U. S. Department of Commerce National Bureau of Standards

RESEARCH PAPER RP1532

Part of Journal of Research of the National Bureau of Standards, Volume 30, April 1943

FURTHER EXPERIMENTAL STUDY OF BEATER PRACTICE IN THE MANUFACTURE OF OFFSET PAPERS

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ABSTRACT

Seventy-three experimental papers have been made in the Bureau's experimental paper mill in studies to determine the relationship between the mechanical beating of the fibers and the properties of offset papers made from them. A previous publication [1] contains the data for the wood-fiber papers. The present article reports an extension of the work to include papers made of rag fibers, and mixtures of rag and wood fibers.

The rag fibers responded to beating differently in some respects than the wood fibers. Old rags withstood the prolonged beating required for the development of maximum strength and optimum formation without the adverse effects of such treatment noted in the preparation of wood fibers. All the rag-fiber papers had appreciably lower expansivity [2] than wood-fiber papers of corresponding bond strength, and the mixture of old-rag fibers with strong sulfite, in equal proportions, produced papers with folding endurance approaching the average for the two pulps. Papers made of the sulfite pulp and wood-fiber filler pulp in like proportions have been found to have fold values little above that of the weaker pulps.

The addition of clay filler to a sulfite paper lowered the expansivity in the machine direction but did not lower it appreciably in the cross direction.

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I. INTRODUCTION

For more than 10 years, the National Bureau of Standards and the Lithographic Technical Foundation have cooperated in research on the paper requirements of the offset lithographic process. After determing the properties of paper desirable for offset printing, papermaking studies were made to find how to obtain the properties. The

[1] J. Research NBS 28, 241 (1942) RP1455.

[2] All references to expansion in this paper pertain to moisture effects.

relationship between the beating of the fibers and the characteristics of papers made from them under controlled conditions was determined.

The experimental papers were made in the Bureau's experimental paper mill. The fibers studied comprised various types of commercial wood pulps, waste papers, and new and old rags, all of which were used singly and in combinations. The beating of the various fibers and selected combinations of them was subjected to controlled variations, and the resultant effects on the properties of the papers were determined by tests of the finished papers. The relationships thus obtained for the wood-fiber papers were published in a previous report.[3] Data on rag fibers and further data on some wood fibers are contained in this article, together with limited data on the effects of clay filler and some information on the application of the results to the printing of war maps.

The research on lithographic papers is carried on with the assistance of the Lithographic Technical Foundation, and the studies were planned with the counsel of an advisory committee of technical representatives of that organization, under the chairmanship of R. F. Reed, Director of Lithographic Research, University of Cincinnati.

II. PAPERMAKING EQUIPMENT

The experimental paper mill at the Bureau is provided with complete semicommercial equipment which is adapted to the experimental manufacture of paper under conditions simulating those of commercial manufacture. Descriptions and photographs of the equipment are contained in previous publications.[4] [5] [6] The equipment used in this investigation was essentially as follows: a 50-pound beater with copper-lined tub and manganese-bronze bars and plate, and equipped with one washing cylinder; a jordan refiner with bars of bronze and steel alloy; a four-plate, flat screen; and a 29-inch fourdrinier papermaking machine with a wire 33 feet in length, two presses, nine 15-inch dryers, a calender stack of seven rolls, and a reel.

III. FIBROUS RAW MATERIALS

Three commercial grades of rags were used, new white shirt cuttings, and two grades of old rags—old white shirt cuttings and "twos and blues." Half-stuff pulps were prepared from these rags by the conventional methods of cooking, bleaching, and beating. The properties of the pulps are given in table 1. The sulfite wood pulp included in the table is the pulp used in the rag-sulfite mixtures and in the sulfite papers made in the previous work, data for which are included in this paper for comparison.

[3] See footnote 1.
[4] Tech. Pap. BS **21**, 338 (1927) T340.
[5] BS J. Research **3**, 904 (1929) RP121.
[6] Paper Trade J. **89**, 19, 60 (1929).

TABLE 1.—*Chemical characteristics of fibrous materials used in experimental manufacture of offset papers*

Fibrous material	Alpha-cellulose [1]	Beta-cellulose [1]	Gamma-cellulose [1]	Pentosans	Copper number	Ash [2]	Resins [2]	Acidity of pulp (glass-electrode method)	
								Cold-water extraction	Hot-water extraction
	%	%	%	%		%	%	pH	pH
Sulfite wood pulp	84.8	1.8	13.4	2.8	2.0	0.2	0.3	5.9	5.5
Half-stuff from new white shirt cuttings	92.9	5.9	1.2	-------	0.4	.1	.2	6.5	6.6
Half-stuff from old white shirt cutting	89.8	9.1	1.1	-------	.3	.2	.2	6.5	6.6
Half-stuff from old "two's and blue's"	90.5	8.8	0.7	-------	.4	.2	.4	6.7	6.7
Soda wood pulp	67.5	28.8	3.7	15.4	3.2	.7	.2	8.6	7.4

[1] Based on total cellulose.
[2] On oven-dry basis.

IV. MANUFACTURE AND TESTING

1. BEATING PRACTICE AND MACHINE OPERATION

A series of papers was made from each selected fiber furnish with controlled variations in the beating. The procedure followed in furnishing the stock to the beater, except as otherwise noted, was as follows: The beater tub was partially filled with water, the pulp was added, and then sufficient water to obtain the desired concentration. The time required for furnishing was approximately 15 minutes. Data on the beating intervals, beater-roll settings, jordan settings, freeness of the stock at the completion of the beatings and at the head box, the distance the water was carried beyond the second slice on the paper-machine wire, and the shrinkage in width while drying are shown in table 2. The position of the beater roll is expressed as the number of turns above (+) or below (−) zero setting, which is the point of contact between the roll and the bedplate. One turn moves the roll 0.008 inch.

The freeness results in table 2 were obtained with a Williams precision freeness tester. This instrument consists of a graduated glass cylinder placed above a metal cone having a valve at the bottom. A No. 80 wire screen forms the bottom of the cylinder. To determine the freeness of stock, the apparatus is filled with tap water to the zero mark, which is slightly above the wire. One liter of the stock to be tested is poured into the cylinder, the valve is opened, and the time require for 1,000 ml of water to drain from the instrument is noted. Two sets of values, distinguished by the letters A and B, are reported. For the A values, samples containing 3 g of dry stock per 1,000 ml were added to the instrument, whereas the values for B are for actual concentrations in the cylinder of 3 g of dry stock per 1,000 ml of mixture.

TABLE 2.—*Data on beating and condition of stock for different types of furnishes*

Paper machine run number	Beater furnish: Fiber (pulp)	Rosin [1]	Alum [1]	Position of beater roll after beating time of—: 0.0 hr.[4]	0.25 hr.[5]	0.5 hr.	1.0 hr.	1.5 hr.	2.0 hr.	2.5 hr.	3.0 hr.	3.5 hr.
		% [2]	% [3]									
1243	100% sulfite wood pulp, no filler	1	1.0	+10	+10	+3	+3	+3				
1244		1	1.0	+10	+10	+3	+3	+2½	+2½	+2	+2	+1½
1245		1	1.0	+10	+10	+3	+3	+2½	+2½	+2	+2	+1½
1311	100% No. 1 white shirt cuttings	1	1.2	+10	+10	+5	+4½	+4	+3½	+3	+2½	+2
1310		1	1.2	+10	+10	+5	+4½	+4	+3½	+3	+2½	+2
1308	Old rags: 66⅔% No. 1 old white, 33⅓% twos and blues	1	1.2	+10	+10	+3	+1	0	−½	−½	−½	−½
1307		1	1.2	+10	+10	+5	+4½	+4	+3½	+3	+2½	+2
1306		1	1.3	+10	+10	+5	+4½	+4	+3½	+3	+2½	+2
1312	50% sulfite wood pulp, 50% old rags (twos and blues)	1	1.2	+10	+10	+3	+3	+3				
1313		1	1.2	+10	+10	+3	+3	+2½	+2½	+2	+2	+1½
1314		1	1.1	+10	+10	+3	+3	+2½	+2½	+2	+2	+1½
1339	100% sulfite wood pulp, 15% filler (clay) added			+10	+10	+3	+3	+2½	+2½	+2	+2	+1½
1340				+10	+10	+3	+3	+2½	+2½	+2	+2	+1½

Paper machine run number	Position of beater roll after beating time of—: 4.0 hr.	4.5 hr.	5.0 hr.	5.5 hr.	6.0 hr.	6.5 hr.	7.0 hr.	7.5 hr.	8.0 hr.	8.5 hr.	9.0 hr.	9.5 hr.	Freeness of stock at completion of beating: A	B	Jordan setting	Acidity at head box quinhydrone method	Freeness of stock at head box [6]: A	B	Sheet shrinkage in width as formed [7]	Distance water was carried beyond 2d slice [8]
																pH			%	*in.*
1243													9	10	+8	4.9	16	19	1.9	8
1244	+1½	+1	+1	+1									15	17	+8	4.9	33	39	2.5	13
1245	+1½	+1	+1	+½	+½	0	0	−½	−½	−1	−1	−1	63	74	+8	4.9	111	129	4.7	43
1311	+1½	+1	+½	+½									195	222	+8	5.2	480	620	3.8	72
1310	+1½	+1	+½	+½	0	0	0	−½	−½	−½			720	850	+8	5.3	1,080	1,220	4.7	(9)
1308													216	252	+8	5.0	500	630	2.5	(9)
1307	+1½	+1	+½	+½									203	242	+8	5.0	575	690	2.5	(9)
1306	+1½	+1	+½	+½	0	0	0	−½	−½	−½			550	630	+8	4.8	1,070	1,200	2.8	(9)
1312													59	70	+8	5.1	130	150	2.8	40
1313	+1½	+1	+1	+1									120	140	+8	4.9	210	245	3.1	60
1314	+1½	+1	+1	+½	+½	0	0	−½	−½	−1	−1	−1	330	385	+8	4.8	640	775	4.4	(9)
1339	+1½	+1	+1	+1									16	19	+8	5.1	42	49	3.1	12
1340	+1½	+1	+1	+½	+½	0	0	−½	−½	−1	−1	−1	68	81	+8	4.8	114	132	4.7	42

[1] Rosin size was added 1 hour and the alum ½ hour before stock was dropped to chest.
[2] Based on dry weight of the fiber.
[3] Based on dry weight of the fiber and rosin.
[4] Lighter-bar up.
[5] Lighter-bar down.
[6] Williams precision freeness tester.
[7] Change in width of dried sheet as wound on reel from width when formed.
[8] Measurement indicates point at which drainage of water from table rolls stopped.
[9] To suction box.

Fifty pounds of pulp was furnished to the beater in each instance. The beaten stock was dropped to a chest and pumped in a continuous stream through the stuff box and jordan to the paper machine without the use of a machine chest. The stuff box was of the conventional regulating-box type, having a constant head over an adjustable orifice. Screen plates with 0.018-inch slots were used. The stock was maintained at 90° F±2° at the head box. Every effort was made to keep the entire machine operation the same for all of the runs, so that all of the differences found in the properties of the papers could be definitely ascribed to the controlled variations in beating.

2. TESTING

All the physical and chemical tests of the pulps and papers were made by the TAPPI methods except the following, for which no official methods were available.

The bond test was that of Sutermeister and Osgood.[7] This test is essentially one of measuring the force required to split paper when the stress acts perpendicularly to its surface.

The degree of curl was determined by the Carson [8] method, which measures the maximum angle of curl of a specimen when one side is in contact with water.

Smoothness was determined with the Bekk [9] instrument, and permeability to air was measured with a Carson Precision Permeability Tester,[10] which measures the rate of air flow through the paper per unit of area with a pressure difference of 1 g/cm^2.

The physical tests were made in an atmosphere of 65-percent relative humidity and 70° F because those conditions were standard when the study was initiated, and they were used for the remainder of the study to keep all the results comparable.

V. DESCRIPTION OF THE EXPERIMENTAL PAPERS

Papers were made with fibers from new rags; old rags; 50 percent of old rags and 50 percent of sulfite wood pulp; and sulfite wood pulp with 15 percent of filler (clay) added. The minimum, medium, and maximum beating treatments of 1½, 5½, and 9½ hours, respectively, as used on wood-fiber papers reported in the previous paper were followed, except that for the all-rag papers 3½ hours was selected as the minimum beating interval and 8½ hours as the maximum. The jordan was used as a mixer only.

The properties of the papers obtained from each furnish by different degrees of beating are contained in table 3. Included in this table are data on three sulfite papers made with minimum, medium, and maximum beating. These papers were reported in the previous publication [11] and are repeated here to facilitate comparison. Papers 1243, 1244, and 1245 are considered representative for sulfite papers made with different degrees of beating.

[7] Tech. Assn. Pap. **24**, 136 (1941).
[8] Paper Ind. Paper World **22**, 246 (June 1940).
[9] Paper Trade J. **94**, 41 (June 30, 1932).
[10] BS J. Research **12**, 567 (1934) RP681.
[11] J. Research NBS **28**, 241 (1942) RP1455.

TABLE 3.—*Properties of experimental offset papers* [1]

Paper machine run number	Fiber furnish (pulp)	Beating time	Jordan setting	Weight, 25×40 in. 500 sheets	Thickness	Density	Opacity, contrast ratio	Bursting strength	Ratio of burst to weight	Tensile properties: Breaking load		Tensile properties: Elongation at rupture	
										Mach.	Cross	Mach.	Cross
		hr.		*lb.*	*in.*	*lb./ft.*^{3}	*%*	*pt.*	*%*	*kg.*	*kg.*	*%*	*%*
1243	100% sulfite wood pulp	1.5	+8	56.1	0.0041	47.3	76	21	37	4.4	2.5	2.5	3.8
1244		5.5	+8	55.9	.0039	49.6	75	26	47	5.9	3.0	2.4	4.7
1245		9.5	+8	55.4	.0038	50.5	71	34	61	7.8	3.6	3.0	7.0
1311	100% new rags; No. 1 white shirt cuttings	5.5	+8	55.2	.0039	48.9	80	26	47	5.8	3.7	3.4	6.2
1310		8.5	+8	55.4	.0035	54.6	79	29	52	6.0	3.9	3.3	7.4
1308	100% old rags; 66⅔% No. 1 old white, 33⅓% twos and blues	3.5	+8	54.3	.0038	49.3	85	18	33	3.8	2.8	3.4	4.8
1307		5.5	+8	57.6	.0042	47.4	85	22	38	4.3	3.1	3.1	4.9
1306		8.5	+8	56.0	.0040	48.4	86	20	36	4.7	3.3	3.4	5.1
1312	50% old rags; 50% sulfite wood pulp	1.5	+8	54.3	.0038	49.4	83	21	39	4.7	2.4	2.7	4.3
1313		5.5	+8	54.3	.0038	49.4	81	24	44	5.4	2.9	2.4	5.6
1314		9.5	+8	54.9	.0035	54.2	79	27	49	6.2	3.4	3.3	7.1
1339	100% sulfite wood pulp with 15% filler (clay) added	5.5	+8	55.0	.0035	54.3	84	11	20	3.5	1.8	2.4	3.0
1340		9.5	+8	57.6	.0034	58.5	82	19	33	5.2	2.3	2.2	4.7

Paper machine run number	Tearing strength: Mach.	Tearing strength: Cross	Folding endurance (Schopper): Mach.	Folding endurance (Schopper): Cross	Expansion for a change of relative humidity of 15 percent: Mach.	Expansion for a change of relative humidity of 15 percent: Cross	Curl	Smoothness (Bekk)	Air permeability	Oil penetration	Sizing value (dry-indicator method)	Bond test
	g	*g*	*Double folds*	*Double folds*	*%*	*%*	*deg.*	*sec.*	*cm³/m²/sec. g/cm²*	*sec.*	*sec.*	*lb.*
1243	148	150	141	33	0.066	0.172	52	19	1,236	20	49	44.3
1244	126	144	390	58	.075	.207	60	20	570	32	51	55.7
1245	97	102	1,527	342	.091	.284	180+	17	52	195	58	85.8
1311	117	117	811	124	.062	.203	68	43	13	225	7	73.8
1310	95	100	656	180	.079	.288	180+	40	41	472	20	90.2
1308	57	55	16	13	.066	.151	43	45	129	83	10	76.3
1307	75	71	43	28	.060	.153	43	36	89	146	11	74.7
1306	63	62	26	28	.069	.177	60	38	58	184	11	83.6
1312	80	90	170	34	.070	.188	53	45	222	69	16	61.8
1313	83	87	297	71	.064	.199	65	47	107	124	15	70.9
1314	65	68	341	89	.079	.252	160	55	24	274	20	95.6
1339	130	128	18	9	.058	.179	45	28	580	40	25	40.8
1340	92	118	174	29	.067	.259	180+	36	91	120	24	65.5

[1] All the physical tests were made under conditions of 65-percent relative humidity and 70° F.

VI. INTERPRETATION AND DISCUSSION OF DATA

Relationships between some of the important properties of the finished papers are shown graphically in figures 1, 2, and 3. In these figures, the scales are so arranged that the data for the various properties are roughly comparable irrespective of their absolute values. For the properties for which low values are desirable, the scales are inverted so that, in all instances, a relatively high position on the scale indicates a high relative quality. The division into three classes is for ease of comparison and is strictly arbitrary.

Figures 1 and 2 show graphically the comparative properties of papers made from different fiber furnishes with like beating treatments. The beating for all papers shown in figure 1 was medium and for those in figure 2 was maximum. The effects of beating on the properties of papers made from sulfite and from old rags are shown in direct comparison in figure 3. The chart shows graphically how the two kinds of fibers respond differently to beating. With continued

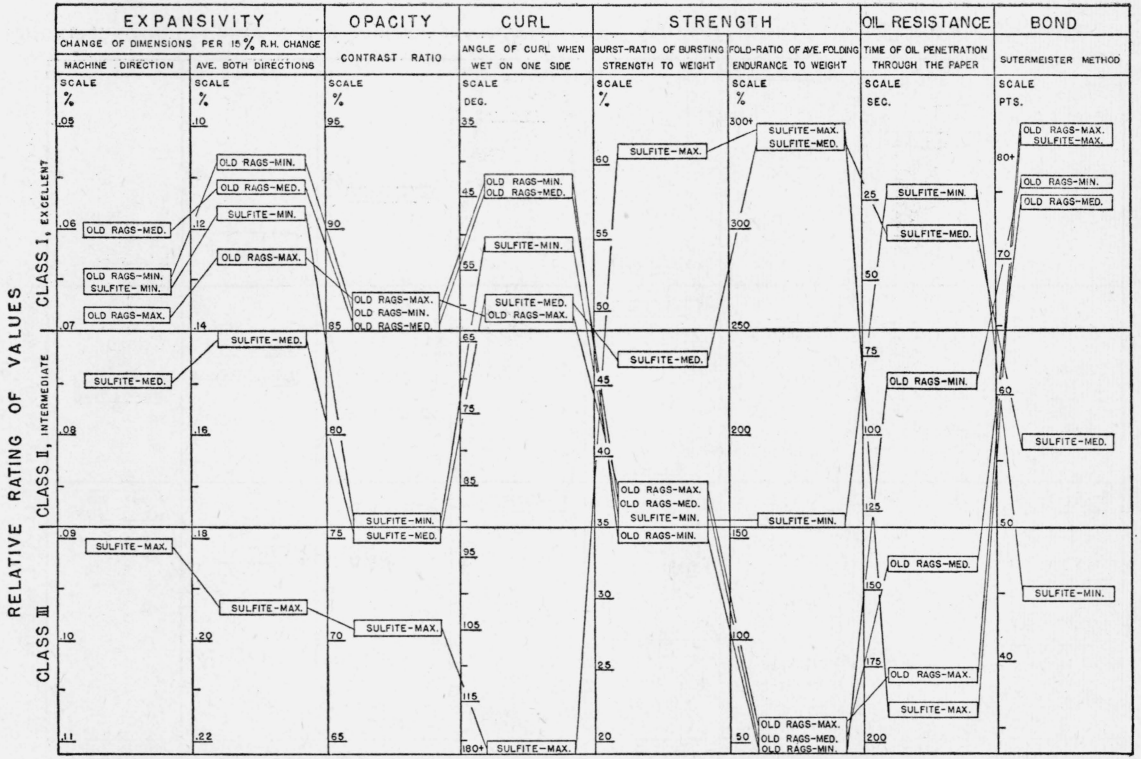

FIGURE 1.—*Relative properties of papers made with medium degree of beating from different fiber furnishes.*

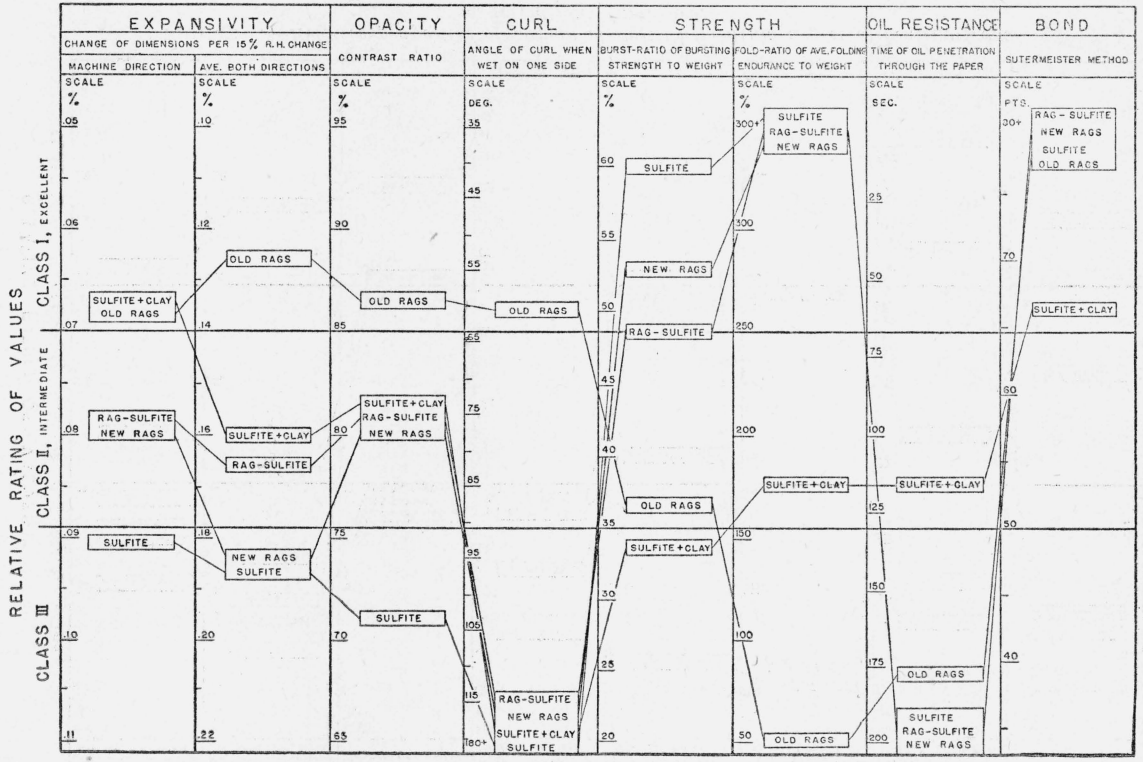

FIGURE 2.—*Relative properties of papers made with maximum degree of beating from different fiber furnishes.*

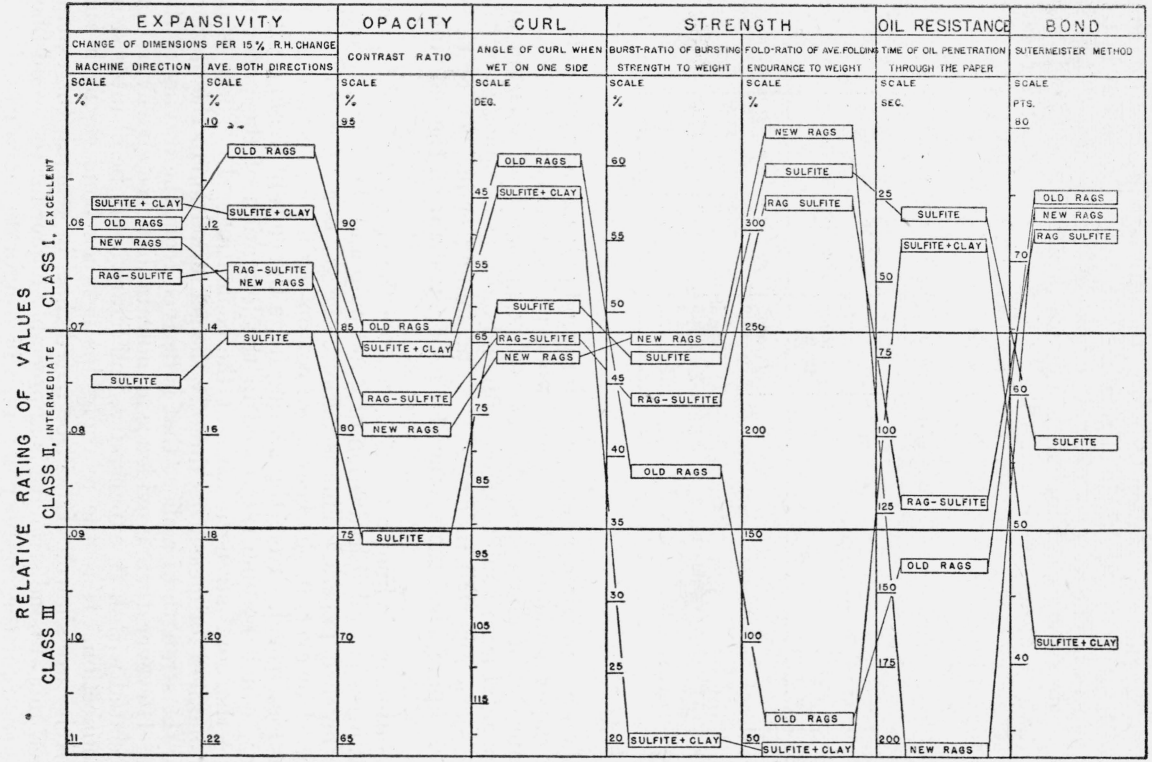

FIGURE 3.—*Relative effects of degree of beating on properties of papers made of sulfite wood fiber and of fibers from old rags.*

beating, the sulfite pulp develops high strength comparatively fast. However, the increased strength is accompanied by obvious effects of hydration, namely, increased expansivity, loss of opacity, and increased tendency to curl. The old-rag fibers show little hydration and apparently can be beaten to obtain the ultimate in formation and finish without the undesirable effects of hydration so apparent in the sulfite papers. The relative over-all effects of beating are shown in table 4. Here the papers included in figures 1, 2, and 3 are graded by an arbitrary scale of values, allowing 12½, 8, or 4 percent for each property for classes I, II, and III, respectively, so that a paper in class I for all properties would obtain a rating of 100 percent.

TABLE 4.—*Ratings of papers in figures 1 and 2.*

Fiber furnish	Rating values		
	Minimum beating	Medium beating	Maximum beating
	Percent	*Percent*	*Percent*
Sulfite wood fiber	78.0	73.5	57.5
New rags	----------	78.0	65.5
Old rags	78.5	78.5	78.5
50% sulfite, 50% old rags	82.0	82.0	57.5
50% sulfite, 50% soda [a]	74.5	74.0	73.5
Sulfite, plus 15% clay filler	----------	70.0	65.0

[a] Data from Research Paper RP1455.

In the work previously reported [12] for wood pulps, it was pointed out that a paper made of a mixture of wood pulps usually had a folding endurance little above that of the weaker pulp. That this did not hold for mixtures of sulfite wood pulp and old rags is indicated by the limited data reported in figure 4. The folding endurance of these mixtures approached the average for papers made from the individual pulps.

A relationship is known to exist between the amount of gel formed in beating or so-called hydration of wood pulp and the bond strength of the finished papers. This is because the gel is a cementing substance. However, in the beating of cotton-rag fibers, comparatively little gel is formed. Here the beating frays the ends of the fibers into fibrillas, which become interlaced in the formation of the paper to provide the bond strength without the cementing gel. There is no known method for measuring directly the gel formation or the proportion of the strength of a sheet that is derived from the fraying of the fibers. However, there is evidence to indicate that excessive hydration is associated with high expansivity, and figure 5 will be of interest in this connection. Here the relationships between bond strength and expansivity are shown. It will be noted that, in general, the expansion per unit of bond strength is appreciably higher for the wood-fiber papers than for the rag-fiber papers, which hydrate much less.

[12] J. Research NBS 28, 241 (1942) RP1455.

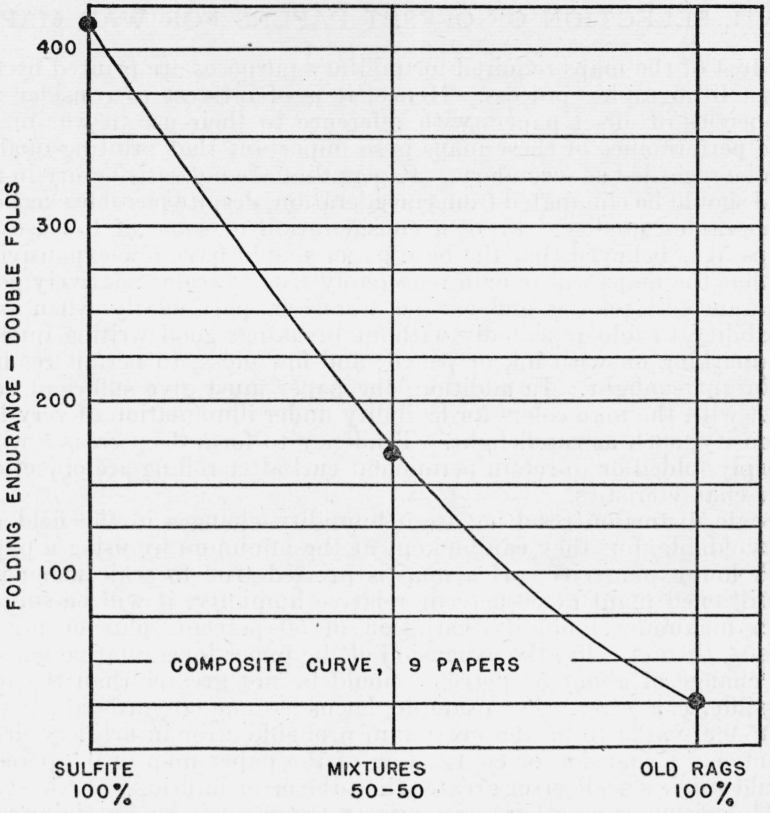

FIGURE 4.—*Relationship between fiber content and folding endurance of sulfite wood fiber, rag, and sulfite-rag papers.*

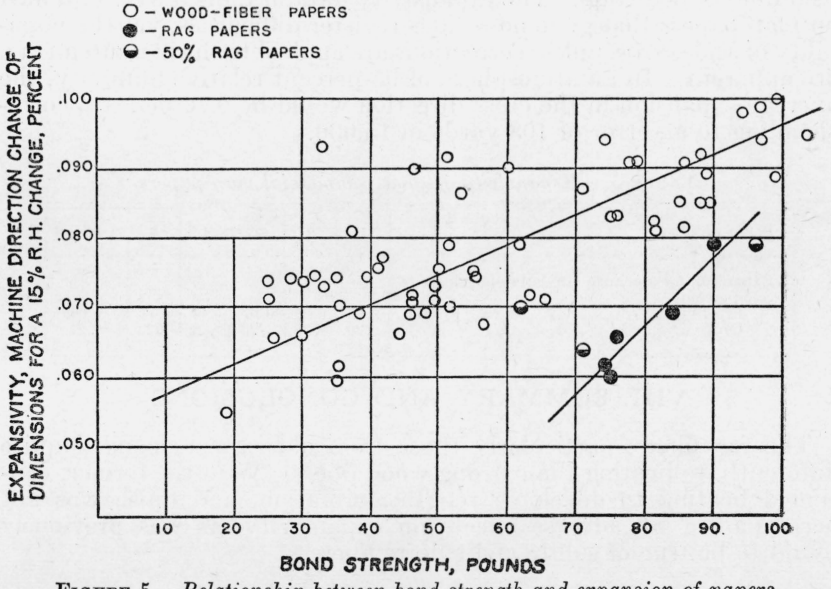

FIGURE 5.—*Relationship between bond strength and expansion of papers.*

VII. SELECTION OF OFFSET PAPERS FOR WAR MAPS

Most of the maps required for military purposes are printed by the offset lithographic process. Hence, it is of interest to consider the properties of offset papers with reference to their use in war maps. The performance of these maps is so important that printing quality can be regarded as secondary. Papers that are not satisfactory in the field should be eliminated from consideration, despite possible excellent lithographic quality. From a consideration of some of the uses of maps, it is believed that the base paper should have low expansivity, so that the maps will remain reasonably true to scale; relatively good resistance to tearing and surface abrasion, particularly when wet; flexibility to fold repeatedly without breaking; good writing quality for marking on with ink or pencil; and low gloss, to permit reading in bright sunlight. In addition, the paper must give sufficient contrast with the map colors for legibility under illumination of very low intensity, such as candlelight. Tendency to form deep creases when sharply folded or to retain permanent curl after rolling are objectionable characteristics.

Scale distortion resulting from humidity changes in the field are unavoidable, but they can be kept at the minimum by using a paper with low expansivity. If a map is printed true to scale in an air-conditioned plant at 50-percent relative humidity, it will be subject to a maximum humidity variation of 50 percent, plus or minus. Hence, theoretically, the expansion of the paper for a relative humidity change of about 50 percent should be not greater than the permissible scale error. For example, let us assume 60 yards in a range of 15,000 yards to be the maximum probable error in artillery firing practice. Expansion or contraction of the paper map of 0.5 percent would cause a scale error greater than the error in firing.

Thus a paper may have expansivity low enough for obtaining reasonably good register in printing and yet produce scale errors in the field due to distortion. The expansivity data in table 5 were obtained on map papers that gave no serious register difficulties, yet the possibility of scale error, unless corrections are applied to the measurements, are apparent. In an atmosphere of 95-percent relative humidity, the average expansion in the cross direction would be 0.72 percent, corresponding to an error of 108 yards in 15,000.

TABLE 5.—*Expansivity of some commercial map papers*

Paper number	1	2	3	4	5	Average
Expansion for a change of relative humidity of 15 percent:						
Machine (%)	0.05	0.06	0.07	0.07	0.08	0.065
Cross (%)	.30	.26	.20	.22	.23	.24

VIII. SUMMARY AND CONCLUSIONS

The rag fibers, particularly those from old rags, responded quite differently to beating than strong wood fibers. With the former, continued beating to develop strength, formation, and finish was not accompanied by adverse effects on expansivity, as was previously found to be true of sulfite and sulfate fibers.

The folding endurance of papers containing old-rag fibers and strong wood fibers in equal proportions was approximately the same as the average of the two pulps, whereas in the case of like mixtures of the same wood fibers with weak filler pulp, the folding endurance was approximately only that of the filler pulp.

The expansion per unit of bond strength of the sheet was appreciably lower for the rag-fiber papers than for wood-fiber papers.

In the production of and use of maps, hygroexpansion of the paper is potentially more serious as a cause of scale error than as a cause of misregister in printing.

WASHINGTON, January 29, 1943.