#1102-13 THE INSTITUTE OF PAPER CHEMISTRY
(Paper Evaluation)
Project Reports

PROJECT REPORT FORM

PROJECT NO. 1102-13
COOPERATOR Institute
REPORT NO. One
DATE February 8, 1950
NOTE BOOK 607
PAGE 72 TO 78
SIGNED

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THE EFFECT OF BASIS WEIGHT ON THE PHYSICAL PROPERTIES OF HANDSHEETS

INTRODUCTION

The problems encountered in paper evaluation and pulp testing by use of handsheet physical evaluation procedures often give rise to insurmountable difficulties in the correct interpretation of experimental data. Even with careful control of methods and procedures, there always remains connected with an operation or test some degree of residual variability. Paper testing is not different in this respect, and the problem must be considered. It is the purpose of this work to study certain aspects of data interpretation. The study is particularly devoted to an examination of the dependence of various strength and physical properties on sheet weight, mass, or substance, and the methods of correcting these data for sheet weight variations.

EXPERIMENTAL PROCEDURE

Two unbleached kraft pulps which have been designated as pulp A and pulp B were beaten in a 1.5 lb. Valley laboratory beater according to the usual evaluation procedures (Institute Method 403) using a 6,500 g. bedplate loading. From these pulps regular British handsheets of nominal oven dry weights 1.05, 1.20, 1.35 and 1.50 grams were made. These were prepared, conditioned, and tested for caliper, basis weight (24x36—480), apparent density, bursting strength, tearing strength, Schopper tensile strength, and stretch according to Institute Methods.

Designation	Identification
Pulp A	Thilmany Unbleached Kraft
Pulp B	Union Bag Unbleached Kraft

RESULTS

Strength and physical characteristics of the handsheets prepared from Pulps A and B have been tabulated in Tables I and II, respectively. These data are the arithmetic average of tests made. For complete data and test conditions refer to code office reports— file nos. 137092 - 137095 and 139101 - 139104.

TREATMENT OF DATA
(Discussion)

In the interpretation of burst and tear data, the usual procedure is to express results in terms of an equivalent 100 lb. ream. That is, to divide the strength property value by the basis weight being used and multiply this result by 100. This calculated result is sometimes referred to as relative bursting strength, relative tearing strength, bursting strength pts./100 lb., tear factor, etc.

Stretch, which is determined to the point of final rupture, is generally calculated as percentage of original test specimen length. Caliper, is usually expressed directly in thousandths of an inch, and apparent density as the quotient of basis weight in lb. and caliper in thousandths. The use of these and similar expressions constitutes at least a tacit implication that strength, or physical properties are directly proportional to the weight or mass of the sheet tested. The full significance of this implication which is elementary, but also basic, is illustrated in Figure 1, where the tensile strength data expressed in lb./in., taken from Tables I and II, are plotted as functions of the air dry handsheet weights. Thus, there are five distinct sets of data, each of which shows the dependence of tensile strength on handsheet weight. From these plots it is evident that linear relationships fit the data of each pulp reasonably well. It is further evident that for only one of the relationships are the tensile strengths directly proportional to the handsheet weight. The basis weights in lb., 24x36—480 ream for each point of the five plots are shown in Tables I and II. For each point tabulated in Tables I and II and plotted in Figure 1, the corresponding tensile strength in lb./in./100 lb. ream has been calculated by the usual direct proportionality method. These calculated values are listed in Tables I and II. The same solutions can, of course, be arrived at by graphic methods. The graphic solution is obtained by connecting the plotted point (sheet weight vs. tensile in lb./in.) to the axis origin and extending this line to find the point of intersection with the vertical 100 lb. basis weight line.

TABLE I

STRENGTH AND PHYSICAL CHARACTERISTICS OF VARIABLE WEIGHT STANDARD PRESSED BRITISH HANDSHEETS

(Pulp A)

Weight of Sheet, g.	Basis Weight, 24x36—480, lb.	Caliper, in.	Apparent Density	Mullen Burst pt.	Mullen Burst pt./100 lb.	Schopper Tensile lb./in.	Schopper Tensile lb./in.100 lb.	Schopper Stretch, %	Elmendorf Tear, g./sheet	Tear Factor
				850 cc. Schopper-Riegler						
1.136	33.5	0.0038	8.8	23.3	70	15.5	46.3	1.8	81	2.42
1.279	37.7	0.0041	9.2	28.0	74	16.7	44.3	1.4	92	2.44
1.445	42.6	0.0050	8.5	29.7	70	18.7	43.9	1.8	116	2.72
1.626	48.0	0.0056	8.6	32.2	67	21.6	45.0	2.4	150	3.12
				700 cc. Schopper-Riegler						
1.134	33.4	0.0030	11.6	46.0	138	27.0	80.8	2.7	43	1.29
1.295	38.2	0.0032	11.9	54.5	143	30.5	79.8	2.7	52	1.36
1.457	43.0	0.0037	11.6	59.4	138	35.8	83.2	2.9	59	1.37
1.615	47.6	0.0040	11.9	67.0	141	42.1	88.3	3.1	68	1.43
				535 cc. Schopper-Riegler						
1.141	33.6	0.0030	11.2	62.7	187	28.8	85.7	3.3	44	1.31
1.311	38.7	0.0033	11.7	73.5	190	31.4	81.1	3.0	52	1.34
1.467	43.3	0.0036	12.0	80.0	185	40.8	94.2	3.3	61	1.41
1.638	48.3	0.0040	12.1	92.0	190	47.5	98.3	3.5	74	1.53
				410 cc. Schopper-Riegler						
1.131	33.4	0.0026	12.8	43.1	129	23.8	71.3	2.5	33	0.99
1.298	38.3	0.0030	12.8	50.5	132	29.8	77.8	2.6	40	1.04
1.466	43.2	0.0034	12.7	58.9	136	36.5	84.5	2.7	49	1.13
1.645	48.5	0.0037	13.1	66.2	136	41.2	84.9	2.9	57	1.18

TABLE II

STRENGTH AND PHYSICAL CHARACTERISTICS OF VARIABLE WEIGHT STANDARD PRESSED BRITISH HANDSHEETS

(Pulp B)

Weight of Sheet, g.	Basis Weight, 24x36—480, lb.	Caliper, in.	Apparent Density	Mullen Burst		Schopper Tensile		Schopper Stretch, %	Elmendorf Tear, g./sheet	Tear Factor
				pt.	pt./100 lb.	lb./in.	lb./in./100 lb.			
565 cc. Schopper-Riegler										
1.142	33.7	0.0036	9.4	41.1	122	21.8	64.7	4.0	72	2.14
1.303	38.4	0.0039	9.8	49.3	128	25.3	65.9	4.0	82	2.14
1.484	43.8	0.0042	10.4	56.8	130	29.8	68.0	4.2	92	2.10
1.615	47.6	0.0046	10.3	61.4	129	32.1	67.4	4.2	102	2.14

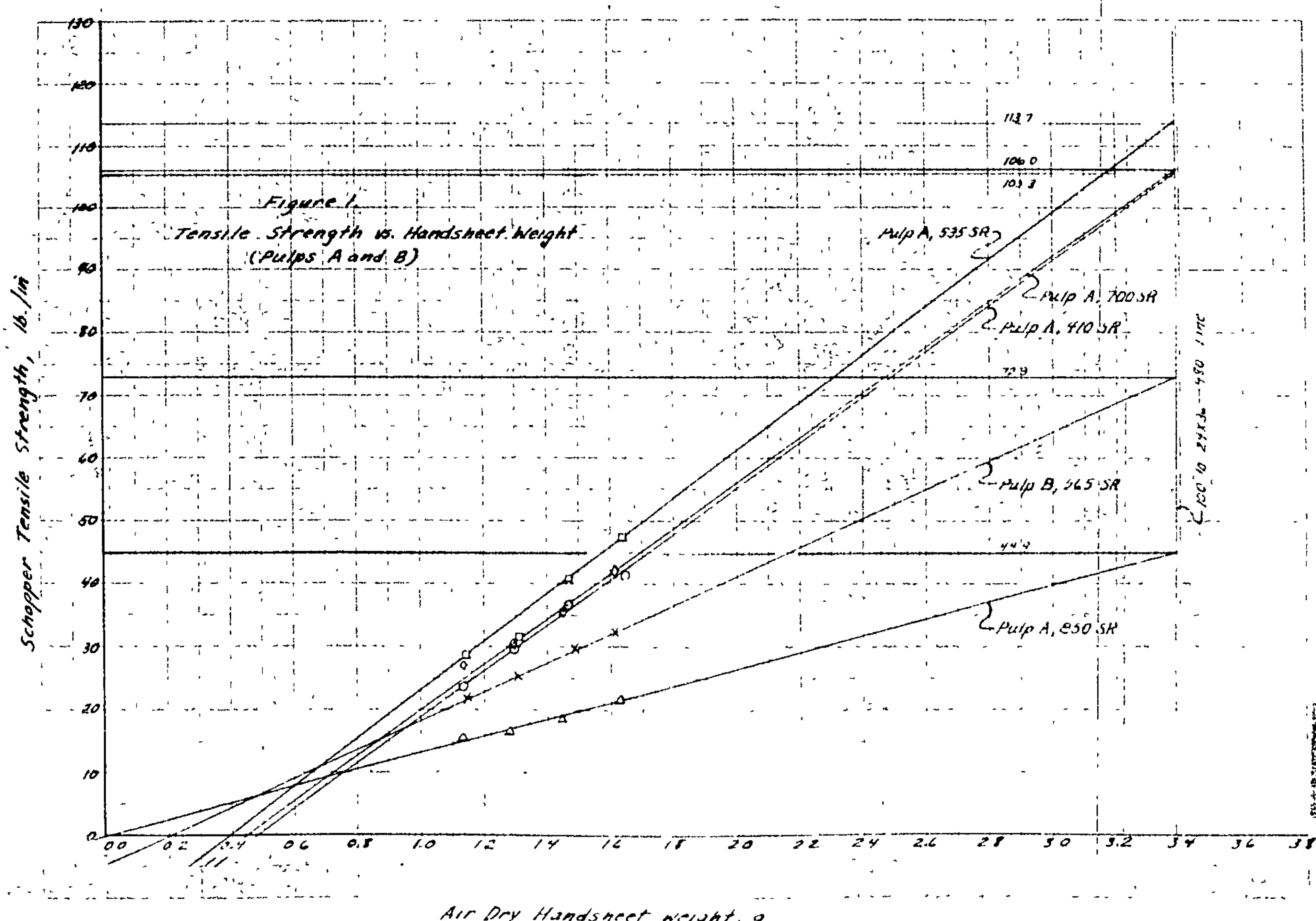


Figure 1.
Tensile Strength vs. Handsheet Weight
(Pulps A and B)
Schopper Tensile Strength, lb./in
Air Dry Handsheet weight, g
Pulp A, 535 SR
Pulp A, 700 SR
Pulp A, 410 SR
Pulp B, 565 SR
Pulp A, 850 SR
113.7
106.0
105.3
72.9
44.9
100 to 24x36 – 480 line
0
10
20
30
40
50
60
70
80
90
100
110
120
130
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8

Semi-graphical methods can also be used to evaluate the slope (m) and b (y intercept) constants. This has been done not only for tensile strength data but also other physical characteristics of the five pulps used in this study. See Figures 2 - 7 and Table III. For convenience of presentation, the discussion will be confined primarily to tensile strength. The principles involved, however, as shown in Figures 2-7 are applicable to the other properties. As previously pointed out, the assumption of direct proportionality is likely to be incorrect. Before considering the second assumption involved, linear extrapolation, it should be noted that the weight tensile strength (lb./in.) relationship may correctly be considered as linear, but not necessarily as a direct proportionality. Therefore, in order to correctly determine the lb./in./100 lb. tensile strengths from the data plotted in Figure 1, the linear relationships should be extrapolated, as shown, to the 100 lb. basis weight line and the tensile strength taken at the point of intersection. In general, as shown in Table IV, the tensile strength (lb./in./100 lb.) values thereby obtained for the five pulps do not agree with the calculated values of Tables I and II.

The reason for this lack of agreement is clear from the elementary geometry of Figure 1. These plots of tensile strength weight relationships are of the algebraic form $y = mx + b$ rather than $y = mx$. As a further check on this point, strength and physical characteristic data from published work of two separate sources (1,2) have been fitted

[1] The Mechanical Properties of Paper as Affected by Its Substance by Julius Bekk published by G. H. Buhrmann's Papiergroothandel N. V. Amsterdam, 1947.

[2] The Relation of Sheet Properties and Fiber Properties in Paper by R. H. Doughty, PTJ 1931, Vol. 93, TS162-167,172.

TABLE III

Pulps A and B

TABULATION OF CONSTANTS m AND b
(Data from Figures 2-7)

Strength or Physical Property	Pulp Identification A 850 S.R.	A 700 S.R.	A 535 S.R.	A 410 S.R.	B 565 S.R.
			m		
Burst	20.53	43.06	58.3	45.84	45.44
Apparent Density	-0.4165	0.556	1.193	0.864	2.36
Tear	188.6, 70.25	55.7	55.7	47.83	63.02
Tensile	12.64	36.10	37.75	36.10	22.21
Stretch	0.178	0.711	0.489	0.777	0.645
Caliper	.00366	.00206	.00193	.00237	.00206
			b		
Burst	-0.12	-2.8	-3.8	-8.7	-10.76
Apparent Density	+9.29	+4.89	+10.13	+11.66	+6.7
Tear	-77.4	-20.6	-20.6	-21.4	-00.1
Tensile	+1.03	-16.3	-14.4	-17.0	-3.5
Stretch	+1.6	+1.86	+2.65	+1.61	+3.23
Caliper	.00037	+.00066	+.00077	-.00007	+.00123

TABLE IV

Identification	Tensile Strength, lb./in./100 lb. From Figure 1	From Tables I and II			
Pulp A, 850 S.R.	44.9	46.4	44.3	43.9	45.0
Pulp A, 700 S.R.	106.0	80.8	79.8	83.2	88.3
Pulp A, 510 S.R.	113.7	85.7	81.1	94.2	98.3
Pulp A, 410 S.R.	105.3	71.3	77.8	84.5	84.9
Pulp B, 565 S.R.	72.9	64.7	65.9	68.0	67.4

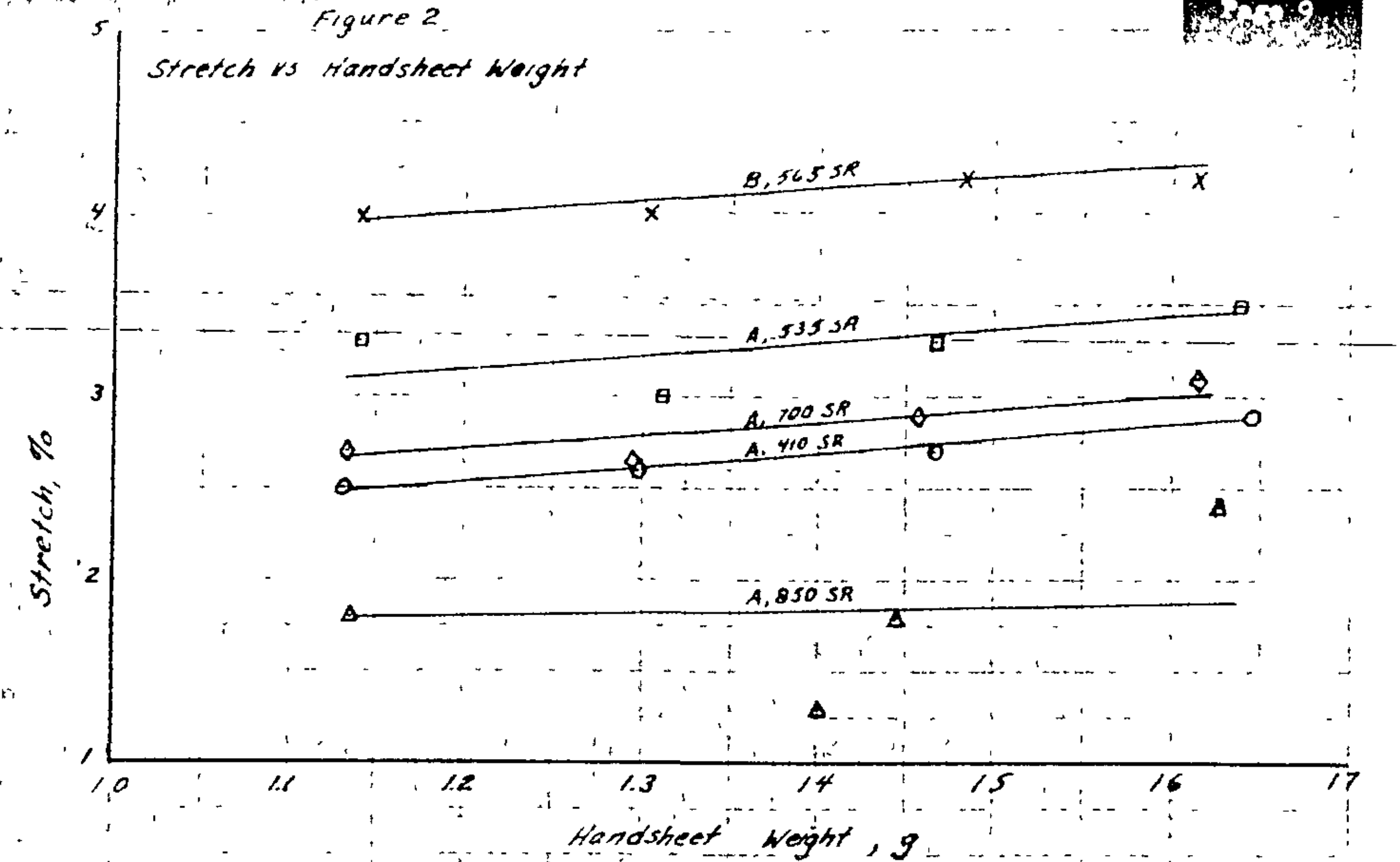


Figure 2
Stretch vs Handsheet Weight

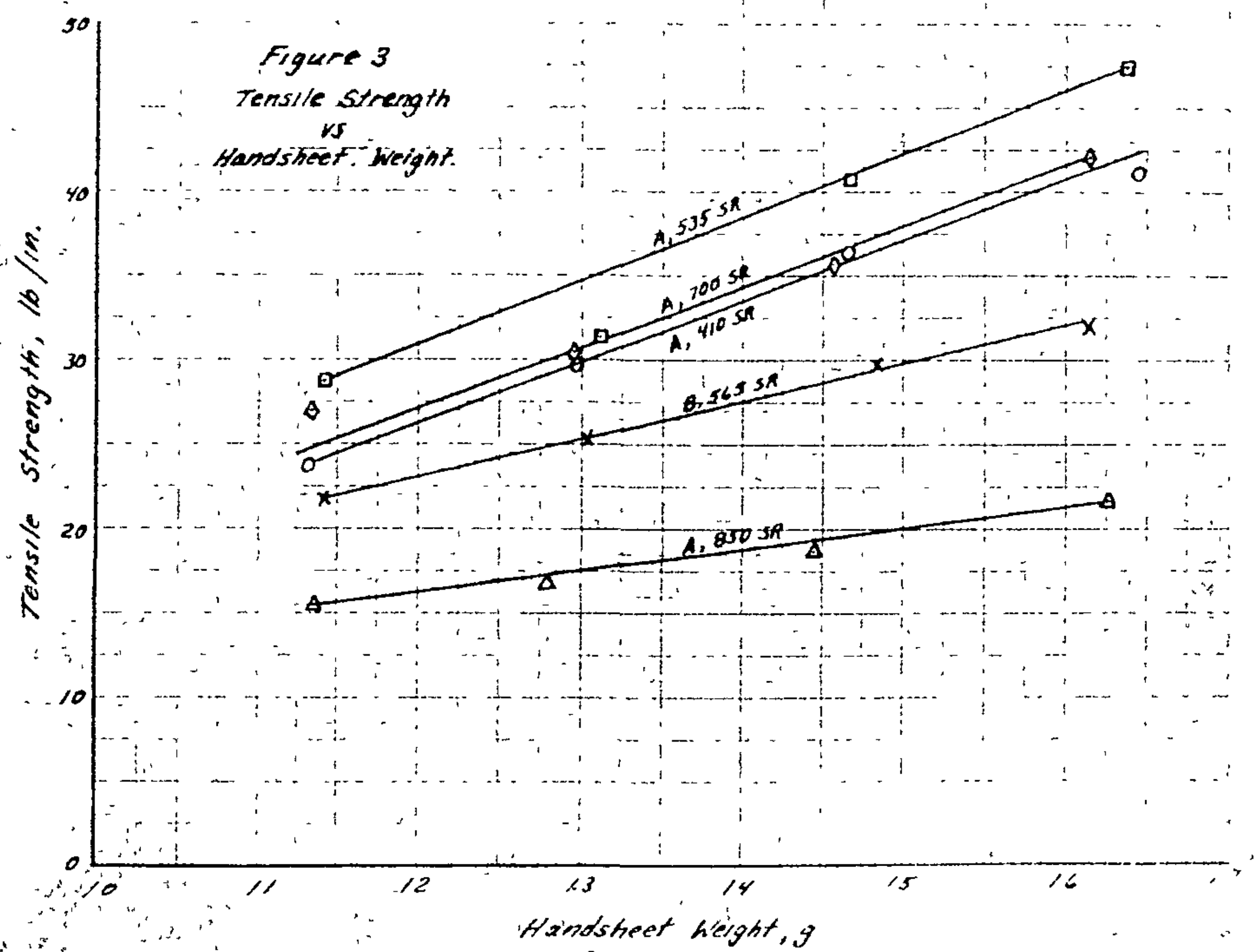


Figure 3
Tensile Strength vs Handsheet Weight

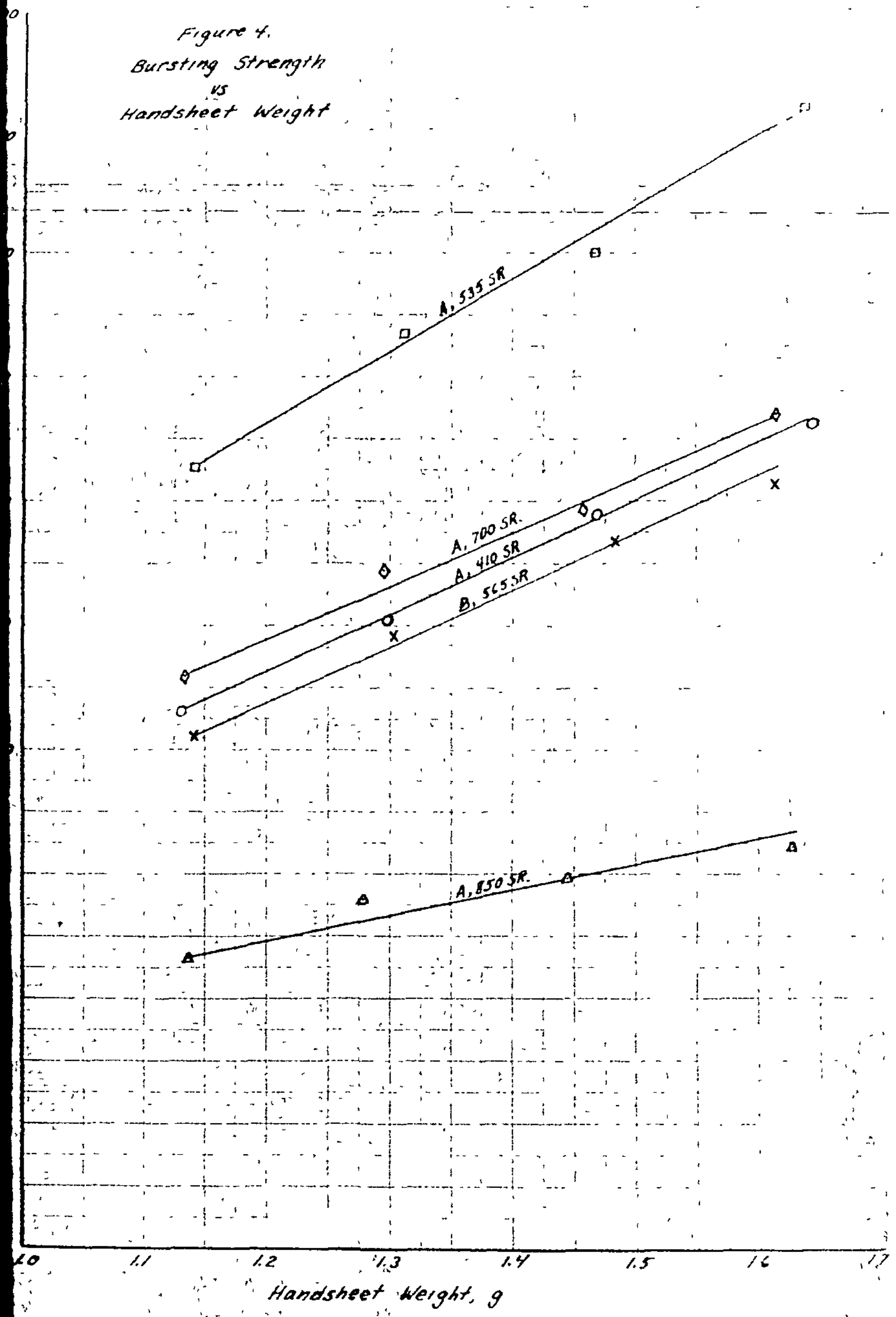


Figure 4. Bursting Strength vs Handsheet Weight

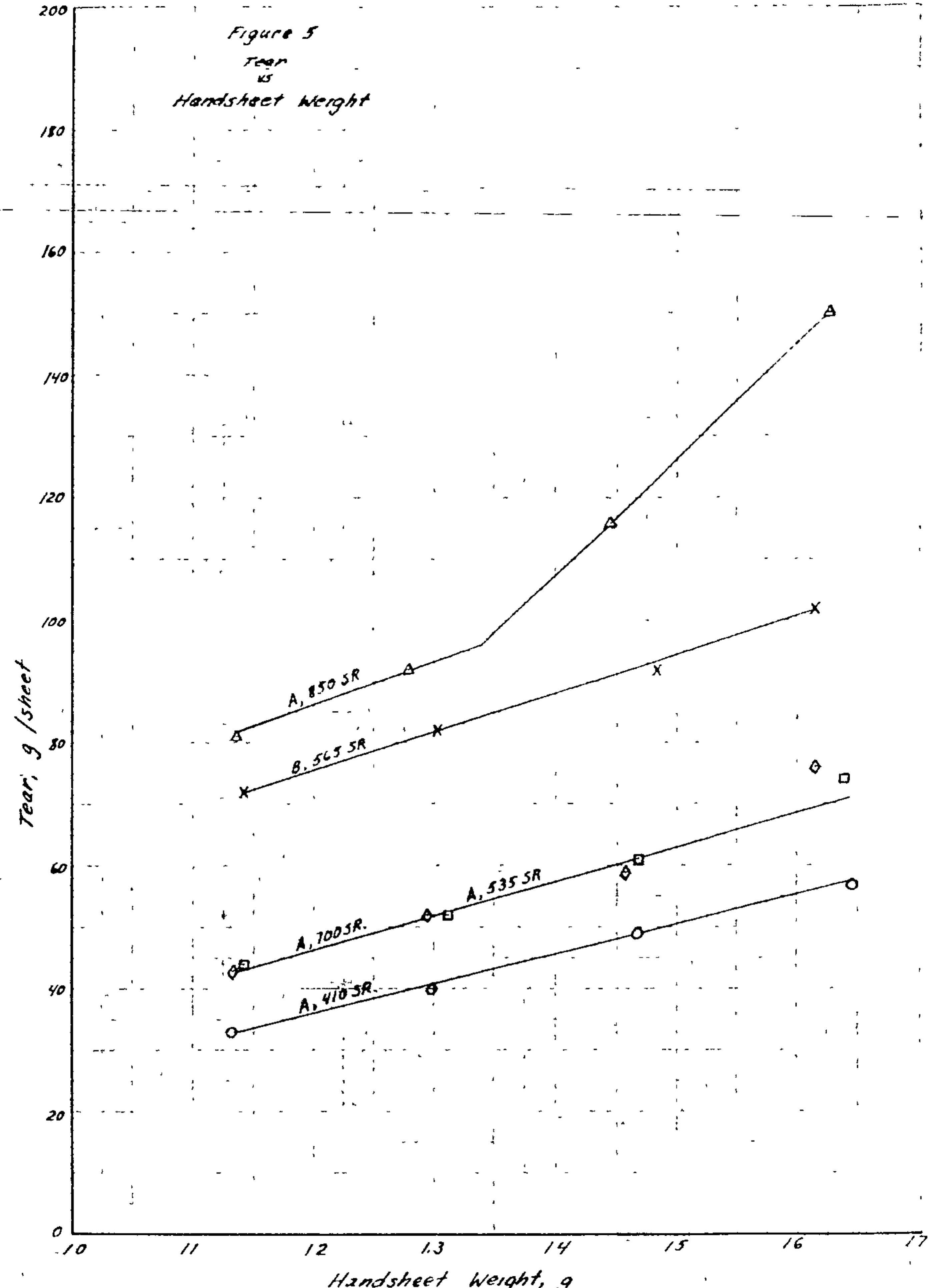


Figure 5
Tear vs Handsheet Weight

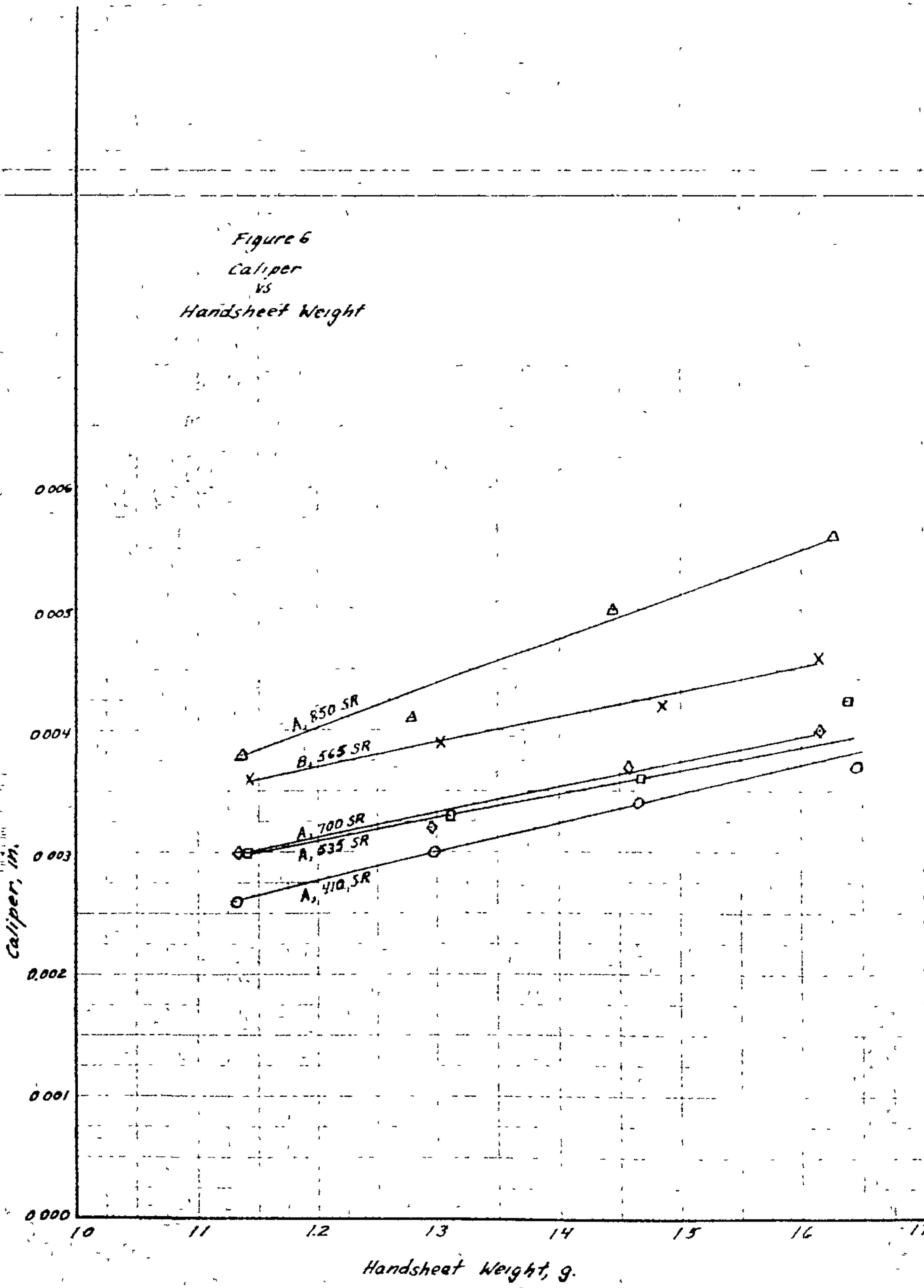
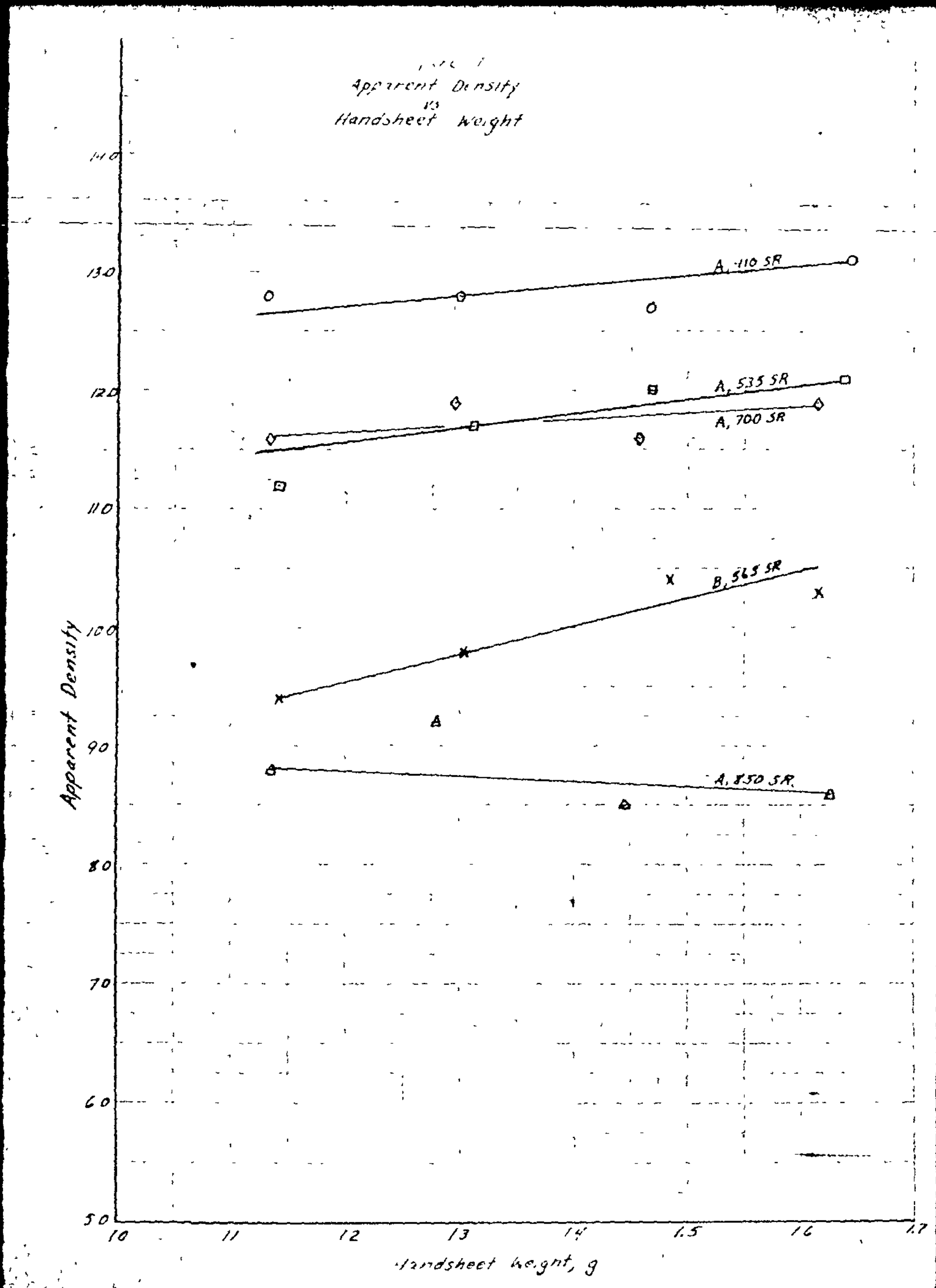


Figure 6
Caliper
vs
Handsheet Weight
A, 850 SR
B, 565 SR
A, 700 SR
A, 535 SR
A, 410 SR
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Caliper, in.
10
11
12
13
14
15
16
17
Handsheet Weight, g.


Apparent Density
vs
Handsheet Weight
A, 110 SR
A, 535 SR
A, 700 SR
B, 565 SR
A, 850 SR
Apparent Density
Handsheet Weight, g
140
130
120
110
100
90
80
70
60
50
10
11
12
13
14
15
16
17

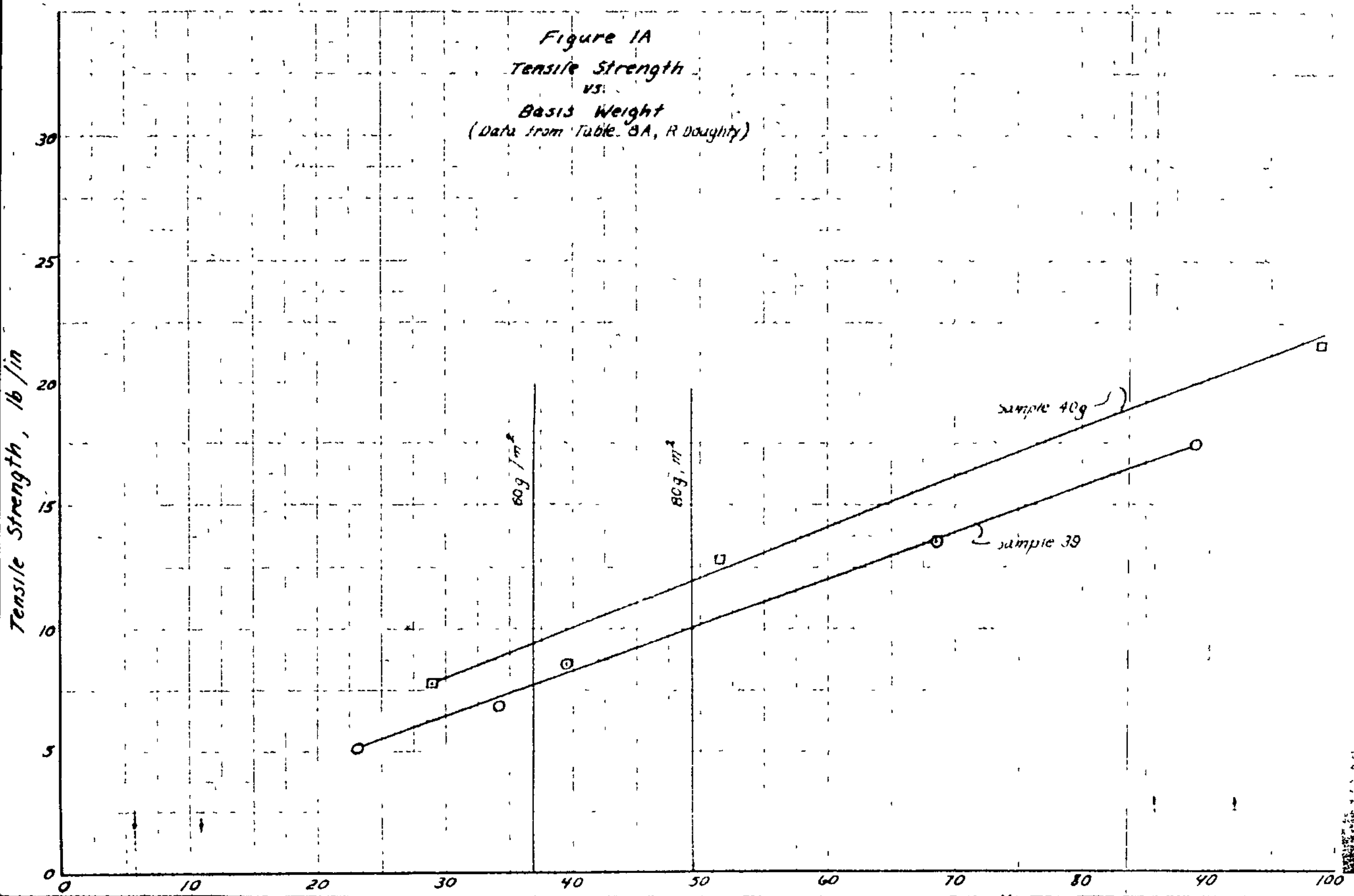


Figure 1A
Tensile Strength
vs.
Basis Weight
(Data from Table 8A, R Doughty)
Tensile Strength, lb/in
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
60g/m²
80g/m²
sample 40g
sample 39

to linear relationships of the form $y = mx + b$ and the constants m and b computed. See Tables 1A to 11A and Figure 1A of the appendix. These data were selected as nearly as possible to represent the same weight range which is covered in Tables I and II.

The use of linear extrapolation to obtain tensile strength in lb./in./100 lb. is, in the strictest sense, open to criticism. For example, if the data given (Tables I and II) were more extensive so as to include sheet weights equivalent to 100 lb. basis weight, the relationship over this wide range of values might then deviate considerably from linearity. However, even in such a case, a portion of the data embodying weight ranges similar to those of Tables I and II might reasonably well be linearly related. It should therefore always be clearly understood that such a use of linear extrapolation is merely a convenient method of correcting for minor weight variations, and not a prediction of strength or physical characteristics of a 100 lb. basis weight sheet. It should be further understood that in most work there would be but one point of each plot shown in Figure 1. With only one point the algebraic form $y = mx + b$ can, of course, not be applied for lack of data to evaluate constants m and b. Therefore, there are three alternative solutions to the general problem of weight variation correction. In the first case where the data consist of two or more points, the form $y = mx + b$ should be used and the constants calculated. In the second case, where only one point is available, constants m and b may be selected from a backlog of data. The third case arises when, with only one point, values for constants m and b can not be determined. Then the algebraic form y = mx, assuming (0,0) as a second point, must be used. It should, however, be realized, as previously stated, that this is merely an approximation. Also, and this is most important, in such an instance a basis weight figure such as nominal basis weight or average basis weight will probably give more accurate results than conversion to pt./100 lb. That is, the use of a direct proportionality relationship where not strictly applicable, introduces errors of magnitude proportional to the degree of extrapolation involved.

SUMMARY AND CONCLUSIONS

Analysis of strength and physical characteristic data of different weight handsheets prepared from the same pulp showed the relationships to be of the general linear form y = mx + b rather than y = mx. It is, therefore, recommended that when data are to be corrected or reduced to a common weight basis, the basis chosen should be of approximately the same order of magnitude as the original data. That is, for a given set of data, the use of average basis weight or nominal basis weight is preferred to the commonly employed 100 lb. basis.

TABLE 1A

SCHOPPER TENSILE STRENGTH
(Data of J. Bekk[1])

Paper Sample	Breaking Length, Km. BW 60 g.	BW 80 g.	Δ 80-60	Constants m	b
A_1	4.98	6.72	+1.74	+0.087	-0.24
A_2	5.16	7.28	+2.12	+0.106	-1.20
A_3	4.74	6.80	+2.06	+0.103	-1.44
B_1	4.08	5.84	+1.76	+0.088	-1.20
B_2	4.14	5.84	+1.70	+0.085	-0.96
B_3	4.44	5.84	+1.40	+0.070	+0.24
C_1	2.94	4.00	+1.06	+0.053	-0.24
C_2	3.42	4.48	+1.06	+0.053	+0.24
C_3	3.96	5.28	+1.32	0.00	0.00
D_1	2.22	3.12	+0.90	+0.045	-0.48
D_2	2.34	3.36	+1.02	+0.051	-0.72
D_3	2.76	3.68	+0.92	+0.046	0.00
E_1	3.96	5.68	+1.72	+0.086	-1.20
E_2	4.32	5.52	+1.20	+0.060	+0.72
E_3	4.14	5.68	+1.54	+0.077	-0.48

Basis weight shown is in g./sq. m.

[1] The Mechanical Properties of Paper as Affected by its Substance, by Julius Bekk.

TABLE 2A

SCHOPPER STRETCH
(Data of J. Bekk)

Paper Sample	Stretch, %			Constants	
	BW 60 g.	BW 80 g.	Δ60-80	m	b
A_1	3.7	3.8	+.1	+.005	3.4
A_2	3.5	3.8	+.3	+0.015	2.6
A_3	3.9	4.1	+.2	+0.010	3.3
B_1	3.2	3.5	+.3	+0.015	2.3
B_2	3.1	3.4	+.3	+0.015	2.2
B_3	3.8	4.2	+.4	+0.010	2.6
C_1	2.9	3.1	+.2	+0.010	2.3
C_2	2.7	2.8	+.1	+0.005	2.4
C_3	3.0	3.3	+.3	+0.015	2.1
D_1	3.9	4.3	+.4	+0.020	2.7
D_2	3.0	2.9	-.1	-0.005	3.3
D_3	2.9	2.9	0	0.00	2.9
E_1	3.3	3.6	+.3	+0.015	2.4
E_2	3.8	3.9	+.1	+0.005	3.5
E_3	4.3	4.8	+.5	+0.025	2.8

TABLE 3A

BURSTING STRENGTH
(Data of J. Bekk)

Paper Sample	Bursting Strength, kg./cm.^{2}			Constants	
	BW 60 g.	BW 80 g.	Δ 60–80	m	b
A_1	3.90	5.44	1.54	+.077	-0.72
A_2	4.08	5.84	1.76	+.088	-1.20
A_3	3.72	5.20	1.48	+.074	-0.72
B_1	3.00	4.40	1.40	+.070	-1.20
B_2	3.18	4.32	1.14	+.057	-0.24
B_3	3.48	4.88	1.40	+.070	-0.72
C_1	1.98	2.88	0.90	+.045	-0.72
C_2	2.22	3.04	0.82	+.041	-0.24
C_3	2.40	3.20	0.80	+.040	0.00
D_1	1.68	2.32	0.64	+.032	-0.24
D_2	1.38	2.00	0.62	+.031	-0.48
D_3	1.56	2.24	0.68	+.034	-0.48
E_1	2.52	3.92	1.40	+.070	-1.68
E_2	3.00	4.08	1.08	+.054	-0.24
E_3	3.12	4.48	1.36	+.068	-0.96

TABLE 4A

TEARING STRENGTH
(Data of J. Bekk)

Paper Sample	Tearing Strength, g. cm./cm.			Constants	
	BW 60 g.	BW 80 g.	Δ 60–80	m	b
A_1	1.32	1.77	+0.45	+.0225	-0.030
A_2	1.272	1.768	+0.496	+.0248	-0.216
A_3	1.326	1.776	+0.450	+.0225	-0.024
B_1	1.020	1.504	+0.484	+.0242	-0.432
B_2	1.128	1.464	+0.336	+.0168	+0.120
B_3	1.050	1.600	+0.550	+.0275	-0.600
C_1	0.978	1.424	+0.446	+.0223	-0.360
C_2	0.870	1.272	+0.402	+.0201	-0.336
C_3	0.762	1.104	+0.342	+.0171	-0.264
D_1	1.434	1.944	+0.510	+.0255	-0.096
D_2	1.038	1.280	+0.242	+.0121	+0.312
D_3	0.900	1.064	+0.164	+.0082	+0.408
E_1	1.002	1.464	+0.462	+.0231	-0.384
E_2	1.128	1.528	+0.400	+.0200	-0.072
E_3	1.128	1.552	+0.424	+.0212	-0.144

TABLE 5A

SCHOPPER FOLD
(Data of J. Bekk)

Paper Sample	Schopper Fold, # of double folds BW 60 g.	BW 80 g.	Δ60–80	Constants m	b
A_1	2719	3504	+785	+39.25	+360
A_2	3209	4757	+1548	77.40	-1435
A_3	3427	4362	+935	46.75	+622
B_1	2175	3526	+1351	67.55	-1878
B_2	2959	4200	+1241	62.05	-764
B_3	3676	4112	+436	21.80	+2368
C_1	298	711	+413	20.65	-941
C_2	498	816	+318	15.90	-456
C_3	515	1531	+1016	50.80	-2533
D_1	74	327	+253	12.65	-685
D_2	36	64	+28	1.40	-48
D_3	49	50	+ 1	.05	+46
E_1	455	775	+320	16.00	-505
E_2	1172	1329	+157	7.85	+701
E_3	1615	3917	+2302	115.10	-5291

TABLE 6A

CIRCULAR TENSILE STRENGTH
(Data of J. Bekk)

Paper Sample	Circular Tensile Strength, kg.			Constants	
	BW 60 g.	BW 80 g.	Δ60-80	m	b
A_1	24.48	33.68	9.20	+0.460	-3.12
A_2	28.68	40.40	11.72	+0.586	-6.48
A_3	24.72	33.84	9.12	+0.456	-2.64
B_1	22.08	31.28	9.20	+0.460	-5.52
B_2	23.58	31.20	7.62	+0.381	+0.72
B_3	25.08	37.92	12.84	+0.642	-13.44
C_1	17.22	23.52	6.30	+0.315	-1.68
C_2	19.50	27.20	7.70	+0.385	-3.60
C_3	22.02	30.24	8.22	+0.411	-2.64
D_1	13.80	19.68	5.88	+0.294	-3.84
D_2	12.72	18.24	5.52	+0.276	-3.84
D_3	15.48	20.88	5.40	+0.270	-0.72
E_1	22.08	32.72	10.64	+0.532	-9.84
E_2	22.20	29.84	7.64	+0.382	-0.72
E_3	22.80	32.32	9.52	+0.476	-5.76

TABLE 7A

BENDING RESISTANCE
(Data of J. Bekk)

Paper Sample	Bending Resistance, g./5 cm.			Constants	
	BW 60 g.	BW 80 g.	Δ 60-80	m	b
A_1	3.4	8.7	5.3	+.265	-12.5
A_2	3.8	8.3	4.5	+.225	-9.7
A_3	3.7	8.0	4.3	+.215	-12.2
B_1	2.8	6.8	4.0	+.200	-9.2
B_2	3.1	6.2	3.1	+.155	-6.2
B_3	2.9	6.3	3.4	+.170	-7.3
C_1	3.3	7.0	3.7	+.185	-7.8
C_2	3.2	7.0	3.8	+.190	-8.2
C_3	3.2	5.7	2.5	+.125	-4.3
D_1	3.9	8.1	4.2	+.210	-8.7
D_2	3.7	7.7	4.0	+.200	-8.3
D_3	3.7	7.8	4.1	+.205	-8.6
E_1	3.5	8.7	5.2	+.260	-12.1
E_2	4.1	8.3	4.2	+.210	-8.5
E_3	3.0	7.5	4.5	+.225	-10.5

TABLE 8A

TENSILE STRENGTH - WEIGHT DATA*

Consistency during Formation, %	Basis Weight, 24x36—500 ream, lb.	Solid Fraction	Ultimate Tensile Strength, lb./sq.in.
Sample 39 - Wet Pressed at 30 lb. per sq. in.			
0.018	23.3	0.244	1240
0.012	34.3	0.254	1180
0.014	39.5	0.255	1300
0.028	68.6	0.268	1240
0.036	88.8	0.267	1230
0.050	123.1	0.268	1100
0.066	160.0	0.261	1020
0.105	260.0	0.266	910
Sample 40 g. - Wet Pressed at 125 lb. per sq. in.			
0.040	28.2	0.387	1980
0.020	28.9	0.381	2400
0.010	26.8	0.379	2530
0.072	50.3	0.392	2270
0.036	51.5	0.400	2310
0.018	51.6	0.397	2400
0.144	100.0	0.395	1730
0.072	99.0	0.402	2050
0.036	101.0	0.398	2180
0.288	199.0	0.374	1430
0.140	194.0	0.383	1880
0.070	191.0	0.380	2030
0.550	369.0	0.393	1210
0.275	385.0	0.391	1390
0.137	394.0	0.392	1530

* Data taken from published work;
"The Relation of Sheet Properties and Fiber Properties in Paper" by R. H. Doughty. PTJ. 1931, Vol. 93, TS162-167,172.

TABLE 9A

CONVERSION OF TABLE 10A DATA*

Basis Weight, 24x36--500 ream, lb.	Solid Fraction	Caliper, in.	Tensile Strength, lb./in.
Sample 39			
23.3	0.244	.00408	5.06
34.3	0.254	.00577	6.81
39.5	0.255	.00662	8.62
68.6	0.268	.01094	13.57
88.8	0.267	.01420	17.48
Sample 40 R.			
28.9	0.381	.00324	7.78
51.5	0.400	.00550	12.72
99.0	0.402	.01052	21.60
194.0	0.383	.02163	40.70

* $\text{Caliper, in.} = .0000427 \; \frac{\text{Basis Weight, lb.}}{\text{Solid Fraction}}$

$\text{Tensile Strength, lb./in.} = \frac{\text{lb./sq. in.}}{\text{caliper}}$

TABLE 10A

TENSILE STRENGTH - WEIGHT DATA
(from Figure 1A)

Tensile Strength, lb./in.			Constant	
BW 60 g.	BW 80 g.	60-80	m	b
7.7	10.0	+2.3	0.115	+0.8
9.4	11.8	+2.4	0.120	+2.2

TABLE 11A

PULP SAMPLE IDENTIFICATION
(Data of J. Bekk)

Pulp	Identification
A	Unbleached kraft
B	Unbleached sulfite
C	Bleached sulfite
D	Bleached linen-rag
E	Unbleached rye-straw, alkaline chlorine process

Pulp Sample	Beating Time, min.	Schopper-Riegler Freeness, °
A_1	40	34.0
A_2	56	43.3
A_3	67	52.5
B_1	16	36.2
B_2	19.5	45.3
B_3	25	55.1
C_1	13	34.0
C_2	16	45.0
C_3	25	53.5
D_1	10	79.9
D_2	30	86.8
D_3	60	91.0
E_1	3	35.5
E_2	8.5	44.7
E_3	1.5	56.1

PROJECT REPORT FORM

CC: Files
Dr. Forman
Mr. MacLaurin
Mr. Kottwitz
Mr. Madison

PROJECT NO. V1102-13
COOPERATOR Institute
REPORT NO. 2
DATE May 4, 1950
NOTE BOOK 607
PAGE 72 TO 78
SIGNED Frank Kottwitz
Frank Kottwitz

Elmo Madison
Elmo Madison

APPARENT DENSITY OF HANDSHEETS

INTRODUCTION

A study of apparent density and its relationship to handsheet strength characteristics has been made. Special attention was given to the consideration of using this physical property as a basis for comparison of strength characteristics, and as such to supplement or replace the commonly employed freeness and beating time references. This report represents findings based upon further interpretation of data cited in Project Report One dated February 8, 1950, Project 1102-13, and embodies additional data obtained from an extension of the original work.

EXPERIMENTAL PROCEDURE

See aforementioned Project Report One.

DISCUSSION OF RESULTS

For complete presentation of data, see Project Report One, pages 4 and 5, and the Appendix of this report.

In the ordinary papermaking and pulp evaluation procedures, changes in apparent density are controlled, produced, or arise primarily as a consequence of beating and/or wet pressing. The latter will be considered first because it represents the simpler of the separate cases. When wet sheets are subjected to compression of various degrees, as was done in this work, the relationship of bursting or tensile strength to apparent density will be of the general form of Figure 1, and the tearing strength versus apparent density plot will follow the pattern of Figure 2. Refer to Appendix A for details.

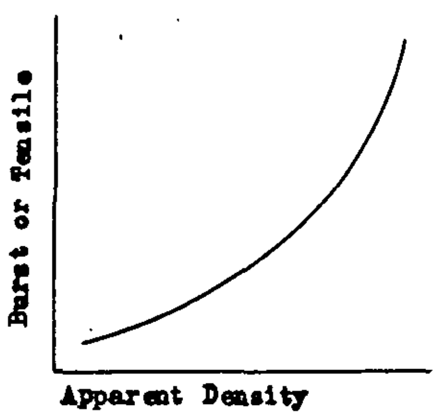


Figure 1.

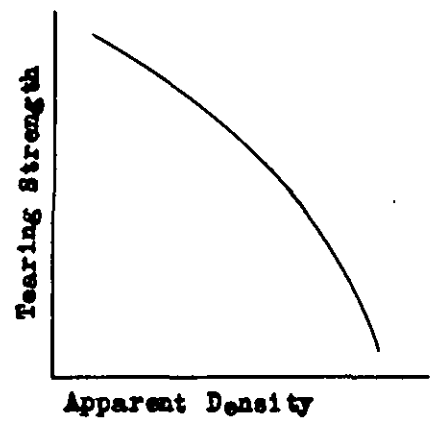
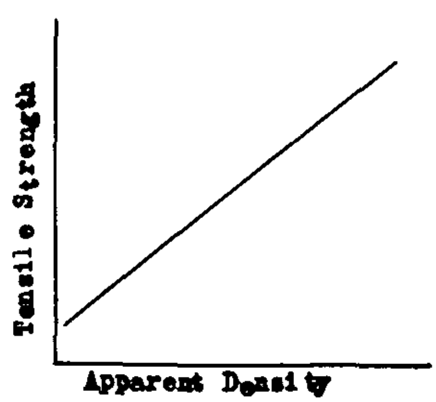


Figure 2.

These relationships can usually be algebraically represented by the form $y = b \times 10^{mx}$ and as such will plot as straight lines on semi-logarithmic graph paper. The exact curve shape of each property will of course be characteristic of the particular pulp, and not entirely free from the influence of beating degree or refining. This may or may not be of practical significance, depending upon the particular case, e.g. from a study of R. H. Doughty's work[1] with unprocessed pulp, the apparent density versus tensile strength relationship does not follow the above form but is noted to be linear as shown in Figure 3.

Figure 3.



1. The Relation of Sheet Properties and Fiber Properties in Paper, R. H. Doughty, PTJ 1931, Vol. 93, TS162-167, 172.

It should also be noted as a matter of interest, that based upon this work, the use of fundamental engineering properties were suggested for paper evaluation methods and in particular, it was advocated that "solid fraction" which is analogous to apparent density, be employed as a reference in conjunction with ultimate tensile strength expressed in lb./sq. in. When this is done, the "solid fraction" and ultimate tensile strength are algebraically related by the form $y = bx^m$ and therefore plot as a straight line on log.-log. graph paper. For more complete reference to this work, see Appendix B.

When handsheets made from pulp beaten or refined to various degrees are subjected to constant wet pressing conditions as done in this study, the changes in bursting strength and apparent density with freeness follow the general patterns indicated in Figures 4 and 5. From interrelationships of these properties, the

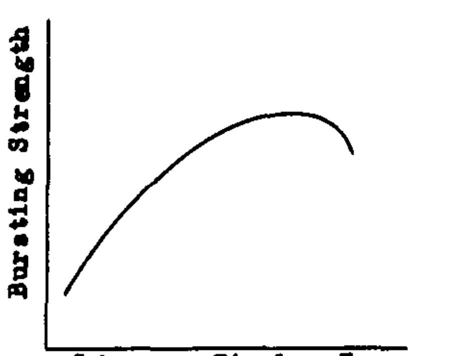


Figure 4.

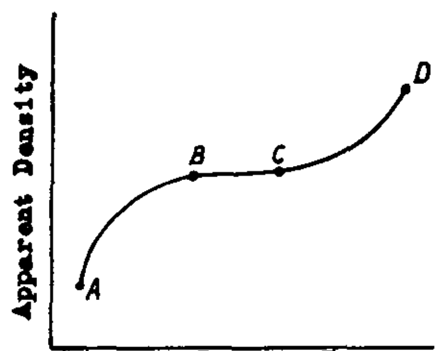


Figure 5.

plot of bursting strength versus apparent density is found to be of the general form shown in Figure 6. For details, see Appendix C.

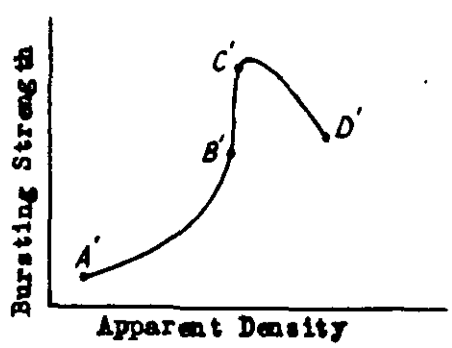


Figure 6.

It is immediately evident that this curve (Figure 6) is not of simple form and probably involves algebraic terms of degree higher than the third. However, as is frequently the case, subdivision can be used to produce geometric sections which may be satisfactorily represented by less complicated expressions, e.g., Section A'B' of Figure 6 which corresponds to the apparent density region of section AB of Figure 5 may be represented by the expression $y= b \times 10^{mx}$ and is therefore linear in x and log y. Section B'C' of Figure 6, if included as a portion of the same plot should introduce but small departures from the same expression. However, any attempt to include section C'D' of Figure 6 corresponding to the apparent density section CD of Figure 5 leads to considerable departure from the original expression, for although C'D' may also be linear in x and log y, that portion of Figure 6 is here involved where the slope is considerably different and therefore involves a separate expression. In the event that the bursting strength-freeness curve does not exhibit a maximum or still more important section CD Figure 5 is not present, the situation is naturally less complicated and quite similar to that if the variable pressing phase of this work which has already been mentioned. A consideration of tensile strength in place of bursting strength follows in general the same pattern, but deviations from the algebraic expressions may be somewhat less pronounced. The same is true of tearing strength and here the deviations may be so small as to be hardly noticeable. (Examples are shown in Figures, Appendix C).

In instances where the degree of beating or refining and wet pressing are variable, the use of apparent density as a reference with bursting, tensile, or tearing strength has not been checked experimentally but will presumably give rise to relationships of different degrees of algebraic and geometric complexity.

These however will quite probably be no more involved than the plot of Figure 6, and in certain instances, may be somewhat simpler.

It should, as a matter of record, be here noted that the subject of sheet caliper has received critical attention[2]. From the cited work it was concluded that roughness of the sheet surface should be given consideration in order to arrive at a more correct expression for sheet density. The authors' present methods for determining what has been termed "corrected apparent specific gravity" which they recommend for use where a more exact figure of density is desired. Determination of "corrected apparent specific gravity", however, is somewhat laborious and therefore probably not feasible for ordinary evaluation work where its use would constitute a questionable contribution.

[2] On the Basis Weight, Thickness and Apparent Specific Gravity of Paper, by C. Gustafsson and Lars Nordman, Pappers-Och Trävarutidskrift För Findland, p.353 N:o 19, 1949.

FK/jh

APPENDIX A

VARIABLE PRESSING STUDY

UNION BAG UNBLEACHED KRAFT PULP

Freeness - Constant

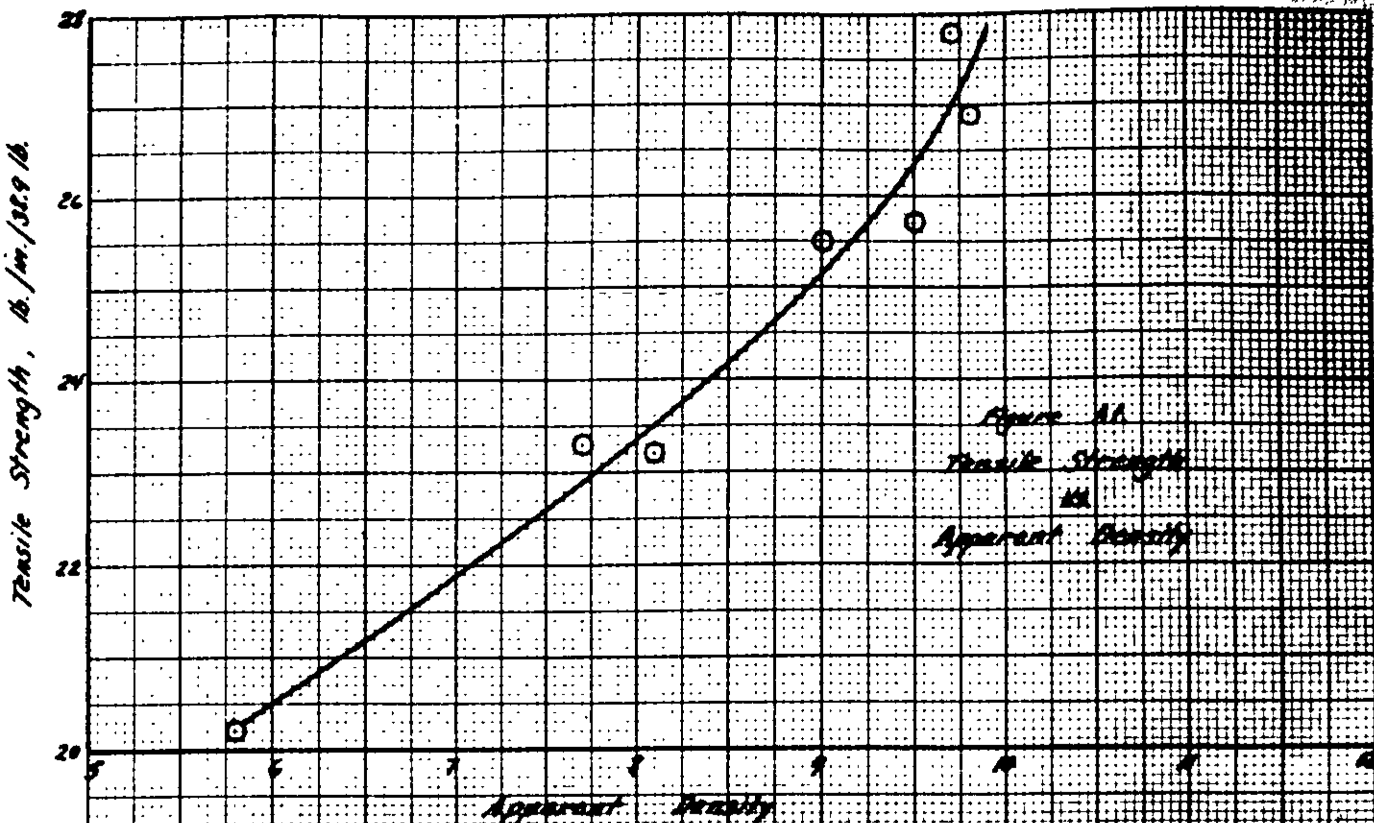
TABLE A1

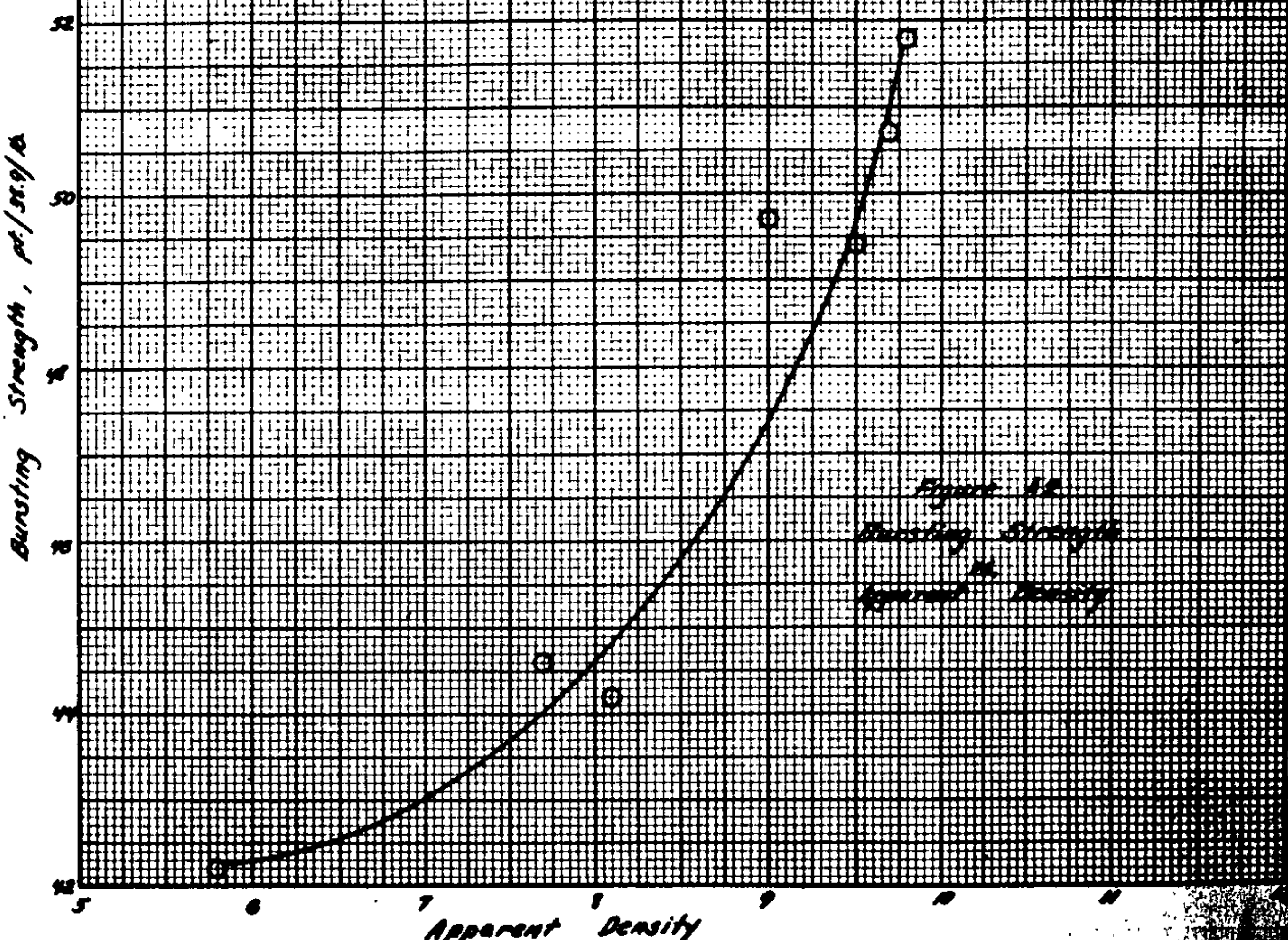
VARIABLE PRESSING STUDY
(Pulp B -Union Bag Unbleached Kraft)
(565 cc. Schopper-Riegler Freeness)

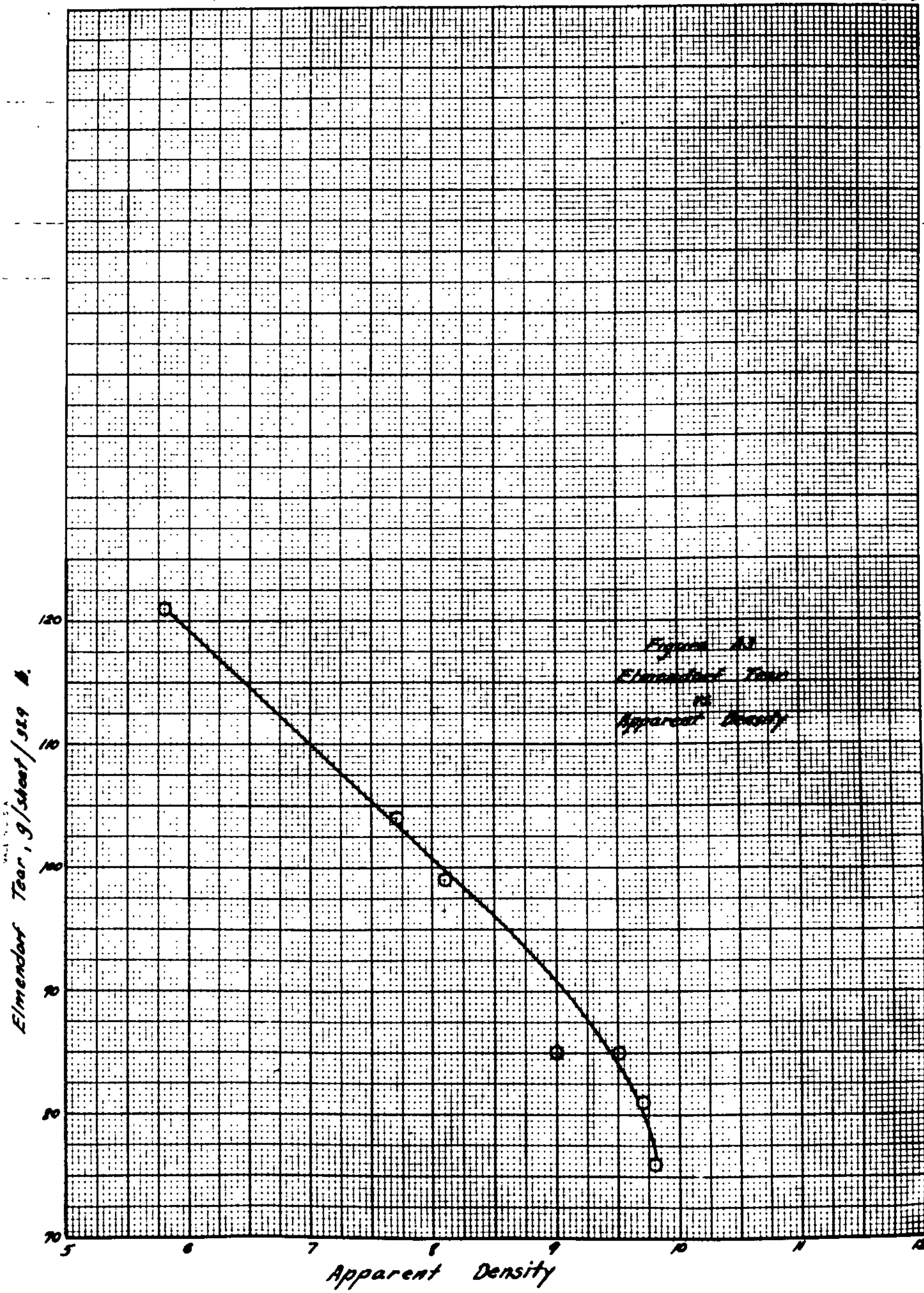
Wet Pressing Pressure, lb./sq. in.	Conditions Time, min.	Basis Weight, 24x36—480 lb.	Caliper, in.	Apparent Density	Mullen Burst pt.	Mullen Burst pt./38.9 lb.	Schopper Tensile lb./in.	Schopper Tensile lb./in./38.9 lb.	Elmendorf Tear g/sheet	Elmendorf Tear g/she 38.9
None	0	38.5	0.0066	5.8	41.7	42.2	20.0	20.2	120	12
0	5.5	38.5	0.0050	7.7	44.2	44.6	23.1	23.3	103	10
20	5.5	38.2	0.0047	8.1	43.3	44.2	22.8	23.2	97	9
50	5.5	38.9	0.0043	9.0	47.9	49.7	25.5	25.5	85	8
70	5.5	39.0	0.0041	9.5	49.5	49.4	25.8	25.7	85	8
100	5.5	39.6	0.0040	9.7	51.6	50.7	28.3	27.8	82	8
50	5.5 + 2	39.3	0.0040	9.8	52.4	51.8	27.1	26.9	77	7

(This pulp was beaten in a 1.5 lb. Valley laboratory beater, formed into handsheets, and tested according to Institute Methods except as indicated above.)

Average basis weight of handsheets 38.9 lb., 24 x 36—480 ream.


Tensile Strength, lb./in./35.9 lb.
20
22
24
26
28
5
6
7
8
9
10
11
12
Apparent Density
Figure A1
Tensile Strength
vs.
Apparent Density


Bursting Strength, pt./35.9 lb.
42
44
46
48
50
52
5
6
7
8
9
10
11
12
Apparent Density
Figure A2
Bursting Strength
vs.
Apparent Density


Elmendorf Tear, g/sheet/
120
110
100
90
80
70
5
6
7
8
9
10
11
12
Apparent Density
Apparent

APPENDIX B

REFERENCE: A QUALITATIVE STUDY OF THE TENSILE STRENGTH - SOLID FRACTION RELATION

..............R. H. Doughty

Tech. Assoc. Papers 14, No. 1, 243-8(1931)

- ABSTRACT -

Results are presented in support of the hypothesis that the properties of the paper sheet and the properties of fiber making up the sheet may be related through a knowledge of sheet structure. The data collected show especially the dependence of sheet strength on solid fraction, which is increased by wet pressing and the changes in this relation caused by various processings of the pulp. The importance of solid fraction in controlling tensile strength and of fiber properties in controlling solid fraction, are emphasized.

The effects observed are explainable by the theory that the fibers are bound in the sheet by forces principally chemical in nature, and that beating results in an increased availability of these binding forces. In addition, it is suggested that in addition to increased availability, there is also an increased efficiency of utilization of these bonds resulting from decrease in particle size on beating, and consequently greater shrinkage of sheets of beaten stuff on drying. Data are presented.

TABLE B-1

(Work of R. H. Doughty)

TABLE 1.—BASIS WEIGHT, SOLID FRACTION, AND TENSILE STRENGTH DATA FOR TEST SHEETS OF UNBLEACHED AND UNPROCESSED SPRUCE SULPHITE PULPS

Sample No.[1]	Consistence during formation, per cent	Wet pressure lbs./sq. in.	Basis weight (24x36—500) pounds	Solid fraction	Ultimate tensile strength lbs./sq. in.
39	0.018	30	23.3	0.244	1240
	.012		34.3	.254	1180
	.014		39.5	.255	1300
	.028		68.6	.268	1240
	.036		88.8	.267	1230
	.050		123.1	.268	1100
	.066		160.0	.261	1020
	.105		260.0	.266	910
40d	.008	2	22.0	.195	1220
		5	20.8	.215	1510
		10	21.7	.201	1280
		20	20.8	.235	1740
		40	21.2	.283	2420
		80	21.4	.320	2790
		125	21.0	.339	3920
		200	21.8	.363	4420
		300	21.5	.373	4900
		500	22.2	.384	4910
		1000	21.6	.396	5570
		2000	21.7	.407	6430
		Av.	21.5		
40a	0.016	2	37.4	.203	1300
		5	38.7	.219	1580
		7.5	40.4	.218	1650
		10	37.7	.241	1980
		15	41.3	.258	2110
		20	37.5	.337	3450
		25	42.2	.325	3240
		30	39.7	.332	3330
		40	41.6	.354	3780
		55	42.7	.376	4250
		75	42.1	.388	4620
		100	38.7	.394	4800
		150	39.5	.429	5870
		200	39.4	.444	6190
		300	41.0	.455	6420
		500	39.9	.476	6890
		1000	42.0	.516	8190
		2000	38.2	.523	8050
		Av.	40.0		

Sample No.	Consistence during formation per cent	Wet pressure lbs./sq. in.	Basis weight (24x36—500) pounds	Solid fraction	Ultimate tensile strength lbs./sq. in.
40e	0.023	2	55.8	0.178	1070
		5	56.5	.190	1170
		10	57.9	.210	1450
		20	55.7	.274	2380
		40	54.7	.347	3670
		80	53.1	.400	4910
		125	56.6	.445	5860
		200	56.1	.462	6390
		300	56.5	.493	7180
		500	55.0	.502	8290
		1000	54.1	.526	9300
		2000	55.7	.548	10190
		Av.	55.6		
40h	0.032	2	76.3	0.202	1300
		5	78.4	.179	1040
		7.5	79.4	.232	1540
		10	78.0	.273	2280
		15	78.8	.287	2340
		20	79.7	.315	2960
		25	77.4	.335	3070
		30	78.1	.352	3620
		40	79.1	.380	4030
		55	77.9	.403	4270
		75	79.2	.417	4790
		100	76.8	.447	5260
		150	77.9	.496	6620
		200	74.9	.512	7030
		300	80.0	.530	7540
		500	74.4	.540	8050
		1000	78.1	.561	8690
		2000	77.6	.600	9550
		Av.	78.0		
40f	0.048	2	120.7	.181	
		5	122.5	.194	
		10	125.3	.222	
		20	119.4	.272	
		40	117.8	.365	
		80	114.3	.425	
		125	117.6	.497	
		200	118.5	.525	
		300	118.0	.550	
		500	116.3	.579	
		1000	115.0	.613	
		2000	114.3	.630	
		Av.	118.3		

Sample No.	Consistence during formation per cent	Wet pressure lbs./sq. in.	Basis weight (24x36—500) pounds	Solid fraction	Ultimate tensile strength lbs./sq. in.
40c	0.062	2	146.9	0.180	922
		5	150.5	.185	934
		7.5	146.8	.192	1088
		10	151.9	.234	1640
		15	150.0	.264	1820
		20	149.9	.268	1940
		25	150.5	.315	2650
		30	141.6	.332	2860
		40	150.9	.343	3050
		55	153.3	.416	4190
		75	148.7	.425	4300
		100	151.7	.454	5060
		150	152.7	.528	6140
		200	151.7	.540	6550
		300	152.1	.556	7780
		500	140.7	.599	9480
		1000	151.4	.622	9000
		2000	148.3	.635	9310
		Av.	149.0		
40g	0.040	125	28.2	0.387	1900
	.020		28.9	.381	2400
	.010		26.8	.379	2530
	.072		50.3	.392	2270
	.036		51.5	.400	2310
	.018		51.6	.397	2400
	.144		100.0	.395	1730
	.072		99.0	.402	2050
	.036		101.0	.398	2100
	.288		199.0	.374	1430
	.140		194.0	.383	1880
	.070		191.0	.380	2030
	.550		369.0	.393	1210
	.275		385.0	.391	1390
	.137		394.0	.392	1530

[1] Pulp samples 39, 40a to f inclusive, and 40g were from three separate digestions numbered 3433, 3444, and 3476, respectively.

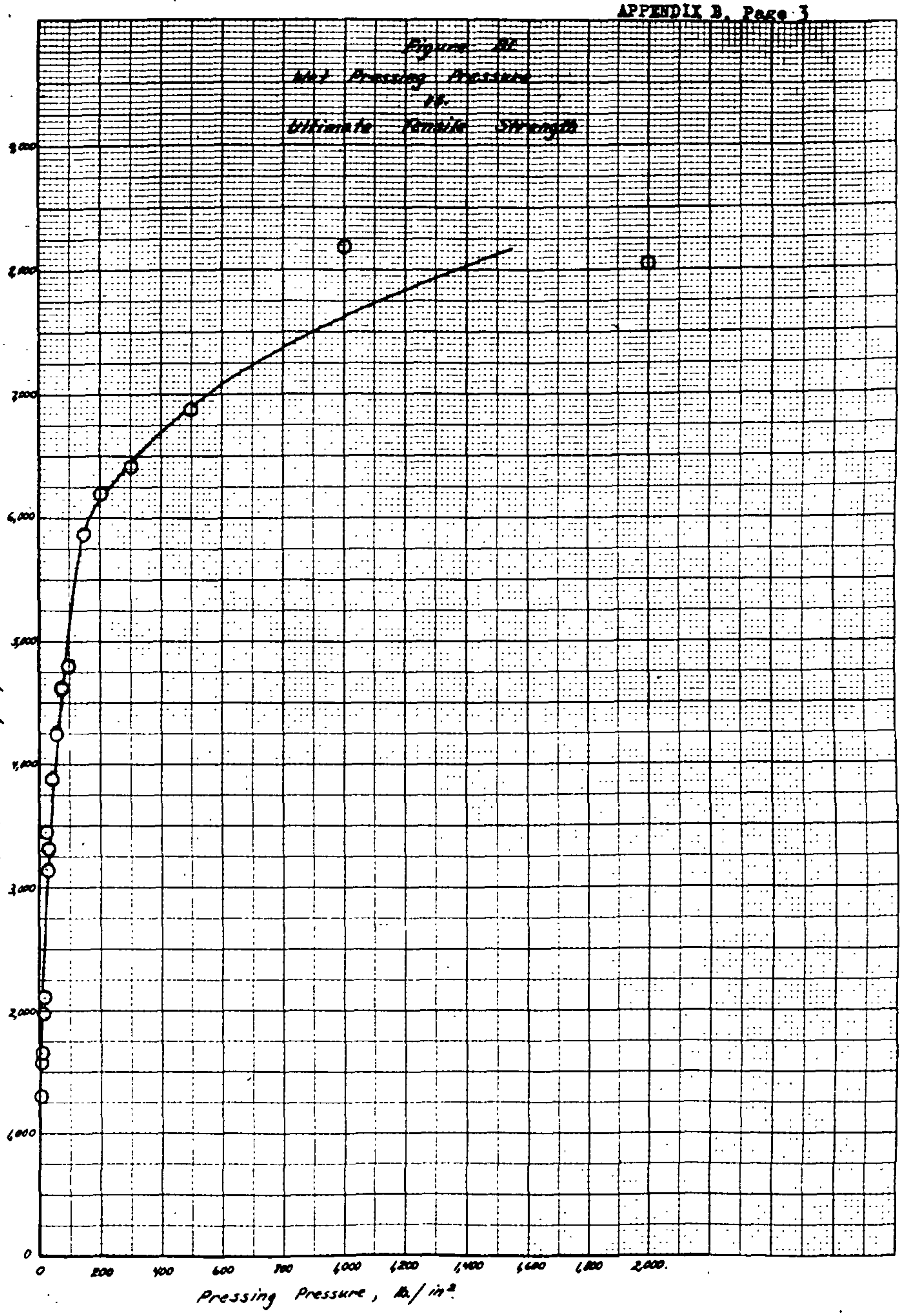
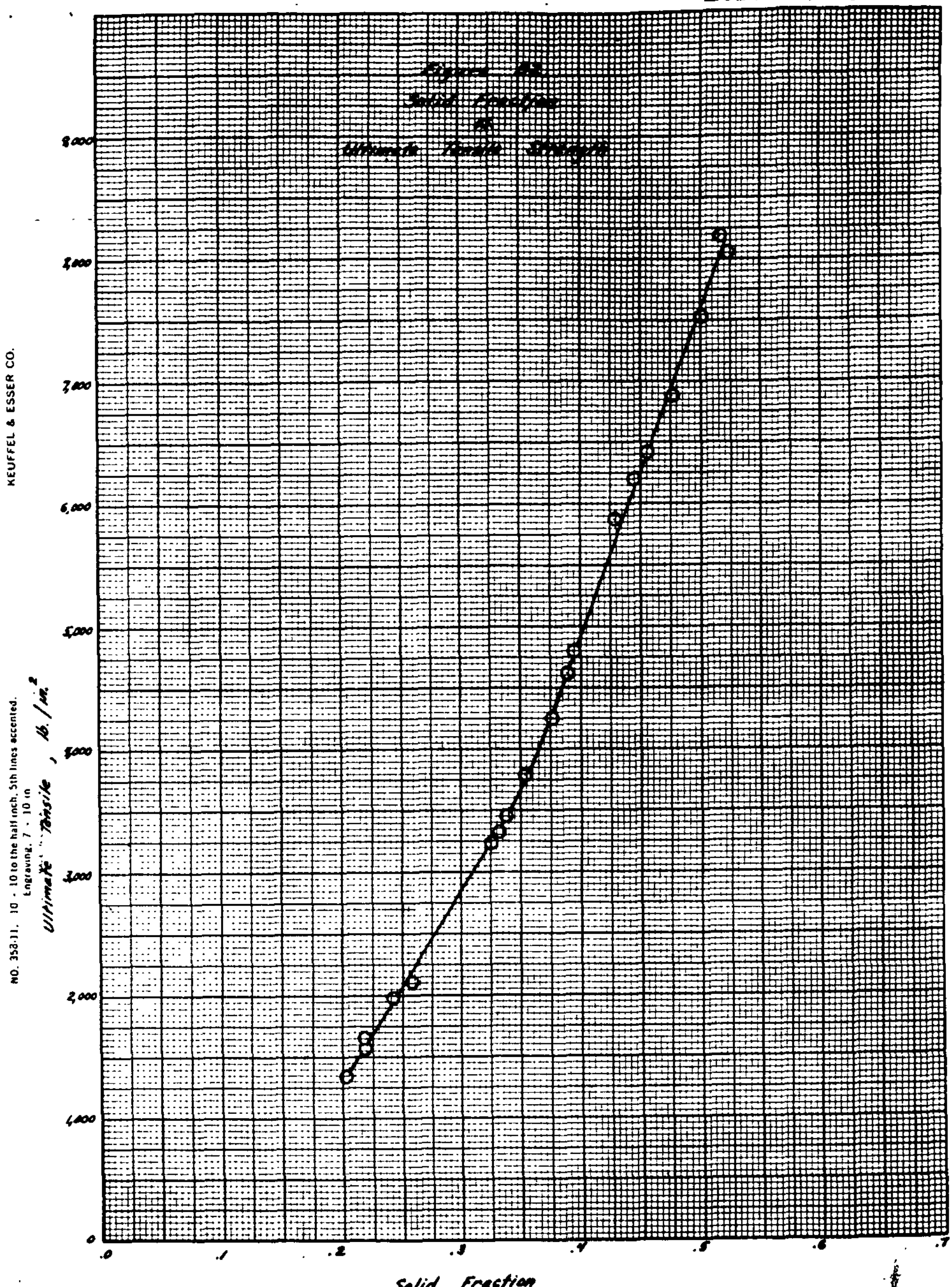
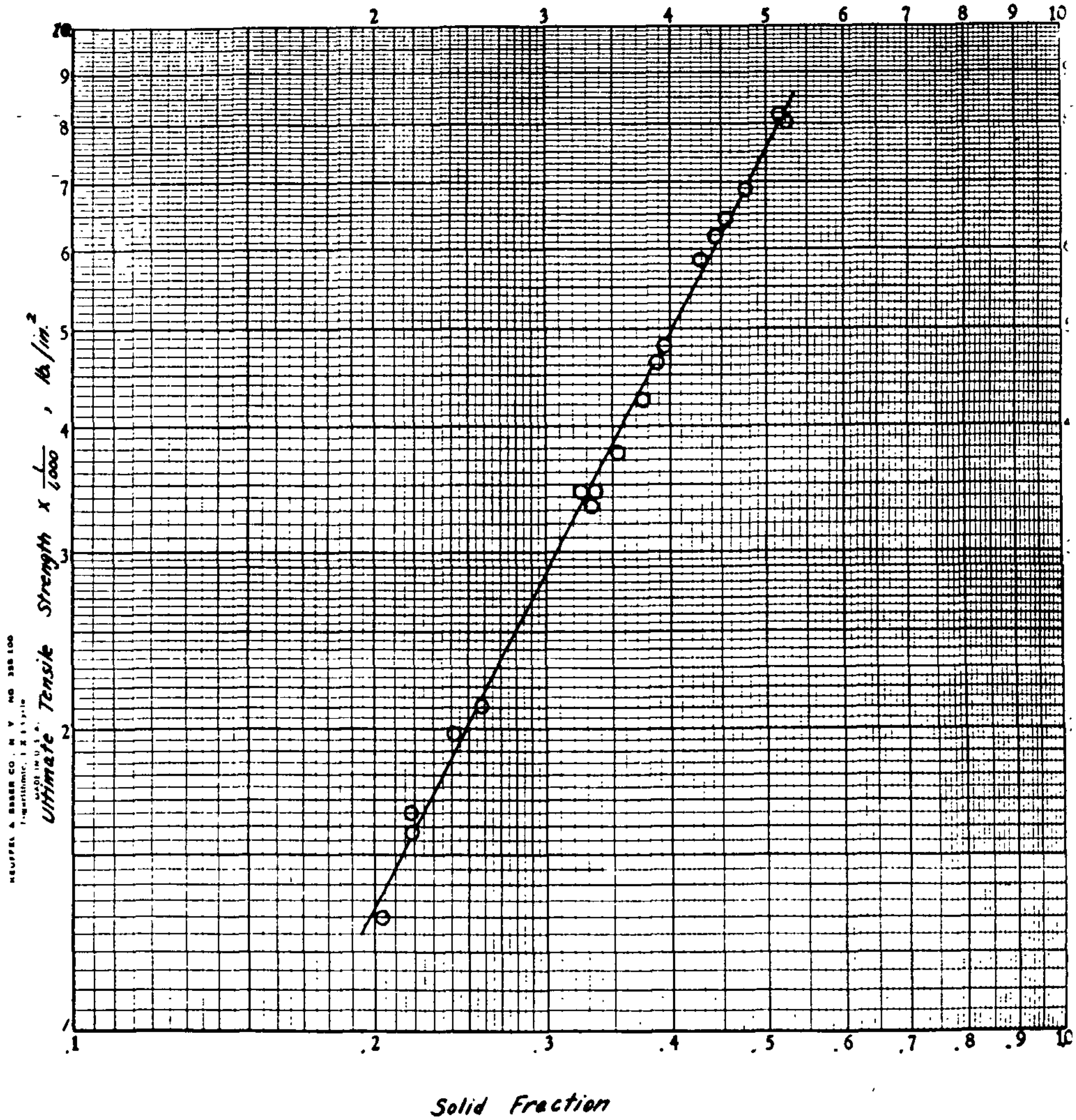


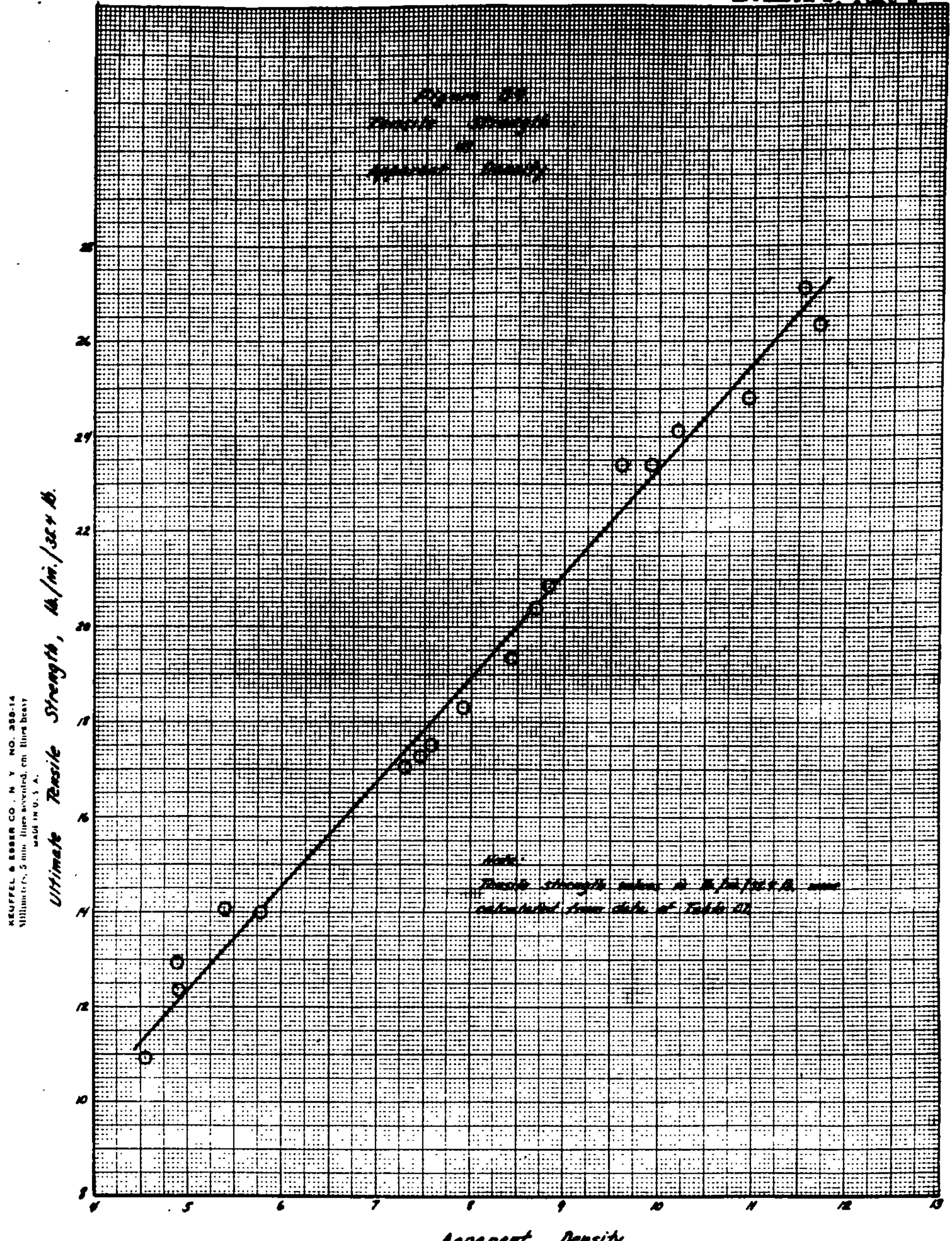
Figure BI
Wet Pressing Pressure
vs.
Ultimate Tensile Strength
Ultimate Tensile, lb/in.²
Pressing Pressure, lb./in.²
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000



Solid Fraction
Ultimate Tensile , lb./in.²
.0
.1
.2
.3
.4
.5
.6
.7
0
2,000
3,000
5,000
6,000
KEUFFEL & ESSER CO.
NO. 358-11. 10 - 10 to the half inch. 5th lines accented.
Engraving, 7 - 10 in

Figure B3.
Log Solid Fraction
vs.
Log Tensile Strength.




Ultimate Tensile Strength,
Apparent Density
4
5
6
7
8
9
10
11
12
13
10
12
14
16
18
20
22
24
26
Note:
KEUFFEL & ESSER CO., N. Y. NO. 358-14
Millimeters, 5 mm. lines accented, cm. lines heavy
MADE IN U. S. A.

APPENDIX C

VARIABLE WEIGHT STUDY

THILMANY UNBLEACHED KRAFT PULP

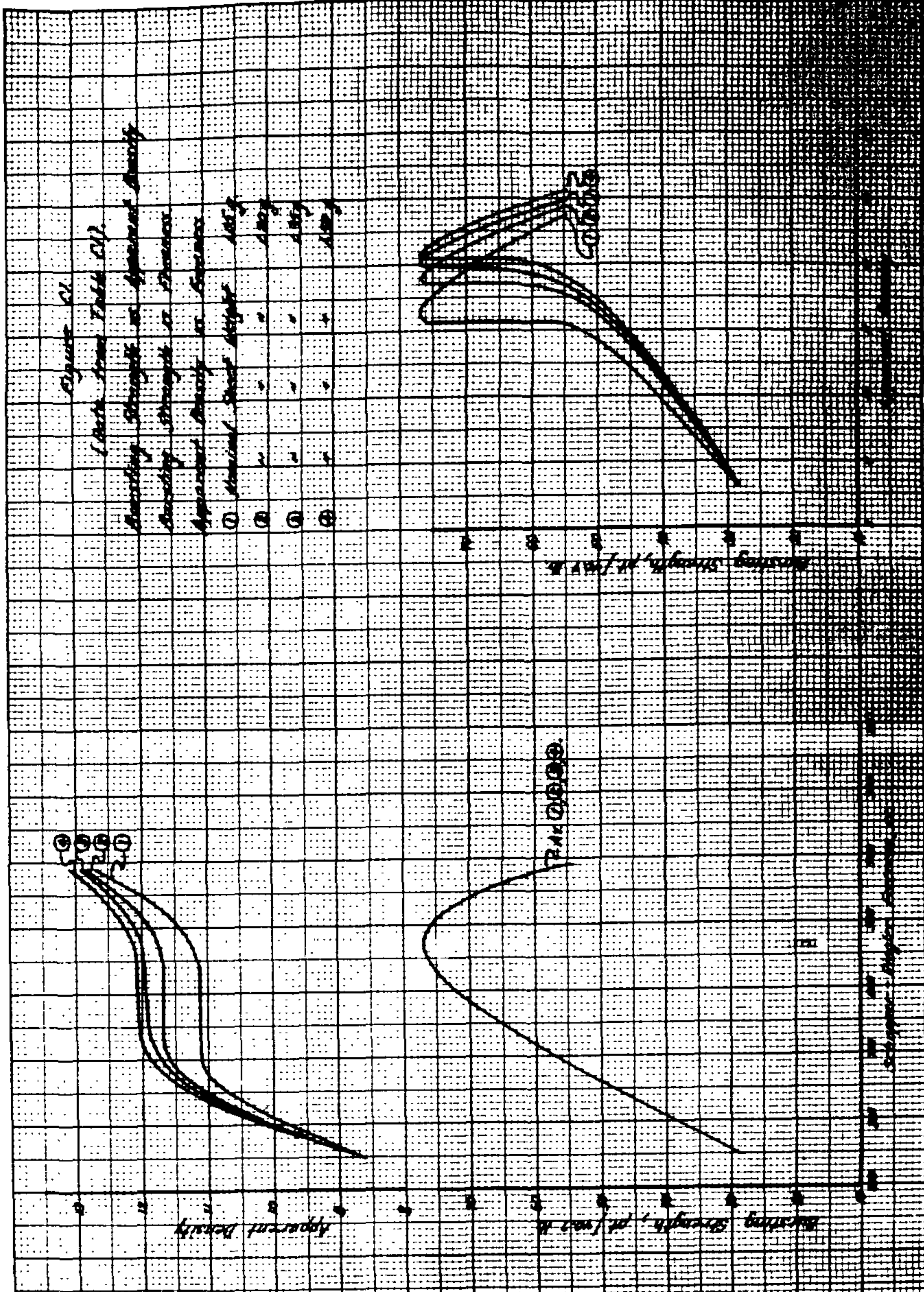
Freeness - Variable

TABLE C-1

VARIABLE WEIGHT STUDY
STRENGTH AND PHYSICAL CHARACTERISTICS OF STANDARD
PRESSED HANDSHEETS
(Pulp A - Thilmany Unbleached Kraft)

Nominal O.D. Wt., g.	Basis Weight, 24x36—480 lb.	Caliper, in.	Apparent Density	Mullen Burst, pt.	Mullen Burst, pt./40.7 lb.	Schopper Tensile lb./in.	Schopper Tensile lb./in./40.7 lb.	Elmendorf Tear, g./sheet	Tear g./sheet 40.7 lb
850 cc. Schopper-Riegler									
1.05	33.5	0.0038	8.8	23.3	28.3	15.5	18.8	81	98
1.20	37.7	0.0041	9.2	28.0	30.2	16.7	18.0	92	99
1.35	42.6	0.0050	8.5	29.7	28.7	18.7	17.9	116	111
1.50	48.0	0.0056	8.6	32.2	27.3	21.6	18.3	150	127
				Ave.	28.6	Ave.	18.25		
700 cc. Schopper-Riegler									
1.05	33.4	0.0030	11.1	46.0	56.0	27.0	32.9	43	52
1.20	38.2	0.0032	11.9	54.5	58.1	30.5	32.5	52	55
1.35	43.0	0.0037	11.6	59.4	56.2	35.8	33.9	59	56
1.50	47.6	0.0040	11.9	67.0	57.3	42.1	36.0	68	58
				Ave.	56.9				
535 cc. Schopper-Riegler									
1.05	33.6	0.0030	11.2	62.7	76.0	28.8	34.9	44	53
1.20	38.7	0.0033	11.7	73.5	77.3	31.4	33.1	52	55
1.35	43.3	0.0036	12.0	80.0	75.2	40.8	38.4	61	57
1.50	48.3	0.0040	12.1	92.0	Ave. 76.5 77.5	47.5	40.0	74	62
410 cc. Schopper-Riegler									
1.05	33.4	0.0026	12.8	43.1	52.5	23.8	29.0	33	40
1.20	38.3	0.0030	12.8	50.5	53.6	29.8	31.7	40	43
1.35	43.2	0.0034	12.7	58.9	55.4	36.5	34.3	49	46
1.50	48.5	0.0037	13.1	66.2	55.5	41.2	34.5	57	48
				Ave.	54.2				

Average basis weight of handsheets 40.7 lb., 24x36—480


Apparent Density

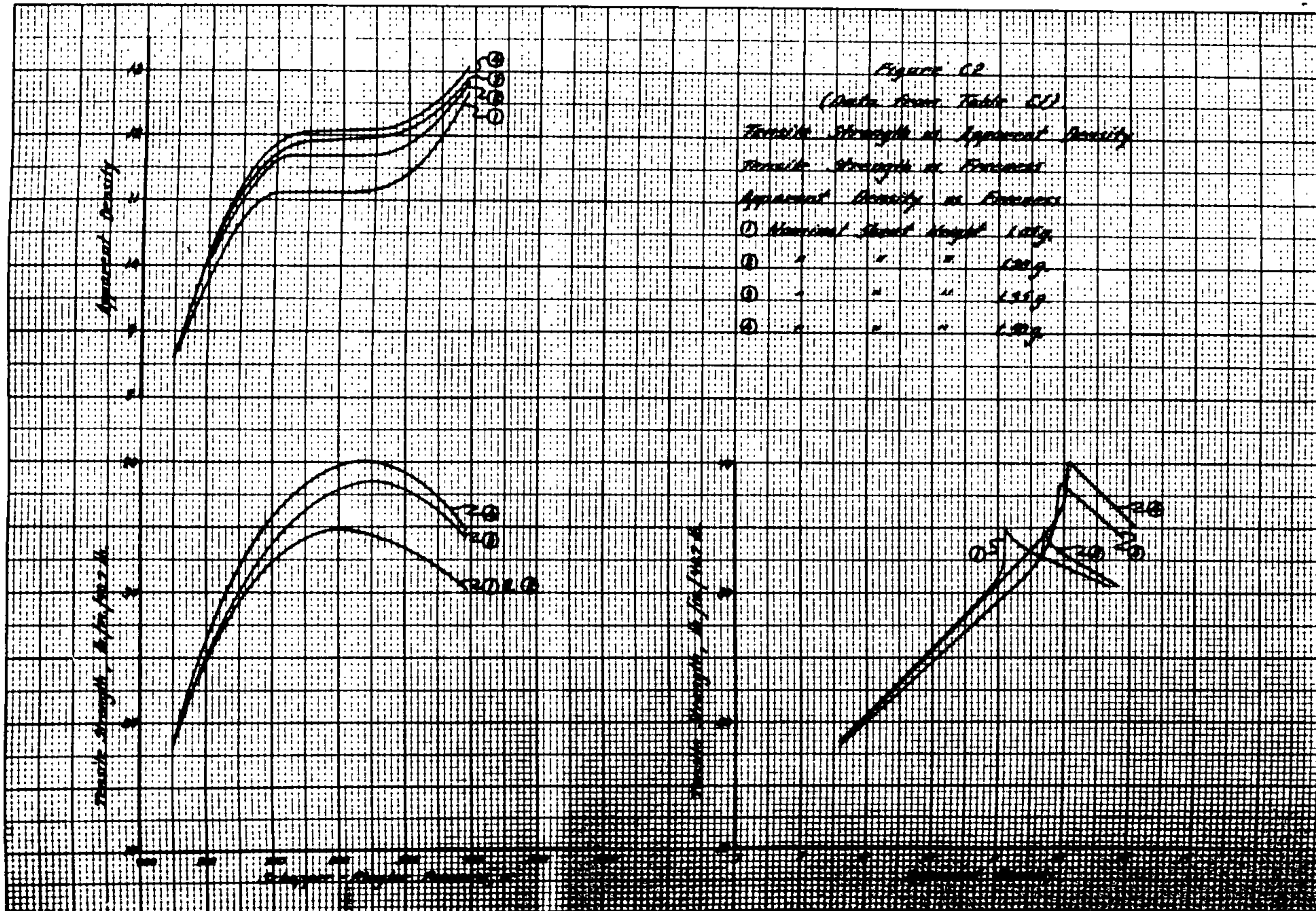


Figure C2
(Data from Table C1)
Tensile Strength vs Apparent Density
Tensile Strength vs Freeness
Apparent Density vs Freeness
① Nominal Sheet Weight
Apparent Density
Tensile Strength

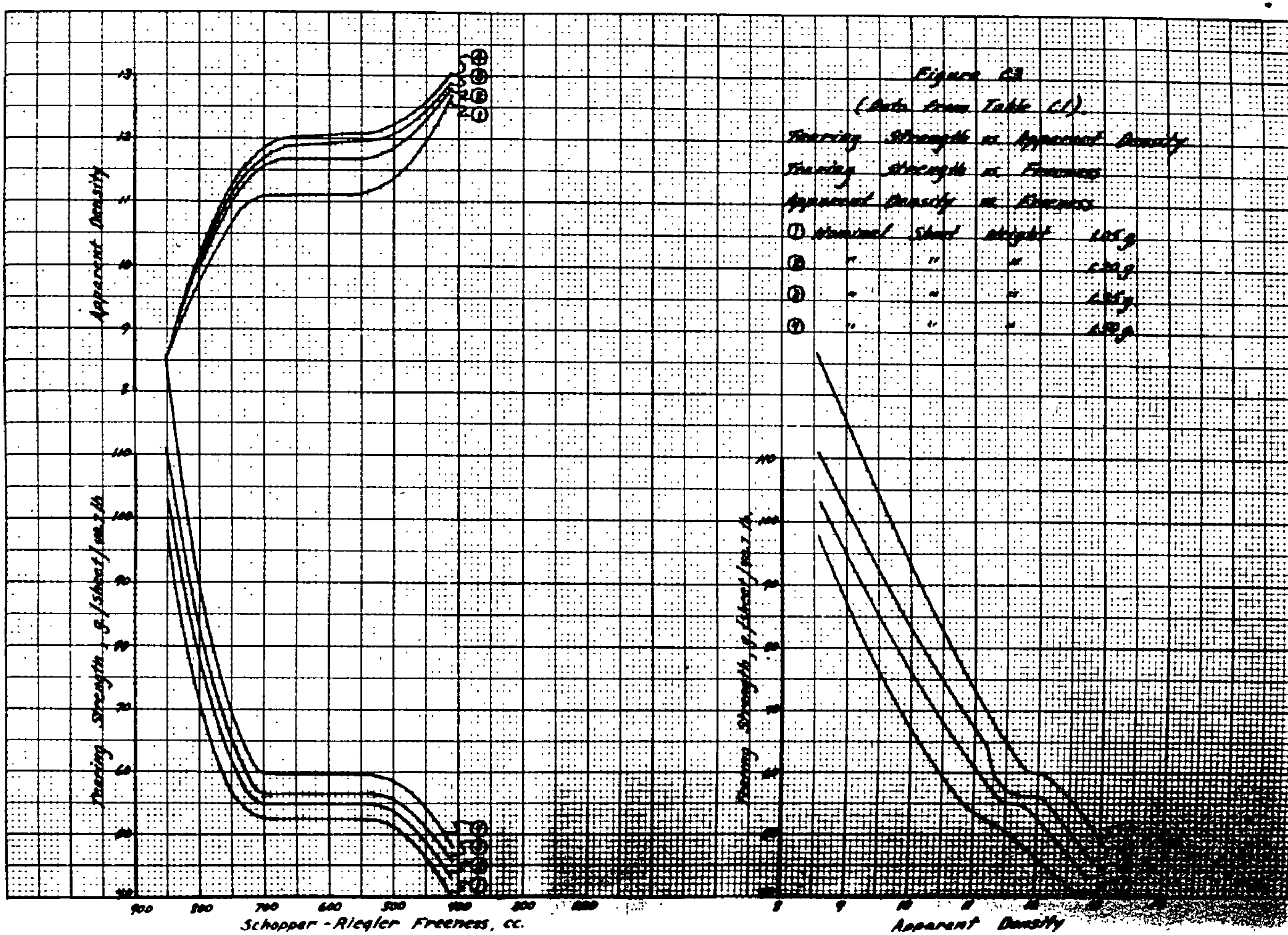


Figure C3
(Data from Table C1)
Tearing Strength vs Apparent Density
Tearing Strength vs Freeness
Apparent Density vs Freeness
Nominal Sheet Weight
Apparent Density
Tearing Strength
Schopper-Riegler Freeness, cc.
Apparent Density

PROJECT REPORT FORM

PROJECT NO. 1102-13
COOPERATOR Institute
REPORT NO. 3
DATE June 26, 1950
NOTE BOOK 607
PAGE 76 TO 77
SIGNED F. Kottwitz

E. Madison

CC: Files
Dr. Forman
Mr. MacLaurin
Mr. Kottwitz
Mr. Madison

"EFFECT OF CALENDERING ON HANDSHEET PROPERTIES"

OBJECTIVE

Reports number one and two of this project covered the findings from a study of the influence of basis weight and wet pressing in the evaluation of handsheets. This report summarizes a similar study of the influence of dry pressing (calendering).

RAW MATERIAL

Union Bag & Paper Corporation - unbleached kraft, 565 cc. Schopper-Riegler freeness. The pulp was taken from the same lot cited in Reports one and two above.

EXPERIMENTAL

A series of British handsheets of nominal weights 1.05, 1.20, 1.35, and 1.50 g. ovendry were prepared according to Institute methods. These were trimmed to the largest possible square sheet and calendered (cold) on the pulping laboratory laminating machine. Sheets from each set of the weight series were calendered seperately: one light pressure pass (1LPP), one medium pressure pass (1MPP), and six medium pressure passes (6MPP). Equipment was not available for determining calender nip or roll pressures. Uncalendered sheets were used as a base line for comparison.

FORM 73

THE INSTITUTE OF PAPER CHEMISTRY

RESULTS

Results of the effect of various degrees of calendering are given in Table I. Within the range of calendering studied the following are indicated:

1. For sheets of basis weight 33.7 and 38.6 lb., 24x36--480 lb. ream, calendering produced a significant increase in tensile strength which passed through a maximum as the degree of calendering was increased.

For basis weights of 43.8 and 48.5 significant improvement of tensile strength was not obtained.

2. Slight improvement of tear factor was realized by light calendering. Heavier calendering produced a decrease in this property.

3. Both apparent density and low angle gloss values were increased by increased calendering.

FK/jh

TABLE I

EFFECT OF LABORATORY CALENDERING ON HANDSHEET TESTS

Calendering	Bursting Strength, pt./100 lb.	Schopper Tensile Strength, lb./in./100 lb.	Tear Factor	Apparent Density	Low Angle Gloss
		(Basis Weight 33.7 lb.)			
None	187	85.7	1.31	11.2	4
1LPP*	188	93.2	1.31	12.0	4
1MPP*	182	98.5	1.12	13.0	5
6MPP*	174	95.6	1.21	14.1	9
		(Basis Weight 38.6 lb.)			
None	190	81.1	1.34	11.7	4
1LPP	187	96.2	1.42	12.7	5
1MPP	189	90.6	1.20	12.7	5
6MPP	174	89.7	1.13	14.1	9
		(Basis Weight 43.8 lb.)			
None	185	94.2	1.41	12.0	4
1LPP	198	94.1	1.45	12.6	5
1MPP	186	97.9	1.45	13.2	6
6MPP	178	95.2	1.47	14.2	10
		(Basis Weight 48.5 lb.)			
None	190	98.3	1.53	12.1	4
1LPP	191	87.2	1.56	12.8	5
1MPP	189	87.0	1.43	13.4	5
6MPP	189	80.7	1.44	13.9	10

* 1 light pressure pass
1 medium pressure pass
6 medium pressure passes

NOTE: Basis weight figures are in lb. 24x36—480 ream.
Data from Code Office reports No. 137829 to 137844, inclusive.

PROJECT REPORT FORM

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PROJECT NO. 1102-13
COOPERATOR I.P.C.
REPORT NO. 4
DATE September 2, 1958
NOTE BOOK Calibration Book No. 8*
PAGE 225 TO 226
SIGNED R Gertz
R. Gertz

L Dearth
L. Dearth

COMPARISON OF LOW ANGLE GLOSSMETER AND MODIFIED BAUSCH AND LOMB GLOSSMETER

In obtaining the gloss readings for the samples used, it was found that there was an appreciable difference in the results from the two glossmeters. The Bausch and Lomb, which had been modified from the original instrument, showed much higher gloss readings on every sample excepting one.

Being an instrument of good resolution, the Low Angle Glossmeter had to have something to hold the samples flat, so that accurate readings could be taken. A Porous Bronze Plate connected to a vacuum pump was used to hold the samples flat.

The readings were taken on both Glossmeters to the nearest half unit and are listed below in Table I. Most of the gloss readings for the Black and Yellow samples were over 100 as obtained on the B and L Glossmeter. These readings are shown in Table I as "100+."

* Paper Evaluation Humidity Room

TABLE I

Sample	Low Angle Glossmeter					Ave.	B and L Glossmeter					Ave.
7	46.0	46.0	47.5	42.5	44.0	45.2	79.0	78.0	79.0	78.0	78.5	78.5
5	60.0	60.0	60.0	61.5	62.0	60.7	76.5	76.0	75.5	76.5	76.0	76.1
4	76.0	76.5	75.0	78.0	77.0	76.5	78.0	78.0	77.5	78.0	78.0	77.9
1	76.0	76.5	76.5	73.0	77.0	75.8	98.0	99.0	97.5	97.5	97.0	97.8
6	59.0	55.5	57.0	56.5	58.5	57.3	78.0	78.0	77.5	78.5	78.0	78.0
3	73.0	71.0	66.5	70.5	73.0	70.8	77.5	78.5	77.5	77.5	79.5	78.1
Creme	69.0	71.5	69.5	71.0	70.0	70.2	98.5	100.0	99.5	100.0	99.0	99.4
Yellow	82.5	82.0	84.0	79.5	82.5	82.1	100+	99.5	100.0	100+	100+	100+
Red	81.5	84.0	79.5	77.0	79.0	80.2	98.5	97.5	98.0	98.0	98.5	98.1
Blue	71.5	70.0	79.0	83.0	76.0	75.9	97.5	98.5	99.5	98.5	99.0	98.6
Black	81.5	75.0	77.0	77.5	74.5	77.1	100+	100+	100+	100+	100+	100+
Green	72.5	71.0	76.0	68.5	70.0	71.6	99.0	98.5	99.0	100.0	99.5	99.2

rg/ld/st

PROJECT REPORT FORM

PROJECT NO. 1102-13
COOPERATOR Institute
REPORT NO. 5
DATE September 12, 1958
NOTE BOOK Calibration Book No. 8
PAGE 229 to 232
SIGNED R. Gertz
R. Gertz
L. Dearth
L. Dearth

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COMPARISON OF LOW ANGLE GLOSSMETER AND MODIFIED BAUSCH AND LOMB GLOSSMETER

In order to compare the Low Angle Glossmeter and the Modified Bausch and Lomb Glossmeter more closely, more readings were taken from samples of a wider gloss range. With the exception of a few low gloss samples under one point on the Low Angle Glossmeter, the Bausch and Lomb showed much higher gloss readings than did the Low Angle Glossmeter. In regard to these low gloss samples, the Bausch and Lomb readings were still higher than the Low Angle readings, but their differences were comparatively smaller than the higher gloss samples, as shown in Table II.

The samples were read in both the "in" and "across" machine directions and read to the nearest half unit and are listed below in Tables I and II.

* Paper Evaluation Humidity Room

rg/ld/mk

[illegible]

TABLE II

	SAMPLE 42				SAMPLE 43				SAMPLE 33			
	LA In	B. & L. In	LA Across	B. & L. Across	LA In	B. & L. In	LA Across	B. & L. Across	LA In	B. & L. In	LA Across	B. & L. Across
Average	6.40	40.50	6.80	39.60	6.51	39.38	6.36	37.60	10.90	62.65	13.30	63.10
Difference	33.75		32.80		32.97		31.36		57.05		48.00	

	SAMPLE 36				SAMPLE 64				SAMPLE 63			
	LA In	B. & L. In	LA Across	B. & L. Across	LA In	B. & L. In	LA Across	B. & L. Across	LA In	B. & L. In	LA Across	B. & L. Across
Average	12.80	58.40	11.83	58.60	18.52	62.90	13.43	58.30	19.05	63.90	17.30	60.40
Difference	46.00		46.63		41.70		42.75		44.85		40.35	

	SAMPLE 38				SAMPLE 37				SAMPLE 4			
	LA In	B. & L. In	LA Across	B. & L. Across	LA In	B. & L. In	LA Across	B. & L. Across*	LA In	B. & L. In	LA Across	B. & L. Across
Average	16.40	58.35	9.95	49.70	16.05	49.30	9.30	46.30	6.70	16.50	6.73	9.20
Difference	39.90		38.40		33.30		37.40		10.11		5.40	

	SAMPLE 2				SAMPLE C				SAMPLE B			
Average	7.46	27.30	7.35	27.00	0.37	4.10	0.36	5.10	5.76	38.10	5.33	36.00
Difference	19.84		20.45		3.73		4.74		32.34		30.67	

	SAMPLE E				SAMPLE F				SAMPLE 35-FINES			
Average	2.16	14.30	2.06	13.30	[illegible]	36.90	43.90	81.30	37.90	84.00	36.00	86.00
Difference	12.14		11.40		36.90		37.70		46.90		49.40	

	SAMPLE 35-FINES				SAMPLE 7		SAMPLE 3		SAMPLE 5		SAMPLE 1	
Average	40.30	80.40	46.30	80.70	56.2	79.5	60.7	76.2	76.0	77.9	73.0	97.0
Difference	31.30		38.80		23.3		16.4		1.4		12.0	

	SAMPLE 6		SAMPLE 3		SAMPLE GREEN		SAMPLE YELLOW		SAMPLE RED		SAMPLE BLUE	
Average	57.3	75.0	70.5	75.1	70.2	99.4	82.1	100+	80.2	98.1	75.9	98.6
Difference	20.7		7.3		29.0		17.9+		17.9		22.7	

	SAMPLE BLACK		SAMPLE GREEN		CALENDERED TYPE 1 FT. COATED				PHOTOCOPY SAFT COATED			
Average	77.1	100+	71.6	99.2	25.53	72.40	41.30	79.90	75.70	78.10	40.90	39.00
Difference	22.9+		27.6		46.30		38.60		2.40		5.90	

PROJECT REPORT FORM

PROJECT NO.	1102-13
COOPERATOR	Institute
REPORT NO.	Six
DATE	April 15, 1968
NOTE BOOK	None
PAGE	TO
SIGNED	Roger H. Van Eperen

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THE EFFECT OF RESTRAINED AND UNRESTRAINED DRYING ON THE PHYSICAL PROPERTIES OF HANDSHEETS PREPARED FROM THREE HARDWOOD PULPS

INTRODUCTION

This study was undertaken to determine the effect of restrained (ring-dried) and unrestrained drying on the physical properties of handsheets. Three hardwood pulps (Institute File No. 68-70068/070) obtained from Dr. Ferdinand Kraft in a study for Western Kraft Corporation were identified as:

Pulp Sample Code	Company Identification
1	Sample 9 - Bleached, Mixed Hardwood (Experimental)
2	Sample 10 - Commercial Pulp (Hardwood)
3	Sample 12 - Commercial Pulp (Hardwood)

Additional data on species identifications and on standard beater evaluations for the three pulps can be found under Institute File No. 67-72588/589, 68-70884/885 and 68-70886/887 (the latter two to be completed in the near future) for Pulp Samples 1, 2 and 3, respectively.

The pulps were beaten to four levels and handsheets were prepared at each level. Half of these were dried under restraint on rings and the other half "floated" on sand so they could dry without external restraint. The freeness at each beating level, the shrinkage of the unrestrained sheets, and the basis weight, thickness, density, tensile breaking length, stretch, tensile energy absorption, tensile stiffness, opacity, specific scattering coefficient, in-plane tearing energy, air permeability, and hygroexpansivity of the handsheets dried with and without restraint are given in this report.

The purpose of this report is only to report the data; therefore, no attempt is made to analyze the relative merits of the two drying procedures or the reasons for any differences in the handsheet properties. However, appropriate comments pointing out the differences in the properties of the handsheets dried with and without retraint are given.

HANDSHEET PREPARATION

PULP PREPARATION

The dry-lap pulp was soaked in water for the required minimum of four hours, disintegrated and beaten in a Valley beater in accord with TAPPI Method T 200 ts-66. For each sample twenty-five grams of pulp (moisture-free basis) was withdrawn from the beater before beating and after beating intervals of 5, 15 and 25 minutes. The pulp was cleared in the standard disintegrator for 15000 revolutions in two lots of 12.5 grams each. The two lots were then recombined and mixed thoroughly.

SHEET FORMING AND COUCHING

The handsheets were formed in a sheet machine as described in TAPPI Method T 205 m-58. As an aid to achieving optimum formation of the handsheets, the drain cock of the sheet machine was opened immediately after stirring.

It is known from past studies that the differential expansion characteristics of the couch material are partially imparted to the handsheet. To eliminate this effect the handsheets, after forming, were covered first with two premoistened Whatman No. 1 filter papers and then with a dry blotter for couching. It is also known that the couch direction will impart a directionality to the handsheets. The handsheets were marked so that the couch direction could be identified for subsequent testing. Two sets of handsheets were prepared as described above, Set 1 to be dried under restraint in standard drying rings and Set 2 to be dried without external restraint.

WET PRESSING

The handsheets of Set 1 were wet-pressed twice at 50 p.s.i., first for 5 minutes and then for 2 minutes. For each pressing the handsheets were pressed in a sandwich comprised of a dry blotter, the two couch filter papers, the handsheet, and a mirror-polished disc.

The handsheets of Set 2 were wet-pressed once at 50 p.s.i. for 5 minutes. For this pressing the handsheets were pressed in a sandwich comprised of a dry blotter, the two premoistened couch filter papers, the handsheet, two premoistened filter papers, and a dry blotter.

DRYING

The handsheets of Set 1 were dried in standard drying rings at 10% R.H. and 23°C. Only the mirror-polished discs were left intact with the handsheets during drying.

The handsheets of Set 2 were placed on a level layer of Ottawa sand (screened to pass a 20 mesh and be retained on a 30-mesh screen) in a room controlled at

98.5% R.H. and 23°C. The sand permitted the handsheets to shrink freely without adhering to the supporting surface. After allowing several days for the handsheets to come to equilibrium with this condition, the moisture content of several sheets was measured and found to be about 50% on the airdry basis. The relative humidity of the room was then slowly lowered over a period of five days, after which the handsheets had a measured moisture content of about 18% on the airdry basis. The handsheets developed some waviness during this drying. This waviness was effectively removed by pressing the handsheets at 1000 p.s.i. while at 18% moisture content. For this pressing the handsheets were sandwiched between four Whatman No. 1 filter papers which had been conditioned in the same environment. Following this pressing, the handsheets were conditioned to equilibrium in the 10% R.H., 23°C. environment.

TESTING PROCEDURES

Shrinkage was measured and the specimens for the remaining tests were cut in the 10% R.H., 23°C. atmosphere. Except for the specimens intended for the measurement of hygroexpansivity, all specimens were then conditioned and tested in a 50% R.H., 23°C. atmosphere. Where applicable, the tests were performed in accord with TAPPI Method T 220 m-60.

SHRINKAGE

The shrinkages of the Set 2 handsheets (those dried without restraint) were determined at 10% R.H. and 23°C. with a steel rule (graduated to the nearest 0.01 inch) using a magnification of about 3X. The diameters, parallel with and perpendicular to the direction of couching, were measured and the differences in dimension relative to the diameter of the sheet mold were computed as percent shrinkages.

LOAD-ELONGATION CHARACTERISTICS

Load-elongation relationships were obtained at a crosshead speed of 2.54 cm./min. for specimens 10 cm. long and 2.54 cm. wide. The long dimension of the specimen was parallel with the couch direction of the handsheet. The tensile strength (computed as breaking length), stretch, tensile energy absorption and tensile stiffness were determined from the load-elongation relationships. The latter two properties were normalized for a sheet having a basis weight of 60 g./sq. m. (ovendry) assuming a linear relationship.

OPACITY AND SPECIFIC SCATTERING COEFFICIENT

The opacity and the reflectances required for determining the specific scattering coefficient were measured with a Bausch and Lomb Opacimeter in accord with TAPPI Method T 425 m-60. The opacity values were normalized for a sheet having a basis weight of 60 g./sq. m. using the Kubelka and Munk charts.

IN-PLANE TEAR

The in-plane tear was determined in accord with a procedure described by Van den Akker, Wink and Van Eperen, Tappi 50, no. 9:466-70(Sept. 1967). The total tearing angle was 12 degrees; the tearing distance, 5 cm.; and the initial distance between clamps, 5 cm. The direction of the line of tear was perpendicular to the couch direction of the handsheets. The in-plane tear results were normalized for a sheet having a basis weight of 60 g./sq. m. assuming a linear relationship.

AIR PERMEABILITY

The air permeability was measured with a Bendtsen instrument over a 10 sq. cm. area, using a pressure gradient across the specimen corresponding to 150 mm. of water.

HYGROEXPANSIVITY

The specimens used for the measurement of hydroexpansivity were transferred directly from the 10% R.H. environment to the test chamber of a Neenah expansimeter. Hygroexpansivity was determined for subsequent exposures to relative humidities of 11.1, 48.6, 75.5, 92.9, 75.5, 48.6 and 11.1%. The tests were performed in a direction parallel with the couch direction of the handsheets.

TEST RESULTS

The average test results are given in Table I. All of the results for each test are grouped for convenience in inspecting the effects of drying conditions and beating on any one property of the handsheets.

The hydroexpansivity results in Table I are summaries of the expansion for a relative humidity change from 11.1 to 92.9%, and the contraction for a relative humidity change from 92.9 to 11.1%. The change in length that occurred at 11.1% R.H. after exposure to 92.9% R.H. is also given. The hygroexpansivity results for each step in relative humidity and for the individual specimens are given in Table II. A plot of the change in length as a function of relative humidity for the handsheets prepared from the unbeaten pulp and the pulp beaten for 25 minutes is given in Figures 1, 2 and 3 for Pulp Samples 1, 2 and 3, respectively.

TABLE I

PHYSICAL TEST DATA FOR HANDSHEETS DRIED UNDER RESTRAINED AND UNRESTRAINED CONDITIONS

Beating time, min.	0	5	15	25
Canadian standard freeness, cc.				
Pulp Sample 1	540	470	345	200
Pulp Sample 2	555	470	435	280
Pulp Sample 3	565	475	430	330
Basis weight, g./sq. m. (oven dry)				
Pulp Sample 1, restrained drying	59.3	60.5	59.1	60.1
unrestrained drying	60.0	61.6	59.8	62.2
Pulp Sample 2, restrained drying	61.0	60.6	60.0	61.0
unrestrained drying	61.8	61.4	62.4	63.3
Pulp Sample 3, restrained drying	60.0	60.3	61.5	61.1
unrestrained drying	60.8	61.6	64.2	63.8
Shrinkage of unrestrained handsheets upon drying to 10% R.H., 23°C., %				
Pulp Sample 1, in couch direction	1.2	2.3	3.4	4.8
across couch direction	1.3	2.3	3.2	4.5
Pulp Sample 2, in couch direction	1.0	1.5	2.1	3.2
across couch direction	1.0	1.5	1.9	3.1
Pulp Sample 3, in couch direction	1.0	1.9	2.6	3.2
across couch direction	1.3	1.8	2.6	3.1
Thickness, microns				
Pulp Sample 1, restrained drying	132	114	104	96
unrestrained drying	107	109	107	107
Pulp Sample 2, restrained drying	117	104	96	91
unrestrained drying	99	99	96	99
Pulp Sample 3, restrained drying	107	99	94	89
unrestrained drying	99	99	99	96

TABLE I (continued)

PHYSICAL TEST DATA FOR HANDSHEETS DRIED UNDER RESTRAINED AND UNRESTRAINED CONDITIONS

Beating time, min.	0	5	15	25
Density, g./cc.				
Pulp Sample 1, restrained drying	0.45	0.53	0.57	0.62
unrestrained drying	0.56	0.56	0.56	0.58
Pulp Sample 2, restrained drying	0.52	0.58	0.62	0.67
unrestrained drying	0.62	0.62	0.65	0.64
Pulp Sample 3, restrained drying	0.56	0.61	0.65	0.69
unrestrained drying	0.61	0.62	0.65	0.66
Tensile breaking length, m.				
Pulp Sample 1, restrained drying	2270	4590	5770	7130
unrestrained drying	2010	3700	4990	6080
Pulp Sample 2, restrained drying	1960	3430	5090	6480
unrestrained drying	1860	3080	4380	5660
Pulp Sample 3, restrained drying	3440	5670	7260	8130
unrestrained drying	3180	4820	6020	7090
Stretch, %				
Pulp Sample 1, restrained drying	1.0	2.2	2.6	3.2
unrestrained drying	1.8	3.8	5.5	7.3
Pulp Sample 2, restrained drying	0.8	1.3	1.9	2.7
unrestrained drying	1.4	2.4	3.7	5.0
Pulp Sample 3, restrained drying	1.2	1.9	2.4	2.5
unrestrained drying	2.2	3.5	4.4	5.4
Tensile energy absorption, g.-cm./sq. cm.				
Pulp Sample 1, restrained drying	9.5	43.8	65.7	98.5
unrestrained drying	15.2	59.6	112	177
Pulp Sample 2, restrained drying	6.2	19.0	41.5	70.3
unrestrained drying	10.0	30.5	65.2	116
Pulp Sample 3, restrained drying	16.5	44.9	73.6	84.6
unrestrained drying	27.8	67.4	103	146

TABLE I (continued)

PHYSICAL TEST DATA FOR HANDSHEETS DRIED UNDER
RESTRAINED AND UNRESTRAINED CONDITIONS

Beating time, min.		0	5	15	25
Tensile stiffness, kg./cm.					
Pulp Sample 1,	restrained drying	270	369	431	469
	unrestrained drying	170	220	245	261
Pulp Sample 2,	restrained drying	251	347	415	462
	unrestrained drying	165	218	252	277
Pulp Sample 3,	restrained drying	372	467	528	531
	unrestrained drying	235	267	293	311
Opacity, %					
Pulp Sample 1,	restrained drying	83.8	81.3	80.0	78.6
	unrestrained drying	83.5	81.5	80.4	78.2
Pulp Sample 2,	restrained drying	83.3	82.1	79.7	78.2
	unrestrained drying	83.1	81.7	79.0	76.8
Pulp Sample 3,	restrained drying	79.6	77.3	74.8	73.6
	unrestrained drying	79.1	77.3	74.5	72.2
Specific scattering coefficient, sq. cm./g.					
Pulp Sample 1,	restrained drying	530	445	433	389
	unrestrained drying	518	453	431	379
Pulp Sample 2,	restrained drying	523	477	427	390
	unrestrained drying	508	459	410	365
Pulp Sample 3,	restrained drying	427	375	340	321
	unrestrained drying	408	370	330	301
In-plane tear, g. cm. (for 5 cm. tearing length)					
Pulp Sample 1,	restrained drying	117	219	283	329
	unrestrained drying	108	229	328	440
Pulp Sample 2,	restrained drying	107	162	214	247
	unrestrained drying	94	164	219	286
Pulp Sample 3,	restrained drying	217	284	308	311
	unrestrained drying	207	294	329	[illegible]

TABLE I (continued)

PHYSICAL TEST DATA FOR HANDSHEETS DRIED UNDER RESTRAINED AND UNRESTRAINED CONDITIONS

Beating time, min.	0	5	15	25
Bendtsen air permeability, ml./min.				
Pulp Sample 1, restrained drying	3190+	2270	1030	226
unrestrained drying	2410	1400	596	161
Pulp Sample 2, restrained drying	2440	1240	605	154
unrestrained drying	1130	612	277	110
Pulp Sample 3, restrained drying	2050	1040	377	151
unrestrained drying	1050	592	223	84
Hygroexpansivity, % expansion for relative humidity change of 11.1 to 92.9%				
Pulp Sample 1, restrained drying	0.321	0.330	0.365	0.400
unrestrained drying	0.967	1.247	1.463	1.788
Pulp Sample 2, restrained drying	0.346	0.332	0.294	0.501
unrestrained drying	0.936	1.117	1.220	1.454
Pulp Sample 3, restrained drying	0.359	0.417	0.451	0.452
unrestrained drying	0.981	1.231	1.345	1.501
Hygroexpansivity, % contraction for relative humidity change of 92.9 to 11.1%				
Pulp Sample 1, restrained drying	0.517	0.637	0.737	0.798
unrestrained drying	0.751	1.072	1.307	1.691
Pulp Sample 2, restrained drying	0.599	0.667	0.692	0.822
unrestrained drying	0.781	0.947	1.135	1.396
Pulp Sample 3, restrained drying	0.573	0.685	0.716	0.765
unrestrained drying	0.821	1.044	1.230	1.432
Hygroexpansivity, % expansion for relative humidity change of 11.1 to 92.9 to 11.1%				
Pulp Sample 1, restrained drying	-0.196	-0.307	-0.372	-0.398
unrestrained drying	0.216	0.175	0.156	0.097
Pulp Sample 2, restrained drying	-0.253	-0.335	-0.398	-0.321
unrestrained drying	0.155	0.170	0.085	0.058
Pulp Sample 3, restrained drying	-0.214	-0.268	-0.265	-0.313
unrestrained drying	0.161	0.187	0.115	0.069

TABLE II

HYGROEXPANSIVITY, %, OF HANDSHEETS UNDER RESTRAINED AND UNRESTRAINED DRYING CONDITIONS

Relative Humidity, %	Beating Time, min.				Beating Time, min.			
	0	5	15	25	0	5	15	25
	PULP SAMPLE 1							
	Restrained Drying				Unrestrained Drying			
11.1 to 48.6								
Strip 1	+0.099	+0.116	+0.178	+0.180	+0.272	+0.357	+0.420	+0.486
Strip 2	+0.102	+0.164	+0.168	+0.172	+0.272	+0.370	+0.431	+0.549
Strip 3	+0.203	+0.134	+0.130	+0.181				
Average	+0.135	+0.138	+0.159	+0.178	+0.272	+0.364	+0.426	+0.518
48.6 to 75.5								
Strip 1	+0.057	+0.064	+0.107	+0.094	+0.263	+0.337	+0.402	+0.497
Strip 2	+0.066	+0.090	+0.098	+0.098	+0.248	+0.317	+0.380	+0.455
Strip 3	+0.106	+0.079	+0.055	+0.091				
Average	+0.076	+0.078	+0.087	+0.094	+0.256	+0.327	+0.391	+0.476
75.5 to 92.9								
Strip 1	+0.097	+0.113	+0.134	+0.138	+0.437	+0.568	+0.636	+0.793
Strip 2	+0.095	+0.113	+0.127	+0.113	+0.441	+0.545	+0.656	+0.794
Strip 3	+0.138	+0.115	+0.095	+0.132				
Average	+0.110	+0.114	+0.119	+0.128	+0.439	+0.556	+0.646	+0.794
92.9 to 75.5								
Strip 1	-0.146	-0.188	-0.211	-0.229	-0.241	-0.348	-0.441	-0.571
Strip 2	-0.135	-0.170	-0.195	-0.210	-0.258	-0.392	-0.481	-0.638
Strip 3	-0.167	-0.204	-0.244	-0.260				
Average	-0.149	-0.187	-0.217	-0.233	-0.250	-0.370	-0.461	-0.604
75.5 to 48.6								
Strip 1	-0.156	-0.191	-0.227	-0.231	-0.236	-0.321	-0.396	-0.510
Strip 2	-0.150	-0.193	-0.225	-0.248	-0.216	-0.315	-0.396	-0.512
Strip 3	-0.164	-0.190	-0.227	-0.240				
Average	-0.157	-0.191	-0.226	-0.240	-0.226	-0.318	-0.396	-0.511
48.6 to 11.1								
Strip 1	-0.205	-0.256	-0.287	-0.317	-0.270	-0.374	-0.439	-0.565
Strip 2	-0.207	-0.250	-0.280	-0.319	-0.280	-0.393	-0.461	-0.588
Strip 3	-0.220	-0.272	-0.316	-0.339				
Average	-0.211	-0.259	-0.294	-0.325	-0.275	-0.384	-0.450	-0.576

The plus sign preceding the hygroexpansivity values denotes expansion; the minus sign [illegible] contraction.

TABLE II (continued)

HYGROEXPANSIVITY, %, OF HANDSHEETS UNDER RESTRAINED AND UNRESTRAINED DRYING CONDITIONS

Relative Humidity, %	Beating Time, min.				Beating Time, min.			
	0	5	15	25	0	5	15	25
	PULP SAMPLE 2							
	Restrained Drying				Unrestrained Drying			
11.1 to 48.6								
Strip 1	+0.158	+0.087	+0.107	+0.189	+0.284	+0.345	+0.385	+0.446
Strip 2	+0.134	+0.100	+0.100	+0.257	+0.307	+0.379	+0.393	+0.459
Strip 3	+0.120	+0.199	+0.120	+0.195				
Average	+0.137	+0.129	+0.109	+0.214	+0.296	+0.362	+0.389	+0.452
48.6 to 75.5								
Strip 1	+0.099	+0.068	+0.072	+0.117	+0.275	+0.328	+0.366	+0.427
Strip 2	+0.083	+0.068	+0.066	+0.151	+0.267	+0.317	+0.328	+0.402
Strip 3	+0.073	+0.102	+0.071	+0.114				
Average	+0.085	+0.079	+0.070	+0.127	+0.271	+0.322	+0.347	+0.414
75.5 to 92.9								
Strip 1	+0.132	+0.117	+0.121	+0.163	+0.399	+0.482	+0.554	+0.657
Strip 2	+0.118	+0.108	+0.108	+0.161	+0.339	+0.384	+0.414	+0.518
Strip 3	+0.121	+0.146	+0.117	+0.157				
Average	+0.124	+0.124	+0.115	+0.160	+0.369	+0.433	+0.484	+0.588
92.9 to 75.5								
Strip 1	-0.174	-0.188	-0.190	-0.229	-0.245	-0.306	-0.372	-0.469
Strip 2	-0.159	-0.168	-0.172	-0.200	-0.217	-0.258	-0.316	-0.406
Strip 3	-0.181	-0.208	-0.208	-0.248				
Average	-0.171	-0.188	-0.190	-0.226	-0.231	-0.282	-0.344	-0.438
75.5 to 48.6								
Strip 1	-0.193	-0.199	-0.219	-0.264	-0.250	-0.313	-0.370	-0.469
Strip 2	-0.177	-0.193	-0.219	-0.258	-0.252	-0.296	-0.369	-0.443
Strip 3	-0.177	-0.216	-0.208	-0.251				
Average	-0.182	-0.203	-0.215	-0.258	-0.251	-0.304	-0.370	-0.456
48.6 to 11.1								
Strip 1	-0.248	-0.268	-0.280	-0.333	-0.305	-0.362	-0.423	-0.518
Strip 2	-0.238	-0.258	-0.285	-0.323	-0.293	-0.360	-0.419	-0.486
Strip 3	-0.253	-0.303	-0.297	-0.357				
Average	-0.246	-0.276	-0.287	-0.338	-0.299	-0.361	-0.421	-0.502

TABLE II (continued)

HYGROEXPANSIVITY, %, OF HANDSHEETS UNDER RESTRAINED AND UNRESTRAINED DRYING CONDITIONS

Relative Humidity, %	Restrained Drying: Beating Time, min. 0	5	15	25	Unrestrained Drying: Beating Time, min. 0	5	15	25
PULP SAMPLE 3								
11.1 to 48.6								
Strip 1	+0.087	+0.170	+0.180	+0.170	+0.367	+0.489	+0.437	+0.553
Strip 2	+0.190	+0.178	+0.231	+0.217	+0.327	+0.376	+0.457	+0.441
Strip 3	+0.179	+0.187	+0.195	+0.199				
Average	+0.152	+0.178	+0.202	+0.195	+0.347	+0.432	+0.447	+0.497
48.6 to 75.5								
Strip 1	+0.062	+0.094	+0.111	+0.099	+0.271	+0.359	+0.365	+0.437
Strip 2	+0.107	+0.103	+0.107	+0.114	+0.256	+0.311	+0.369	+0.380
Strip 3	+0.104	+0.102	+0.102	+0.116				
Average	+0.091	+0.100	+0.107	+0.110	+0.264	+0.335	+0.367	+0.408
75.5 to 92.9								
Strip 1	+0.103	+0.146	+0.142	+0.148	+0.339	+0.425	+0.468	+0.556
Strip 2	+0.109	+0.124	+0.136	+0.135	+0.401	+0.503	+0.594	+0.637
Strip 3	+0.136	+0.147	+0.147	+0.159				
Average	+0.116	+0.139	+0.142	+0.147	+0.370	+0.464	+0.531	+0.596
92.9 to 75.5								
Strip 1	-0.154	-0.204	-0.204	-0.221	-0.234	-0.290	-0.365	-0.438
Strip 2	-0.144	-0.172	-0.178	-0.189	-0.283	-0.375	-0.446	-0.506
Strip 3	-0.188	-0.217	-0.217	-0.246				
Average	-0.162	-0.198	-0.200	-0.219	-0.258	-0.332	-0.406	-0.472
75.5 to 48.6								
Strip 1	-0.158	-0.217	-0.227	-0.236	-0.252	-0.327	-0.384	-0.457
Strip 2	-0.177	-0.203	-0.211	-0.223	-0.254	-0.321	-0.380	-0.427
Strip 3	-0.177	-0.199	-0.223	-0.240				
Average	-0.171	-0.206	-0.220	-0.233	-0.253	-0.324	-0.382	-0.442
48.6 to 11.1								
Strip 1	-0.234	-0.283	-0.299	-0.311	-0.303	-0.374	-0.431	-0.531
Strip 2	-0.238	-0.272	-0.278	-0.299	-0.316	-0.403	-0.453	-0.505
Strip 3	-0.249	-0.289	-0.312	-0.328				
Average	-0.240	-0.281	-0.296	-0.313	-0.310	-0.388	-0.442	-0.518

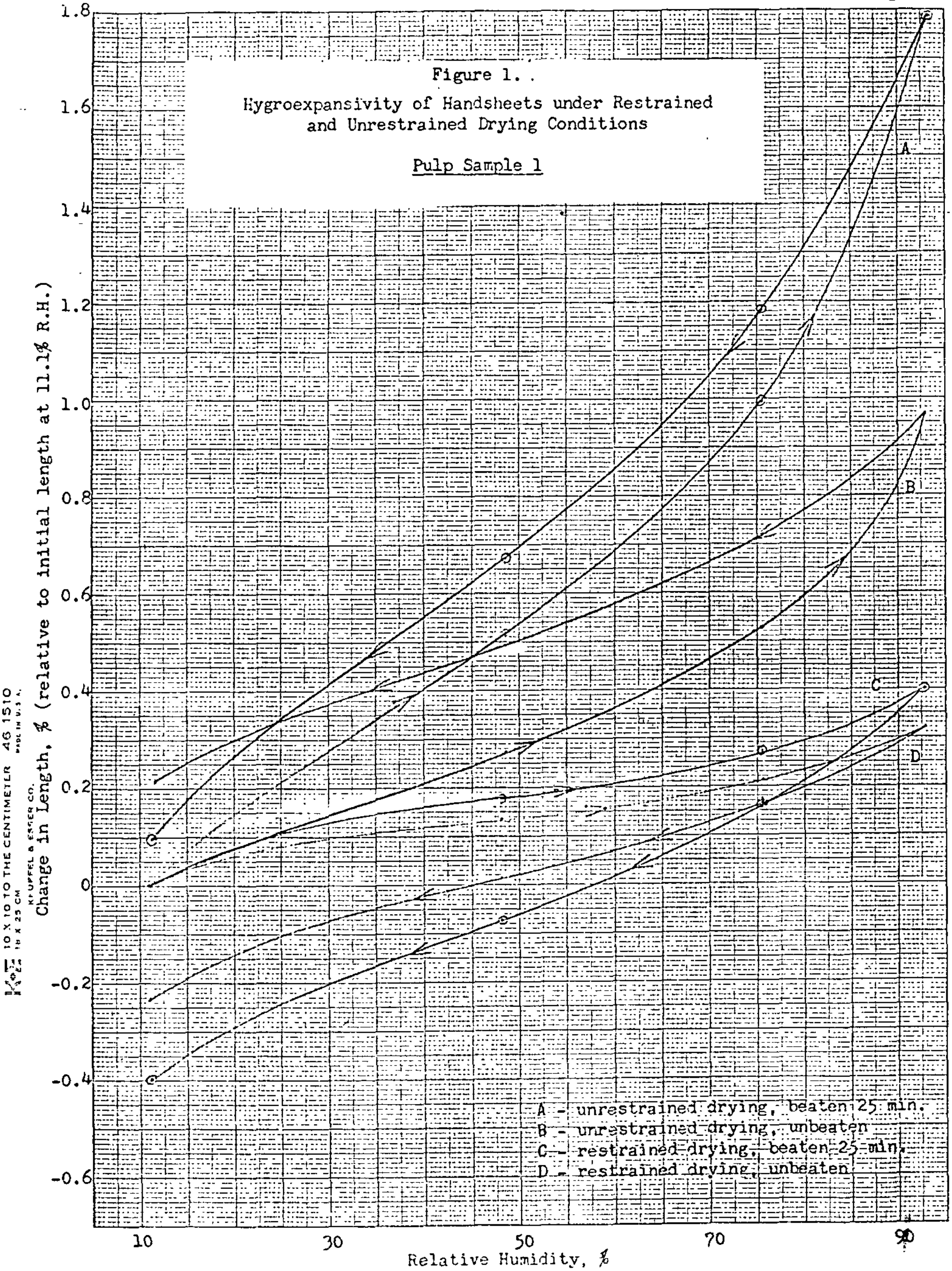

Figure 1.

Hygroexpansivity of Handsheets under Restrained and Unrestrained Drying Conditions

Pulp Sample 1

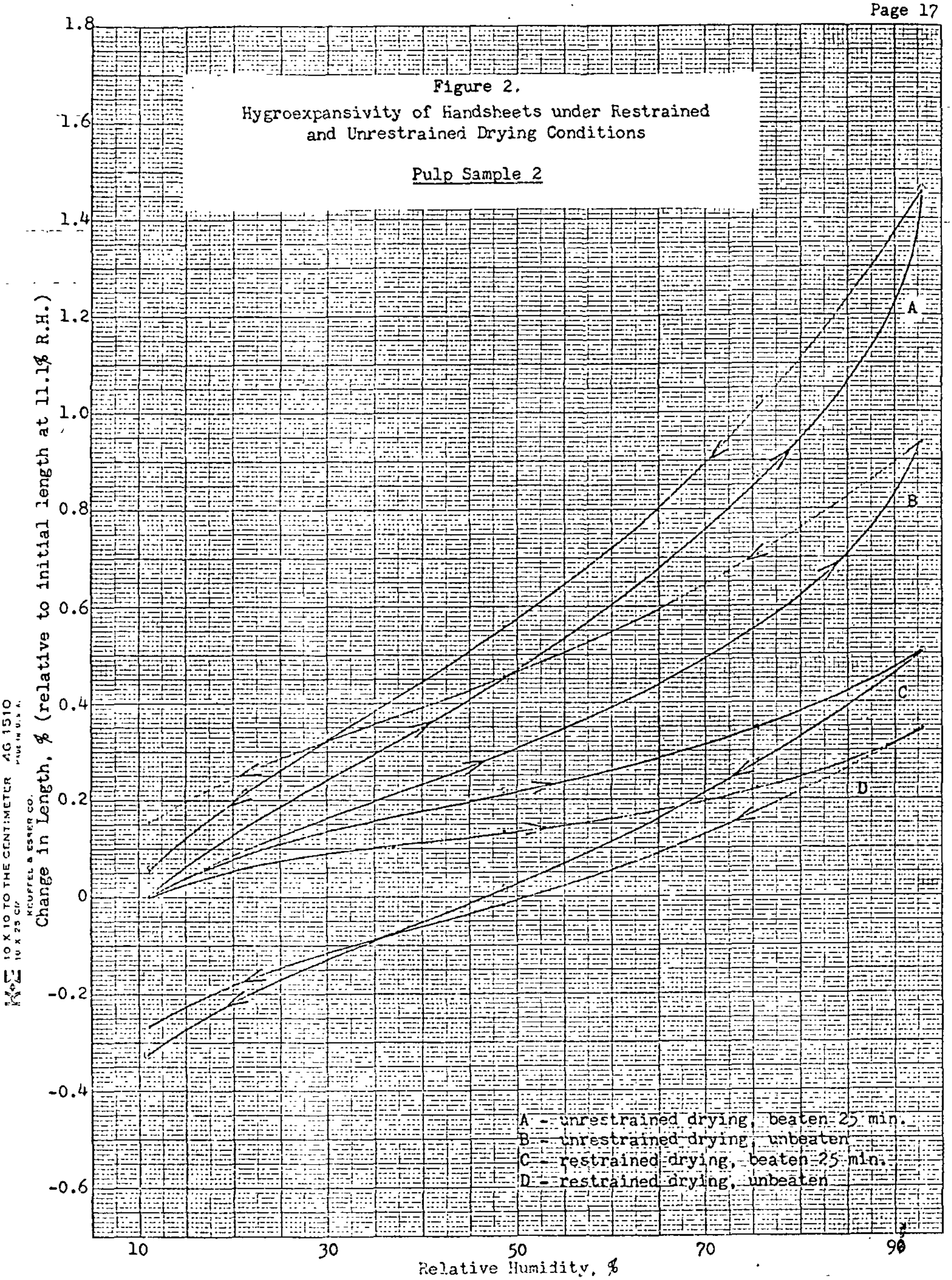
Figure 2.
Hygroexpansivity of Handsheets under Restrained and Unrestrained Drying Conditions
Pulp Sample 2
Change in Length, % (relative to initial length at 11.1% R.H.)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
10
30
50
70
90
Relative Humidity, %
A
B
C
D
A - unrestrained drying, beaten 25 min.
B - unrestrained drying, unbeaten
C - restrained drying, beaten 25 min.
D - restrained drying, unbeaten
10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO.
AG 1510

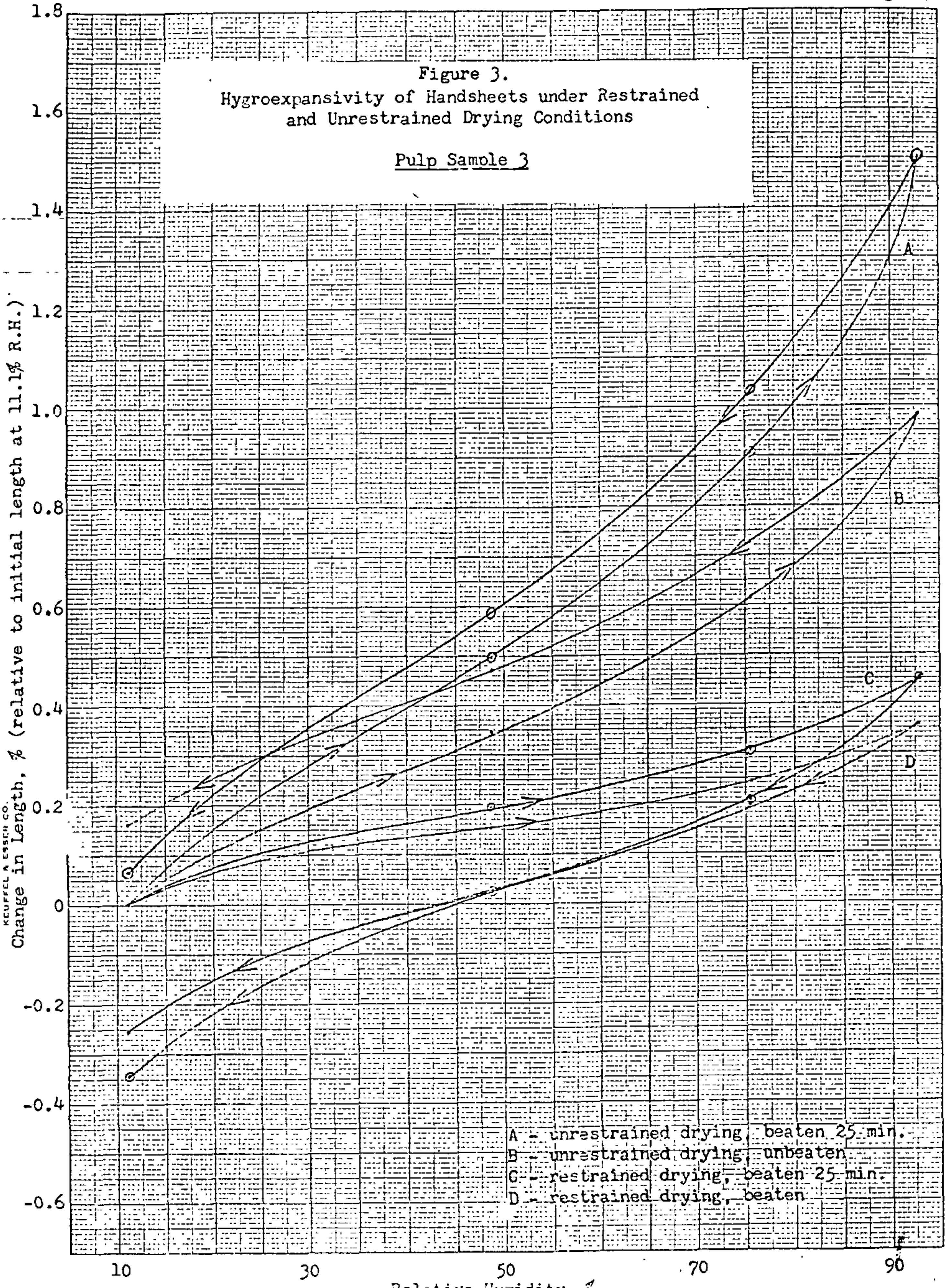
Figure 3.
Hygroexpansivity of Handsheets under Restrained and Unrestrained Drying Conditions
Pulp Sample 3
Change in Length, % (relative to initial length at 11.1% R.H.)
Relative Humidity, %
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
10
30
50
70
90
A
B
C
D
A - unrestrained drying, beaten 25 min.
B - unrestrained drying, unbeaten
C - restrained drying, beaten 25 min.
D - restrained drying, beaten
10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO.

COMMENTS ON DIFFERENCES IN HANDSHEET PROPERTIES

The following comments are given in the order in which the data appear in the report.

1. The basis weight of the sheets dried without restraint is somewhat higher than for the ring-dried sheets as a result of the shrinkage that occurred during drying of the former.

2. The shrinkage that occurred during drying of the sheets dried without restraint increased with beating; the amount of shrinkage was the same for measurements made in and across the couch direction.

3. The thickness and density of the sheets dried without restraint did not change very much with beating; the ring-dried sheets exhibited the more typical behavior, with the thickness descreasing and the density increasing with increased beating.

4. The tensile breaking length of both the ring-dried sheets and the sheets dried without restraint increased with beating, although the latter had a somewhat lower strength and increased at a somewhat lower rate.

5. The stretch of the sheets dried without restraint is about double that of the ring-dried sheets at all levels of beating. Stretch increased with beating.

6. The tensile energy absorptions reflect the changes in tensile breaking length and stretch.

7. The tensile stiffness of the sheets dried without restraint is about 60% of that of the ring-dried sheets. Both increase with beating at about the same rate.

8. The specific scattering coefficients of the sheets dried without restraint is about 5% lower than that of the ring-dried sheets.

9. The in-plane tearing energy of the sheets dried without restraint increases at a greater rate with beating than that of the ring-dried sheets. It is at a lower level for the unbeaten sheets and at a higher level for the beaten sheets.

10. The air permeability of the sheets dried without restraint is much lower than that of the ring-dried sheets.

11. The hygroexpansivity of the sheets dried without restraint is about 3 to 4 times that of the ring-dried sheets for increases in relative humidity from 11 to 93%, and less than 2 times for subsequent decreases in relative humidity to 11%. In both cases, the hygroexpansivity increases with beating.

12. The ring-dried sheets exhibit a net shrinkage at 11% R.H. when exposed to a relative humidity cycle of 11 to 93 to 11%. The amount of shrinkage increases with beating. The sheets dried without restraint exhibit a net expansion when exposed to the same humidity cycle. The amount of expansion decreases without beating.

13. The observations in Item 12 for the sheets dried without restraint suggest that there was, in fact, no external restraint on the sheets during drying. A sheet dried under restraint would be expected to exhibit a net shrinkage at 11% R.H. after relaxing at 93% R.H. A sheet dried without restraint would be expected to have the same dimension at 11% R.H. both before and after exposure to 93% R.H. The increase in dimension at 11% R.H. observed for the sheets dried without restraint is attributed to creep resulting from the small force (5 g.) applied to the specimens during the hygroexpansivity measurement. This is consistent with the data where the greatest increase is noted for the weaker unbeaten sheets.

14. Much greater variability exists in the hygroexpansivity results of individual specimens for the ring-dried sheets than for the sheets dried without restraint. The variability, for the ring-dried sheets, is less after exposure to 93% R.H. than before.