78	3.07	3.73	3.40	+22.3
K	3.91	4.26	4.08	5.16	5.76	5.46	+33.8
M	4.24	3.67	3.96	4.69	4.98	4.84	+22.2
O	3.72	4.19	3.96	4.80	4.78	4.79	+21.0
P	3.41	3.89	3.65	3.83	3.95	3.89	+ 6.6
R	4.01	4.06	4.04	5.44	4.70	5.07	+25.5
Composite			3.72			4.46	+19.9

[a] Based on Control as reference.

TABLE A-4

EFFECT OF MOISTURE CYCLING ON CROSS-MACHINE TENSILE

Code	Control			Cycled to 90-97% R.H.			Diff., %[a]
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	
C	18.3	19.6	19.0	17.8	19.1	18.4	-3.2
F	19.0	18.0	18.5	17.7	18.4	18.0	-2.7
H	18.2	16.0	17.1	19.2	17.5	18.4	+7.6
I	21.9	21.7	21.8	22.0	23.0	22.5	+3.2
J	20.8	22.0	21.4	23.6	22.4	23.0	+7.5
K	18.8	20.6	19.7	18.6	19.8	19.2	-2.5
M	21.6	21.6	21.6	20.7	21.5	21.1	-2.3
O	17.0	17.5	17.2	16.4	16.6	16.5	-4.1
P	16.3	16.6	16.4	16.3	16.0	16.2	-1.2
R	19.2	20.0	19.6	20.6	18.6	19.6	0.0
Composite			19.2			19.3	-0.5

[a] Based on Control as reference.

TABLE A-5

EFFECT OF MOISTURE CYCLING ON CROSS-MACHINE STRETCH

Code	Stretch, %						
	Control			Cycled to 90-97% R.H.			
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	Diff., %[a]
C	3.4	3.8	3.6	4.1	4.4	4.2	+16.7
F	3.4	2.7	3.0	3.7	3.6	3.6	+20.0
H	4.1	3.8	4.0	4.7	5.6	5.2	+30.0
I	2.1	2.2	2.2	2.6	3.0	2.8	+27.3
J	3.3	3.0	3.2	3.7	3.6	3.6	+12.5
K	3.4	4.1	3.8	3.7	4.3	4.0	+ 5.3
M	3.8	3.4	3.6	4.0	3.9	4.0	+11.1
O	2.1	2.0	2.0	2.3	2.3	2.3	+15.0
P	3.8	3.5	3.6	4.1	3.8	4.0	+11.1
R	2.3	2.5	2.4	3.0	2.8	2.9	+20.8
Composite			3.1			3.7	+19.4

[a]Based on Control as reference.

TABLE A-6

EFFECT OF MOISTURE CYCLING ON CROSS-MACHINE TENSILE ENERGY ABSORPTION

	Tensile Energy Absorption, ft. lb./ft.^{2}						
	Control			Cycled to 90-97% R.H.			
Code	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	Diff., %[a]
C	5.54	6.70	6.12	6.32	7.37	6.84	+11.8
F	5.64	4.25	4.94	5.68	5.82	5.75	+16.4
H	6.50	5.56	6.03	7.61	8.78	8.20	+36.0
I	3.90	3.94	3.92	4.73	5.57	5.15	+31.4
J	5.72	6.36	6.04	6.83	6.62	6.72	+11.3
K	5.52	7.34	6.43	5.95	7.21	6.58	+ 2.3
M	7.07	6.43	6.75	6.89	7.06	6.98	+ 3.4
O	2.92	2.84	2.88	2.98	3.12	3.05	+ 5.9
P	5.30	5.23	5.26	5.76	5.33	5.54	+ 5.3
R	3.76	4.37	4.06	5.21	4.45	4.83	+19.0
Composite			5.24			5.96	+13.7

[a]Based on Control as reference.