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# WEARING QUALITY OF EXPERIMENTAL CURRENCY-TYPE PAPERS

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ABSTRACT

Fourteen groups of high-grade papers, differing in fiber composition, were made in the Bureau's experimental paper mill. Papers within the groups differed in the beating treatment of the pulp, in the surface-sizing treatment, and in the use or omission of melamine resin. Of the several kinds of fibers studied, caroa mixed with cotton appears to approach most nearly the desirable characteristics associated with linen-content currency paper. The high-quality wood fibers available do not appear suitable for use in currency paper. Melamine resin in currency-type paper improves folding endurance, tensile and bursting strength, strength after crumpling, stretch, resistance to abrasion, and closure of the sheet. It greatly increases the strength of the paper when wet. However, it makes the dry paper somewhat easier to tear.

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## I. INTRODUCTION

United States paper currency prior to 1941 was printed on paper composed largely of fibers derived from new linen cuttings imported from Europe. Several hundred tons of linen cuttings were required annually in the manufacture of the currency paper. It became necessary to find suitable substitutes for linen pulp in case of interruption of the foreign supply of linen cuttings. The supply problem was attacked in various ways, being eased by the use of additional cotton

[1] Nearly all members of the Bureau's Paper Section contributed in some measure to this project. It is desired especially to acknowledge the assistance of Martin J. O'Leary and Joshua Missimer in the manufacture of the experimental papers; of Vernon Worthington in the development of the special testing apparatus; and of W. K. Wilson, Thelma L. O'Brian, V. Worthington, Irma G. Callomon, and Alice J. Adams in making the many hundreds of physical and chemical tests of the papers.

fiber to replace a part of the linen and by the use of flax paper-making fiber produced from domestic flax straw. During this time the National Bureau of Standards was engaged on another approach to the problem.

For several years the Bureau has cooperated with the United States Treasury Department in efforts to improve the quality of currency paper and to prolong its useful life. During the period of concern over the supply of linen fiber, this cooperative work has included the use of the Bureau's experimental paper-making and testing equipment to study the paper-making properties of other kinds of fibers that might be available for use in making currency paper, and to evaluate the wearing quality and other pertinent properties of high-grade papers made from these fibers. The work included also some further observations on the effect of variations in paper-making technic, particularly on the effect of melamine resin in currency-type paper.

The papers studied were made in the Bureau experimental paper mill for the threefold purpose of having papers of known composition and history, of having definite information about the paper-making processes used, and of obtaining some unusual combinations of paper-making materials.

Since the previous work at the Bureau on the production of currency paper,[2] some new testing methods have been developed to aid in predicting the serviceability of paper currency, and other testing methods have been improved or standardized. These added tools help to give a better estimate in the laboratory of the properties and behavior of currency-type papers. In addition to the Schopper folding-endurance tester, which has been relied on chiefly in previous work to evaluate the wearing quality of currency paper, the MIT (Massachusetts Institute of Technology) folding-endurance tester, a crumpling apparatus, an air permeameter, and two types of abrasion testers have been used in the present work to aid in evaluating wearing quality.

## II. PAPER-MAKING EQUIPMENT

The Bureau's paper mill is equipped to make paper on a semi-commercial scale under practical mill conditions. The equipment employed in the manufacture of the currency papers included a rag cutter; duster; rotary boiler; 50-pound copper-lined wood-tub beater, having manganese-bronze bars and plate, and equipped with a washing cylinder; jordan refiner, with bars of a bronze and steel alloy; four-plate screen; 29-inch Fourdrinier paper-making machine, with wire 33 feet long and having two presses, nine 15-inch dryers, a small machine stack of seven rolls, and a reel; surface-sizing bath and drying cabinet; and a five-roll supercalender.[3]

## III. PAPER-MAKING RAW MATERIALS

The fibrous materials employed were the kinds commonly used in currency paper and in other high-grade papers, and in addition two kinds (caroa and sisal) not ordinarily used in this country for the purpose. The linen fiber was obtained from linen cuttings, and the

[2] Tech. Pap. BS 21, 89 (1926) T329; BS J. Research 3, 899 (1929) RP121.

[3] Descriptions and photographs of the equipment are contained in the following publications: Tech. Paper. BS 21, 338-341 (1927) T340; BS J. Research 3, 904-905 (1929) RP121; Paper Trade J. 89, TS194 (Nov. 7, 1929).

cotton fiber, from hosiery clippings and muslin cuttings, all of which, in paper-making parlance, are designated as "new rags." There were four groups of the new rags: light-colored linen cuttings (graded as white and cream); dark-colored linen cuttings (graded as gray and brown); unbleached cotton hosiery clippings; and unbleached muslin. There were also four types of bleached wood pulps—sulfate, sulfite, hard alpha, and soft alpha.[4] In addition, there were two pulps made from leaf fibers, caroa and sisal.

## IV. MAKING THE EXPERIMENTAL PAPERS

### 1. PREPARATION OF THE RAG HALF-STUFF

The procedure followed in the preparation of the rag half-stuff (partially pulped rags that have been boiled, washed, beaten out of weave, and bleached) was essentially the same as the general practice in the commercial production of high-grade papers from rags. It has been described in previous Bureau publications.[5]

The constant factors in the cooking of the rags were as follows:

| | |
|---|---|
| Weight of oven-dry fiber | 106 lb. |
| Volume of water | 52.5 gal. |
| Initial temperature | 70° to 80° F. |
| Duration of initial temperature | 1 hr. |
| Time for raising to cooking temperature | 1 hr. |
| Cooking temperature | 250° to 260° F. |
| Duration of cooking temperature | 5 hr. |
| Cooking pressure | 30 to 40 lb./in.$^2$ |

Commercial caustic soda (96 percent sodium hydroxide) was used in the cooking liquor to cleanse the rags. The amount used was varied according to the kind of rags being treated. For cotton rags (hosiery and muslin) the amount was 2 percent of the weight of rags; for light-colored linens, 3.5 percent; and for dark-colored linens, 5 percent.

The bleaching operation was begun in the washer (beater used as washer) and was completed in the drainer. Only a small amount of bleaching agent was used to brighten the half-stuff, no attempt being made to bleach it white.

The four groups of rags mentioned in the previous section were kept separate throughout these preparatory processes, until they were blended in the beater.

### 2. PREPARATION OF CAROA AND SISAL PULPS

Previous work [6] at the Bureau on caroa fiber has shown that the preliminary process employed in the separation of the fiber from the plant is an important factor in determining the properties of the pulp. Description of the procedure used to produce the caroa and sisal pulps from the harvested plant was not supplied, but it is assumed that the plant fibers were cooked, washed, partially bleached, and washed again. For use in currency-type paper it was desirable that the pulps be somewhat whiter than those received. Therefore, they were given additional bleaching and washed again.

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[4] Sulfate pulp is a typical strong pulp made by cooking wood by the sulfate process, in which the loss of alkali is made up by adding sodium sulfate. Sulfite is made by cooking chips in an acidic solution, usually bisulfite of calcium. Hard alpha is a sulfate pulp that is given a further purification treatment. Soft alpha is a special form of sulfite wood pulp, highly purified by removing the undesirable forms of cellulose normally found in wood pulps.

[5] Tech. Pap. BS **21**, 91 (1926) T329; BS J. Research **3**, 902 (1929) RP121; J. Research NBS **14**, 651 (1935) RP794.

[6] Tech. Pap. BS **21**, 323 (1927) T340.

The sisal pulp as received seemed somewhat raw and therefore was given further cooking before the additional bleaching and washing. The cooking procedure was that usually used at the Bureau for rags. The amounts of chemicals used were 5 percent of lime and 5 percent of sodium sulfite, based on the weight of the dry pulp.

### 3. BEATER AND PAPER-MACHINE OPERATIONS

The method of beating the half-stuff to prepare it for forming a sheet on the paper machine followed very closely that used for previous experimental production of currency paper and described in a previous publication.[7] The characteristic feature of the method was the gradual lowering of the beater roll.

Before the furnish, that is, the various paper-making materials blended in the beater, was added to the beater, the roll was raised off the plate in order to give clearance to the lumps of half-stuff. The tub was partially filled with water, half-stuff from the drainers was introduced, and additional water was run in until the desired dilution was obtained. After some circulation of the furnish, the roll was gradually lowered, by definite amounts and at fixed intervals, to brush out the fibers and reduce them to optimum length. 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. (At settings below zero, the roll is practically freely suspended and riding on the fiber furnish.) Table 1 gives these positions and the corresponding time intervals for the two beating procedures (*A* and *B*) used.

TABLE 1.—*Schedule of roll settings for beating stock*

| Procedure *A* | | Procedure *B* | |
|---|---|---|---|
| Beating interval | Position of roll [a] | Beating interval | Position of roll [a] |
| *hr* | | *hr* | |
| 0 | [b] +10 | 0 | [b] +10 |
| 1/6 | [c] +10 | 1/6 | [c] +10 |
| 1/4 | +6 | 1/4 | +3 |
| 1 | +5 | 1 | +2 |
| 1½ | +4 | 1½ | +1 |
| 2 | +3 | 2 | +½ |
| 2½ | +2 | 2½ | 0 |
| 3 | +2 | 3 | 0 |
| 3½ | +1½ | 3½ | −½ |
| 4 | +1½ | 4 | −½ |
| 4½ | +1 | 4½ | −1 |
| 5 | +1 | 5 | −1 |
| 5½ | +½ | 5½ | −1 |
| 6 | +½ | 6 | −1 |
| 6½ | +½ | 6½ | −1 |
| 7 | +½ | 7 | −1 |
| 7½ | 0 | 7½ | −1 |
| 8 | 0 | 8 | −1 |
| 8½ | 0 | 8½ | −1 |
| 9 | 0 | 9 | −1 |
| 9½ | 0 | | |
| 10 | −½ | | |
| 10½ | −½ | | |
| 11 | −½ | | |
| 11½ | −½ | | |
| 12 | −½ | | |

[a] Expressed in turns of the handwheel, which raises or lowers the beater roll. When under positive control, 1 turn of the handwheel changes roll position 0.008 inch.
[b] Quick-raising lever up.
[c] Quick-raising lever down.

[7] Tech. Pap. BS **21**, 96 (1926) T329.

The beaten pulp (stuff, stock) [8] was run into the stuff chest, and from there it was pumped in a continuous stream through the stuff box and the jordan refiner to the paper machine. Pumping the stock from the jordan directly to the paper machine is considered better practice than discharging it into a machine chest and subsequently withdrawing it as needed. By the former (direct) method, changes in the character of the stock indicated as desirable by conditions at the screen, on the paper machine, or in the finished sheet can be effected rapidly by suitable adjustments of the jordan.

The stuff box was of the familiar regulating-box type having a constant head over an adjustable orifice.

Screen plates with 0.024-inch slots were used.

The paper-machine head box (or flow box) was equipped with baffles to mix the stock thoroughly and uniformly as it went to the wire (bronze-wire cloth). There were two slices [9] on the paper machine

The temperature of the stock at the head box was maintained at 110°±2° F.

The manipulation of the beater roll (procedure *A* or *B*) and the time of beating the various furnishes are given in table 2. Departures from the beating schedules of table 1 are discussed below. With three exceptions, 48 pounds of pulp was furnished to the beater for each run.

In the preparation of stock for making paper 11 (cotton and hard alpha),[10] beating procedure *A* was followed, except that the beating was continued for an extra hour. It was expected that when rag half-stuff and wood pulp were mixed the circulation would be faster, so the weight of the pulp was increased to 50 pounds. However, the circulation did not increase, necessitating the extra hour of beating. Even then the beaten fiber was considered fairly long, but the stock gave no trouble on the paper machine. Fifty pounds of pulp was also used in preparing stock for making papers 13 and 13M3 (sulfite). Beating procedure *B* was followed to the roll setting of —½ (see table 1), and the roll was not lowered below this setting. The beating time was 7 hours.

Beating procedure *B* was used in preparing stock for papers 14 and 14M3 (soft alpha), except that the beating was stopped at the end of 8 hours, as the stock was then considered satisfactory. Beating procedure *B* was also used in preparing stock for paper 14x, but the beating time was lengthened to 12 hours.

The caroa and sisal pulps were evidently not refined as much as would be considered desirable for use in currency-type paper, and therefore gave some trouble. The results obtained are not necessarily representative of what might be accomplished under optimum conditions.

The first run of caroa pulp (paper 6x) was beaten for 7 hours by procedure *B*. The stock in the beater felt slimy, doubtless because of the large amount of pithy material in the caroa pulp. The beating shortened the fibers very little, presumably because the pithy material lubricated the surfaces of the beater bars and reduced the cutting and

[8] "Stock" is used in this paper to mean the beaten and refined pulp, together with any added materials, diluted and ready to be formed into paper on the paper machine. It is synonymous with "stuff," but is now more generally used in the paper industry.

[9] The slice is an adjustable crosspiece that controls the depth of the stream of stock that flows on to the paper-machine wire and keeps the surface even. A machine making fine papers usually has two slices.

[10] The grouping of the papers and the designations are explained in note 1 under table 2.

brushing action. An attempt to jordan and screen the stock in the usual way as it flowed to the paper machine was unsuccessful. The fibers collected in bunches in the jordan, which ultimately was used only as a pump. The stock, furthermore, would not go through the 0.024-inch slots in the screen plates. Consequently, it was run through the jordan with the plug pulled away from the bars, and was not screened.

After the pulp for the second run of caroa fiber (paper 6) had been furnished to the beater and circulated for a few minutes, the stock was made acid by the addition of alum (1.9 percent, based on the weight of the dry pulp). Although beaten for 9 hours, the fibers were long. When the stock was being jordanned, at +2 setting, the load on the jordan motor was practically at its capacity. The stock did not screen easily, and continuous scraping of the screen plates was required to keep the stock passing through. The pH at the head box was 5.0. The formation of the finished sheet was "wild" (irregular).

The cotton-caroa stock for paper 7 was made acid with alum (1.5 percent, based on the weight of the dry stock). The pH at the head box was 5.0.

During the beating of the sisal pulp for paper 8, the beater water began to get cloudy shortly after the pulp was added to the beater, as though the pithy, or natural resinous, material was being beaten into a fine suspension. Alum solution was added and the water became clear. The amount of alum used was 2.0 percent of the weight of the dry stock. The beating time (procedure *B*) was reduced to 7 hours. The pH of the stock at the head box was 6.4. The finished paper was well sized and had a very smooth and waxy finish, although neither resin size nor wax had been added.

The cotton-sisal stock for paper 9 was beaten only 8 hours (procedure *B*). It was made acid with alum (1.5 percent of the weight of the dry pulp). The pH at the head box was 6.0. The finished paper was sized somewhat, but not as well as that made from sisal only (paper 8).

## 4. PAPERS CONTAINING MELAMINE RESIN

The chief reason for retiring paper currency from service is the surface disintegration resulting from wear, which impairs the legibility of the printed matter. Improved bonding between fibers has been achieved very successfully in certain types of paper by the addition of melamine resin during fabrication. To see if it would improve the surface, reducing fuzzing, and lessen the tendency to scuff, crack, and wear away, a small amount of melamine resin (3 percent of the weight of the dry stock) was incorporated in a few of the experimental currency-type papers. Otherwise, each of these papers was made in the same manner as the corresponding unsized paper having the same group number.

For the first trial, paper 10M1 (companion to 10), the prepared melamine-resin solution was added in the machine chest, and the stock was run at pH 6.9, which was obtained by buffering with soda ash (method 1 of adding melamine resin).

For the second trial, paper 10M2, the melamine-resin solution was added continuously to the stock after it left the screen but before it reached the head box. This method of introduction permitted sufficient agitation and mixing of the melamine-resin solution with the stock at the point of addition. The pH of the stock at the head box was approximately 6.5, with no buffering material added (method 2).

In a third run, paper 10M3, the stock was made slightly acid with alum in the stuff chest, and the melamine-resin solution was added continuously between the screen and the head box (method 3). The pH of the stock leaving the chest, and in the stuff box, before the melamine-resin solution was added, was 5.0, and at the head box it was 4.4. The paper-machine wire was brightened very noticeably, as much as or more than when it is given a regular acid-cleansing treatment.

These three trial runs of hard-alpha pulp indicated that the addition of melamine resin in the chest (method 1) did not develop as much strength in the paper as did methods 2 and 3. Accelerated curing at 260° F for 10 minutes indicated also that the polymerization, or curing, of the resin developed more slowly when method 1 was used than when method 2 or method 3 was used. There was some evidence, however, that excessive use of alum in method 3 to catalyze or hasten the polymerization of the resin may have impaired the permanence of the papers so made.

In making papers 3M2 (companion to 3) and 5M2 (companion to 5), the melamine-resin solution was added according to method 2. The pH at the head box was 6.9 and 6.6, respectively.

In making papers 13M3 (companion to 13) and 14M3 (companion to 14), the melamine-resin solution was added according to method 3, except that the stock was not made quite so acid in the chest. In making paper 13M3, the pH of the stock leaving the chest was 6.6, and of that at the head box, 5.0 to 5.4. In making paper 14M3, the corresponding values were 6.0 to 6.5 and 5.2 to 5.5.

## 5. SURFACE SIZING THE PAPERS

To facilitate printing the paper by the wet-intaglio process used in making paper currency and to improve the folding endurance and resistance to wear, currency paper is given a surface-sizing treatment with glue. Portions of the 14 groups of experimental papers were similarly surface sized. The waterleaf (unsized) paper was run through a solution of animal glue at approximately 130° F, then between a pair of squeeze rolls to remove the excess sizing solution, and dried in a festoon drier. The desired finish was imparted to the paper by supercalendering.

In these surface-sizing experiments two glue-sizing solutions were used. One contained 4 percent of glue and 0.15 percent of alum (3.75 percent of the weight of the glue), and had a pH of 4.7. The other contained 4 percent of glue and 0.01 percent of formaldehyde (0.25 percent of the weight of the glue), and had a pH of 6.1. The addition of alum or formaldehyde to glue has a tanning effect on the glue, increasing its water resistance and making it more effective as a surface-sizing agent.

Portions of all the papers made, except 6x, were surface sized with the glue-and-alum solution, and other portions of seven of them were surface sized with the glue-and-formaldehyde solution. (See table 2 and note 1 thereunder.)

## V. METHODS OF TESTING THE PAPERS

### 1. OFFICIAL METHODS

All the physical and chemical tests of the papers were made by the official methods of the Technical Association of the Pulp and Paper Industry,[11] except the tests involving abrasion, crumpling, and the measurement of air permeability. All the physical tests were made under the standard hygrometric conditions of 50-percent relative humidity and 73° F, unless otherwise stated.

### 2. WEAR BY CRUMPLING

This method of testing has been described in a previous publication,[12] but the crumpling apparatus used in this work differs from that previously described. It is a much simpler, hand-operated apparatus (fig. 1), which crumples the paper under a fixed pressure instead of to a fixed volume. The crumpling cycle is identical with that previously described, although it is not achieved in the same manner.

The photograph (fig. 1) shows the crumpling device and also the device for rolling the specimen (a 2⅝-inch square of paper). The apparatus with which the specimen is rolled consists of a split sheath, *R*, within which there is a two-tined fork integral with a rod that passes through a bearing and terminates in the knob *N*. The specimen of paper is inserted as shown through the slot in the sheath and between the tines of the fork, and is then rolled into a cylinder by rotating knob *N* (which rotates the fork inside the sheath). The entire rolling device is then lifted from its support, and the rolled paper is delivered into the tube *C* by placing the rolling device vertically above the tube, with the open end of the split sheath in contact with the open end of the tube, and then pressing knob *N* downward. This operation pushes the fork, with its engaged roll of paper, into tube *C*, after which the fork is withdrawn and disengaged, leaving the specimen in the tube.

Tube *C* is free to move up and down within the supporting cylindrical guide *B*. Within tube *C* there is a rod or piston (not shown), the lower end of which rests upon the short end of the lever *L*. At the other end of this lever, a weight, *W*, is fastened.

The specimen is crumpled in the following manner. The open end of tube *C* (containing the rolled cylinder of paper) is closed by a cap, *K*, which is locked in place. Tube *C* is then forced downward by hand, the force being communicated from cap *K*, through the roll of paper, to the piston within tube *C* and thence to lever *L*. The limit on the applied pressure is set by the moment of weight *W* which is lifted when the pressure reaches about 150 pounds per square inch.[13] In this process the paper specimen is reduced from a cylinder, 2⅝ inches long, to a crumpled wad, about ½ inch long. Tube *C* is then

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[11] Copies of the official methods may be obtained from the Association at 122 East 42d Street, New York 17, N. Y.

[12] J. Research NBS **26**, 467 (June 1941) RP1390.

[13] This maximum crumpling pressure was fixed by placing a weight of 22.1 pounds on the piston, which is 11 mm in diameter, and adjusting the position of weight *W* on lever *L* until the two moments were balanced. The weight was then fastened to the lever with a setscrew.

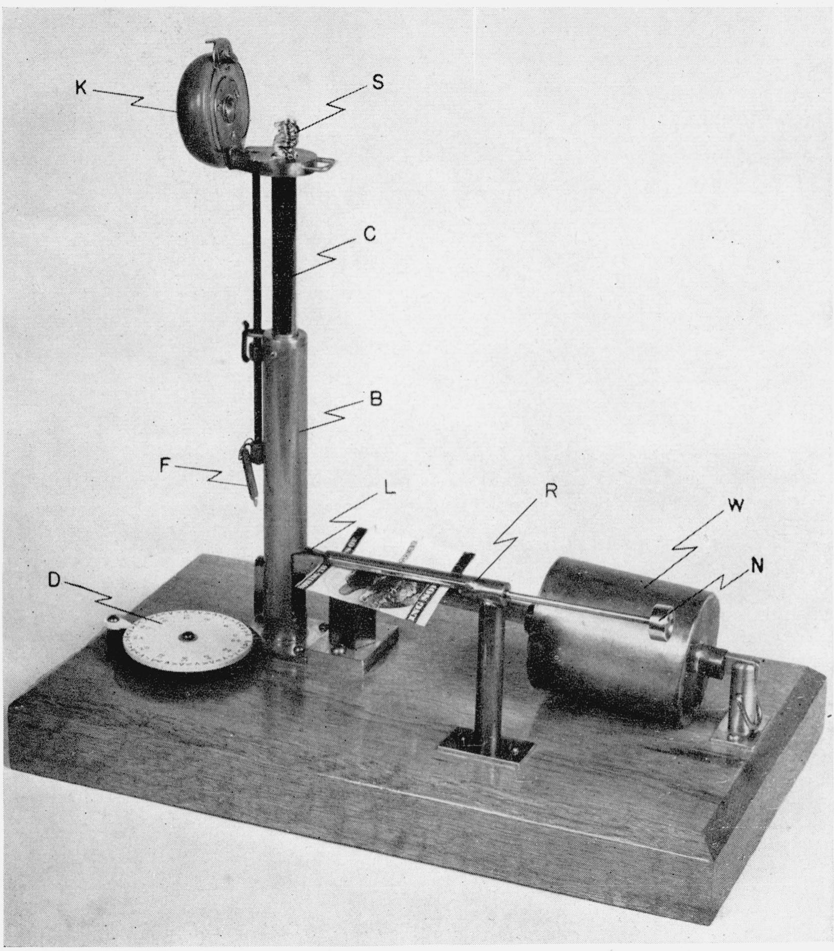


FIGURE 1.—*Crumpling Apparatus.*

raised to the position shown in figure 1, and cap *K* is unlocked. The protruding, crumpled specimen, *S*, is removed and straightened out by hand, after which it is again put in the rolling device, *R* (oriented a quarter turn from the previous position) rolled up, transferred to tube *C*, and crumpled again.

At each crumpling stroke a pivoted finger, *F*, moving downward with tube *C*, engages one of the holes in the counter disk, *D*, and advances the disk one space. The number under the pointer indicates the number of times the specimen has been crumpled.

The counter disk also carries arrows to indicate how to place the specimen in the rolling device. Before a specimen is crumpled, an identifying mark is placed on one edge. The first time the specimen is put in the rolling device, *R*, this mark is placed to the left, at the tip of the fork. Each succeeding time it is advanced a quarter turn. The arrow on the numbered dial, *D*, under the pointer indicates in which one of the four possible positions in the rolling device one is to place the identifying mark on the specimen for the next rolling and crumpling operation.

Five specimens of each paper were crumpled 16 times (4 cycles). The effect of this crumpling treatment was measured by the change in air permeability and in tensile strength produced by the crumpling. When paper is creased or crumpled the interlaced fibers are disturbed, the bonds are loosened, and the disarranged structure becomes less compact, weaker, and more permeable to air under pressure.

Air permeability therefore is a very sensitive measure of this structural change. This measurement was made with a permeameter built to accommodate specimens of the size used in the crumpling apparatus (see footnote 12). Tests were made on identical specimens before and after the specimen had been crumpled 16 times. Each of the 5 crumpled specimens was then cut in the cross direction into 4 strips, and these 20 strips were used in determining the tensile strength of the crumpled paper. The average values for the two tests have been tabulated, and also the percentage retention of the tensile strength after the crumpling treatment (percentage of the normal cross-direction tensile-strength values in table 2).

## 3. SURFACE WEAR

As already stated, melamine resin was added to some of the papers to see if it would reduce surface disintegration. Tests of these papers, in comparison with the untreated papers, were made with the Taber abrasion instrument,[14] fitted with number CS–17 abrasion wheels, operated under a load of 1 kg each. The conventional circular specimens, clamped at the center, were not stiff enough to remain flat under the action of the abrasion wheels. Octagonal specimens were therefore used, being fastened to the turntable by turning the apexes down over the edge and binding them with a clamping ring.

Six specimens of each of the papers tested were used, half being abraded on one side and half on the other. The values tabulated (table 6) are in each case the average of the six tests.

[14] Paper Trade J. **119**, 24 (July 20, 1944).

## 4. SCUFFING OF WET PAPER

The same papers were tested by rubbing them while wet, until a hole was worn through. An instrument for making such a test was described several years ago.[15] Since then it has been somewhat modified. The abrading surface, originally of rubber, has been replaced by a chromium-plated metal surface, and the clamping device has been improved. The apparatus is illustrated in figure 2.

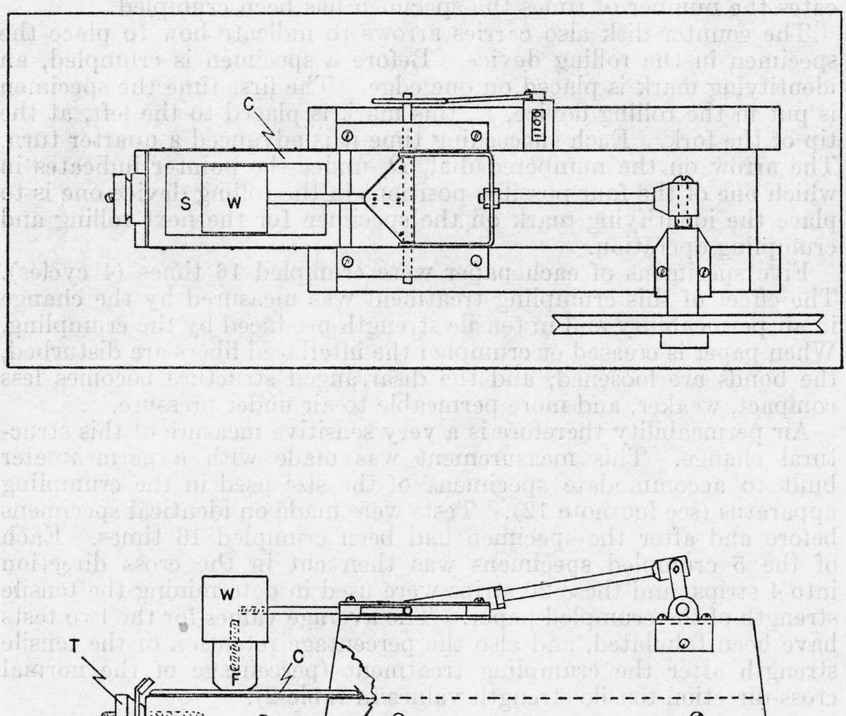


FIGURE 2.—*Sketch of apparatus used to evaluate the resistance of wet paper to scuffing.*

The specimen, *S*, is held at its edges by a rectangular clamping frame, *C*, which serves also as the sides of a shallow basin to hold water placed on the specimen to keep it wet during the test. The clamping frame is held down by a sliding wedge, *R*, moved by turning a thumb

[15] Paper Trade J. **84**, TS13 (Jan. 13, 1927).

nut, *T*. A spherical surface, having a radius of curvature of half an inch, shaped on the end of a brass cylinder, *F*, and chromium plated, is moved back and forth in contact with the specimen by a motor-driven crank shaft. Additional pressure is applied by weight *W*. A load of 2.5 pounds was used in these tests. A ratchet counter registers the number of oscillations of the rubbing surface. This test, although not strictly a measure of surface abrasion, inasmuch as a hole is worn entirely through the specimen and the result is in some measure influenced by the strength of the wet paper, appears to indicate major differences in the resistance of papers to scuffing while wet.

The values given (table 6) are averages of 5 tests in each case.

## VI. RESULTS OF TESTS

The characteristics of the currency-type papers made are shown by the data[16] in table 2. In this table the papers have been placed in 14 groups according to fiber composition. They consist of machine-finished, waterleaf (unsized) papers; the same surface-sized with glue, tanned with alum (a) or with formaldehyde (f); machine-finished papers containing melamine resin (M); and the same surface-sized with glue, tanned with alum (a).

Paper 3a may be considered the norm of the table as it most resembles the currency paper in use today. All folding-endurance values have been rounded off to the nearest 100 double folds.

All physical properties tabulated, except resistance to tearing, were improved by surface sizing the papers with glue. The data indicate no clear-cut advantage of formaldehyde over alum as tanning agent for the glue. In most instances the folding endurance was greater when the glue was tanned with formaldehyde. The tensile strength was also greater for the papers having a high linen content, but was less for most of the others. Bursting strength and resistance to tearing, however, fared about equally well with the two tanning agents. Stretch at failure was greater in most cases with the alum tanning, which also produced a better closed sheet in all cases (lower air permeability).

In a few of the groups two beating treatments were used. It appears that beating procedure *A* produced a little better paper than did procedure *B*. In two groups the beating (by procedure *B*) was varied in time only. The caroa pulp was benefited by the longer beating period, except that the resistance to tearing was decreased somewhat. The soft-alpha wood pulp, however, benefited little if any by the longer beating time. In all cases the longer beating time, regardless of procedure, resulted in a better closed sheet (lower air permeability).

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[16] In previous research (reference 2) at the Bureau on the production of currency paper, the testing was done at 65-percent relative humidity and 70° F. Folding endurance tests at 65-percent relative humidity of a few of the papers made in the present research indicate that these papers are comparable in quality to papers of like composition made in the older research projects.

TABLE 2.—*Properties of experimental currency-type papers*

[All physical tests were made at 50-percent relative humidity and 73° F.]

| Designation [1] of papers | Areal weight (half million square inches) [2] | Thickness | Folding endurance in hundred double folds | | | | | Tensile strength [5] | | | | Stretch at failure | | Resistance to tearing [6] | | Bursting strength [7] | Air permeability [8] | | Acidity | | Glue content | Melamine-resin content |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Schopper | | MIT | | Composite | Machine | Cross | After 16 crumples | | Machine | Cross | Cross | Machine | | Before crumpling | After 16 crumples | Cold | Hot | | |
| | | | Machine [3] | Cross [4] | Machine | Cross | | | | Cross | Retention cross | | | | | | | | | | | |
| LINEN. BEATEN 12 HOURS BY PROCEDURE *A* (SEE TABLE 1) | | | | | | | | | | | | | | | | | | | | | | |
| | *lb.* | *in.*× $10^{-4}$ | | | | | | *kg/cm* | *kg/cm* | *kg/cm* | % | % | % | *g* | *g* | *Points* | *csm* | *csm* | pH | pH | % | % |
| 1 | 61 | 36 | 30 | 23 | 19 | 14 | 22 | 7.3 | 4.1 | 2.7 | 67 | 3.0 | 8.4 | 120 | 117 | 45 | 2.0 | 113 | 7.2 | 7.3 | ------ | ------ |
| 1a | 61 | 33 | 23 | 28 | 16 | 32 | 25 | 8.7 | 4.8 | 3.5 | 72 | 4.5 | 9.8 | 96 | 91 | 62 | 0.2 | 60 | 6.5 | 6.8 | 1.3 | ------ |
| 1f | 62 | 36 | 29 | 36 | 34 | 42 | 35 | 9.5 | 5.1 | 3.7 | 73 | 3.8 | 9.2 | 98 | 90 | 59 | .8 | 75 | 6.9 | 7.4 | 1.9 | ------ |
| COTTON (1 PART) AND LINEN (3 PARTS). BEATEN 12 HOURS BY PROCEDURE *A* | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 60 | 37 | 34 | 28 | 19 | 14 | 24 | 7.1 | 3.9 | 2.6 | 66 | 2.9 | 7.2 | 121 | 126 | 46 | 2.2 | 146 | 6.5 | 7.0 | ------ | ------ |
| 2a | 62 | 36 | 30 | 33 | 29 | 31 | 31 | 8.5 | 4.9 | 3.5 | 71 | 3.9 | 10.1 | 112 | 107 | 63 | 0.2 | 79 | 6.5 | 6.8 | 1.3 | ------ |
| 2f | 62 | 34 | 32 | 38 | 37 | 42 | 37 | 8.4 | 5.2 | 3.6 | 69 | 3.7 | 12.0 | 113 | 101 | 65 | .9 | 96 | 6.8 | 7.5 | 2.0 | ------ |
| COTTON AND LINEN (EQUAL PARTS). BEATEN 12 HOURS BY PROCEDURE *A* | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 61 | 37 | 34 | 28 | 24 | 11 | 24 | 6.9 | 3.7 | 2.4 | 66 | 2.7 | 7.6 | 132 | 133 | 45 | 2.6 | 186 | 6.7 | 7.3 | ------ | ------ |
| 3a | 62 | 34 | 28 | 34 | 32 | 28 | 31 | 8.4 | 4.3 | 3.4 | 80 | 4.3 | 11.6 | 117 | 108 | 60 | 0.3 | 105 | 6.4 | 6.7 | 1.3 | ------ |
| 3f | 64 | 35 | 36 | 43 | 35 | 30 | 36 | 8.5 | 4.9 | 3.5 | 70 | 3.9 | 8.8 | 124 | 117 | 65 | 1.2 | 130 | 6.9 | 7.7 | 2.0 | ------ |
| 3M2 | 61 | 35 | 46 | 52 | 65 | 122 | 71 | 9.2 | 5.6 | 4.3 | 76 | 3.9 | 10.0 | 107 | 95 | 62 | 1.0 | 42 | 6.1 | 6.0 | ------ | 2.9 |
| 3M2a | 62 | 33 | 41 | 52 | 83 | 104 | 70 | 9.7 | 5.9 | 5.1 | 88 | 4.1 | 11.4 | 83 | 75 | 70 | 0.1 | 28 | 5.9 | 6.0 | 0.9 | 2.9 |

COTTON (3 PARTS) AND LINEN (1 PART). BEATEN 12 HR. BY PROCEDURE *A* (4X BEATEN 8 HR. BY PROCEDURE *B*)

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4x | 62 | 39 | 27 | 16 | 18 | 6 | 17 | 6.7 | 3.5 | 1.9 | 56 | 2.2 | 6.7 | 141 | 140 | 40 | 5.4 | 396 | 7.2 | 7.1 | | |
| 4xa | 66 | 38 | 36 | 50 | 22 | 26 | 34 | 8.9 | 5.0 | 3.3 | 67 | 4.0 | 9.7 | 132 | 139 | 63 | 1.0 | 177 | 6.0 | 6.3 | 1.7 | |
| 4 | 61 | 38 | 32 | 14 | 25 | 8 | 20 | 6.5 | 3.6 | 2.1 | 57 | 2.6 | 7.8 | 142 | 138 | 43 | 2.9 | 293 | 6.4 | 6.6 | | |
| 4a | 64 | 36 | 35 | 37 | 37 | 23 | 33 | 8.9 | 4.9 | 3.2 | 65 | 4.0 | 9.6 | 126 | 122 | 62 | 0.3 | 142 | 6.3 | 6.8 | 1.3 | |
| 4f | 62 | 37 | 36 | 29 | 47 | 28 | 35 | 8.0 | 4.7 | 3.1 | 66 | 3.9 | 9.6 | 109 | 114 | 60 | 1.4 | 209 | 6.8 | 7.6 | 2.0 | |

COTTON. BEATEN 12 HR. BY PROCEDURE *A* (5X BEATEN 8 HR. BY PROCEDURE *B*)

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5x | 61 | 39 | 31 | 18 | 14 | 8 | 18 | 6.1 | 3.6 | 1.9 | 54 | 2.2 | 6.9 | 142 | 156 | 34 | 5.5 | 442 | 7.2 | 7.6 | | |
| 5xa | 65 | 39 | 37 | 59 | 27 | 32 | 39 | 8.8 | 5.0 | 3.4 | 68 | 3.7 | 9.4 | 130 | 145 | 64 | 0.8 | 168 | 6.0 | 6.2 | 1.9 | |
| 5 | 62 | 38 | 33 | 20 | 24 | 9 | 22 | 6.3 | 3.6 | 2.0 | 56 | 2.5 | 7.6 | 154 | 156 | 40 | 3.1 | 329 | 6.6 | 7.2 | | |
| 5a | 66 | 35 | 28 | 30 | 37 | 22 | 29 | 8.5 | 5.0 | 3.1 | 63 | 4.7 | 10.8 | 135 | 134 | 60 | 0.3 | 169 | 6.1 | 6.2 | 1.3 | |
| 5f | 64 | 36 | 40 | 39 | 36 | 28 | 36 | 8.3 | 4.9 | 2.9 | 59 | 3.7 | 9.7 | 118 | 125 | 66 | 1.7 | 275 | 6.7 | 7.6 | 2.1 | |
| 5M2 | 60 | 36 | 44 | 53 | 80 | 93 | 68 | 9.3 | 5.5 | 4.6 | 83 | 4.0 | 10.1 | 99 | 113 | 65 | 1.3 | 87 | 5.7 | 5.7 | | 2.5 |
| 5M2a | 61 | 33 | 44 | 56 | 88 | 119 | 77 | 9.9 | 6.2 | 5.4 | 87 | 4.3 | 11.6 | 90 | 85 | 80 | 0.1 | 57 | 5.6 | 6.0 | 1.0 | 2.5 |

CAROA. BEATING PROCEDURE *B*, 9 HOURS (6X, 7 HOURS)

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6x | 62 | 49 | 18 | 20 | 17 | 16 | 18 | 6.6 | 3.8 | 2.9 | 77 | 3.3 | 9.5 | 187 | 175 | 45 | 17.4 | 1,192 | 8.1 | 7.6 | | |
| 6 | 62 | 43 | 22 | 32 | 20 | 18 | 23 | 7.6 | 4.3 | 3.2 | 74 | 3.8 | 11.7 | 163 | 164 | 53 | 8.2 | 509 | 5.8 | 4.8 | | |
| 6a | 62 | 42 | 21 | 32 | 26 | 32 | 28 | 8.2 | 4.7 | 4.1 | 87 | 4.7 | 12.1 | 143 | 144 | 67 | 0.7 | 269 | 5.4 | 4.7 | 2.4 | |

COTTON AND CAROA (EQUAL PARTS). BEATEN 9 HOURS BY PROCEDURE *B*

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 64 | 39 | 29 | 23 | 18 | 9 | 20 | 7.1 | 3.9 | 2.5 | 64 | 3.4 | 10.5 | 146 | 156 | 51 | 4.0 | 287 | 5.7 | 4.6 | | |
| 7a | 65 | 38 | 35 | 31 | 26 | 21 | 28 | 8.5 | 4.5 | 3.3 | 75 | 4.0 | 11.3 | 131 | 120 | 63 | 0.2 | 147 | 5.4 | 4.8 | 1.4 | |

SISAL. BEATEN 7 HOURS BY PROCEDURE *B*

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 61 | 41 | 16 | 16 | 11 | 8 | 13 | 6.3 | 3.4 | 2.1 | 61 | 3.9 | 10.8 | 144 | 147 | 39 | 5.3 | 978 | 6.4 | 5.4 | | |
| 8a | 65 | 41 | 15 | 22 | 13 | 16 | 17 | 7.1 | 4.1 | 2.9 | 71 | 3.1 | 11.2 | 120 | 124 | 51 | 0.5 | 484 | 5.9 | 5.2 | 2.3 | |

See footnotes at end of table.

TABLE 2.—*Properties of experimental currency-type papers*—Continued

| Designation [1] of papers | Areal weight (half million square inches) [2] | Thickness | Folding endurance in hundred double folds: Schopper, Machine [3] | Schopper, Cross [4] | MIT, Machine | MIT, Cross | Composite | Tensile strength [5]: Machine | Cross | After 16 crumples: Cross | After 16 crumples: Retention cross | Stretch at failure: Machine | Stretch at failure: Cross | Resistance to tearing [6]: Cross | Resistance to tearing: Machine | Bursting strength [7] | Air permeability [8]: Before crumpling | Air permeability: After 16 crumples | Acidity: Cold | Acidity: Hot | Glue content | Melamine-resin content |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **COTTON AND SISAL (EQUAL PARTS). BEATEN 8 HOURS BY PROCEDURE *B*** | | | | | | | | | | | | | | | | | | | | | | |
| | *lb.* | *in.*× $10^{-4}$ | | | | | | *kg/cm* | *kg/cm* | *kg/cm* | % | % | % | *g* | *g* | *Points* | *csm* | *csm* | pH | pH | % | % |
| 9 | 61 | 38 | 20 | 20 | 10 | 7 | 14 | 6.5 | 3.6 | 2.1 | 57 | 3.2 | 8.9 | 148 | 156 | 38 | 4.0 | 355 | 6.1 | 5.1 | ------ | ------ |
| 9a | 63 | 39 | 24 | 23 | 12 | 14 | 18 | 6.9 | 4.0 | 2.6 | 65 | 3.2 | 8.9 | 128 | 139 | 48 | 0.4 | 215 | 5.7 | 5.0 | 1.7 | ------ |
| **HARD-ALPHA WOOD PULP. BEATEN 9 HOURS BY PROCEDURE *B*** | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 59 | 37 | 15 | 8 | 17 | 26 | 17 | 6.3 | 3.1 | 1.6 | 50 | 2.0 | 7.1 | 76 | 72 | 37 | 17.9 | 2,438 | 6.4 | 6.4 | ------ | ------ |
| 10a | 64 | 37 | 14 | 12 | 14 | 14 | 14 | 8.7 | 4.6 | 2.9 | 64 | 2.9 | 9.5 | 65 | 57 | 53 | 3.1 | 1,404 | 5.9 | 5.8 | 2.3 | ------ |
| 10f | 62 | 34 | 12 | 13 | 13 | 10 | 12 | 7.7 | 4.3 | 2.6 | 59 | 2.4 | 7.7 | 66 | 57 | 49 | 7.8 | 1,867 | 6.4 | 6.4 | 2.7 | ------ |
| 10M1 | 60 | 37 | 18 | 13 | 16 | 12 | 15 | 7.6 | 3.8 | 2.5 | 67 | 2.4 | 6.8 | 68 | 61 | 44 | 17.2 | 1,672 | 6.3 | 6.1 | ------ | 2.7 |
| 10M1a | 64 | 36 | 10 | 15 | 22 | 25 | 18 | 8.5 | 5.1 | 3.3 | 64 | 2.6 | 8.5 | 57 | 51 | 55 | 2.9 | 1,107 | 6.1 | 6.0 | 1.7 | 2.7 |
| 10M2 | 60 | 35 | 17 | 20 | 9 | 14 | 15 | 8.3 | 4.9 | 3.4 | 70 | 2.5 | 8.7 | 56 | 53 | 52 | 8.6 | 695 | 6.0 | 5.8 | ------ | 3.0 |
| 10M2a | 61 | 33 | 14 | 17 | 33 | 41 | 26 | 8.9 | 5.4 | 3.7 | 69 | 2.8 | 9.8 | 53 | 48 | 60 | 1.3 | 543 | 5.7 | 5.9 | 1.6 | 3.0 |
| 10M3 | 59 | 33 | 18 | 20 | 29 | 42 | 27 | 8.7 | 4.7 | 3.5 | 75 | 2.9 | 8.6 | 56 | 53 | 51 | 3.8 | 488 | 4.8 | 4.9 | ------ | 2.5 |
| 10M3a | 62 | 33 | 15 | 18 | 34 | 47 | 29 | 8.7 | 5.3 | 3.9 | 74 | 3.0 | 10.6 | 51 | 47 | 59 | 0.2 | 383 | 5.0 | 5.1 | 1.4 | 2.5 |
| **COTTON AND HARD-ALPHA WOOD PULP (EQUAL PARTS). BEATEN 13 HOURS BY PROCEDURE *A* (11X, 9 HOURS BY PROCEDURE *B*)** | | | | | | | | | | | | | | | | | | | | | | |
| 11x | 60 | 38 | 21 | 13 | 12 | 5 | 13 | 6.0 | 3.2 | 1.9 | 60 | 2.1 | 6.6 | 116 | 130 | 34 | 5.0 | 736 | 6.7 | 7.3 | ------ | ------ |
| 11xa | 66 | 40 | 24 | 30 | 19 | 22 | 24 | 8.0 | 5.0 | 3.1 | 61 | 3.7 | 9.6 | 113 | 119 | 56 | 0.5 | 415 | 6.0 | 5.2 | 1.6 | ------ |
| 11 | 60 | 38 | 23 | 15 | 13 | 5 | 14 | 6.2 | 3.5 | 1.9 | 53 | 3.0 | 6.9 | 128 | 131 | 32 | 3.7 | 688 | 6.5 | 6.8 | ------ | ------ |
| 11a | 62 | 35 | 22 | 22 | 18 | 13 | 19 | 7.3 | 4.3 | 2.7 | 63 | 2.9 | 8.5 | 112 | 103 | 50 | 0.3 | 396 | 6.1 | 6.1 | 1.5 | ------ |
| 11f | 64 | 38 | 23 | 29 | 24 | 21 | 24 | 8.3 | 4.5 | 3.0 | 66 | 2.9 | 7.5 | 107 | 105 | 55 | 1.7 | 521 | 6.6 | 6.9 | 2.1 | ------ |

**SULFATE WOOD PULP. BEATEN 9 HOURS BY PROCEDURE *B***

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 60 | 38 | 15 | 18 | 15 | 16 | 16 | 9.3 | 4.9 | 3.0 | 62 | 2.4 | 8.5 | 92 | 76 | 52 | 2.5 | 1,087 | 7.3 | 7.2 | ------ | ------ |
| 12a | 62 | 36 | 11 | 16 | 18 | 21 | 17 | 8.9 | 5.4 | 3.9 | 72 | 2.7 | 9.8 | 80 | 73 | 59 | 0.3 | 740 | 6.7 | 7.1 | 1.5 | ------ |

**SULFITE WOOD PULP. BEATEN 7 HOURS BY PROCEDURE *B***

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 60 | 37 | 8 | 7 | 6 | 4 | 6 | 6.6 | 3.6 | 1.5 | 41 | 1.6 | 5.2 | 62 | 61 | 34 | 12.1 | 2,841 | 6.6 | 6.5 | ------ | ------ |
| 13a | 63 | 36 | 7 | 10 | 12 | 9 | 10 | 8.1 | 5.0 | 2.7 | 55 | 2.2 | 7.2 | 54 | 50 | 51 | 3.0 | 1,771 | 6.3 | 6.3 | 1.9 | ------ |
| 13M3 | 61 | 35 | 9 | 12 | 25 | 20 | 17 | 8.7 | 4.9 | 3.1 | 63 | 2.9 | 7.3 | 53 | 47 | 45 | 3.6 | 859 | 5.2 | 5.2 | ------ | 2.5 |
| 13M3a | 62 | 33 | 7 | 10 | 17 | 22 | 14 | 8.9 | 5.3 | 3.3 | 63 | 2.4 | 8.3 | 47 | 45 | 49 | 0.2 | 639 | 5.5 | 5.5 | 0.9 | 2.5 |

**SOFT-ALPHA WOOD PULP. BEATING PROCEDURE *B*, 8 HOURS (14X, 12 HOURS)**

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14x | 60 | 37 | 3 | 2 | 2 | 1 | 2 | 5.1 | 2.9 | 1.4 | 49 | 2.2 | 7.2 | 57 | 59 | 28 | 11.3 | 1,417 | 6.9 | 7.1 | ------ | ------ |
| 14xa | 64 | 37 | 4 | 5 | 7 | 6 | 6 | 7.1 | 4.3 | 2.3 | 54 | 3.0 | 8.9 | 54 | 56 | 44 | 2.0 | 939 | 5.8 | 5.8 | 2.5 | ------ |
| 14 | 59 | 36 | 5 | 2 | 2 | 1 | 3 | 5.5 | 2.4 | 1.0 | 42 | 2.2 | 4.8 | 73 | 70 | 31 | 41.2 | 3,382 | 6.3 | 6.2 | ------ | ------ |
| 14a | 62 | 36 | 6 | 6 | 7 | 6 | 6 | 6.7 | 4.1 | 2.3 | 56 | 2.5 | 7.6 | 55 | 51 | 48 | 18.9 | 2,207 | 6.0 | 5.9 | 2.7 | ------ |
| 14M3 | 60 | 37 | 10 | 13 | 22 | 16 | 15 | 7.0 | 4.7 | 3.1 | 67 | 2.9 | 8.2 | 55 | 52 | 50 | 15.5 | 777 | 5.2 | 5.2 | ------ | 2.7 |
| 14M3a | 63 | 36 | 8 | 11 | 21 | 27 | 17 | 8.2 | 5.0 | 3.5 | 71 | 3.2 | 8.1 | 52 | 48 | 57 | 3.4 | 624 | 5.4 | 5.4 | 1.7 | 2.7 |

[1] The papers are numbered by groups (14 in all), according to fiber composition. An "x" following the numeral indicates a subgroup having beating treatment different from that of the remainder of the group. Surface-sized papers are indicated by a final "*a*" or "*f*", signifying that the glue sizing was tanned with alum (*a*) or with formaldehyde (*f*). "*M*" followed by 1, 2, or 3 indicates that the paper contains melamine resin added by method 1, 2, or 3:

Method 1.—Melamine resin was added to the stock in the machine chest. The stock was run on the paper machine at a pH of 6.9 (obtained by buffering with soda ash).

Method 2.—Melamine resin was added continuously to the stock between screen and head box.

Method 3.—The stock was made acid in the chest with alum. Melamine resin was added continuously to the stock between screen and head box.

[2] Weight of a hypothetical ream of 500 sheets, each measuring 25 by 40 inches, that is, the weight of half a million square inches of paper.

[3] Machine direction, or with the grain of the paper.

[4] Cross direction, or against the grain.

[5] Tensile strength was measured by breaking a strip of paper 1.5 cm wide and 10 cm long between clamps. The usual practice is to report the breaking force for the full width, kilograms per 1.5-cm width, but the data for this table have been reduced to unit width (kg/cm). The tensile data include strength in the cross direction after the paper had been crumpled 16 times, and the percentage retention of strength after the crumpling treatment. See text for method of crumpling.

[6] In tabulating the data for resistance to tearing, the designated directions tested are reversed to make the data comparable with those of the other tests. In paper-testing usage the direction tested is generally designated as the principal direction of orientation of the fibers ruptured, but in the tearing test (Elmendorf), according to official nomenclature, the direction designated is the direction of the tear, which is oriented 90 degrees to the principal direction of the fibers ruptured.

[7] Determined as bursting pressure in pounds per square inch by a particular apparatus and procedure (TAPPI T403m). Because the bursting pressure depends on the area tested, and because of the chance of confusing the pressure unit with the conventional unit of strength of materials, it has become customary to designate the unit of bursting strength as "points".

[8] The unit of air permeability, *csm*, is an abbreviation of cubic centimeters of air flowing in a second through a square meter of the material under unit pressure difference (1 g/cm $^2$).

The addition of melamine resin substantially improved all physical properties listed in the table, except resistance to tearing, which was decreased. A possible exception is the paper 10M1, to which melamine resin was added in the machine chest by method 1, only moderate improvement being apparent in this paper in comparison with its companion made without melamine resin. It is apparent also that surface sizing with glue, in addition to the adding of melamine resin, still further improved the quality of the paper, with the exception of resistance to tearing. Addition of melamine resin to the cotton and to the cotton-linen mixture, and subsequent surface sizing, nearly doubled the tensile strength and bursting strength, and increased the wearing quality (folding endurance and strength after crumpling) two- to threefold, but lowered the resistance to tearing about a third.

From table 2 it appears that, whereas the MIT folding endurance is usually lower than the Schopper for plain papers, it increases more rapidly than does the Schopper folding endurance as a result of surface sizing. When melamine resin is added the MIT value becomes considerably greater than the Schopper value in most cases. As the two kinds of folding-endurance tests do not agree very well, a composite value, which is the average of both tests in both directions, is also included in table 2.

To help in assessing the worth of materials that might be substituted for linen fiber in currency-type paper, table 3 has been prepared, in which the values for a given property have been expressed as percentages of the corresponding value of paper 3a. The composite folding endurance is used, and the values for stretch, tensile strength, and resistance to tearing were calculated from the mean value of the two directions of the papers in each instance. This table permits the paper-making properties of the various fibers studied to be compared with those of linen fiber, in terms of the requirements of currently used currency paper, represented by paper 3a.

By currency-paper standards cotton makes a good paper, except that it is somewhat soft and lacking in a kind of intangible superiority universally associated with currency and bank-note papers containing linen fiber. The data in table 3 indicate that the cotton paper is a very excellent product, except for a too open and "soft" structure, reflected in a comparatively low air resistance after the laboratory wearing treatment by crumpling. The caroa paper is also of superior quality, except that its air resistance is lower still.

It is observed that this tendency toward a "soft" structure produced by most of the fibers appears to be counteracted by the addition of melamine resin. The improvement is remarkable in the cotton paper, 5M2a, and most of the other properties are enhanced also. No papers were made with caroa fiber and melamine resin in combination. The melamine resin is not an unalloyed advantage, however, inasmuch as it tends to reduce the resistance to tearing. Both cotton and caroa papers are very resistant to tearing and can stand considerable loss in this respect without becoming inferior to currently used currency paper.

TABLE 3.—*Properties* [1] *of single-fiber-component papers expressed as percentage of the corresponding value for paper* [2] *3a*

| Designation [3] of papers | Kind of fiber | Composite folding endurance | After 16 crumples: Tensile strength | After 16 crumples: Air resistance | Stretch | Bursting strength | Tensile strength | Resistance to tearing |
|---|---|---|---|---|---|---|---|---|
| | PAPERS SURFACE SIZED WITH GLUE | | | | | | | |
| | | % | % | % | % | % | % | % |
| 1a | Linen | 81 | 103 | 175 | 95 | 103 | 108 | 83 |
| 5a | Cotton | 93 | 91 | 62 | 101 | 100 | 109 | 120 |
| 6a | Caroa | 90 | 121 | 39 | 107 | 112 | 104 | 128 |
| 8a | Sisal | 55 | 85 | 22 | 85 | 85 | 90 | 109 |
| 10a | Hard alpha | 45 | 85 | 7 | 75 | 88 | 106 | 55 |
| 12a | Sulfate | 55 | 115 | 14 | 74 | 98 | 116 | 68 |
| 13a | Sulfite | 32 | 79 | 6 | 57 | 85 | 106 | 46 |
| 14a | Soft alpha | 19 | 68 | 5 | 62 | 80 | 88 | 47 |
| | PAPERS CONTAINING MELAMINE RESIN AND SURFACE SIZED WITH GLUE | | | | | | | |
| 5M2a | Cotton | 248 | 159 | 184 | 100 | 133 | 131 | 78 |
| 10M3a | Hard alpha | 94 | 115 | 27 | 85 | 98 | 110 | 44 |
| 13M3a | Sulfite | 45 | 97 | 16 | 64 | 82 | 115 | 41 |
| 14M3a | Soft alpha | 55 | 103 | 17 | 72 | 95 | 107 | 44 |
| | PAPERS CONTAINING MELAMINE RESIN AND NOT SURFACE SIZED | | | | | | | |
| 5M2 | Cotton | 219 | 135 | 121 | 90 | 108 | 120 | 95 |
| 10M3 | Hard alpha | 87 | 103 | 22 | 72 | 85 | 106 | 49 |
| 13M3 | Sulfite | 55 | 91 | 12 | 66 | 75 | 109 | 45 |
| 14M3 | Soft alpha | 48 | 91 | 14 | 70 | 83 | 96 | 48 |
| | PAPERS CONTAINING NO MELAMINE RESIN AND NOT SURFACE SIZED | | | | | | | |
| 5 | Cotton | 71 | 59 | 32 | 62 | 67 | 80 | 139 |
| 10 | Hard alpha | 55 | 47 | 4 | 54 | 62 | 74 | 66 |
| 13 | Sulfite | 19 | 44 | 4 | 41 | 57 | 82 | 55 |
| 14 | Soft alpha | 10 | 29 | 3 | 46 | 52 | 61 | 64 |

[1] The percentage values given are the mean for the machine and cross directions. The folding-endurance values are the mean of MIT and Schopper values in both directions.
[2] The present standard type of currency paper composed of equal parts of linen and cotton fibers.
[3] The numbering is the same as that in table 2, the "M" signifying the addition of melamine resin.

It seems probable therefore that, in case of necessity, a judicious combination of cotton, caroa, and melamine resin might be substituted for linen fiber in currency paper without loss of quality of the paper, provided it did not in some unforeseen manner displace the nice balance of characteristics of linen-content paper associated with the rather complex process of printing and production of paper currency. The wood fibers do not appear suitable for use in currency-type papers, nor does sisal seem promising.

Some special tests were made on the machine-finished papers containing melamine resin and the companion papers made without melamine resin. A brief statement of the findings, which are not tabulated, follows. The melamine resin decreased the opacity slightly, about 4 percent on the average. It appeared to increase the water resistance slightly (measured by the dry-indicator test and the curl test, both of which are described in TAPPI methods), but the papers containing the mealmine resin were still water-leaf. The grease resistance also was increased slightly. In neither case, however, was the improvement of any consequence. Expansivity was not altered significantly by the addition of melamine resin.

These papers were also aged for 72 hours at 100° C. and the deterioration, evaluated by the change in folding endurance, is shown in table 4. The pH of all the papers listed in this table was greater than 5 (see table 2). The data obtained indicate that the papers containing melamine resin compare favorably in stability with similar papers containing no melamine resin, provided the acidity is not greater than the maximum allowable for good stability of papers in general, that is, provided the pH is not less than 5.

TABLE 4.—*Comparison of the effects of accelerated aging for 72 hours at 100° C on papers containing melamine resin and on their companion papers made without the resin*

| Designation [1] of papers | Ratio of Schopper folding endurance after aging to that before aging | |
|---|---|---|
| | Machine direction | Cross direction |
| COTTON AND LINEN | | |
| 3 | 0.91 | 1.04 |
| 3M2 | .81 | 0.94 |
| COTTON | | |
| 5 | 1.03 | 0.95 |
| 5M2 | 0.82 | 1.00 |
| HARD-ALPHA WOOD PULP | | |
| 10 | 0.73 | 0.75 |
| 10M2 | .71 | .80 |
| SULFITE WOOD PULP | | |
| 13 | 0.75 | 0.86 |
| 13M3 | .78 | .83 |

[1] The numbering is the same as that in table 2, the "M" signifying the addition of melamine resin.

TABLE 5.—*Improvement in strength of wet paper resulting from addition of melamine resin*

| Designation [1] of paper | Strength ratio, wet [2] to dry | | | | |
|---|---|---|---|---|---|
| | Bursting strength | Tensile strength | | Tearing resistance | |
| | | Machine direction | Cross direction | Cross direction | Machine direction |
| | | | **COTTON AND LINEN** | | |
| 3 | 0.06 | 0.03 | 0.04 | 0.42 | 0.40 |
| 3M2 | .73 | .40 | .42 | 1.45 | 1.32 |
| | | | **COTTON** | | |
| 5 | 0.08 | 0.03 | 0.06 | 0.42 | 0.31 |
| 5M2 | .81 | .47 | .55 | 1.70 | 1.27 |
| | | | **HARD-ALPHA WOOD PULP** | | |
| 10 | 0.09 | 0.03 | 0.04 | 0.62 | 0.49 |
| 10M1 | .35 | .32 | .37 | 1.71 | 1.52 |
| 10M2 | .52 | .39 | .44 | 1.09 | 0.81 |
| 10M3 | .46 | .36 | .40 | 1.86 | 1.70 |
| | | | **SULFITE WOOD PULP** | | |
| 13 | 0.09 | 0.03 | 0.04 | 0.95 | 0.71 |
| 13M3 | .47 | .31 | .36 | 1.51 | 1.26 |
| | | | **SOFT-ALPHA WOOD PULP** | | |
| 14 | 0.05 | 0.02 | 0.06 | 0.48 | 0.44 |
| 14M3 | .46 | .42 | .44 | 1.25 | 1.08 |

[1] The numbering is the same as that in table 2, the "M" signifying the addition of melamine resin.
[2] The wet papers had been soaked in water for 24 hours before they were tested.

TABLE 6.—*Improvement in surface-wear resistance imparted by melamine resin in the paper, and by glue surface sizing*

| Designation [1] of papers | Materials added to improve the quality of the surface | Resistance to abrasion | | |
|---|---|---|---|---|
| | | Taber (dry) | NBS (wet) | |
| | | | Machine direction | Cross direction |
| | **COTTON AND LINEN** | | | |
| | | *Rev/mg* | *Oscillations* | *Oscillations* |
| 3 | None | 6 | 9 | 9 |
| 3a | Surface sizing (glue, alum) | 18 | 19 | 17 |
| 3M2 | Melamine resin | 20 | 625 | 540 |
| 3M2a | Melamine resin and surface sizing | 21 | 671 | 713 |
| | **COTTON** | | | |
| 5 | None | 2 | 10 | 9 |
| 5a | Surface sizing | 25 | 29 | 21 |
| 5M2 | Melamine resin | 12 | 725 | 596 |
| 5M2a | Melamine resin and surface sizing | 32 | 898 | 778 |
| | **HARD-ALPHA WOOD PULP** | | | |
| 10 | None | 4 | 6 | 5 |
| 10a | Surface sizing | 14 | 30 | 21 |
| 10M2 | Melamine resin | 14 | 218 | 191 |
| 10M2a | Melamine resin and surface sizing | 18 | 259 | 275 |
| | **SULFITE WOOD PULP** | | | |
| 13 | None | 3 | 7 | 6 |
| 13a | Surface sizing | 10 | 59 | 45 |
| 13M3 | Melamine resin | 11 | 128 | 98 |
| 13M3a | Melamine resin and surface sizing | 14 | 160 | 152 |
| | **SOFT-ALPHA WOOD PULP** | | | |
| 14 | None | 3 | 4 | 3 |
| 14a | Surface sizing | 12 | 25 | 27 |
| 14M3 | Melamine resin | 11 | 255 | 227 |
| 14M3a | Melamine resin and surface sizing | 17 | 335 | 293 |

[1] The numbering is the same as that in table 2, the "M" signifying the addition of melamine resin.

The use of melamine resin in paper is ordinarily for the primary purpose of increasing the strength of the paper when wet. Paper currency is of course sometimes handled when wet. The improvement in the strength of wet paper imparted by melamine resin is shown in table 5. The improvement is very striking in all of the experimental papers containing the resin.

As previously stated, one of the chief reasons for adding melamine resin to some of these experimental papers was to see if it would improve the surface, and lessen its tendency to scuff, crack, or wear away. Table 6 shows the resistance to abrasion of both dry paper and wet paper. Although both types of test are rather erratic, the differences are great enough to indicate that the melamine resin does help to improve the resistance of the surafce to abrasion.

The abrasion tests on the dry paper indicate that the glue surface sizing and the melamine resin are about equally effective in minimizing the ordinary surface wear. The two together, however, give even better results.

WASHINGTON, September 25, 1945.