Physical Testing of Boards and Containers and Interpretation of Results

Prepared for

The Fourdrinier Kraft Institute
(Project 1108)

by

THE INSTITUTE OF PAPER CHEMISTRY

Preliminary Report

Part II

Appleton, Wisconsin

June 1, 1945
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AND INTERPRETATION OF RESULTS

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FOLDING ENDURANCE


A brief description of the calibrator which is described by Carson and Snyder in National Bureau Standards, Tech. Paper No. 357.


This method corresponds to TAPPI Standard T 423.


Folding Endurance. The folding endurance test has much significance, ranking along with bursting and tearing strength among the physical strength properties most to be desired in many types of papers. Folding endurance is of particular importance in such papers as box lining, bag, bond, ledger, currency, cover, index, and in numerous other applications where paper is subjected to harsh or repeated folding. The marked difference in folding endurance with the grain and across the grain is evidence that sheet structure has an important bearing on this quality. However, results are influenced in varying degrees by surface treatment, such as sizing and calendaring. Some types of surface coatings affect the values, particularly when the coatings are absorbed into the fibers to the extent that they may be stiffened, softened, or otherwise altered. The effect produced by changes of fiber characteristics is illustrated by the fact that the moisture content of the paper has a much more pronounced influence on the folding endurance than on any other of the common physical tests. Because of the marked influence of atmospheric conditions, it is most important that tests be conducted in the prescribed manner under standard relative humidity and temperature conditions. Since specimens are folded while under tension, the tensile strength of the paper may also have some effect on its folding properties. While folding endurance is an empirical property, it also defines one of the elements of utility, as well as of manufacture. The values obtained are absolute.


The specimen is held under standard tension by two jaws of the floating type which move in the same horizontal plane without rotation. They are kept in perfect alignment by frictionless supports. A reciprocating blade double folds the specimen between the quadrant rollers until it breaks at the crease. The number of double folds is registered on a 4-figure counter. At the point of rupture the counter is instantly disengaged and the motor stopped.
It appears that a strong fiber-to-fiber bond and a good sheet formation preventing separation of individual fibers are highly important for obtaining a high folding strength. The following factors contribute to higher folding endurance: Cooking and bleaching processes favoring high individual fiber strength and retention of gel-forming material in the fibers, a beating operation forming this gel with a minimum of fiber destruction, a forming size, means of securing a random fiber orientation in the sheet, and proper calendering procedures with regard to temperature, moisture and pressure.

This article is primarily a plea for standard conditions of temperature and humidity. It is pointed out that a sample folded at 65% relative humidity and 70°F will show a test averaging approximately double that shown by the same sheet conditioned and tested at 50% and if the temperature be raised to 90 degrees and the relative humidity to 70 or 75%, the tear may be tripled or even more. The fold test is the most susceptible to small changes in temperature and relative humidity but tear and Millon and other tests are affected to an appreciable degree. The fact that folding endurance is being recognized as one of the most significant physical tests for high grade papers is demanding uniform testing conditions.

The new Schoppor bonding and tensile strength tester for paperboard is pictured and briefly described.

An abstract from a pamphlet distributed by Foreign Paper Mills, Inc., describing the Naumann-Schoppor bonding tester. Examples of practical application are pointed out. Similar to the article by Naumann in Wochbl. Papierrfabr.

Description of apparatus and methods.
Folding Endurance


The review includes a discussion of the Schopper endurance bending tester.


An analysis is given of the results of folding tests made on several consignments of mold-made paper. The methods of analysis are not given but the article is of interest in that it gives examples of the value of statistical analysis in drawing deductions as to the significance of individual factors influencing the property being measured. From the data presented, conclusions are drawn concerning the effect upon folding strength of such factors as selection of the sample shoots, the particular instrument employed in making the test, the direction of the shoot, the humidity to which the paper was subjected in seasoning and the consignment from which the samples were selected.


The Schopper folding tester, which is designed to test the bending endurance of paper and its resistance to such types of wear as involve creasing and folding, is so constructed that a number of variables are introduced by reason of the several rollers and other working parts which are driven by the specimen being tested. These mechanical variables affect the folding results in much the same manner as do errors in adjusting the tension applied to the specimen during the test and apparently can in general be expressed as equivalent effective tension. The tension on the specimen is very critical, the effect on the folding results being inversely proportional to something like the tenth power of the tension (according to available data). The variables listed are: folding blade and linkage, quadrantal rollers, supporting rollers, and tension on the clamp springs. Under the adjustment of the clamp spring there is a discussion of the vertical suspension method and calibration in place, including the frictionless pulley and a new method involving a balanced bell-crank lever. Small errors in adjustment are, for the most part, inconsequential but errors in adjustment amounting to more than about 5 grams in tension become serious. The friction in the rollers, particularly in the vertical quadrantal rollers, may be considerable. Static friction in the quadrantal rollers equivalent to 50 to 100 grams tension appears to be unavoidable. A method is suggested for measuring roller friction.
Folding Endurance


Folding endurance is discussed on p. 14-15. The calibration of the Schopper folding machine is described.

435. Clark, James d'A. Method and apparatus for testing the folding endurance of paper and like materials. U. S. patent 2,179,116 (Nov. 7, 1939); C. A. 34:1486; Papermaking Abstr. 1941:70.

This covers the Thwing multiple fold tester.


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437. Clark, James d'A. Method and apparatus for testing the folding endurance of paper and like materials. U. S. patent 2,179,116 (Nov. 7, 1939); C. A. 34:1486; Papermaking Abstr. 1941:70.

This covers the Thwing multiple fold tester.

438. Drying upon the paper machine. Papier-Ztg. 61, no. 60: 1134-1135 (July 23, 1936); B. I. P. C. 7:71.

The importance of uniform moisture conditions in testing rooms is stressed. An example is given, in which variations of 1% above or below the standard moisture content resulted in variations of 200 or more double folds.


A very brief description, with illustration, of the M. I. T. folding tester.


A very brief description, with illustration, of the M. I. T. folding tester.


It is pointed out that this tester (developed about 1917) produces an abrupt flexure in a standard way and imposes the pressure along the line of fold and to a fixed and predetermined degree, entirely free from friction. The operation of the tester is described. A chart shows the relation of folding endurance and other properties to the rate of beating.
A description is given of the Schopper folding endurance tester and of the conditions for carrying out the test as employed in the PATRA laboratories.


The control methods for paper strength testing at the Papyrus plant of the Waldhof Pulp Mills include tensile strength (breaking length), number of folds, and bursting strength. However, only the two former are considered in this study, in which the mean values were obtained from the control testing laboratory's protocols with data extending over a ten-month period. An attempt was made to measure the effects of varying conditions existing at different stages of the manufacturing process on the strength of the finished sheet. In preparing his graphs, Heury used the arithmetical mean (\( \bar{g} \)) of strength tests carried out with strips cut in the machine direction (\( J \)) and in the cross direction (\( G \)). The strength ratio of \( \frac{J}{G} \) is termed \( R \), and, when \( J = G \), \( R = \frac{G(2 + 1)}{2} \). Two different types of slow stock (70-75° S.-R.) and three classes of free stock (35-40° S.-R.) were used. When the number of folds were plotted against grams per square meter, the maximum strength lay within the range 55-70 grams per square meter. According to practical tests, the weight/volume of the finished sheet does not increase linearly with the amount of stock that flows on the wire in a given time. Here, too, the curves follow a course and show maxima similar to the folding endurance-weight/volume graphs. However, similar relationships did not obtain between \( M \) for breaking length and grams per square meter of the finished sheet. The tearing length is a measure of the felting of the fiber throughout the length of the strip, whereas the folding endurance is limited to an exceedingly narrow area, and thus serves to record the behavior of individual fibers. In machine-made papers, this test is especially valuable in showing the relation between fiber orientation and strength. These and other instances serve to show that the folding endurance test is of marked practical value. Determinations of the percentage moisture of the sheet as it enters the dry end of the paper machine strengthens the hypothesis that shrinkage, which is at its maximum with those papers that retain most water, is correlated with the folding endurance data. With a moisture content increasing from 0 to 15%, the number of folds increase and the tearing length decreases. The effect of tension during manufacture was noted and the results were supplemented by the use of a new laboratory instrument for measuring the percentage of stretch in test sheets made in sheet machines. This instrument is fully described and furnishes a quantitative measure of the effects of the degree of beating and of water content of the stock on the elongation of the sheet under tension.


One of the two jaws, similar to the one designed by M. I. T., oscillates through an angle of 270 degrees and is at its center provided
Folding Endurance

with two edges between which the paper is clamped and over which the paper is bent alternately. The folding therefore always occurs along one and the same line. The jaw, with the exception of the edges, is made of a very light metal and when changing the direction of folding the speed is reduced; the effect of inertia, which would introduce stray unknown forces, is thereby eliminated. The other jaw holds the paper under tension which may be adjusted from 0.25 to 10 pounds. The jaws do not move so as to cause the tension to fluctuate; as the points of contact and friction near the fold are simple, there are very little wear and friction to interfere with the results. The usual speed is 320 folds per minute.


A method has been developed for the evaluation of the strength and stiffness of fiber boards by a static bending test from which the moduli of transverse strength, rupture, and elasticity are obtained. These values are expressed in terms that evaluate the structural properties of the material and not simply the properties of the piece under test. The values can be regarded with little or none of the qualifying data necessary in the empirical methods applied in mills at the present time. The method is simple and inexpensive and has been shown to be sufficiently accurate for the purpose. It may be applied to boards of a wide variety and is particularly useful in determining the strength of insulating and wall boards. A further application is in the testing of pulp for strength, where it has been found to have a particular value in the evaluation of groundwood pulp.


The results of this extensive study are presented in a series of 17 tables. It did not cover papers of high folding endurance. The wide differences obtained in individual tests are due to nonuniformity of the paper and not to any fault of the machines. Averages of tests in both directions for 9 papers which had from 2 to 210 double folds indicated that the folding number increased 1.26% when the tension was reduced from 1000 to 900 grams, 23.2% from 1000 to 600 grams, and 71.1% from 1000 to 400 grams. In the vicinity of 1000 grams, the folding number is affected approximately 1% for each gram change in tension. The folding endurance is affected 1.5% for every 0.01 in. change in distance between the slotted plate, which creases the paper, and the rollers between which the paper passes. When the rollers were set at 0.33 and 0.54 in. from the plate, the average percentage increase in the folding number for the greater distance was 13%. He recommended a distance of 0.33 in. In a study of the operating speed it
was found that the average percentage differences of the folding numbers, using 115 revolutions per minute as a basis, were: 45, 99%; 60, 96%; 30, 114%; 100, 105%; 109, 88%; 130, 96%. He recommends a speed of 100 to 120 revolutions per minute.


Data are given for 55 papers.

446. Herzberg, W. Further experiments with the Schopper tester. Mitt. kgl. mech.-tech. Versuchs. 26:131 (1908); Papier-Ztg. 33, no. 56: 2179-2180 (July 12, 1908); C. A. 3:246.

Variations of results obtained with the Schopper tester are due to faulty manipulation and lack of uniformity of papers tested. The machine works admirably with proper handling and the results check very closely. The following suggestions are given for obtaining best results: keep as free as possible from dust, clean weekly with soft brush, overhaul thoroughly every month, use for papers up to 150 grams per square meter only.

447. Herzberg, W. Further results with Schopper's folder. Mitt. kgl. Material. 25, no. 1:26-40 (1907); Papier-Ztg. 32, no. 27:1184 (April 4, 1907); Wochbl. Papierfabr. 36, no. 1646-1547 (May 18, 1907); Papier-Fabrik. 5:931 (1907); C. A. 1:2490.

The experience of the Materialprüfungsamt up to October, 1905, with the Schopper machine for testing the resistance of paper to folding was as follows: Complaints regarding its results were found to be due either to lack of care of the machine or to non-homogeneous samples. Tests of different parts of the same paper agreed well. Ten tests on each of all the classes tested agreed completely and 93% of the control tests put the paper in the same class as the first test. The results of 26 other control tests from October, 1905 to October, 1906, are given in tables. Of these, 93% agreed with the first classification, and all the others were just on the border between two classes.


Hand folding gives higher results than machine folding; e.g., a paper which showed 30 double folds by hand gave 37 on the machine.


It has been customary at the Materialprüfungsamt to make a test for resistance to folding on 20 strips from each sample of paper, 10 in
each direction. The results obtained during the past years on 925 samples have been examined comparatively, to see whether testing 5 strips from each direction would not give equally satisfactory results. To make the comparison, the average of the first ten tests on each sample was compared with that of the last ten. Out of the 925 papers, of all classes, 794 or 86% were placed in the same folding class by the first ten as by the last ten tests. It is concluded that ten tests are sufficient unless the paper gives results very close to the lower limit for its class, in which case 20 should be taken.


Tests on strips 50 mm., 15 mm., and 5 mm. wide gave values (averages of machine and cross directions) of 55.75, 5700 and 5475 m.; results are also given for six samples using strips 15 and 50 mm. wide.


Tests of 918 papers showed that the folding strength is greater in the machine direction in about 66% of the papers and greater in the cross direction in the remainder. Variations between individual specimens of a given class of normal papers are much greater in the case of the folding test than in the tensile or stretch tests.

452. Herzberg, W. Variation in the fold-number in trial strips from the same sheet. Mitt. kgl. Material. 30:176-180; Wochbl. Papierfabr. 43, no. 34:340-347 (Sept. 21, 1912); Papier-Ztg. 37, no. 55:1936 (July 11, 1912); C. A. 5:5185.

Ordinary writing papers show a maximum variation of over 200% in the machine direction and 100% in the cross direction. The influence of moisture in paper on the folding number was found to be: 50% relative humidity, folding number of 50; at 65%, 66; at 80%, 87.


The instrument comprises a rotary disk having a suitable scale around a portion of its periphery, and a ring-shaped piece around the disk, a suitable portion of the ring also being graduated. A weighted pendulum arm with a pointer at the top is pivoted at the center of the disk so as to be rotatable independently of the disk. The latter carries two pins against which the test sample is laid and is held in place by means of a third pin connected by a small arm to the pendulum arm. Displacement of the disk causes the pendulum to exert a bending stress on the cardboard, the amount of bending being measured on one of the scales and the strength of the sample on the other.
between the anvils under pressure due to the weight of the upper jaw assembly. While the lower assembly is on the way up, the specimen is forced into the correct position for creasing by means of pins (7) which move alternately to the right and to the left, just touching the specimen approximately at the point where the crease will be formed. The pins are operated by a lever actuated by a cam which is driven by the same shaft that moves the lower jaw assembly. By this time the lower assembly comes into contact with the upper assembly, the pins have been moved out of the way. The reciprocating motion of the lower jaw assembly is imparted by means of a moving bar operated by cams at either end. As the lower jaws move away from the upper jaws, the paper specimen is straightened and as the supporting bar continues to drop, the entire weight of each lower jaw assembly is supported by the corresponding test strip. This tension is maintained until the supporting bar starts its upward motion. As the bar passes the zero point—that is, that point in the cycle at which the specimen is always inserted—all tension is removed. As the second cycle begins, the folding pins come into action again, this time touching the test strips from the opposite side so that they fall in the opposite direction. The pins are moved out of the way, the jaws come together, and the strip is creased. This action is continued until the test specimen breaks. At this point the lower assembly is no longer supported by the specimen as it formerly was during one part of the cycle. Instead, the lower assembly rides all the way down on the supporting bar, and the arm which operates the counter for that particular specimen or head is disengaged. The instrument was studied from the standpoint of accuracy of construction, the effect of tension, and the effects resulting from the mass of the assembly. An approximately linear relationship existed between the log of the folding endurance and the tension for papers of relatively high endurance, whereas for weaker papers the curves departed from linearity and developed a rather characteristic curvature with the convex side toward the origin. Investigation indicated that the units do not act independently and that comparable results cannot be obtained unless the same number of heads were used at the same time. The sample having the poorer formation would, in general, give the lower results on this instrument, since the breaking of the weaker strips would subject the stronger specimens to undue stress. Certain suggestions are made for improving the instrument.


A mathematical discussion is given of results obtained for the folding endurance by means of the Schopper apparatus. Two variables are considered: (1) uniform tension and different strip widths and (2) variable tension with constant strip width.

Folding Endurance

In the Schopper folding machine, it is very important that the spring tension be 1000 grams. By reducing the tension 500 grams, the fold was increased over 1000%. It is recommended that the rollers be 0.015 inch from the folding plate and firmly set in this position. A variation of between 0.015 and 0.018 inch did not show a very wide discrepancy in results. When the clearance was more than this, great discrepancies were observed. Data are given for five laboratories, from which the following conclusions are drawn. The relative humidity at which the paper is run is the source of greatest error; a difference of 3 to 5% in relative humidity shows a marked variation in results. The error caused by paper, machine, and method of operation is less in testing the paper cut against the machine direction. It is recommended that paper be tested only in the cross direction. A given machine checks itself within about 10% as the maximum except in an occasional instance; any wider variation must be attributed to the paper or method of operation. It appears that the error caused by relative humidity is more marked between 55 and 70 than between 45 and 55%; therefore, it may be advisable to run tests at a lower humidity. A tolerance of approximately 50% in the cross direction must be allowed, in consideration of the results from various laboratories; therefore, the value of the folding number in purchasing paper on specification is questioned. It does not seem that a minimum value can be stated, because there is no ultimate standard machine to which the paper can be referred and a machine will not check itself within 10%. If a folding number is to be specified, it is recommended that a tolerance above and below the number determined upon as being satisfactory be allowed. The following tolerances, recommended by F. P. Veitch, seem to cover the field:

<table>
<thead>
<tr>
<th>Number of Folds</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-40</td>
<td>10</td>
</tr>
<tr>
<td>40-100</td>
<td>25</td>
</tr>
<tr>
<td>100-200</td>
<td>50</td>
</tr>
<tr>
<td>200-500</td>
<td>100</td>
</tr>
<tr>
<td>500-1500</td>
<td>250</td>
</tr>
<tr>
<td>1500-3000</td>
<td>500</td>
</tr>
<tr>
<td>3000- Up</td>
<td>1000</td>
</tr>
</tbody>
</table>

Work should be carried out on paper before it is tub sized. Data indicate that the engine-sized paper is sometimes increased as much as 1000% by a 10% W. glue tub size. It is also recommended that work be done on the folding machine after removing one of the plates, which should give a single rather than a double fold. Some work of this kind indicates that there is a definite ratio between the single and double fold on different types of paper. At present the author feels that the folding number may or may not express the quality of the paper. However, by running folding tests on the engine-sized paper, the treatment of the raw material can be very carefully supervised and improperly prepared stock can be corrected.
In a co-operative study of the folding tester, results were obtained from 12 machines. In general the machines were adjusted by the method of Veltch, Sammet, and Reed and this could not be the cause of the variation in results. When the humidity was not controlled or varied during the tests, there was a noticeable variation in the tests. With the exception of humidity, no reason could be given for the discrepancy in results. The 12 sets of results varied from a 1 to a 72% deviation from the average number of folds. The number of folds in the cross direction ran very much more uniform than those in the machine direction. On the whole, any given machine seemed to run consistently above or below the average. However, there were not sufficient data to draw any general conclusion.


Kirchner, Ernst. Board testing apparatus. Wochbl. Papier-Fabr. 50, no. 18:1051-1055 (May 3, 1919).

An apparatus is described and illustrated for determining the maximum bending strength coefficient. Results are given for six types of boards.


The cardboard to be tested is clamped in a hinge and the angle through which it may be bent without breaking is measured and the tension required for breaking is registered by means of a spring.

Kirchner's new testing apparatus for cardboard and paper. Wochbl. Papier-Fabr. 50, no. 23:1563-1564 (June 7, 1919).

Results are given for 5 handmade boards.


The ranges and relative merits of the new bending tester and the old fold tester are discussed. No simple correlation between the results of the two instruments is obtained. For paper, the mean deviations of 50 determinations, the probable errors in the averages and the ranges in the maximum and minimum values were practically the same for the new and the old instrument. The errors of the measurements for thin cellulosic foils or films were greater for the old
than for the new tester. The ratio of folding to bonding numbers varies from one for writing paper to 100 for tissue. Representative data are given which show the variations of folding and bonding numbers as a function of tension. With few exceptions, the curves of the logarithm of the bonding numbers versus tension for different directions for a given paper and for different basis weights of the same stock extrapolate linearly to a common value of bonding number for zero tension. The same can be said of the logarithm of the folding number versus tension curves. It is assumed that the extrapolated bonding number for zero tension may be interpreted as a "material constant" of the stock.


An apparatus, designed particularly for artificial leather, measures the force necessary to produce a given lateral displacement of the central portion of the sample and also the force required to push the opposite edges of a sample toward each other through a given distance. The apparatus consists of a platform, a pair of vertical rails rising therefrom, a carriage slidably up and down between the rails, the platform and carriage having a pair of opposing grooves, one over the other, to receive the opposite edges of a piece of sheet material to be tested, and an upright standard horizontally slidably on the platform toward and from the plane of the grooves.


An apparatus for testing artificial leather and the like consists of a base, a standard, a vertical guide supported by the standard above the base, a plunger vertically movable in the guide, an elongated roll horizontally supported on the lower end of the plunger, a platform to receive weights carried by the plunger, a work-supporting anvil mounted on the base and adjustable toward and from the path of the plunger, means for clamping the work on the anvil with a portion projecting into the vertical path of the plunger, and means for indicating the angle of bend of the projecting portion of the work.


The Schoepf folding tester is the recognized standard machine for determining the resistance offered by a paper to repeated folding; the number of folds is a reliable measure of its cohesive properties. The folding effect is produced by a slotted steel plate which, by its reciprocating motion, folds a (tensioned) strip of paper backwards and forwards until it breaks. The speed of this machine should be 120 r.p.m. The various items involved in the calibration are listed. It is a very sensitive apparatus and demands more attention to maintain than any other
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The head piece and the tension springs are the most important parts. If the rollers or the slotted plate get out of alignment, the test strip is subjected alternately to oblique stresses and will break too early. Lack of lubrication on the roller bearings will cause uneven wear in the bearing pin holes; under this condition, the results are excessively high.


An illustrated description of a motor-driven apparatus.

Multiple folding endurance tester (Thwing). Instruments 9, no. 5:59 (March, 1936).

Ten folding tests can be made simultaneously in this new 10-spindle device. Specimens (15 cm. wide) are held in cam-action locking grips and are alternately folded under compression and straightened out under tension. A definite sharp fold is made under the compression load. The compression load is 0.5 kg. Depending upon the grade of paper the tension load may be varied from 0.5 to 3 kg. A tripper folding device alternately folds the paper in two directions. A counter registers the number of folds made to the breaking point. If desired, tests can be made on fewer than ten spindles. A clutch is provided to disengage the driving mechanism while test pieces are being inserted in grips.


In expressing the results obtained for the resistance of paper to folding, by means of the Schopper folding machine, the tensions between the springs holding the paper are plotted as abscissas, and the number of double folds which the paper resists is plotted on the ordinate axis. The resulting curves have the form of hyperbolas. These may be reduced to straight lines by plotting the numbers proportionally to their logarithm, which may be done on paper ruled for that purpose. The inclinations of the straight lines so obtained indicate the law according to which the resistance of the particular paper varies with the tension, whereas any point outside the main line may be recognized as an experimental error and corrected as such.


Bending Test. The official technical test for bending—four samples each, with the grain running the long way and the short way, shall be
carefully cut from the liner or container to be tested. The samples shall be 15 mm. (0.59 inch) wide and of sufficient length to insure a firm smooth grip in the jaws of the tester, and shall be cut from unwrinkled, unscored, and unblemished stock. The test sample shall be clamped in the tester (H. I. T.) without the central portion (to withstand the bending) being touched by the hands, the tension adjusted to 1 kilogram, and the specimen folded through a combined angle of 270 degrees until it breaks. Each of the two sets of four samples (to be folded with and against the grain, respectively) shall be similarly tested and the average number of folds each way shall determine compliance with the specification. Not more than one of each of the sets of four tests may fail short of the required number. However, if either or both of the two sets of tests is below the specification, a series of 12 re-tests of that test or tests shall be made, of which not more than three may fail to comply, with the average of all 12 meeting the specification, for acceptance. A simple substitute test, indicative in a crude but reasonably reliable way of bending qualities to be desired, can be made by hand manipulation of sample boxes and sections of double-faced board cut from them. The flaps of the box shall be doubled completely back upon the sides, first inwardly and then outwardly, along the horizontal scores, each bend being tightly pressed down by the hand. This bending shall be repeated until a total of three bends have been made inwardly and three outwardly, and the board inspected both inside and outside, for cracking or failure of the board. Further, two pieces, approximately 5 inches square, shall be cut from an unscored and unprinted section of a box, and each shall be hand scored by means of a ruler or other fairly sharp straight-edge, to break down the corrugations but not break or cut the surface of the facing. Two scores shall be made at right angles to each other bisecting the board with and against the grain. One sample shall be folded against the grain or with the corrugations (the grain runs at right angles to the corrugations), then doubled back upon itself with the grain, and shall show no sign of failure when the second fold is pressed down tightly by the hand. The other sample shall be folded with the grain, then doubled back upon itself against the grain, and shall show only slight tearing at the corner representing the junction of the two folds when pressed down tightly by the hand. The interpretation of the bending qualities of the board from this last test is necessarily a matter of experience in making the test and should be considered as merely indicative of general strength or weakness.


This is a supplementary report to the study of Carson and Snyder [No. 433], which discussed the relation of some of the mechanical variables to the test results in the light of data then available and described a newly developed device for adjusting the tension on the specimen. This device, which is a dead-weight tester involving the use of a balanced bell-crank lever, has been improved and adapted to the measurement of the friction of the rollers; this method is described in detail. The roller friction has been observed to vary from 25 to 220 grams equivalent tension and is usually from 50 to 80 grams for
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rollers in good condition. A variation from 25 to 100 grams is objectionable but is about the best that can be done, considering the limitations of the tester. A test is described for detecting poor alignment of the rollers. A number of suggestions are given concerning the care and adjustment of the folding tester; a procedure is outlined for periodic inspection; this is essential for the best results.

472. National Bureau of Standards. The testing of paper. --Circu-

lar No. 107. Feb. 12, 1921.

A brief description of folding endurance is given on p. 17-18.

474. Naumann, M. Board testing. Zellstoff u. Papier 5, no. 11:
437-439(Nov., 1925); T. S. 82:301.

The construction and application of the Naumann-Schopper paper

board bending tester are described. Constructional sketches of the

machine are given.

475. Naumann, M. A new apparatus for testing the bending strength

and the bending angle of board, etc. Wochbl. Papierfabr. 55, no. 53:
2073-2077; no. 35:2262-2265; no. 36:2263-2268(Aug. 16, 30, Sept. 6, 1924);
T. S. 84:247.

The new Naumann-Schopper bending tester for heavy papers, cardboard,

etc., is described at considerable length. The results of actual tests

are reproduced in order to demonstrate what may be expected of the in-
srument. The following advantages are claimed for the tester: constant

control of product; influence of thickness and pressure on the bending

properties can be ascertained; manufacturing variables can be studied;

the angle of break is easily determined; and the uniformity of the card-

board may be followed. The above has been translated into English and

published as Booklet No. 507 of Louis Schopper.

476. Naumann, M. Schopper bending tester. Papier 29, no. 8:965-
966(Sept., 1926); T. S. 84:278.

A test piece 50 mm. wide is held in jaws, the inner walls of

which are at an angle of 180 degrees. By turning a hand wheel the

inner jaw is given a rotary motion, and the upper jaw, which carries

a weight pendulum, offers a resistance equal to the bending strength

of the test piece. It therefore only partially follows the displace-

ment of the lower jaw and the angle between the two gradually decreases.

The test is continued until the test piece breaks, and the scale

reading gives the bending resistance in kJ and the bending angle in

degrees, the latter being the maximum angle to which the product

can be bent. The curve between the resistance and the bending angle

is automatically recorded. This is covered by U. S. patent 1,559,466
(Oct 27, 1925).

477. New folding endurance tester (Author Testing Instrument

Specifications are given for the folding test using the Schopper folding tester. The test specimen is 15 ± 0.25 mm. in width and 70 mm. in length; the apparatus is driven at such a speed that 90-120 double folds per minute are effected. The test gives information about certain properties of paper, such as the durability, which cannot be obtained by other instruments. In the Schopper tester, a test strip of the paper is held by two clamps attached to helical springs, and the folding is carried out by the reciprocating action of a vertical blade. The tension of the springs on the paper is such that, when the paper is extended to its full length, each spring exerts a pull of 770 grams; when the folding blade is at the limit of its travel, however, and the paper is bent to the maximum, the pull exerted by each of the springs is 1000 grams. Disadvantages of the folding test are that strong papers (those that resist upwards of 1000 double-folds) require a long time for the completion of the test and the results on a narrow strip may show such variations as to cast doubt on the accuracy of the figures. There are inherent difficulties in the nature of the test. Thus, a thin paper has less stress upon the fibers of the outer arc of the fold and less crush upon the fibers of the inner arc, than is exerted in the case of a thicker paper. The folding test is particularly susceptible to atmospheric influence. It is impossible to correct the folding test even approximately for variation in substance. There is no definite ratio between the width of the strip and the folding figure and it is necessary to standardize on one width. Samples of a paper 10, 15, and 16 mm. wide gave values of 245, 301, and 366 double folds. A heavier paper tested at 55, 64, and 72% relative humidity, gave values of 675, 997, and 1587 folds, respectively. Details are given of the calibration of the spring.


Tests were made at 60°, 70°, and 85° F. at a relative humidity of 55%. A rise in temperature causes a decrease in folding endurance, the effect being more marked with tests made in the machine direction than those made in the across machine direction. The results show the need of controlling the temperature within limits of approximately 10° F. The effect of the relative humidity was studied by making tests at 25, 30, 40, 45, 55, and 65% at a temperature of 70° F. (except 65%, which was at 65° F). The results show very marked increases in the folding endurance in the machine direction as the humidity increases. There is a much less but more uniform increase in folding endurance in the across direction with the increasing relative humidity. The increase in results in the machine direction is very marked, being from 153 to
Folding Endurance

140% at 65 rather than at 25% relative humidity; the results in the cross-direction are 17 to 29% through the same range. The increase between 45 and 65% varied from 40 to 253% in the machine and 0 to 104% in the across machine direction. Interesting results were obtained for different types of papers. Thus, in changing from 45 to 65% relative humidity, the results for the machine direction showed increases of 276% for kraft, 354% for rope, and 74% for unbleached sulfate; in the across machine direction, 60% for rope, 13% for kraft, and 330% for unbleached sulfate. Tab-sized bend and ledger papers showed considerable increase in the machine direction but different results do not show the same percentage increase. These results indicate that it is impossible to secure any factor for calculating folding endurance results at one condition to equivalents at another or to a standard condition. Because of the wide difference in the effect of atmospheric conditions on folding endurance, the comparative test values of papers cannot be the same at different humidities and temperatures. Therefore, it is paramount that, in the selection and adoption of a standard testing condition, this condition must be in harmony with the use and service demanded of the paper. The folding endurance in the machine direction of all papers tested is higher at 65% relative humidity than that of the across machine direction. The difference between the folding endurance results in the machine and the across machine directions is much greater with all papers at 70°F and 65% relative humidity than it is at 70°F and 45 to 50% relative humidity. The folding endurance results in the across machine direction at 70°F and 45 to 50% relative humidity are greater with some papers than those in the machine direction. The advantages of using 50% relative humidity for testing are pointed out.


In connection with work being carried out by the Bureau of Standards for the United Typothetae of America, tests have been made on 94 commercial bond papers and 39 ledger papers. From the results it appears that the folding endurance results are the most indicative of serviceability, durability, and quality, and show the most striking variation in the papers tested. Therefore, the folding endurance test, properly interpreted and in combination with the bursting or tensile strength, may be found sufficient to classify these papers.


From a comparison of the results obtained on two different boards, it is concluded that there is a relationship between the results obtained with the two instruments but that its determination would require further tests on a more extended range of samples. Though the Mullen tester does not permit distinguishing between machine and cross directions, it gives a good discrimination between the two sides of the test piece, and for a given set of samples, it gives characteristic results which are in all points comparable with those of the bending tester. It presents the same drawback of slippage between the jaws, but it is much simpler and quicker to operate.
From a detailed analysis of the mechanism of the action of the Naumann-Schopper flexometer and of the information which it gives, illustrated by means of an example of the results obtained with a given sample and of the curves which can be calculated and plotted from them, the author concludes that the instrument permits of distinguishing between the two faces of a sample of board and of revealing the internal defects which may exist in the sheet. The operation of obtaining the results and information, however, is long and tedious and they should be coordinated with a view to subsequent comparisons.


Paper is subjected to friction by drawing it over stationary plates and simultaneously subjected to repeated folding until separation of the material occurs.

Schopper, Alfred. Apparatus for testing the bonding strength of pasteboard, cardboard, etc. U. S. patent 1,559,466 (Oct. 27, 1925); T. S. 3:204.

The test piece is attached to two plates, which are rotatable about a common axis, so that, by moving them in an angular relation with each other, the test piece is bent and broken. The rotation of one of the plates from a position of rest is opposed by a progressively increasing force produced by a weighted pendulum or equivalent device; means are provided for measuring the angle through which each plate is moved.


Reference is made to a new type of folding endurance tester, suitable for testing paper and board, called the endurance folding tester. A sample strip 15 mm. wide is bent under constant tension until failure occurs. The upper sample holder bends the paper through 90 degrees to the left and to the right of the equilibrium position. The lower clamp applies tension to the strip by means of adjustable weights. The radius of curvature of the edges of the upper clamp are 0.01 mm. The instrument operates at a speed of 110 bends per minute. Physico-mathematical considerations and a large number of tabulated test data and graphs are given.

The Naumann-Schopper bending tester was used. The test specimens were 2 x 6 inches. The inner faces of the two clamp jaws are in the same plane with ends touching when the instrument is in zero position. The outer surfaces are adjustable to permit the insertion of boards of different thicknesses. The board is bent by turning a hand wheel, which causes one of the clamps to revolve about a center. The resistance of the board to the applied stress causes the other clamp, which is fastened to a weighted pendulum, to revolve about the same center. The total movement of the second clamp is dependent upon the resistance the board offers to the increasing load applied through the movement of the first clamp. When the board is broken, a maximum indicating pointer, which follows the movement of the second clamp, indicates the bonding strength on a scale. Data are given for five samples of boards. The results are compared with flexural strength tests carried out on a modified tensile strength tester. In general the Naumann-Schopper tests are higher because of the use of a wider test specimen and a shorter test span. Flexural strength tests are commonly made by supporting the test specimen on two separated parallel knife edges and applying a load to the specimen at midspan through a third knife edge parallel to the other two. In testing board, however, rods have been found more satisfactory than knife edges, the rods used for binder boards being 1/8 inch in diameter. The rods were used in the form of stirrups clamped in a standard type of paper tensile breaking strength tester. The details of the stirrup device are shown. The size of the specimen was 1 x 5 inches. Data are given for the breaking load and the deflection at rupture for the longitudinal and crosswise directions. In addition the bursting strength and the tensile properties are given.


The results of folding endurance tests made on several tensamark kraft papers differing in room weight and in degree of calendering are given. The coefficients of variation vary over a relatively small range without any regular trend. This suggests that, for this particular series at least, the variability of the folding test is not influenced either by the room weight, the degree of calendering of the paper, or by the direction of the test strip and that the factor of greatest influence is the formation of the sheet. The values of the probable error of the mean permits certain conclusions as to the significance of the variations observed in the several runs. It is also possible to calculate the number of tests required to produce an average, the maximum error of which will fall within a predetermined limit.

In the M. I. T. folding tester, a strip of paper is fastened at one end in a tension clamp, which is actuated by a spring. The other end of the strip is fastened in an oscillating clamp, the jaws of which terminate in rounded edges near the center of oscillation. This clamp oscillates through an angle of 135 degrees each way from the vertical and in so doing bends the paper, first one way and then the other, around the curved edges of the jaws. The tension on the specimen is determined by the displacement of the tension clamp at the time the strip is fastened in the two clamps. Some of the features of this design are: No alignment rollers are required and there are few working parts which are driven by the specimen. The tension is practically constant throughout the folding cycle. The tension may be adjusted easily to any desired value within the capacity of the spring, thus permitting reasonably rapid testing of a wide range of papers. Manipulation of the plunger under lead so as to allow it to come to rest first on the downward stroke and then on the upward stroke indicated that the possible error in applying a given tension to the specimen is of the order of about 25 grams, which is in conformity with results of the determination of the average frictional resistance for a tension of 0.5, 1.0, and 1.5 kg. In addition to this friction in the plunger bearing, another source of uncertainty in the applied tension results from small vertical displacements of the specimen itself, necessitated by the fact that a small portion of the specimen must be wrapped around the edges of the jaws of the oscillating clamp. The choice of a folding clamp such that the specimen to be tested nearly fills in the distance separating jaws will minimize the tension changes. The change in effective tension resulting from the curvature and position of the folding edges is in most cases small. An error of 50 grams in the tension applied to the specimen might result in an error of 15 to 20% in the folding results, depending upon the absolute value of the tension; actually, this is probably high. The curvature of the folding surfaces is discussed but, because of the difficulty in obtaining data on this question, it was not studied. Variation in the folding rate between 130 and 200 double folds per minute did not appear to affect the results appreciably. Data obtained with six M. I. T. testers showed that if the folding surfaces were always made of the correct contour, if the variation in applied tension were minimized, and if a sufficiently large number of tests were made and averaged, the tester would yield consistent results. There is no semblance of correlation between the results obtained with the M. I. T. and the Schopper testers. The M. I. T. results are always lower, probably because the tension in the case of the M. I. T. tester is nearly constant at 1 kg., whereas the tension in the case of the Schopper tester varies from 1 to about 0.3 kg. during the folding cycle and because, in the former case, the sample is being continuously bent, whereas in the latter it is bent only while it is being pushed between the folding rollers and while it is under tension of about 0.8 kg. It is evident that the specimen is not treated in the same way in the two types of testers. A proposed method is given for making M. I. T. folding tests.
The standard covers the Schopper folding endurance for papers having a thickness of not more than 0.01 inch and the M. I. T. folding endurance which can be adjusted for papers of any thickness. There is no constant relation between the test values obtained with the two types of testers.


Replies are given from a number of mills regarding the influence of such factors as cooking time, cooking temperature, bleaching, beating, sizing, fillers, jordering, drying, machine speed, etc., on the folding endurance of paper.


A general discussion is given of the method of using the Schopper folding tester (this is now covered by TAPPI Standard 423 m). A brief discussion is given of the M. I. T. folding tester.


The Schopper tester is used; the calibration and accuracy are discussed. Mention is made also of the Green folding tester, designed for use with hand sheets; it is applicable to any sheet irrespective of bulk or tensile strength. A brief description is given of this tester.


To ensure that the clamps holding the ends of the test strip shall move in a true horizontal plane without any lateral yielding or oscillation about a horizontal axis, horizontal rollers of substantial width are provided on which the clamps are made to rest. Vertical adjusting means for the supporting rollers are provided.


In this machine strips of paper 1.5 cm. wide are held between two jaws, the lower of which rotates through a given angle and the paper is thus folded forward and backward around a certain radius. The upper head is attached to a weighing system so that a definite tensile load may be applied to the sample during the folding operation.

The Schopper folding endurance tester (German patent 94,901) has previously been studied only by Herzberg. This test is designed to imitate, in a general way, the practical conditions involved in the handling, folding, and crumpling of paper. The numerical expression—the number of double folds resisted—is an indication of the quality and, probably, of the durability of the paper. Six machines were used in this study; they were standardized with the rollers set at 0.015 inch (Herzberg used 0.013 inch); results obtained with machines in which the rollers were set at 0.015, 0.017, and 0.019 inch were closely concordant. A method of standardizing the machine is given. Folding tests should be made at approximately 120 revolutions or double folds per minute. The test samples were conditioned at 65° and 65% relative humidity. Bond, book, and ledger papers were examined. The averages of ten tests on the same or on different machines, using a paper of low or high folding endurance, are not widely different, when the machines have been carefully adjusted and the tests made under uniform temperature and humidity conditions. A closer agreement is obtained by making 20 tests. The great irregularity in paper is shown by the maximum and minimum results obtained on each paper with each machine; 21 to 42% of the individual results vary less than 10% from the true mean; 47 to 75% vary less than 20%, and 69 to 89% vary less than 30%. At this time, 16.1% may be regarded as the maximum allowable variation from the mean of averages of two series of 10 tests on the same machine. The data indicate that the difference between individual results is caused by variations in the paper and not to irregularities in the machine. In routine testing, the folding endurance is determined only in the weaker direction, which is usually the cross machine direction. The average of five tests will generally indicate the range of folding endurance of a paper, but for closer and more reliable averages, it is advisable to make 10 or even 20 tests. The averages of two sets of 10 tests should not vary more than 16% and those of 20 tests not more than 11% from their mean. Distinct differences in quality may be observed in papers; the folding endurance numbers of which differ by 10 when the folding endurance is from 10 to 40 folds, by 25 between 40 and 100, by 50 between 100 and 200, and by 100 between 200 and 500. It is believed that the instrument is valuable for indicating the probable durability of paper and its suitability for specific purposes.
HYGROEXPANSIVITY


The Schopper wet-stretch tester is an admirable instrument. By fixing a time limit of 5 minutes for a test, very reliable comparative tests have been obtained. Papers giving a big stretch under the conditions of the test gave a greater expansion in a humid atmosphere than those which gave a low stretch. One strong objection to the test is the tension which is applied; however, it is difficult to suggest a remedy.


An apparatus is described by which it is possible to measure the extension of ten strips at one time. The samples are placed in the apparatus and dry air is passed through until the samples are completely dry. After the length has been measured by means of a micrometer, moist air of the desired humidity is passed through (time not stated) and the length again measured. A microscope is used for reading the micrometer.


In a study of the effect of relative humidity on the dimensional changes of paper, the paper was humidified at 50% relative humidity and 76° F., placed in sample holders to accommodate strips about 25 cm. long (held taut by weights with a mass of 32 grams) and then in glass tubes, through which air was passed at a definite humidity (15 and 95%), the rate being about 5 liters per minute; the elongation was measured by means of a microscope (the accuracy was about 0.1%). Samples were also immersed in water at 23° C. for 1 minute and the elongation measured. Normal bond papers change in dimensions about 0.6% in the machine direction and 1.6% in the cross direction, when the relative humidity varies from 95 to 15%. The basis weight and furnish seem to have little effect on these changes. The machine and cross directions change about the same amount when the relative humidity is lowered from 50 to 15%; if the relative humidity is changed from 90 to 9%, the cross direction expands about 7 times as much as the machine direction. There is no good correlation between dimensional changes caused by varying the relative humidity and the expansion produced by actual wetting of the sheet.
Davis, Harold S. New methods for measuring the effects of temperature and humidity on the dimensions of paper. Paper 31, no. 12: 7-15 (Jan. 10, 1921); World's Paper Trade Rev. 79, no. 10: 604, 606 (March 8, 1923); T. S. 76: 196; C. A. 17: 678.

An illustration and a brief description are given of a conditioning apparatus consisting of a glass tube 0.75 inch in diameter and 3 feet long, through which conditioned air was passed; the conditioning tube was surrounded by a glass jacket through which water at any desired temperature could be passed. Paper strips 20 inches long were suspended from adjustable supports at the top of the conditioning tube and were attached at the bottom to aluminum pointers. The pointers were arranged so that each inch the pointer moved corresponded to a change of 0.1% in the length of the paper. With constant relative humidity, the dimensions of the paper are substantially constant over a temperature range of 70-100°F. When the absolute humidity is decreased at a constant temperature, the dimensions decrease and vice versa. The rate at which the paper changes its dimensions is dependent upon the rate of flow of the air over it. The rate at which the paper increases its dimensions with rising relative humidity is somewhat greater than the rate at which it decreases with falling relative humidity, but the difference between the two is not very great. The rates at which the paper changes its dimensions in a moderate current of air are fairly rapid, being nearly complete in 5-10 minutes. The rates are increased with rise in temperature.


A mechanical gage or extensometer was developed for measuring film shrinkage and an optical extensometer, suitable for both paper and film. The latter employs two 32-mm. Micro-Tessar objectives, one movable and one fixed. These lenses are in fixed focus on the upper surface of the plate-glass top of the instrument. By means of prisms the beams from the lenses are brought to focus on a Hammar-Frodham photometric cube, which brings the separate images into juxtaposition. A brass tube fitted with a lens and hard-rubber cap with a small hole constitutes the eye-piece of the instrument; this is focused on the photometric cube. At the right of the box a micrometer is fitted to move the lens and measure its displacement. At the other end of the box is a dial gage, which also indicates the position of the lens. Either micrometer or dial gage may be read; the latter is preferable because of ease of reading. The distance between lenses is 6 inches.

Determination of the influence of moisture on the dimensions of paper. Papier-Fabr. 22: 629 (Oct. 19, 1924); T. S. 81: 70.

The Schopper test for determining the influence of moisture on paper is sketched and described.

This is an extension of the work of H. S. Davis. An expansiometer has been designed, which consists of a conditioning chamber (a glass tube 1.5 inches inside diameter and 2 feet long) which is capped top and bottom with brass collars, through holes in each of which are placed two sliding brass rods, adjustable vertically by set screws and terminating at the top and bottom in clamps to hold strips of paper. The two lower rods are connected to two pointers, so counterpoised as to put practically no strain on the paper strips. The humidity of the air in the chamber is controlled by the use of the proper strength sulfuric acid solution. The pointers are so designed that, with a 10-inch strip of paper, each small division on the scale corresponds to a change of 0.01% in the length of the paper strip. If the paper is completely dehydrated and then tested under increasing humidity conditions, more concordant results may be obtained and the paper comes to equilibrium in a much quicker time than when the tests are started at a higher humidity and the humidity conditions are subsequently lowered. The results from tests on 12 different types of paper showed that the percentage elongation between 20 and 80% relative humidity is approximately a straight line. The elongation is considerably greater in the cross than in the machine direction. In most cases, the increase in elongation between 80 and 100% humidity is considerably greater than that between 60 and 80%.


The apparatus (designed by Riesenfeld) consists of an airtight glass container, which has a hair hygrometer, a thermometer, and a sample of paper. The expansion and contraction of the paper are measured at different humidities.


Data are given for the expansion and contraction of paper with humidities of 15 to 85% for 11 papers. The readings were made by means of a microscope mounted over a steel scale graduated in fifths of a millimeter. The effect is greater in the cross than in the machine direction. For the most part, the curves are similar to the moisture content curves. In some cases, there is a tendency for the rate of change to decrease with the higher humidities.


Data are given showing the change in expansion (in and across), using 65% relative humidity as the base line, when the samples are humidified at 40, 50, 65, and 75% relative humidity (ascending series) and at 75, 65, 50, and 40% relative humidity (descending series).
Hygroexpansivity


The samples consisted of strips of paper, 5 cm. wide and 50 cm. long (i.e., along the cross direction of the paper), which were coiled to give cylinders 40 cm. long and 1 cm. in diameter. A piece of nickel-steel wire, 0.051 cm. thick, was fastened at the top and another piece of wire at the bottom of the cylinder by means of sealing wax; the lower extremities of the two wires were in close proximity to each other, and their distance apart could be measured by a cathetometer. For the measurement of the rate of expansion of paper by water vapor in the absence of air, the sample was hung vertically inside a glass cylinder immersed in a water bath at 25°C, and connected with a source of water vapor and a vacuum pump. A method is also described for the measurement of the rate of expansion in the presence of air, the moisture being supplied by a stream of compressed air. A second apparatus was constructed for the measurement of the adsorption of water vapor by paper and the magnitude of the resulting extension at various humidities. The equilibrium extension and moisture adsorption took place at the end of about 30 hours, and no further change was observed at the end of 100 hours. Experiments were also carried out with the wet extension test of TAPPI, in which the sample on a sheet of clean plate glass was covered with a film of water for 10 minutes, after which the change in length was determined. Values are reported for the equilibrium moisture content of 20 typical papers, as well as their expansion in both machine and cross directions, in an adsorption-desorption cycle from 5 to 95% relative humidity and back. The previous moisture history of the paper markedly influences its subsequent humidity-extension behavior. Most of the results are presented in the form of curves.


This is largely a review of the work of Fromm, Griffin, and Winkler.


Linear Expansion. The maximum linear expansion is determined from a specimen 3 x 12 inches that has been cut parallel with the long direction of the board and from a like specimen cut at right angles thereto. The expansion is measured between two points approximately 10 inches apart on the center line of each specimen. The specimens are conditioned for 24 hours at 50% relative humidity and measurements are made of the distance between the two reference points. The specimens are then conditioned for 24 hours at 97% relative humidity, after which
the distance between the two reference points is again measured. The expansion may be measured by any convenient method, provided that the results are accurate within 0.005 inch. The measurements are made in air, conditioned as specified in each case, or as quickly as possible after each specimen is removed therefrom. The linear expansion is reported as the increase in length between the reference marks, expressed as a percentage of the length at 50% relative humidity. Sodium dichromate may be used for an atmosphere of 90% and potassium sulfate for 97% relative humidity.


Data are given for the average change in linear dimensions between 35 and 65% relative humidity for 5 papers (the method used is not stated). Between 0 and 80% relative humidity, the dimensions of a sheet of paper vary in almost direct proportion to the humidity, according to earlier investigators. The present results check the percentage change across the grain, but parallel to the grain there is a distinct difference. The change in offset paper across the grain is from 4 to 8 times that in the machine direction.

511. Roberts, D. The curling and waving of papers. Pulp Paper Canada 38, no. 8:461-463 (July, 1933); T. S. 90:158; C. A. 27:4923.

The percentage expansion was obtained by measuring the length of strips of papers, cut in the machine and cross direction, at equilibrium with air at 45% relative humidity at 75°F. and then by a second measurement of the length of the strips after equilibrium at 95% relative humidity at 75°F. The method employed a box in which the samples were conditioned, clamps for the strips, and means for measuring the length of the strips with no tension beyond that which was necessary to counterbalance each movable clamp and keep the strip taut for the measurement.

The results for 14 papers show that the greater expansion is always in the cross direction of the fibers.


An extensometer consists of a metal framework, at one end of which is pivoted a lever, the shorter end of which bears against one end of the specimen and the longer end serves as a pointer as it moves along the scale. The scale is graduated directly in percentage of a definite length to which the specimen is originally cut. The indicating lever is counterweighted to insure that it will always be in contact with the board.
At the opposite end of the framework there is pivoted on the framework a second lever, one end of which bears against the end of the specimen. This lever is adjustable to provide a means of adjusting the position of the specimen until the pointer registers zero. A specimen so adjusted in an extensometer and exposed to a relative humidity higher than that corresponding to the moisture content of the specimen will expand and push the pointer along the scale which indicates directly in percentage the expansion of the board at any time. The expansion in the long direction of all boards studied was less than that in the short direction, the ratio in the case of laminated boards being from 1/5 to 1/6. Data are given (for the short direction) for boards exposed to an atmosphere containing saturated water vapor, after which the specimens were immersed in water for an hour.


Expansivity is the capacity to change dimensions. Moisture expansivity is indicated by expansion or contraction with increase or decrease of moisture content, respectively. Practically the same value will be obtained by measuring either contraction or expansion, if conditions are properly controlled. For convenience, the expansivity is determined by measuring contraction. The TAPPI Standard is based on the method of Weber and Geib.


A sensitive spirit level vial is suspended from the lower end of the test specimen, which is cut in the form of a long strip. One end of the vial is supported by the paper specimen and the other end is supported by a pair of sharply pointed wire feet. The test specimen is supported at its upper end by a simple micrometer arrangement. The lower end of the strip is maintained at constant elevation by means of the spirit level vial, and changes in length are measured at the upper end by means of the micrometer. The pitch of the micrometer screw and the length of specimen are so chosen that the percentage change in length may be read directly from the micrometer dial. The construction of the instrument is described. A double system is used, so that hygroexpansivity for the machine and cross-machine direction may be measured simultaneously.


The original Neenah expansimeter was designed to accommodate two test specimens; the determination of hygroexpansivity is intrinsically
slow and therefore an apparatus has been designed which will accommodate
20 specimens at one time. Detailed drawings are given for the new
instrument. Each of the 20 specimens is suspended from a rod which
bears up against a micrometer screw. The specimen supports, in turn,
one end of a small spirit level vial. The other end of the vial is
supported by a short length of 0.001-inch steel ribbon, so that a
vertical motion of the lower end of a specimen causes the level vial
to tilt. With the lower end of the specimen held at constant elevation
by means of the level vial, change in length is measured at the top
(to the nearest 0.001 inch) with the micrometer. The metal supporting
members clamped at each end of a vial have weights chosen in such a manner
that very little force is required to lift the end of the vial supported
by the specimen. If it is desired to place the specimen under an appreciable
tension, the required force is obtained by placing a suitable weight on
the connecting link between the lower end of the specimen and the level
vial. The length of specimen between the lines of clamping is nominally
10 inches. A method of maintaining constant relative humidity within
the apparatus is discussed. Constancy of temperature is important.

216. Weber, Charles G., and Cobb, R. M. K. Register studies in
1932)(RP 480); B. I. P. C. 3:38.

Changes in paper dimensions were determined by means of a rule
designed for measuring the displacement of reference marks on large
sheets of paper. It is equipped with two magnifying glasses, each with
a small glass reticule having a vertical cross hair mounted directly
underneath. One magnifier may be placed at any point within the range
of the scale (24 to 64 inches) and readily set so that its cross hair
will coincide with any division on the scale. The other magnifier is
set over the second reference mark by means of its micrometer adjustment.
The distance between the reference points may be read to 0.001 inch.

Eleven papers were conditioned and tested in atmospheres of 30, 45,
65, and 75% relative humidity. Tensions of from 9 to 455 grams were
applied to specimens 15 inches wide and the elongation for each increment
of tension was observed. The results did not indicate any significant
differences in elongation between the various samples tested. The
greatest differences in the elongation of the different papers occurred
at 75% relative humidity; the widest difference was less than 0.1% for
the cross direction; differences for the machine direction were much
smaller. The minimum variation between the expansions of the different
papers occurred at 65% relative humidity and changes in expansion for
changes in relative humidity were of smaller magnitude in the vicinity
of 45% than at other humidities used.

217. Weber, Charles G., and Colb, Martin N. V. New test for
dimensional changes in offset papers. J. Research Natl. Bur. Standards

The apparatus consists essentially of a wooden cabinet approximately
40 inches high, 16 inches wide, and 12 inches deep (inside dimensions).
The specimen is held in clamps, the lower one being fixed and the upper
one being suspended from a light flexible cable which leads over a pulley.
Tension is applied to the specimen by a dead-weight load on the other end of the cable, the tension being equal to the difference between the total load and that required to move the upper jaw. The pulley shaft extends through the back of the cabinet and a mirror is mounted on the end outside the cabinet. Movement of the mirror, through rotation of the shaft, changes the position of a spot of light reflected by the mirror to a graduated scale near the base of the cabinet. Expansion or contraction of the specimen turns the shaft through travel of the cable over the pulley. Using the ratio of the radius of the pulley to the distance of the mirror from the scale, the change in length of the specimen can be calculated from the travel of the light beam on the scale. The same paper was tested under dead-weight tensions ranging from 50 to 1000 grams for the specimen two inches in width. Although increased tension resulted in stretch of the specimen as indicated by the separation of the curves, for the range of tensions used, nearly all the stretch occurred at humidities above 70%. Varying the tension from 25 to 500 grams per inch of width did not change appreciably the slope of the curve in the region below 70% humidity. Hence, if the expansivity is taken from this part of the curve, precise control of tension is not important. There is a possible error in the expansion and contraction of the cabinet and large variations in temperature during a test should be avoided. A suggested method of test is appended.


The studies were made in a room of approximately 1080 cu. ft. in which humidity and temperature were controlled by means of a humidifying-dehumidifying unit capable of conditioning air at the rate of 2500 cu. ft. per minute, thus providing a change of air every 30 seconds. Dimensional measurements were made accurately to 0.002 of an inch on specimens 24 x 24 inches by means of a micrometer rule. Within the range of about 30 to 72.5% relative humidity, at 83°F., the dimensions vary directly with the moisture content irrespective of the cause of the moisture change. The data obtained for different humidities with constant temperature and for different temperatures with constant humidity result in a single regular curve. The paper having the greatest number of fibers parallel to the machine direction will have the lowest dimensional change in that direction, because this direction is parallel to the diameter of the largest number of fibers. Coated papers had the largest dimensional change per unit of moisture content variation and machine-finished offset papers had the lowest. Surface sizing with starch increased the dimensional changes slightly.
IMPACT TEST


The principal faults of the revolving drum test are that it is difficult to repeat an identical test and that a container is subjected to shocks, falls, impacts, and stresses not encountered in normal handling and in transportation. The test gives quite accurate results over a long series of tests but this situation does not work out satisfactorily when only one or two containers are available for study. The need for another type of device led to the development of the inclined impact tester. Some of the ideas considered in its development are outlined. The angle of the incline was selected at 10 degrees; reasons are given. The maximum fall obtainable is 4 feet 2 inches and from this height, disregarding friction, which is present, the speed at the instant of impact is 11.2 miles per hour. The friction is so small in comparison with the force of the free-running loaded dolly that it need not be considered.

521. New incline impact testing device. Fibre Containers 23, no. 12:40, 74 (Dec., 1938); Converter 13, no. 4:22 (April, 1939); B. I. P. C. 9:265.

A brief description is given of the tester.

522. Pleasence, A. V. New fibre container developments. Fibre Containers 24, no. 6:28-29, 63 (June, 1939); Paper Box and Bag Maker 88, no. 3:92-93, 89 (Sept., 1939); Shears 57, no. 559:42-43 (July, 1939); B. I. P. C. 9:577.

The inclined impact testing device consists of a track inclined 10 degrees to the horizontal. At the foot of the track is a strongly braced bumper whose face is 10 degrees from vertical, forming a right angle with the plane of the track. The packages to be tested are placed on a dolly with roller-bearing casters which run on the track. The loaded dolly is rolled up the track to a predetermined point and, when released, rolls down the track at increasing speed until the package strikes the face of the bumper. The force of the impact is determined by the speed of the track at the moment of impact, which is practically constant for any given length of run, and increases with the length of the run; it is proportionate to the aggregate weight of dolly and package. The package is placed exactly flush with the front end of the dolly so that the impact will not be affected by the package sliding on the dolly. The impact may be applied to any face or any edge of the package by positioning it on
the dolly. A movable hazard in the form of a 4 x 4-inch timber may be attached to any part of the face of the bumper. This may be used to concentrate the impact across the top or bottom edge or center of the package or at any desired corner. The speed of impact may be correlated with the impact force of a freight car in switching by the use of a Savage impact register attached to the dolly. The Freight Container Bureau finds that it is possible to determine by this means the length of run corresponding to freight car impact at a given switching speed and thus determine whether or not the container will give protection under the speeds of switching usually encountered. The weight of the contents causes the package to bend and twist, and the measure of this distortion determines the amount of clearance or cushioning necessary to protect the contents, or the extent to which the container must be strengthened. The device occupies a floor space of about 25 x 4 feet and materials for its construction cost about $50.


The Conbur impact tester is essentially a dolly, running on a 10-degree inclined track, impacting a rigid bumper. Its value, in addition to the simple form, lies in the possibility of positioning hazards of various kinds on the bumper and also on the dolly. By the use of these attachments, there can be developed almost every sort of impact which containers encounter in handling and shipping. Its use is illustrated by the testing of containers containing canned foods, in which it was shown that the cases impacted sidewards withstand about twice the forces they could withstand lengthwise with appreciably less denting of the cans. Studies have indicated that far more accurate measurements can be obtained on the tear resistance of boards along horizontal edges than is possible with the revolving drum. By positioning a specified load behind the case, and by using a standard impact recorder on the dolly, the crush resistance of the cases under impacts can be determined and correlated with the results of the Olsen crush tester.


The best use of the incline impact tester is to simulate the stresses and strains which containers encounter when slowed as a carload in freight cars. When a freight car is impacted, there is a distinct vertical as well as a horizontal impact. To simulate this condition, holes have been drilled in the inclined track about 12 inches apart and round headed carriage bolts with washers inserted in these holes. When the dolly moves down the track, there is a series of vertical impacts, followed by the definite horizontal impact. It is probable that there should be a load on top and one behind the box being tested.


This article is concerned principally with the incline impact tester. The test simulates the destructive forces of freight car impacts, 95% of which occur in yards and 5% in trains. This test should be used if the container moves in carload lots, whereas the drum test should be used if the
container is to move by parcel post, express, or local freight. Certain
modifications of the test are possible. As an example, a plank positioned
on the face of the bumper so that it contacts the extreme top edge or
the extreme bottom edge of the container at-impact will simulate the
forces of a direct drop on the edge and set up an edgewise diagonal
stress in the container; a small block positioned so that it contacts
the container at impact adjacent to the corner will establish a strain
similar to a cornerwise diagonal compression test.

Paper 24, no. 21:21-27 (July 30, 1919); Fibre Containers 4, no. 9:8-9
(Sept., 1919); C. A. 13:5010.

Because the determination of the bursting strength does not give
sufficient information concerning the strength of fiber board under
service conditions, an impact tester has been designed for the purpose
of establishing minimum impact requirements for the different weight or
thickness of boards. The tester consists of a two-kg. hammer, which
is guided by two vertical rods. The upper end of the hammer is so
constructed that it can be held in position and released from a crosshead
which can be moved up and down the guide rods and locked in position by
set screws. The right-hand guide rod is graduated to 0.5 cm. and is
adjustable to allow for variations in the thickness of the boards tested.
By raising or lowering the crosshead the hammer may be adjusted to any
desired height above the plunger. The plunger weighs one kg. and has a
spherical lower end, the diameter of which is 2 cm. The plunger rests
in the center of the fiberboard to be tested, which is clamped under
the clamping plate operated by a lever, in the center of which is a
circular hole 8 cm. in diameter. A hole in the base of the tester of
the same diameter corresponds exactly to the hole in the clamping plate.
This plate is 5 x 7 inches and, because of the large clamping area,
the board may be firmly clamped with but little pressure and without
crushing the board. The test strips are 5 inches in width. The bursting
height is the distance at which the hammer just drives the plunger
trough to the shoulder of the bevel. There is practically no parallel-
ism between the results with the impact tester and those with the Mullen
tester.

227. Sawney, O. R., Hartford, Charles E., Richardson, Roger W., and
Whittenore, Edward R. Experimental studies on the production of insulating
102. June 10, 1931. 64 p.

Impact Test. The tester consisted of a vertical steel rod support-
ting two horizontal steel arms. The lower arm was set with the under
side at zero. The upper arm was set at the desired height for the test.
The cover on the test cup at the bottom was replaced by the board to
be tested. This cup was adjusted so that the zero setting on the plunger
rod resting on the board was zero. A weight attached to the upper arm
was allowed to drop to the top of the plunger. The instrumentation in the
board under the force of the falling weight was read from the gradu-
ations on the plunger that project below the lower face of the fixed arm.
Impact Test

528. TAPPI. Impact resistance of fiberboard shipping containers. TAPPI Standard T 801 sm-44. 2 sheets.

The impact resistance of fiberboard containers or boxes is an arbitrary measurement of the energy required to rupture the box by impact when successive blows of increasing force are applied in the prescribed manner. The result is expressed as the final distance, in feet, traveled by a dolly, carrying the loaded box, along an inclined plane to a bumper before rupture of the box occurs. The device consists of the incline impact testing device developed by the Freight Container Bureau.


Inclined Impact Tester. Since impact is the cause of most failures to containers in transit, a device was recently developed which is inexpensive and simple in operation. With it the intensity of impact can be controlled and repeated as often as desired. Full sized containers are subjected to test with the intention of recording the effects of shock on the container itself as well as on the contents and cushioning materials used on the interior. The device consists of a long inclined runway having steel tracks and a rise of 4 ft. 2 inches. A ball bearing equipped wheel truck or dolly capable of carrying the largest container, runs on this track. A bumper block is located at the base of the runway, having sufficient strength to resist repeated shocks. The angle of the runway is 10 degrees and the truck when started at the top attains a speed at instant of impact, disregarding friction, of 11.2 miles per hour. Tests are seldom if ever conducted, starting at the top because destruction of the container would be assured. Therefore markings along the track are desirable so that tests can be repeated from a definite point. Slow motion moving pictures record permanently the exact conditions existing at the moment of impact which can be studied anytime later and in absolute detail. Further than this, these picture records are of considerable value when comparing conditions on similar containers, tests on which are run at various times. When rigged with properly located scales, within focus of the camera, the distance in which the shock is absorbed can be recorded and the efficiency of the inner packing determined. The container to be tested is placed on the truck or dolly and by means of a small winch or rope block the truck it pulled up the incline to the desired starting point where it is released. Being acted upon by the force of gravity only it attains a speed commensurate with the starting position and each successive test, weights being equal, will produce identical impacts.
PUNCTURE TEST


This is the same as TAPPI Standard T 503 m-44.


The three vital factors in fiber shipping container quality are resistance to crushing, puncture, and tearing at score lines. The author indicates that these three properties can be measured by the Beach puncture tester. The comparative stiffness of combined board or solid fiberboard can be measured by the puncture tester and, when made on different grades of board, should parallel results obtained on tube tests or compression tests on boxes with uniform fabrication from the same grade of material. The puncture tester, constructed with different weights to give varying amounts of energy and having an acceleration and deceleration produced by gravity alone (except for the comparatively small percentage of the total energy absorbed in puncturing the material being tested), would seem to be the simplest mechanical apparatus for measuring the resistance to puncture of all grades of boxboard material. Actually, it has been found that the results are comparable for all grades of material from 9-point corrugating material to 600-lb. MT double-wall corrugated board and are independent of the fiber formation, depending solely on the basic fiber strength of the material being tested, weight per 1000 sq. ft., and the stiffness of the material. The puncture test results will parallel the Mullen test results on boards having the same fiber formation and furnish. The puncture tester makes three tears, approximately 1.5 inches in length and at angles of 120°, proceeding from a central point, irrespective of the grain direction of the liners or the corrugations. The numerical results are a sum of the tear resistance and stiffness of the material but either factor can be eliminated to determine the other; consequently, the puncture tester is a definite measure of tear resistance of score line strength of all grades of box board and has the additional advantage of tearing the corrugating medium simultaneously with the liners.


The desired features of the instrument were: (1) rupture a considerable amount of material to avoid small variations; (2) rupture all components of combined materials equally and, as far as possible, simultaneously; (3) rupture along defined lines so that the rupture would be independent of such factors as grain direction and direction of corrugations;
(4) rupture in a sufficient number of different directions so that the results would be an average strength in all directions; (5) itself have relatively few inherent variations because of friction, gages, and springs; (6) be calibrated in definite units of energy, and which could be duplicated and checked without elaborate apparatus or difficulty.

The final apparatus involves the use of a pendulum, on the end of which is fixed a rod bent in the form of an arc of 90 degrees. To the end of the rod is affixed a metal point having the shape of a triangular pyramid, one inch in height. Advantages of the pendulum principle are listed. The test specimen (corrugated board or similar material) is held between two clamping plates which are approximately at the level of the axis of the pendulum. The upper plate is fixed and the lower plate is held by spring pressure against the material. The pendulum is held up by a trigger and stop in a horizontal position. If there is no material between the clamping plates and the trigger is released, the pendulum will swing through an arc of 180 degrees to the horizontal position, except for a small retardation from friction; this friction is compensated for by an adjustable stop against the pointer. If material is between the clamping plates, some of the energy of the swing will be used up by the puncturing point punching through the material and, consequently, the pendulum will not swing as far as 180 degrees by the amount of energy that has been used. The pointer remains at its maximum reading position by a simple friction bearing. There are no variables in the apparatus except the friction of the bearings and the pointer sleeve. With the use of high-grade ball bearings this friction is constant and very small.

In the model described, the bare pendulum weighs 9 pounds and the center of gravity is 5.43 inches from its axis, so that its potential energy when in the horizontal position is 48.87 inch-pounds; additional loads are provided to give total potential energies of approximately 87.9, 183.25, and 357.5 inch-pounds. The apparatus will test materials ranging from 0.016-inch liner board to combined solid fiber or corrugated board of the heaviest grades manufactured. In order that the apparatus give comparable results when used with different weights, it is only necessary to keep the velocity of the puncturing point practically uniform, other factors being constant. Much of the energy of the pendulum is used in bending the specimen so that it is also a measure, to a certain degree, of the stiffness of the material. By cutting a "Y" in the material before making the test, with each leg of the Y slightly longer than the tear which will be made by the point in its usual rupture, the stiffness of the material alone can be measured. The chief reason for choosing the triangular pyramid form of point was that it duplicates the corner of a box, the angle formed by the edges being 90 degrees. Results of tests are given. An appendix by E. H. Hull gives the theory of the compound pendulum as used in this type tester.


The tests were carried out on three types of boards: one with a 42-lb., dry-finish Fourdrinier on both sides and 0.009 kraft corrugations; one with 90-lb. 0.030-inch Fourdrinier kraft liners; and one with 95-lb.
cylinder kraft liners and 0.009 kraft corrugating sheet. The material was conditioned at 65% relative humidity and the tests were made continuously within the space of a few hours by an experienced operator. Five hundred tests were made. Puncture tests were made half with one leg of the puncturing point parallel to the corrugations and the other half with the leg perpendicular to the corrugations. The curves for the 42-lb. Fourdrinier and the 95-lb. cylinder kraft boards lie quite close together; there are exactly the same number of tests having zero deviation from the average for both materials and the spreads (including 100% of the tests) are so close together that the points cannot be distinguished on the curve. The values are 10.8% for the 42-lb. board and 11% for the 95-lb. board. The number of tests necessary for 99% probability are:

<table>
<thead>
<tr>
<th>Possible error, %</th>
<th>42-lb. Fourdrinier</th>
<th>90-lb. Fourdrinier</th>
<th>95 lb. Cylinder</th>
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<tbody>
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</tr>
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<td>2</td>
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<td>32</td>
<td>20</td>
</tr>
</tbody>
</table>


In the Thwing impact tester, a heavy plunger, falling in vertical guides, punctures the specimen by its impact. The work done in piercing the specimen is determined from the initial energy of the plunger and the compression of the springs placed at the bottom of the guides, which absorb the remainder of the energy left in the falling plunger after the specimen is pierced. A description and illustration of the tester are given. The formula for the calibration of the instrument is developed. With the exception of papers which stretch inordinately, the strongest material which actually can be tested is one requiring about 77 inch-pounds of energy in being punctured. The tester was designed to test heavy boxboards which, through service conditions, are often subjected to direct impact such as this tester is intended to simulate. Because of the manner in which the data are expressed, the results are not directly comparable with those obtained with any other paper-testing device. However, results obtained with the Mullen bursting strength tester are included, because it was thought that the two instruments might grade a series of papers in the same order. Tests with kraft wrapping paper showed that the order in which the specimens are graded is different for the two testers. One reason for this is the nature of the test. In the Mullen tester, the specimen is subjected to a uniformly increasing pressure until it bursts; in the Thwing tester, the specimen is subjected to a direct impact sufficient to cause its rupture. Another reason for the differences is that the capacity of the impact tester is too high for this type of paper. In tests on heavy boxboards, the mean percentage deviation of the individual test values from the average values obtained with the impact tester is lower than that obtained with the Mullen tester.
This is an indication that the impact tester is capable of producing consistent results. For readings on the Millen tester from 100 to 300 points, the approximate relation—Thwing impact value = 0.156 Millen bursting points—holds within about 15% of the observed values. The Thwing tester is not suitable for testing single plies of light weight paper, because the resistance of such paper is insufficient to give an adequate scale reading. The significance of the results in terms of serviceability of the board can be determined only through extensive experience.


This relates to the Beach puncture tester. The tester will determine the strength of boxboard from 0.014-inch liner to 0.140-inch solid kraft, as well as waterproof boxing material. It will also measure the strength, without deforming or flattening the corrugations, of corrugated board of various grades. The tester consists of a pendulum on the end of which is a rod bent to form an arc of 90 degrees; the point is shaped like the corner of a box to simulate actual shipping conditions. The unit holds the material to be tested firmly between two clamping plates which are level with the axis of the pendulum. The pendulum is operated by a trigger and, as this is tripped and the released pendulum swings through its arc, the number of degrees less than 180 degrees through which it swings is a measure of the energy dissipated in puncturing and bonding the test sample.


A brief description is given of the puncture tester, formerly known as the Beach puncture tester and also known as the G. E. boxboard tester. It is designed for the measurement of the stiffness or the resistance to puncture of fiberboard and similar material. The energy possessed by the bare pendulum is not sufficient to enable it to puncture strong materials, and auxiliary weights are supplied which increases the capacity of the instrument 2, 4, and 8 times. The test procedure is outlined. The samples should be placed in the clamping plates in such a manner that on one half of the tests the loading edge of the puncture point makes a tear in one direction of the material and, on the other half of the tests, in a direction perpendicular to those tears. The puncture point should hit on the outside liner of corrugated board and on the smooth side of the uncombined board. If low readings are obtained, they are not necessarily the result of poor fiber strength but may be caused by any one of the following conditions: poor liner adhesion; crushed corrugations; poorly shaped corrugations; poor quality...
of corrugation. Instrumental maladjustments, such as an unstable foundation, too much pointer friction or tightness of pendulum collar cause high readings. Making tests too close to the edge of the material or too close to each other on the surface of the material also may be the reason for high readings. Generally, however, high readings are the results of tests made on an unusually sound area of the sample.

536. Hull, E. H. Theory of compound pendulum as used in pendulum-type puncture tester. Appendix to article by Beach (No. 531).


The Beach puncture tester, an instrument for measuring the work required to pierce a paperboard with a pyramidal point, has been investigated as regards principles of method and design. Fundamental measurements made upon the instrumental constants and scales showed the latter to be accurate. Frictional losses were found to be small and of such nature as to be allowed for, with one exception: an appreciable loss occurred from the method of mounting the auxiliary weights. A significant error was found in the displacement of the release mechanism when the auxiliary weights were added to the pendulum system. Strain-energy set up in the puncture arm was found to result in appreciable error. The effect of sharpness of the edges and point of the puncture head was investigated for a number of boards, and a consistent relationship between test results and sharpness was not found; this led to the conclusion that, whatever the ultimate significance of the instrumental reading, a difference between a pair of readings on different boards is not significant. The influence on test results of thin films of tacky and lubricating materials was measured; it was found that the nature of the surface of a specimen could, under certain conditions, affect the puncture work quite materially; doubt is expressed that differences of this origin reflect the relative abilities of two boards to withstand puncturing forces. The effect of varying the size and angular orientation of the triangular sample aperture was observed with the view of establishing manufacturing tolerances on these variables. Results are virtually independent of the angle between sample aperture and puncture head for angles up to about 7 degrees. Specific suggestions are made for improving the instrument.


The Beach puncture tester is a very simple mechanism, essentially a pair of clamping plates which hold the board with crushing while a pointed pendulum swings against an exposed section of the board. The pendulum has a point in the form of a three-sided pyramid with rounded edges, simulating the impact of the corner of a wooden box or similar rectangular object. The amount of energy required to force the point through the board is read directly on a scale. For testing different grades of board, various weights are attached to the pendulum and there is a different scale on the dial for each weight.
Puncture Test

539. TAPPI. Puncture test of container board. TAPPI Standard T 803 m-44. 2 sheets.

The puncture test is a measure of the energy required to force a puncture head of designated size and shape completely through a sample of container board. The measured value is dependent upon the resistance to puncture and the stiffness of the board. The test may be used satisfactorily in place of a determination of the bursting strength. The apparatus is described and illustrated and the procedure for its use is detailed. A method is given for determining the stiffness of the board or by differences a measure of the puncture resistance not dependent on stiffness.


The following tests were made on the built-up board samples: normal adhesion, Beach adhesion, Hinde and Beach crush, bursting strength (Jumbo Millen), Beach puncture, and Beach stiffness. Compression tests (top-to-bottom), impact tests (Corbur tester), and small revolving drum tests were carried out on the containers. The general conclusions from the tests are summarized as follows:

Some tests, such as the flat crush, obviously indicate how well the corrugating material serves to hold the liners in position so as to follow the fundamental principles embodied in truss construction, which is the basic idea of the design. The ability of corrugated board to resist flat crush is usually much greater than any stresses encountered in loading up to failure, which generally results from some other weakness. Certain minimum strengths should be set, however, above which no corrugated board will fail by crushing, provided that the basic principles underlying the whole idea are adequately followed. The bursting strength of the flat stock (either liner or corrugating paper) gives indications which yield information on the material used and are of value. To go beyond this, however, by extending the use of the bursting strength testers to the testing of built-up board is a questionable practice. The results are of doubtful value because they cannot be used with any assurance that they indicate in any way the probable performance or serviceability of the container made therefrom. The puncture test on the built-up board, used as a means of ascertaining both toughness and stiffness, gave results which correlated reasonably well with the performance of the boxes made therefrom as indicated by the over-all consideration of the compression, drum, and impact tests. In so far as the number of samples and tests and the scope of the studies under discussion justify, the puncture test seems to indicate all-around fitness to a higher degree than any one of the performance tests taken alone, and the value indicated seems to correspond with the integrated value of all three of the performance tests, with due weight being given to the relative importance of each test in indicating the serviceability of
the container under consideration. It is acknowledged, however, that
two series of tests (such as are herein discussed), extensive and time-
consuming as they may be, are obviously inadequate for the establishment of
fundamental principles or rigid rules for procedure, and that the studies
should be extended to include every type and make of flat stock, ad-
hesive, design, fabrication, and combination encountered in the industry.

541. Werner, A. W. Manufacture of fibre shipping containers.

Puncture Resistance. The resistance to puncturing is usually tested
by cropping a pointed object from a predetermined height on the face of
the box and observing the extent of the failure. The amount of punctur-
ing will depend upon the size of the box face and the quality of the
board as well as upon the nature and weight of the point. Comparisons
obtained through testing boards of a standard size are more accurate
than those obtained through testing the faces of completed boxes.
SCORE TESTS


The apparatus comprises means for applying a combined action of tension, tearing and repeated bending to a specimen while it is bent over and drawn firmly against a sloping edge. In the case of scored boards representing material from an edge of a fiber box, the specimen may be bent initially at an angle of approximately 90 degrees, the bend being parallel to and at the score, so the score may be in contact with the sloping edge during the test. The number of times that the test piece is bent through a predetermined angle, together with the maximum tension applied before it is torn apart, is taken as an indication of the amount of rough handling which the finished box will withstand. The stationary clamp of the instrument consists of an adjustable jaw mounted on a fixed jaw having an extension in the form of a plate with a transversely sloping edge over which the test specimen is bent. The other clamp is carried by an oscillating arm which is equipped with mechanism tending to stretch the test specimen by drawing the clamp away from the axis of oscillation of the oscillating arm. The latter is moved back and forth through the desired angle. The two clamps are so placed that when the oscillating arm is in its central position the planes of the clamping surfaces are at right angles to each other, intersecting, if extended, in a line approximately at the axis about which the oscillating arm oscillates. In making the test the specimen is bent over the sloping edge, which is approximately on a line through the axis of rotation of the oscillating arm, and the ends of the test piece are held by the two clamps, so that the position simulated that in which the material is placed in a set-up and loaded box. The test piece is bent back and forth at the sloping edge and the tension caused by the force applied to the movable clamp causes the specimen to tear along the sloping edge. By using, for the extension of the fixed jaw of the stationary clamp, plates terminating in edges having different slopes, the severity of the test can be varied. Suitable means are provided for determining the number of bonds and the maximum tension which the test piece sustains before failing.


Fiberboard Score Test. A specimen containing a scored edge is cut from the box and tested in combined bending, tearing, and tension by means of the score tester. On the machine are two clamps, one mounted on a stationary inclined ledge at the top and the other on an oscillating arm. This arm is connected with a driving mechanism by means of which it can be made to swing through various angles and at different speeds. The movable clamp is connected through a calibrated compression spring to a screw and ratchet wheel which causes a downward movement
Score Tests

of the movable clamp when the oscillating arm moves back and forth. The test specimen, which is 1 inch wide and about 4.5 inches long, has the score midway between its ends and at right angles to its length. It is first bent through an angle of 90° at the score and is then clamped in the machine with the score resting at the sloping edge at the end of the extension of the lower jaw of the stationary clamp. Thus, when the machine is in motion, the specimen is bent back and forth at the sloping edge, and the tension caused by the force applied to the movable clamp causes the specimen to tear along the sloping edge. This action simulates the conditions which are encountered by the edges or scores of a loaded fiber box when it is subjected to rough handling or to the skewing and racking caused by the swaying of a moving freight car. The test is continued until the specimen fails, and the maximum pull and the total number of bends which the specimen withstood are taken as measures of the ability of the box to withstand rough handling. The degree or intensity of the tearing can be changed to simulate different conditions by modification of the sloping edge, together with the possible variations in speed, angle of swing of the oscillating arm, and rate at which the tension is increased. A combined bonding and tension action without tearing can be obtained by using an edge having a horizontal ledge over which the tension and bonding is applied to the specimen instead of a ledge having a slope or inclination.

Quinn, Don. Simple strength property tests. Fibre Containers 25, no. 6:41 (June, 1940).

A description is given of the "Mullen strip test." It is similar to the test described in the following abstract. Test results and, for comparison, drum tests are given for four boards.

<table>
<thead>
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<th>Lot</th>
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</thead>
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<tr>
<td>4</td>
<td>148</td>
<td>97</td>
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</tbody>
</table>


If one box has cylinder-formed liners and the other has Fourdrinier-formed liners, the bursting strength is not a very dependable criterion of their retention of contents strength properties (this is defined as that property of a container which enables it to hold the contents intact as a unit during its life of service). The operation of crossing depreciates the strength of a board. Thus, the standard bursting test, which is made over uncroosed sections, is not a criterion of the strength along the edges. The following method is suggested. Use the the standard Mullen or Cody machine. Cut the strips 1-1/8 inches wide. This width of strip can be positioned over the orifice of the
tester without danger of either edge contacting the edge of the orifice. One set of strips has the corrugations perpendicular to the length of the strip, the other has the corrugations parallel to the length. In each instance, the creased edge lies across the width of the strip. Position the creased edge exactly over the center of the rubber diaphragm of the bursting tester. The clamp pressure must be tight, otherwise slippage will occur. The outer facing should be up in this test. If the specimens are cut from boxes with vertical corrugations, the strips with corrugations perpendicular to the length represent the vertical edges and those with corrugations parallel to the length give the record for the horizontal (flap) creases.


Score Tester. Investigations have clearly demonstrated the need for a test on the scores of fiber boxes, since the strength of the score appears to depend more upon the condition of the board at the time of scoring and upon the scoring process than upon the quality of the board. A fiberboard score tester has been designed by the U. S. Forest Products Laboratory to test the score of a fiber box. A specimen 1 inch wide and about 4-1/2 inches long, containing the scored ridge midway between the ends, is cut from the box and by means of the testing machine, the sample is tested in combined bending, tearing, and tension; the action of the machine is quite similar to the forces causing failure at the scores in actual service. Tests on the scored edges of the box are especially valuable for determining the efficiency of the scoring process.
SERVICE TESTS

547. Jiggle tester.—Fibre-Containers 25, no. 3:56 (April, 1940); B. I. P. C. 10:398.

The Jiggle tester (illustrated) simulates the jogging and bumping motion which shipping containers receive riding in freight cars and motor trucks. One or more loaded containers are placed on a suspended platform to which motion is imparted by means of a series of rotating cams carefully timed so as to produce various combinations of vertical and lateral movements in a definite sequence. The speed can be regulated so as to obtain a slow jogging motion or a rapid vibratory action. Containers are subjected to this treatment for a definite period of time and then examined and tested to determine the effect on case rigidity, bond adhesion, etc. It is believed the test will be particularly valuable in determining the effect of prolonged vibratory motion on the adhesive structure of corrugated boxes.


The weaving test is designed to simulate the side swaying or rolling of a moving freight car, or the repeated starting and stopping of a car. The swaying action of a train is reproduced on the testing machine by an oscillating table or car, which can be made to move horizontally forward and backward at different speeds through any distance up to a maximum of 8 inches. The box to be tested is fastened rigidly to the table by clamps along two of its bottom edges and a weight equal to the average load carried by a container in the bottom tier of a loaded car is fastened on the top. When the machine is put into operation, the container is carried back and forth with the movement of the table. This test affords a means of comparing boxes with respect to their rigidity, which is indicated by their resistance to weaving or skewing. The test may be continued until complete failure occurs but usually the box or crate is tested on the machine until the joints are loosened and then it is taken to a drum-testing machine.

Impact-Shear Test. The oscillating table is used also to simulate the starting and stopping action of a freight car, which produces an impact shear in the container. For this test, the box is suspended freely and above the table by two metal straps. The supporting straps form a parallelogram suspension and horizontal guides, fitted with rollers to reduce the friction, allow the box to swing only in the direction of its length, which is parallel to the motion of the table. Two stops are fastened securely to the table and the ends of the box strike against them as the table moves forward and backward. Any desired weight may be placed on top of the box during the test. The number of complete oscillations of the table before failure of the box is indicated by an automatic counter.
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Reference is made to the comparison microscope of E. Stach, which has been modified for testing surfaces of paper, etc. Illustrations of two kinds of paper are given.


The apparatus is constructed to measure the contact pressure required to cause slippage between two contacting surfaces of the material under test with a predetermined torque, the smoothness of the sample being measured as a function of the pressure exerted to prevent slippage.


The Bokk, Williams, and Gurley testers are modifications of the air-leak method of measuring smoothness. From the standpoint of testing the printability of paper, these testers are open to the following objections. In the Williams tester, the pressure of 14 pounds per square inch is in no way comparable with printing pressures which are of the order of hundreds of pounds per square inch; because the paper is clamped between two hard surfaces, the paper is not subjected to the same forces as those which are produced on a printing press. The Gurley tester is open to the same objections. The Bokk tester is subject to the first of the above objections but is free of the second, because the rubber is the counterpart of the backing or blanket which is used on the cylinder of a printing press. These instruments measure a smoothness but not the right kind. The author discusses general objections to the air-flow method of measuring smoothness, and points out that the real requirement is some measure of the number and size of spots which lie below a plane, the position of which, relative to the paper, is fixed by the pressure conditions specified.


The Bokk smoothness tester is illustrated, and its method of operation is outlined. Data are given showing the reproducibility of the results and values for nine types of paper. The apparatus may also be used for the determination of the porosity of paper (results are given for 13 types of papers).
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553. Døkk, Julius. "What the printing-process demands of paper. Paper-Maker 89, no. 5:71-73; no. 6:88-93(May, June, 1935); World's Paper Trade Rev., Tech. Convention No. 8, 11-12, 14, 16, 19-20, 22, 24, 27-28, 30, 32, 34, 36, 38, 43-44, 46, 48, 50, 52, 54, 57; dis-
cussion, 104, no. 7:554, 556, 558, 561; no. 8:634, 636, 639-640, 642;
no. 9:671-672, 674, 727, 729(March, Aug. 16-30, 1935); Proc. Tech.
discussion, 44-63(Oct., 1935); B. I. P. C. 5:252.

Only those methods of measuring smoothness have proved feasible
which measure resistance to air penetration, instead of measuring the
volume of the cavities. The paper under test is placed with the side
under investigation in contact with a polished glass plate having an
area of 10 sq. cm.; it is covered with a soft rubber plate and sub-
jected to a pressure of 10 kg. (i.e., 1 kg. per sq. cm.). The hole in
the supporting glass plate is 1 sq. cm. in area and is connected with
an air container and a mercury manometer. The smoothness number is
the time interval (in seconds) which is required by 10 cc. of air to be
sucked through between the lower plate and the paper surface, at a
vacuum of 0.5 atmosphere. It is also necessary to determine how ad-
mitted air is distributed between the two surfaces which are pressed
together and through the structure of the paper itself. This is done
by determining the time occupied by 10 cc. of air in passing wholly
through the structure of the sheet; the paper is coated on both sides
with a thick layer of silver by the cathode-atomizing process. The
correction factor is so small in the case of ordinary printing papers
that it can be neglected.

554. Bonétien, C. New testing methods and instruments for de-
temining the quality of printing paper (newsprint in particular) and
a summary of the results. Svencck Pappotst. 42, no. 7:195-209
(April 15, 1939); Paper-Maker 98, no. 4:135-140; no. 5:141-146;
no. 6:149-154(Oct.-Dec., 1939); Papier-Fabr. 37, no. 51:398-400; no.
52:401-406(Dec. 19, 22, 1939); Pulp Paper Mag. Canada 41, no. 1:20-26;
no. 3:23-234(Jan., Feb., 1940); Papir-J. 27, no. 22:347-351; no. 24:
375-37B, 380(Nov. 30, Dec. 30, 1939); 28, no. 1:1-7; no. 2:15-20
(Jan. 31, Feb. 17, 1940); B. I. P. C. 9:156; C. A. 34:3087; B. C. P. A.
1940B:351.

In determining smoothness in testing for printing quality, the
measurement should be carried out in such a manner that not only the
porosity of the paper is precluded, as far as possible, from affecting
the result, but so that, at the same time, the recesses in the surface,
in preference to its elevations, are more distinctly recorded. This
is done by measuring the passage of air, not over a ground surface but
under a narrow edge, allowing the air to pass down into the recesses
on one side, under the edges, and then up on the other side. Such an
apparatus is illustrated, which also shows the necessity of the breadth
of this edge being adopted in proportion to the size of the recesses,
in order that the latter may at all enter into the process of measuring.
The tester is placed on the surface of the paper during testing. The
test can be affected by means of a current of air which, at a very low
constant pressure, travels at so high a velocity that the latter can
be measured. This instrument operates at a constant pressure of only
15 cm. of water.
Various published methods of measuring the smoothness of surfaces are described. Good visual characterization can be obtained by observation at a magnification of 3 diameters in light coming from one side at an angle of about 4 degrees to the surface.

Data are given to support the following conclusions: A single determination with machine-finished paper requires 1 to 2 minutes. The limits of error are at the most 2.5%. For reliable results, 10 individual measurements should be taken at various places on the sample. The test should be carried out at a constant moisture content. By means of this test, it is possible to distinguish between the wire and felt side of a paper sheet.

The instrument is designed for making instantaneous and permanent chart records of irregularities in finished surfaces such as metals, paper, etc. It consists of an analyzer head, a calibrating amplifier, and a direct inking oscillograph. The analyzer head consists of the pickup arm and its drive unit; the arm contains a piezoelectric crystal actuated by a sapphire tracer point. The crystal element of the pickup arm has the property of generating a voltage proportional to the vertical motion of the tracer point as it moves over the surface under test.

In a discussion of gloss and its relation to roughness, Clark mentions a roughness tester used in Scotland, consisting of an inclined plane on which the paper was stretched and a wooden block around which another piece of the same paper was wrapped. The angle of the plane was inclined until the block began to slide down, that angle giving a measure of the roughness of the paper.

The apparatus consists of a glass block having a light reflecting base surface on which a paper sheet to be tested is laid, and oppositely
beveled edges, each at an angle of 45 degrees to the base surface, means for pressing the sheet on the base surface, means for projecting a light beam normal to one of the beveled edges through the block onto the paper-glass interface, and means for measuring the intensity of the reflected beam emerging from the other of the beveled edges. It is possible by this apparatus to determine the percentage of the paper surface which is actually in good optical contact with the glass, and this fraction should serve as a measure of the smoothness of the paper surface at the pressure in question. The apparatus described in the patent provides for pressures from 0 to 11,000 pounds per square inch.


In testing smoothness, two pieces of the same sample are placed upon steel plates which have been ground to a perfect fit. A mechanism is described whereby a rubbing action is set up between those sheets. If the sheets are smooth, they will slip over each other easily; if they are rough, this slippage will not occur and a weight is changed (position and magnitude) until an end point is reached. The device is calibrated to give readings in units of torque (kg.-cm.) exerted around the axis to which the weighted bar is pivoted. Newsprint gave readings in the range of 12 to 37 units. This instrument gives a good correlation with the Bokk tester, but the readings are somewhat more reproducible. This is probably because of the larger samples used. In a series of readings, the maximum deviation is about 5%. Readings of about 30 indicate that the paper has sufficient smoothness to take an even impression in printing, and yet is not so smooth that difficulties would be encountered in folding and conveying mechanisms.


A sample of paper is rotated under a 1-mm. ball feeler, the vertical motion of which actuates a light lever arm. A rider on the arm stands on a smooth plate in such a way that it "walks" with the motion of the arm. The distance traveled is a measure of the vertical motion of the feeler and is reported as millimeters per meter length of paper. A second reading with a 10-mm. ball corrects for the gross inequalities in the surface not classed as roughness. Readings can be duplicated within 5%, and inequalities of 0.0003 mm. can be detected.


An illustration and brief description of the apparatus and its operation are given.

Air, at a low, uniform pressure, is supplied by an inverted cylinder, floating freely in an outside cylinder partly filled with oil. The air is forced downward, through an open tube, to the upper orifice plate against which the sample is clamped. Each 50 cc. is marked by rings on the inner cylinder. The test consists in timing the rings as they drop past the upper edge of the outer cylinder. In the smoothness test, the paper is held between the upper orifice plate and a lower plate having a plane annular ring, polished optically flat. The contact area is 1 square inch. Light pressure (3 pounds per square inch) is provided by an unweighted lower arm. Eight thicknesses of paper are tested at one time, which gives an over-all, top-bottom average of 16 surface areas in one reading. The smoothness value is the time in seconds to leak 50 cc. of air (for more rapid work, the actual reading may be on 25 cc. of air leak). The paper pad is perforated by a punch before testing, in order to eliminate the porosity factor. The test may also be carried out with an 8-ply folded sample.

A description is given of the Gurley No. 4160 R. D. smoothness tester. It measures the surface porosity or the rate at which air flows through the inequalities in the surface of the paper. A measurement of the time in seconds for a 5-cc. air flow is taken as a measure of the inequalities of the sample and indicates the "finish."

An apparatus was constructed for measuring smoothness at increased pressures. It consisted of a block of gray iron which was bored and threaded to receive the optical flat of the Bokk tester, drilled with air passage, and connected by copper tubing through a brass adaptor to the mercury column of the Bokk tester. The block of gray iron carrying the optical flat is placed on the platform of the heavy factory scale and centered beneath the screw of an arbor press, the side tension members of which are bolted to the main frame of the scale. By the use of this apparatus, it became possible to determine the approximate smoothness of samples according to the Bokk principle but under pressures up to 400 pounds per square inch. The data covering boards of higher caliper and lower smoothness are, for all practical purposes, linear relationships between smoothness and pressure. One sample showed a tendency toward curvilinear trend with constantly decreasing slope. This type of trend is apparent also on other samples having a comparatively high Bokk smoothness. This particular phenomenon was attributable to the increasing effect of lateral porosity. These data show that one can extrapolate the trend established by smoothness obtained at 50 and 100 pounds per square inch and make a close practical extrapolation of the smoothness which is likely to be attained at greater pressure. The ratio of the smoothness at 100 to that at 50 pounds per square inch varies from 1.26 to 1.93 for various boards.
The Bokk smoothness tester is briefly described, and its method of operation is outlined. The following limitations of the instrument are pointed out: (1) It is assumed that the spaces formed between paper and glass open into each other so as to form continuous air channels. Although microscopic examination shows that this is true in most cases, it is possible to have a rough surface with a honeycomb or closed cellular structure which will have a very high Bokk smoothness figure, because the surface provides for open passages from the circumference to the center of the glass ring. (2) Because of the compressibility of paper, the smoothness changes rapidly during the first few minutes of the application of pressure. (3) The rate of flow of air through a tube, other things being equal, depends upon the fourth power of the radius of the tube. This means that the effect of the larger air channels is greatly weighted at the expense of the smaller, and a surface which provides a few large and many small channels may appear to be rougher than actually is the case. Thus, the instrument fails to differentiate between a surface on which the irregularities are large but comparatively few, and one on which they are small but numerous.

The roughness tester is based upon the principle of direct determination by mechanical means of the deviations from a fixed plane of the paper surface at a series of points. Although it employs the tracer principle, it differs in that the detector needle makes contact by means of an intermittent vertical motion which eliminates the objectionable side stresses and plowing effect of continuous tracing. The paper to be tested is held by a clamp consisting of a fixed upper contact piece and a moveable lower contact piece. The upper piece has a 0.254-mm. diameter hole through which the detector needle makes contact with the paper surface. This needle consists of a steel stylus, the point of which is ground to a truncated cone having a flat end 0.053 in. (0.0013 inch) in diameter; a load of approximately 0.05 gram is employed on the needle. About 500 readings are taken on one sample. Among the factors investigated were the atmospheric conditions and mechanical disturbances, clamping pressure, diameter of the detector needle hole, pressure of the detector needle, diameter of the needle point, and number of readings per sample. Values are given for a number of typical papers. The standard deviation of the readings is least influenced by the error of measurement than the arithmetic average. A curve, in which Ingersoll gloss is plotted against roughness, shows the inadequacy of the gloss measurement to evaluate roughness.

A description is given of the two testers, and a discussion is presented of the theory of the Bokk tester. From the data for a large number of papers, it is concluded that the two testers do not measure the same properties of a paper sheet. The results lead to the suspicion that the Bokk readings are influenced by transverse porosity and to greater extent than in the case of the Gurley instrument. The Bokk readings, which are high in comparison with the Gurley readings on the same samples, were taken on papers having a relatively high porosity. If a correlation exists between the two instruments, the difference in the effect of transverse porosity could logically be accounted for by the design of the instrument, because the air pressure at a given rate of air flow is higher in the Bokk than in the Gurley tester.


This article is devoted principally to a discussion of the smoothness characteristics of printing paper under the headings: typical surface defects of uncoated papers; surface defects due to the coating process; surface defects due to both the uncoated sheet and the coating. Mention is made of a device for making a single measurement on a large area of paper. For this purpose, a separate panel and attachment were built to be used on a brightness tester. The sample could be rotated through 180 degrees about an axis at 22.5 degrees to the fixed direction of the incident light beam. The possibilities of the method were not thoroughly investigated.


Under methods for measuring the smoothness of a free surface, there are considered the following methods: direct measurement of the surface contour by means of a microscope with micrometer focusing adjustment; direct measurement by means of a small "rider" under which the paper surface is caused to move; electrical "pick-up" method; friction methods; methods utilizing oblique illumination; and electrical capacitance method. The second section considers methods for measuring the smoothness of a compressed surface, which include the method of air resistance (the basic principle of the Bokk, Gurley, and Williams testers) and the Davis smoothness tester. The promise and limitations of each method are considered briefly. Details are given of preliminary work on the electrical capacitance method, in which the electrical capacitance is measured of a system consisting of two brass plates separated by a sheet of paper and of a system in which one of the brass plates is replaced by a liquid mercury surface. The results were compared with Bokk and Gurley tests; no correlation existed between any one of the three sets of instrumental data and visual grading. The investigation of the Davis tester showed that the instrument does not grade coated papers in
agreement with the visual grading and that, taking formation into account, the instrument seems to give a reasonably good measure of printing smoothness on finished coated papers. A variation in the tester is suggested, in which the face of the glass prism is covered with a thin, uniform film of clear oil; with this modification, the area of optical contact, with increasing pressure, would increase at a rate depending on smoothness and compressibility and the thickness of the oil film. It is apparent that the pressure required for nearly the whole of the available surface to come into optical contact would be reasonably low.


The Williams smoothness tester provides for measuring a constant volume of air, which is compressed and applied to the center of a clamp holding a folded-over sample of paper under definite pressure, in such a way that the air can pass between the two surfaces of the paper. The results may be corrected for the transverse passage of air through the sheet structure (transverse or plane porosity); provisions are made for this measurement. The various units of the instrument were studied, including the air measuring cylinder, the timing mechanism, the clamping device, the calibration standard, the measurement of the transverse porosity, and the reproducibility of the results. A comparison is also given from the results of the Williams and the Bock smoothness testers. It is concluded that transverse porosity accounts for all or practically all of the air escape when smoothness readings are made on coated samples of high smoothness. As a corollary to this, it must be concluded that, in the case of very smooth papers, smoothness readings made on this type of instrument are principally a measure of transverse porosity rather than a measure of smoothness. Also, it is doubtful if the formula used for calculating the corrected smoothness is applicable under these conditions. From these results it would seem that all instruments based on this principle are influenced to an appreciable extent by transverse porosity. The results given here cast some doubt upon the value of these instruments for use with very smooth coated papers and indicate the necessity of applying the transverse porosity correction to all tests. When factors affecting transverse porosity, such as thickness, apparent density, and furnish are considered, it is apparent that transverse porosity can vary widely without a necessary variation in smoothness and if the uncorrected smoothness reading, which is a measure of both smoothness and porosity, were used, erroneous conclusions might be drawn. The Williams tester measures a similar quality to that measured by the Bock instrument but differences do exist and the two testers do not measure exactly the same quality. It should be said at this point that whatever lack of correlation is shown in these results is not a criticism of either instrument. As pointed out before none of the instruments based on this type of test can measure a single fundamental property. Rather, the results are affected by several conditions; therefore, the value of any instrument lies in its ability to evaluate a paper for a specific use requirement.
The Gurley-Hill S-P-S tester was designed to measure the softness (or compressibility), porosity, and smoothness of paper. In each case, the measurement consists of observing the rate of air leakage over or through the paper specimen. Uniform air pressure is supplied by means of an inverted hollow piston floating freely in a cylinder partly filled with oil. The air is forced downward, through an open central tube, to the upper orifice plate against which the sample is clamped. Interchangeable lower test plates provide for measuring softness, porosity, or smoothness. Uniform clamping pressure is provided by means of a lever; one end supports the lower plate and other end supports weights calibrated to give the desired pressure on the paper. The rate of air leakage over or through the specimen, depending upon the property being measured, is determined by timing the movement of the graduations on the piston as they pass the upper edge of the outer cylinder. Except for the interchangeable lower plates and the lever arm, the instrument is similar to the Gurley Improved Densometer. In the Gurley-Hill S-P-S rapid smoothness test, eight thicknesses of paper are perforated and held between the upper orifice plate and a solid lower plate having a plane annular ring, stated to be optically flat. The test does not differentiate between felt and wire side smoothness but gives an average value for sixteen surfaces. By means of the lever arm, unweighted, a pressure of 3 pounds per square inch is provided over a contact area of 1 square inch. The smoothness value is defined as the time in seconds for 50 cc. of air to pass. For rapid routine control testing of smoothness, a single sheet may be folded 8-ply. The pad thus formed is perforated and tested without unfolding. For more accurate work, eight separate plies should be tested. The following aspects of the smoothness procedure were investigated: (1) Proportionality of observed time to volume of air flow; (2) proportionality of observed time to number of plies used in each observation; (3) effect of orientation of wire and felt sides of adjacent plies; and (4) effect of grain orientation in adjacent plies. The observed time in this test was directly proportional to the volume of air flow and inversely proportional to the number of plies tested at one time. The results correlate fairly well with Bekk readings but very poorly with Gurley R. D. smoothness values. For papers within the ordinary range of smoothness, the testing of 8 plies simultaneously yields an average and reproducible instrumental reading. For very smooth papers, the number of specimens tested at one time may be increased to twelve or perhaps even sixteen and the volume of air flow reduced to 25 cc. The results thus obtained can be referred with small error to standard conditions. However, for accurate work, conversion factors should be determined for each class of paper. Orientation of both the sides and direction of grain of adjacent specimens tested simultaneously apparently had no effect on the smoothness values obtained. In grouping a number of specimens to be tested simultaneously, precaution should be taken to arrange concentrically the punched perforations in the sheets. The Gurley-Hill S-P-S tester measured in a reproducible manner certain properties of paper similar to those measured by the Bekk smoothness tester and the Gurley densometer. However, poor correlation was found between
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S-P-S softness and Federal compressibility and between S-P-S smoothness and Gurley R. D. smoothness.


With this apparatus, a numerical indication can be obtained of the relative smoothness of any number of samples and compared with the indication obtained from a satisfactory sample adopted as standard; the operator can determine with great accuracy whether the finish of the sample is above or below standard and to what degree. The principle of the instrument consists in placing a sheet of the paper on a smooth plane surface, causing a smooth-faced drag to be moved over the surface of the paper by the action of a predetermined force (such as gravity), and obtaining an indication of the mean rate of movement. Preferably, the drag is always moved through a fixed distance, and the indication is of the time occupied by the drag in traveling that distance. In practice, it has been found that best results are obtained if the table is set at an angle of about 27 degrees to the horizontal and if the weight overbalances the drag in the ratio of about 10:9.


Smoothness is one of the most important properties of paper from the standpoint of printing. Brief reference is made to the Beck, Gurley, and Williams testers, and a proposed TAPPI standard is outlined for the Beck test of the relative printing smoothness of paper.


Two beams of substantially identical intensity are directed from a constant source of light upon the opposite faces of the sample to be tested, and the light reflected from the surfaces is then directed to a photoelectric cell. The two light beams originating from the source are alternately interrupted in such a fashion that the rays falling on the photoelectric cell from each beam vary sinusoidally with time and are 180 degrees out of phase, so that equal areas of the photocell are illuminated alternately. One side of the surface to be tested is smeared with ink so that it appears darker than the clean surface, the degree of darkening depending directly upon its smoothness. The light now reflected from the smeared surface is considerably less than that reflected from the clean surface, thus producing an alternating current in the circuit of the photocell. The alternating current is amplified in a specially balanced amplifier until it is of sufficient magnitude to operate an indicating meter. The beam of light which is directed on the clean side of the test surface is now reduced in area by means of an iris diaphragm until the reading of the indicating meter is brought to zero, at which point
the beams of light reflected from the smudged surface and the clean surface are equal. The relative smoothness of the surface may then be read directly from the iris diaphragm, which may be suitably calibrated to read percentage smoothness.


This article contains a brief review of the measurement of printing smoothness, with reference to the work of the Institute of Paper Chemistry, Haleday, and that of the author.


The invention provides an instrument for measuring the smoothness of paper by determining the time required for a known quantity of air under known pressure to escape between a smooth true plane of standard dimensions and a sample piece. It permits the determination of this property for each side of the same sheet separately and simultaneously.

578. Paper testing device. Ind. della carta, Jan. 31, 1924; T. S. 79:147.

An apparatus for measuring the surface smoothness of paper is based on the resistance it offers to the movement of a point—that is, on the basis of the attrition which develops when a point traverses the sheet under constant conditions. The device consists of a pendulum carrying a pen which touches the sheet as in writing. The sheet is placed upon a horizontal plane with a to-and-fro motion. The oscillations of the pendulum are proportional to the smoothness of the paper.


An appendix (page 354 of the Proceedings) describes an apparatus for viewing the surface of paper which is under pressure. A glass plate is held by jaws, which are shaped to allow a microscope objective to approach, while giving the maximum possible support to the glass. The sample is pressed against the glass by a plunger, spring, and screw. The pressure can be determined from the compression of the spring; thus far it has been possible to attain a pressure of 100 pounds per square inch. If an intense and narrow beam of light is projected on the end of the glass
in a direction normal to the plane of the diagram, the points of contact between the paper and glass appear bright against a dark background.


The method suggested for the slip of paper is the same as that given by Clark (No. 558).


This instrument (developed in the Scandinavian laboratories) is a modification of the Bekk smoothness tester. The principle is the same, in that the speed at which air is made to flow across the paper surface is a measure of the roughness of the surface but, instead of causing the air to flow between the rough paper surface and a smooth glass ring of considerable area, the new instrument uses a narrow ring, the breadth of which is less than the cavities which are likely to be present in the surface of the paper. In order to minimize the errors resulting from the porosity of the paper, the pressure used to drive the air across the paper is reduced to a constant value of about 15 cm. of water and the rate at which it flows is measured by means of a rotameter. The roughness of the paper surface is measured by placing the paper to be tested on a smooth glass plate as a support. The tester is placed on top, and the position of the cone in the rotameter column gives an immediate reading of the roughness. By increasing the pressure on the tester, the effect of the compressibility of the paper can be studied. An additional appliance also enables the instrument to be used for porosity measurements.


The significance of smoothness in printing papers is discussed. Among the methods listed are the Bekk smoothness tester, the Williams smoothness and plain porosity tester and the Gurley smoothness tester; the last has been modified to produce the Gurley-Hill softness tester, which is also adapted to make smoothness tests; mention is made also of the Davis method. These methods all give relative readings for smoothness, but because of variations in the pressures and methods of measuring, the numerical readings of one are not directly convertible into any other.


A brief description is given of the apparatus, and comparative figures are reported for the Bekk smoothness and the Ingersoll gloss for three types of newsprint.
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A brief description of the tester is given. From a series of tests, the experimental error was assumed to be 2.5%. Experiments with materials other than rubber (vinylite resin in acetone, tinfoil and acetone, lacquer and cellophane) showed that the use of any adhesive or means of insulation other than soft gum rubber entails useless labor and detracts from, rather than adds to, the accuracy of the tests. The results at 65% relative humidity were approximately 10% lower than those at 50% relative humidity. Tests on some 300 samples of commercial newsprint gave average smoothness values of 43 seconds on the felt side and 51 seconds on the wire side. Smoothness increases regularly with the amount of calendaring. A comparison of newsprint from 5 mills showed a variation from 47 to 92 seconds for the wire side and 41 to 106 seconds for the felt side; similar variations in smoothness were found for samples from the same mill. No definite relationship could be established between the smoothness and rate of oil absorption of newsprint and mimeograph papers.


A uniform air supply is provided by means of a definitely weighted cylinder, closed at the upper end but open at the bottom, which is allowed to fall a definite distance into a mercury reservoir that acts as a seal to the lower end of the compression column. The end point of the test is accurately and automatically determined by means of a plunger rod attached to the falling cylinder which makes an electrical contact, closing the circuit of an electromagnet which is connected through a spring and pull rod to a stop watch. Uniform clamping pressure is secured by a screw clamp with a diaphragm hydraulic press foot, and the exact pressure is accurately indicated upon a gage. Holes or perforations in the center of the folded sample or of the sheets allow free access of air to the space between the two surfaces which are under test. The method of operation is described. The accuracy of the test is doubled by having two surfaces of paper in contact. Planoradial porosity is the time required to force a definite quantity of air, under standard pressure conditions, a fixed distance through the actual pores or texture of the sample in the same plane as that of the sample. After the finish of both sides of a paper has been determined, a perforated piece of rubber is inserted between the folded surfaces of the sample and the clamping pressure brought to standard conditions. A measured quantity of air at a definite pressure is forced out through the pores or fiber in the same plane as the sample to a distance equal to 0.5 inch.

The smoothness of a sample of paper is determined by measuring the time (in seconds) required for a definite amount of air at a definite pressure to be forced between two surfaces of the sample folded upon itself, perforated in the center, and clamped between rubber-faced plates which seal the two outside surfaces of the folded sample against any escape of air. The compressed air supply is obtained by a weighted cylinder, open at the bottom end, and descending into a reservoir of mercury. The sample under test is clamped at a definite pressure, as indicated upon an accurate pressure gage. To make a test, it is only necessary to raise the central column to a given height and latch it. The sample is inserted and clamped to the desired pressure; a lever unlatches the falling column, and the time is indicated by a stop watch or Telechron clock. Various experimental data are given.


The Williams tester consists of a base in which a vertical outside cylinder is inserted. Inside and concentric with this is a 1/8-inch pipe reaching practically to the top of the outside cylinder, which is connected with the sample clamp and furnishes a means of conducting the compressed air to the sample. The annular space between the 1/8-inch pipe and the large outside cylinder forms a mercury reservoir. A thin, movable cylinder, open at the bottom, is inserted in this annular space. The operation of the instrument is described, as well as the method of making a test. Barometric pressure, as well as the temperature and humidity conditions, is an important function of all smoothness testers of the air-flow type. Standard permanent test plates should be available for checking any smoothness testing instrument. In specifying a definite compression area, both the inside and outside diameters of the limiting circles should be given. By using square clamping plates, smoothness and plane porosity tests may be made upon a sample with an air flow of equal velocity over the entire surface of the sample tested. It is possible, by means of square test plates, to make smoothness and plane porosity tests both in the machine direction and across the sample. The reading upon the Williams instrument may be correlated with those of the Beck instrument when these are taken under carefully controlled conditions.


A brief description is given of the Williams electric smoothness and formation tester. An illustration is included.

STIFFNESS, SOFTNESS, RIGIDITY


The Witham-Bellows stiffness tester was used as an attachment to a Schopper tensile tester; for these tests the weight was removed from the pendulum and a small counterweight was added to the top of the tester to balance the pendulum at zero with no load. The operation of the instrument is described and illustrated. Tests showed that the percentage average deviation for a series of papers was between 0.9 and 5.7 with an average of 2.9. Tables give results showing the effect of wire versus felt side, effect of number of sheets tested, effect of inaccurate alignment on accuracy, and effect of moisture content, pulp furnish, and fillers on the stiffness values. Stiffness decreases with increasing relative humidity: Machine and cross directions, oven dry, 62.7 and 25.1; 80% relative humidity, 34 and 13. A bulkier sheet of higher groundwood content had the higher stiffness. A paper with the same furnish but a higher filler content was distinctly softer and more pliable.


The previously described instrument has been improved. The principle of operation is the same, the sample to be tested being clamped between clips so that it forms a semi-circular arc of 10 cm. diameter; the whole arrangement is placed upon the pan of a balance adjusted to the equilibrium position. To make a determination, the clamps are lowered 1 cm., so that the arc touching the glass plate is deflected. The weights necessary to be added to the balance to produce equilibrium in this position give an indication of the resistance to bending. Tabulated data of tests with various kinds of paper are included; the conditioned samples were tested at 40, 65 and 90% relative humidity. Comparatively little difference could be noted between 40 and 65% relative humidity, whereas an appreciable difference resulted when the humidity was changed from 65 to 90%; different furnishings being affected to different degrees. Stiffness varies in machine and cross directions of the paper; in certain papers a good agreement was found between the ratio of stiffness in cross and machine direction and the ratio of tearing strength in machine and cross directions. In other papers, notably coated papers, this relation could not be established.

The apparatus is similar to that used for measuring compressibility by a dynamic load (see Compressibility). The height of the rebound is read on a scale fitted at the side and the elasticity of the paper is expressed as the percentage which this value represents compared with the height of rebound obtained from the uncovered steel support. An apparatus is also shown for measuring the resistance of paper to bending stresses within the elastic limit. The sample piece is arranged so that it forms a semicircular arc of 10 cm. diameter, provided no flattening is produced under the influence of its own weight. The whole arrangement is placed upon the pan of a balance which is adjusted to the equilibrium position; a plate of glass is placed above the arrangement in such a way that its lower surface, when the balance is adjusted, is exactly 4 cm. above the baseplate holding the paper. The weights necessary to be added to the balance to produce equilibrium in this position represent the force necessary to press down the semicircular strip by a distance of 1 cm.; when the value is calculated for a strip 1 cm. wide, it represents the resistance to bending or the stiffness of the paper.


A description of the Zander stiffness tester is included.


An apparatus is described and illustrated for measuring the stiffness of paper and boards. The force necessary to bend a strip of definite width and length through a measurable arc is determined.


Brecht, W., and Blikstadå, P. A new instrument for testing the stiffness of papers and boards. Papier-Fabr. 38, no. 4:17-22 (Jan. 26, 1940); Ind. carta 7, no. 1:15 (Jan., 1940); B. I. P. C. 10:300.

A new instrument has been developed for measuring the bending stiffness of paper and board. One end of the sample strip to be tested is fixed to a cylinder so that it follows the curve of the cylinder for a certain distance, a weight being attached to the other end of the strip. The force required to revolve the cylinder is taken as a basis of the measurement. Strictly, for each paper thickness a certain cylinder diameter should be used; because this is not practical, a series of cylinders are used, the diameters of which form a geometrical sequence. The best relation of the weight in grams to the cylinder radius in mm. was found to be 4.5. The theory of the measurement is discussed. The application of the bending test method to the determination of elasticity is described.

After a theoretical discussion of the resistance to bending and elasticity in general, bending formulas for paper, cardboard and similar materials are derived. - 17 references.


A description is given of the Brown Company paper softness tester, which measures the force necessary to crumple a wad of the specimen into a definite volume; hence, it is different in principle from the usual commercial stiffness testers. It has the great advantage of being very inexpensive and can be built from ordinary laboratory equipment at a cost of less than $5.00. It is sufficiently reliable on the types of paper where softness is an important factor, such as napkin stock, facial tissue, lightweight toweling and similar stocks.


A stiffness tester is described for use with crumpled paper. Because the results did not give the necessary information for the problem in hand, the apparatus was not completely developed, although there were indications that a very sensitive and significant measure of plane shoots might be obtained by further development of the instrument.


An apparatus is illustrated and briefly described. The stiffness is taken as the load in grams required to bend a sample through an angle of 90 degrees.


A review is given of the types of stiffness testers under the headings: cantilever, beam, column, folding, modified cantilever and pendulum. A new method is proposed, which is now the basis of the TAPPI method.

Two flexible rolls are mounted near the upper edge of and vertically to a vertical board, which supports an inclined straight guide, the longitudinal axis of which passes through the line of contact of the rolls. The end of a test strip of convenient length and width is engaged between the rolls and the latter are slowly turned until the free end of the test strip barely touches the guide. The stiffness number of the material (defined as a number proportional to the cube root of the elastic moduli) is read off directly on a scale marked on the guide.

Davis, D. S. Nomographs for rigidity, stiffness and softness of paper. Paper Ind. 17, no. 6:409 (Sept., 1935); T. S. 103:35; B. I. P. C. 6:146.

Two charts are given, one which permits the computation of rigidity, stiffness, and softness, and the other of the rigidity factor.


Illustrations are given of the stiffness tester used by Schulz and Ewald [No. 626]. Data are given for strips from 5 to 13 cm. in length. The effect of length is not as great as previously assumed.

Fucco, R., Inc. Paper testing instruments make possible new tests. [Smoothness, fuzz and stiffness testers]. Instruments 6, no. 1:22 (Jan., 1935).

Diagrams and description of the stiffness tester.

Gurley, R. D. Stiffness tester. Paper Trade J. 99, no. 25:43 (Dec. 20, 1934); Paper Ind. 16, no. 8:573 (April, 1935); Instruments 8, no. 1:22 (Jan., 1935); see also Gurley Bulletin No. 1420 (Feb. 1, 1935); B. I. P. C. 5:129.

The stiffness of the paper is measured by clamping a prepared sample in a moveable arm and drawing the paper over the top of a weighted pointer until the bending of the paper releases the pointer. The amount of deflection of the pointer, read on a scale at the bottom, is the measure of stiffness. The clamp holding the sample can be raised or lowered on the arm, permitting the use of samples from 1 to 4.5 inches in length. The pointer can be loaded with weights of 5, 25, or 50 grams, placed at any one of three distances below the pointer. The clamp arm is rotated by a wire belt running from a capstan handle, which is turned in order to move the paper. The operation of the instrument is described.

Stiffness, Softness, Rigidity

The stiffness (in milligrams) of a strip of paper is measured by the following relation: Stiffness = \( S = \frac{EPW}{12L^2} \), where \( L \) = length of sample under test, which is measured from edge of clamping device to the point of application of the force; \( W \) = width of paper strip; \( T \) = thickness of paper; and \( E \) = Young's modulus = stress/strain in the direction of axis of test strip. The same measure of stiffness is used in both the Smith-Tabor and the Gurley stiffness testers. This measure of stiffness is the force in milligrams which must be applied to the free end of the paper sample in order to produce a specified bending. Consequently, the stiffness readings in the Smith-Tabor tester can be converted to Gurley stiffness readings. It appears that results are more reproducible on the Gurley instrument than on the Smith-Tabor. In order to obtain reproducibility of results, it is necessary to quote the sums of the instrumental readings for "with" and "against" the curl of the sample. For optimum reproducibility, the end-points of the readings should be approached slowly. As a further precaution, samples should be handled as little as possible. Samples of paper boards should be clamped just firmly enough to prevent slipping or pull-out of the sample from the clamping device. The sensitivity of the Gurley instrument can be varied over a larger range than on the Smith-Tabor instrument. The sensitivity can be changed in 23 different ways on the Gurley by a combination of the available loads, while there are only three possibilities on the Smith-Tabor. The range of both instruments may be extended by using samples of different widths in addition to the simultaneous measurements of more than one sample. Still another possibility is the use of samples of different lengths on the Gurley instrument. Data were obtained to check these points with the following results: (1) Stiffness readings are directly proportional to the width of the sample. (2) Stiffness readings vary inversely as the square of the length of the sample for samples longer than 2.5 inches. The Gurley conversion factors which are sent with the instrument are in error by as much as 40% for samples shorter than 2.5 inches. The errors depend on the type of paper measured. Hence, consistent correction factors for the tabulated conversion factors are not available. (3) More than five samples of paper of low stiffness should not be simultaneously measured. (4) The conversion factors for the Gurley and Smith-Tabor stiffness readings to a common basis of milligrams for a sample of one by three inches are given. The experimental verification for these conversion factors is shown by the curves in Figure 7. The data include results of 32 different samples of paper board for both machine and cross direction. The average of five readings should be taken for accurate results. The outside limit of reproducibility is 5% for the Smith-Tabor instrument and 3% for the Gurley instrument. The Smith-Tabor instructions for use of the "ultrasensitive" attachment indicate that the regular scale readings should be divided by 10. Experimental data for very low stiffness indicate that the factor would better be 12.

The reading of the Gurley instrument is highly dependent upon the nature of the edge of the paper sample and the smoothness of the surface. An apparent increase in stiffness is produced by any friction between vane and paper. The effect of the edge and surface of the sample is eliminated in the Carter, although the length and width should be accurately established. The Gurley is very sensitive to length of sample. The angle of bend being larger in the Carter tester, the force required is correspondingly larger and thus more accurately measurable. However, the disadvantage due to the deformation of the paper is objectionable. It would be instructive to build a Carter tester using an angle of bend comparable to that of the Gurley. If an accuracy in the determination of this bend comparable to that obtained by the method employed in the Gurley tester could be secured, the advantage of the static reading of the Carter would be obtained without the disadvantages of either instrument. The zero of the Carter instrument is not as dependable as desired. Any friction in the bearings is objectionable in establishing the zero. As the curves indicate, however, stiffness as measured by the Carter tester is closely comparable to that as measured by the Gurley. The curves are very nearly straight lines, and the experimental points fit the curves very closely. The Gurley tester is useful over a wide range of papers, but for light papers the Carter is very convenient, readings being obtained in a shorter time than with the Gurley. The weight of the paper would tend to lower the value of stiffness as measured on the Carter while increasing the value as measured by the Gurley. This is a possible explanation of the fact that the curves do not tend to pass through the origin. For papers whose stiffness is very high, the Carter instrument is unsuited, because of the uncertainty in the force to produce 90-degree bonding, this force varying with time. For such papers the Gurley tester is to be preferred. All papers were ranked in the same order by both instruments, and any departure from the curves are within the experimental error.


The operating technique for the Clark paper softness tester has been studied in some detail. The overhanging length of the paper strip inserted in the roller mechanism of the instrument has been found to bear a straight-line relationship to the angle of rotation necessary to cause the strip to fall over. The correlation between Clark rigidity and Gurley stiffness was poor for limp papers but somewhat better for stiff paper. One of the principal reasons for this poor correlation was found in the large source of error in the Gurley method, wherein errors range up to about 90% of the apparent Gurley stiffness. Clark rigidity was found to correlate well with flexural rigidity as determined by a research method involving a torsion pendulum. Subjective tests for softness of facial tissue, towel tissue, waxing glassine and broad wraps correlate with the mean of the machine direction and the cross direction Clark softness values. The accuracy of determinations carried out on the Clark paper softness tester depends largely on the nature of the paper tested. For heavy, uniform papers, five determinations in each direction are sufficient, but at least ten representative strips in each direction are necessary for lightweight papers.
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610. Isnard, Raymond. The testing of cardboard. Elasticity or rigidity and folding. Papeterie 43, no. 11:578-586 (July 10, 1921); Paper Trade J. 73, no. 16:40, 42, 44 (Oct. 20, 1921).

The general principles of the testing of the strength of beams may be applied to the testing of the rigidity (or elasticity) of cardboard. If a strip of cardboard is placed on two supports at a distance 1 apart and subjected to a load P at its center, the deflection \( f \) is \( (P3/4EI) \), where \( E \) is the modulus of elasticity and \( I \) the moment of inertia of the section. In the apparatus used, a strip 1 x 10 cm. is supported on knife edges exactly 50 mm. apart, so that 25 mm. project at either end. A graduated lever, pivoted at one end, carries a third knife edge, by means of which the load is applied to the middle of the test strip. The weight of the lever and knife edge is counterbalanced by means of an adjustable counterpoise and the load is carried by means of a rider on the lever arm. The deflection on applying the load is read by means of a mirror fixed to the lever and a scale graduated in mm. If \( d \) and \( D \) are the distances of the deflecting knife edge and of the scale from the mirror, \( P \) the equivalent load at the center of the test strip, \( n \) the reading on the scale and \( c \) the thickness of the board, \( E = 6250PD/nc^3 \). The limit of accuracy is not greater than 6%. If the test strip is folded completely over (presumably without creasing), weighted in this position for 15 minutes, released, and allowed to stand for several hours, it will finally attain a definite "fold angle" which varies from 20 to 25 degrees for very rigid cardboard to 60 degrees for roofing felts. Comparative tests on various samples can be obtained only by applying the test in exactly the same manner in each case. If properly carried out, this test will class boards in the same order as the determination of the elasticity.


A simple stiffness tester is described, in which the paper strip (30 mm. wide) is supported on a concave surface by means of a cylinder; shot is dropped onto the paper until it bonds; the weight of shot is a measure of the stiffness.


This is apparently a translation of the manufacturer's announcement of the V-5 stiffness gage.

Determination of the relative flexibility or stiffness of thin sheet electrical insulating materials by means of the flexometer (Pierce, J. Textile Inst. 21:477(1930)) promises to have application to papers (both untreated and varnished) and other materials. With many materials the plain rectangular strip specimen curls and kinks, sometimes to such an extent as to make any reading impossible; in such cases, by using a pear-shaped-loop specimen much more consistent readings were obtained. The method of making the test and of calculating the results is explained.


The test sheet, of definite length, is clamped on a rotatably mounted arm. A freely movable pointer, pivoted coaxially with the arm, has one end positioned so as to contact the free end of the test strip. The arm is rotated so that the test strip causes a deflection of the pointer until the deflection of bending of the strip causes it to slip off the end of the pointer arm. The stiffness of the test strip is obtained from the maximum deflection of the pointer.


The cardboard is cut into strips and each strip is fastened in a clamp in such a manner that the length of the strip extending out of the clamp is exactly 20 cm. The weight of the strip causes it to bend and form a parabolic curve. The curve is more or less flat, depending on the stiffness and the weight of the board. When the paper has no stiffness at all, it will fall down almost vertically; and when it possesses absolute rigidity, it will remain perfectly horizontal. The distance through which the board bends is characteristic of the stiffness. Stiffness increases with the weight per sq. m. The deflection of the strip diminished more with increase in weight per sq. m. with sample cut in the machine than in the cross machine direction. Moisture diminishes the stiffness of the board. The composition of the pulp, the nature of the sizing, the method of beating and the calendaring all have an effect on stiffness.


A study of the stiffness of tag, index, bond, and ledger papers, carried out mostly on a Curley stiffness tester (with a few tests on the Savant instrument), gave the following indications as to the value of stiffness testing for paper quality. Stiffness is largely a matter of manufacturing manipulation and is, therefore, not a factor of fiber quality except in so far as different kinds of fibers are subjected to differences in manipulation, as in beating, in the sizing added, and in any other sources of fiber cementation. For the heavier papers, stiffness is much more sensitive to beater hydration than is tearing resistance;
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it is also probably less sensitive to fiber weakness and to the shortening of fiber length than is tear. For thinner papers which are beaten to maximum strength, as are bonds and ledgers, stiffness has no particular advantage in sensitivity over tear; for such papers stiffness brings less distinction between rag and wood papers than does tear. Stiffness for some grades of paper should be a valuable test as a measure of beating hydration.


A complete description is given of the use of the Smith-Tabor stiffness tester, and a comparison is made of the Muller strength, freeness, and Smith-Tabor readings for a sample of fiber board.


Two new paper softness testers are announced (by the Thwing Instrument Co.), one for routine testing and the other for research work.


This tester is manufactured by the Toledo Precision Devices, Inc. but was originally developed by Remington-Rand, Inc. (cf. Stuart, W. H.). It is mounted on a Toledo paper ream autogage and consists of a special bracket supporting an adjustable loading member which contacts one end of a sample to be tested. The other end of the test strip rests on an aluminum plate on the scale arm. In testing, each strip is inserted in the gap between the aluminum plate and the end of the plunger. The handle is turned slowly and steadily to bend the paper. The pressure is indicated on a chart. The maximum point registered represents the stiffness.


The importance of rigidity has increased since the advent of automatic feeders which speed-up the flat-bed printing machines. Beating is an important factor in producing rigidity; good fiber length and addition of starch and silicate of soda may also increase the degree of rigidity. Records of tests for rigidity should be kept when it is ascertained that the tests have been conducted under standard and normal conditions.


An instrument is described on which it is possible to measure the angle through which a specimen of cloth droops when a definite length is held out over an edge. By means of a mathematical formula, this angle is converted into a term called the bending length of the material.
(i.e., the length of fabric that will bend under its own weight to a definite extent); the stiffer the material, the longer the bending length. The standard procedure for determining the bending length may be varied with regard to the shape and dimensions of the-test specimen for very stiff or very limp materials. Although developed for textiles, the principle might be applied to the testing of paper.


The paper is held in a horizontal direction and supported at each end, or it sags in the center of its own weight. The angle of this bend is measured. The paper strips are 15 x 120 mm, and 100 mm. project beyond the clamp. After being in place for 15 minutes, the angle between the vertical through the point of clamping and a line through this point and the free end of the strip is taken as the measure of the stiffness. The weight of the paper and moisture content are influencing factors.


A discussion of the Saxl tester and the Schloer flexometer. 22 references are given, all pertinent ones being contained in this bibliography.


A stiffness tester is described, which was designed for cloth or yarn, but which might be applied to paper. It consists of a clamp in which the test specimen is inserted and a balance (with sliding weights) with a sensitivity of 0.02 gram.

625. Schoeller, F. Method of determining the bending elasticity of pliable materials, especially carton papers. German patent 646,253 (May 16, 1934).


A strip of paper, 20 mm. wide and 80 mm. long, is fastened horizontally and a weight is added until the strip bends. The distance of the weight from the fixed end of the paper indicates the stiffness of the sample.
Because of the difficulty of measuring the stiffness of paper by the usual static method, a dynamical method is proposed in which an elastic restoring force derived from the stiffness of the paper controls the vibration of an inertia system of long period. The paper strip is cut in the required direction, accurately parallel, and of the standard width (2 inches). It is then formed into a ring tightly round a mandrel and its two ends are clamped together by a screw clip, which fits into a groove milled out of the mandrel parallel to its axis. The clip carrying the paper ring is screwed in position on the bob of a pendulum. The free period of the pendulum is measured after it has been adjusted by means of a leveling screw to a value of about 8 seconds. The next step is to fix the side of the ring remote from the pendulum, which is done by means of a large rectangular block which slides on the base plate and carries a linear clamp which can be slipped over the ring and screwed up tight without disturbing the pendulum. The coupled period of the pendulum is now measured by timing several sets of ten complete oscillations. The oscillations are conveniently initiated by means of an air jet from a rubber bulb directed against the bob. The linear relation between the displacement and the force applied to the paper ring was confirmed by a static method for displacements up to 3 cm. on a ring 22.25 mm. radius. The close correlation which exists between the substance and stiffness allows the individual stiffness values to be corrected to the nominal substance if the actual substance of each sample is measured and the result can be expressed as the average stiffness in dynes cm. at the nominal substance. A linear relation exists between relative humidity and stiffness; adequate accuracy of stiffness measurement is obtained if the relative humidity is controlled within ±1%. The mathematical theory of the paper ring is developed.

The test strip is mounted vertically in a suitable yieldable holder. The top of the strip is deflected by means of a pivoted pointer which is moved manually over a suitable graduated scale to the position where the test strip disengages from the pointer and springs back. The scale is graduated on either side of the vertical, so that readings can be taken by bending the same strip in both directions. Means are provided for increasing the range of the instrument according to the type of material to be tested.

The term rigidity is used in the special sense of stiffness—i.e., resistance to bending through a small angle. The present method of testing depends upon the estimation of the force required to deflect the center of a strip of board through a definite distance when the ends of the strip are free and rest on two rollers. The measurement is made below the point at which the board takes on a set—i.e., below the elastic limit. A strip of board 3 cm. wide and a convenient length, usually 12 cm., rests on shoulders at the base of the supporting rollers, which are 10 cm. apart. Pressure is applied to the center of the strip through a roller on the bottom end of a pointer, whose upper end travels over a scale showing the horizontal travel of the roller in mm. The sample is held in place before pressure is applied by the pointer, which is exactly balanced at the pivot except for a horizontal projection giving rise to a small sustaining force sufficient to hold the sample against the roller. The pressure is applied by a weight arm pivoted independently on the same spindle as the pointer, and having a stop which maintains it at right angles to the pointer while the weight is being applied. There are two positions for the weights on the weighing arm, one being exactly twice the distance of the other from the fulcrum.

Four weights may be used: 3.33, 12.5, 50 and 100 grams. Details are given of the method of conducting the test and calculating the results. Certain precautions are outlined. The pressure on the sample is independent of the reading of the pointer. The construction of the apparatus is such that the pressure is applied only on the center line of the test strip when the scale reading is zero. At any other reading, it takes effect at some point above the center line and at the highest reading commonly obtained, (at 6 in.) the point of contact has risen 0.48 in. At least four samples are used for an average result. The rigidity of a board is proportional to the cube of its thickness, the density being constant. It is also proportional to the square of the thickness, the substance being constant; at a given thickness, the rigidity is proportional to its density; mathematical proof is offered. From these relations may be derived the equation: 

\[ \text{Rigidity} = K \times (\text{thickness})^3 \times \text{density}, \]

in which \( K \) is termed the rigidity constant.

Values for \( K \) have been determined for a variety of boards; it has a characteristic value for each distinct class of board. From the approximately constant value of \( K \) for each type, it follows that rigidity of a board can be calculated with fair accuracy if its type, caliper, and substance are known. Practical methods of controlling rigidity are discussed. A theoretical discussion of the nature of rigidity is included.


An apparatus for determining the initial stiffness of paper from substance 20- to 15-point bristol. Test specimens 1.5 x 3.5 inches are clamped in the pendulum and the pointer is moved slowly across the scale to the position where the strip slides from beneath the finger gage and snaps back to vertical. The average of the right and left scale readings represents the initial stiffness.

The apparatus is illustrated. The sample to be tested is placed in the clamp and the dial rotated. The reading is taken when the sample touches the gage. The operation is repeated against the opposite gage. The averages show the pliability in one direction. To determine the pliability the opposite way of the grain, the clamp is loosened and samples turned 90 degrees. To determine the resiliency or elasticity, the pliability test is carried out, the sample being allowed to remain bent from 5 to 30 minutes or until the plastic flow has ceased. Rotate the dial until material tends to leave the gage, take readings, subtract the average pliability and average resilience readings from 100, divide the basic result by the pliability results and multiply by 100; this gives the resilience in per cent.

632. Stiffness of paper. Zellstoff u. Papier 6, no. 2:77-78 (Feb., 1926); T. S. 85:112A.

The stiffness test for paper and its interpretation are briefly discussed. The article is a review of a paper by Crolard in Mon. papeterie Française.


The equipment consists of a Toledo scales and a Black and Decker drill stand with special vertical shaft, coil spring, collar, and test strip holding plate. The test strips are placed between the end of the scale beam and the plunger of the stand. Pulling the hand lever on the stand forces the plunger down and bends the test strip (1 x 3 inches).

634. Taber, Ralph F. Apparatus for measuring the stiffness of flexible materials. U. S. patent 2,065,275 (Dec. 8, 1936); T. S. 105:104.

The invention provides a pair of relatively movable members for bending the test strip with suitable means for limiting the movement of the members in each direction relative to each other. A separate handle or lever, that may be operated either manually or mechanically, is provided for operating one of the members. The motor used for mechanical operation is controlled so that it will stop automatically when the strip has been flexed the desired amount, and signalling means are provided to indicate when this stage has been reached. Means are provided for measuring both the initial and basic stiffness of the material so that the amount of plastic flow can be determined and the elastic properties of the material calculated therefrom. Cf. Smith and Taber, U. S. patent 2,113,389. (No. 628).


A very brief announcement of the V-5 stiffness gage and triple-cut shear for measurement of stiffness and resilient qualities of paper, etc.
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The weighing system is of the pendulum type. The face of the specimen clamp is mounted exactly on the center of rotation, insuring constant length of the moment arm. When the load is applied to the free end of the test specimen, a torque is imposed on the holding means that is accurately weighed by the deviation of the pendulum from the vertical. Indication is made by the simple alignment of the pendulum in the 15-degree angle graduation on the loading disk. Under sustained loading the test specimen, especially, if it is one of the softer materials, exhibits considerable elastic fatigue in the form of a drift to a lower stiffness. The first registration of the lines indicates initial stiffness which should be recorded; additional readings are taken until no further change occurs over a period of one minute. The last reading represents the normal stiffness. After the first reading there will be noticed a residual deflection or temporary set that slowly decreases and may eventually disappear. The normal oscillation of the pendulum between tests tends to neutralize this residual force and should be neutralized, if necessary, by manually oscillating the pendulum weight back and forth a few times.


Rigidity is defined as the property of a paper or paperboard of resisting an applied bending force, its flexural resistance, and is proportional to $EI$, where $E$ is Young's modulus and $I$ the moment of inertia. Stiffness of paper or paperboard is its ability to support its own weight, the inverse of flabbiness or limpness. It is proportional to $EI/W$, where $W$ is the basis weight. The softness of a paper is the feeling of softness when a sheet is crumpled in the hand. This depends upon the ease of crumpling, together with the absence of sharp edges in the crumpled sheet. It is inversely proportional to the rigidity $EI$ modified by a function of the thickness of the sheet. The method is a modification of that of Clark.


A general description of the apparatus and its applications.


A general discussion, including definitions, significance and interpretation of results, application of tensile strength, test methods, cutting the test strips, home-made apparatus and commercial instruments.

The apparatus provides for means to lead the free margin of a sheet, which is secured along its opposite parallel margin, by means of a weighting chain, one end of the chain being provided with an element by means of which it may be readily attached to or detached from the sheet, and mechanism being associated with the chain for rapidly adding to or subtracting from, under the close control of the operator, that portion or part of the chain which is actually supported by the free edge of the sheet. The weight necessary to bring the free margin of the sheet undergoing test into a predetermined position may be added to the free margin thereof. The chain weight is suspended in space and offers no resistance to horizontal movement of the free margin of the sheet. The apparatus consists of a base, sheet margin retaining or holding means, and weight-applying mechanism.


An instrument for testing the flexibility of paper comprising a support in which a sample of paper to be tested is loosely mounted, a bending device for bending the paper both lengthwise and crosswise of the grain and for moving the paper flatwise through the support, a liquid receptacle connected with the bending device and a calibrated tube for delivering liquid to the receptacle.
STRETCH


A British instrument for measuring the stretch of paper when moistened and its shrinkage when dried.


In a test designed to show a stress-strain relationship, a Tuckerman optical strain gage was used as means of measuring the stretch. The specimens of board, 1 x 6 inches in size, are clamped in a horizontal position, each clamp overlapping the specimen by one inch. The optical strain gage, which measures the extention in an initial length of one inch, is placed at the middle of the 4-inch portion of the specimen between the clamps. The rear clamp is attached to the dial scale by means of a flexible chain passing around a ball-bearing pulley mounted behind the box. The dial scale is hung from the movable head of a box-testing machine and tension is applied to the specimen through the scale by operating the movable head upward at the desired speed. Simultaneous readings of stretch and load are made until a currently plotted stress-strain diagram shows that the proportional limit has been passed. The gage is then removed and the application of load is continued until the specimen breaks. With the 1-inch gage used for the tests, readings to 0.000004 inch can be obtained. The gage has a capacity of about 0.005 inch but it can be reset during the test and the stretch to maximum load determined. A scale of 150-pound capacity is used for test liners. Another scale of 50-pound capacity and graduated in 0.1 pound is used in testing corrugating papers.


Data are given to show the effect of rate of loading on the stretch of a sulfite ledger paper and also the variation in results for stretch obtained by a number of cooperating laboratories.


A description is given of the new Schopper water-elongation tester for paper. The stretch properties of paper, either after immersion in water or exposure to moist air, can be ascertained with this apparatus. Actual tests of samples immersed in water for one minute and then allowed to stretch for three minutes are reported.

A brief description and illustration is given of the Negrotti and Zambra stretch recorder. The sample strip of paper up to 6 inches long and about 0.25 inch wide is held by a small spring clip at each end and is suspended from a hook at the top of the supporting frame, the bottom clip being attached to a link connected with a crank of variable length on the open-arm spindle. A small counterbalance weight keeps the paper in tension. After mounting the sample, the recording pen is set to a suitable position on the chart by means of a screw at the top of the supporting frame. This moves the top suspension hook vertically over a small range. The tubular cover is then placed over the paper-supporting frame and conditioned air is passed over the sample by connecting the top of the tube to suitable humidifying or drying apparatus. The chart is arranged so that each division represents an alteration in the length of the sample of 0.002 inch and the full pen travel an alteration of 0.1 inch. If the sample is 6 inches long, this represents a 1.6% alteration in length.


A swinging pendulum acts through the medium of controlling means upon the test piece by a piston. The controlling means connect the pendulum and the piston at an adjustable point and sever this connection at another adjustable point, so that the amount of work done on the test piece during the swings of the pendulum—i.e., the work done between the beginning and the end of engagement of the pendulum and piston—is always the same. The power by which the material opposes deformation acts against the attacking force, whereby the total work of the pendulum is reduced, resulting in a loss in amplitude, so that the pendulum approaches a position of rest more quickly than if it swings freely. This decrease in amplitude furnishes a basis for calculating the elasticity of the material.


The significance of stretch and the load-elongation curve are discussed briefly. The measurement of stretch by means of the Author universal tensile strength tester, the Clark stretch tester, the Schopper electrically driven strength tester, and the Scott Scrigraph is examined in some detail. The principle of the Scott Scrigraph is satisfactory. The particular model used in this study was of rather low sensitivity. The stretch indicating mechanism of the Schopper instrument is dynamically unbalanced to such a degree that the indicator jumps to higher readings when the instrument is jarred by the failure of the specimen. This fault was temporarily minimized by counterbalancing. The Author and the counterbalanced Schopper instruments agree fairly well but indicate stretches which are seriously high, as compared with values obtained with the Scott instrument. The reason for the discrepancy rests in the fact that both Author and Schopper instruments are so designed as
to include in the indicated stretch or elongation reading some of the elongation which occurs after start of the specimen failure. Stretch values obtained with the Clark instrument tend to be less than those obtained with the Amthor or Schopper instruments. The elongations measured with this instrument also include part of the failure elongation mentioned above, although a smaller part than those measured with the Amthor and Schopper testers. The Clark tester was not compared with the Scott instrument. Corroborating published results of other workers, it was found that stretch decreases as the length of the specimen increases. Contrary to suggestions in the literature, tests with two papers showed no change in stretch with change in rate of loading, and showed that stretch tends to increase with increase in specimen width.


A series of paper strips of uniform length and width are rigidly secured at one end within a closed chamber through which suitably conditioned air is circulated. The free end of each strip is placed under uniform tension, which is the same for all strips, and each strip is connected to a suitable indicating number whereby any change in length due to stretching of the paper will be registered in such a way that comparison may be made among the various samples under test.


Strips of paper of a definite length are wound around a pin which is rotated. The strips are held fast to the end which is not wound around the pin. The incomplete return revolution of the pin when it is released is a measure of the elasticity of the paper. The apparatus consists of a tube which is rotatable and which is slotted for introducing the paper strip, of a stopping device for the free end of the strip, and an indicating device for showing the angular rotation of the tube. In order to secure more certain fastening of the paper strip, a second tube is inserted with the outer tube. The second tube is carried along by the outer tube by friction and carries the indicator which travels over the scale. The indicator is loaded with a weight which brakes the back rotation and is so dimensioned that the graduations on the scale correspond to about gram weights. The crank of the instrument is turned so that the indicator passes through an angle of 360 degrees; the crank is then released and the shaft is allowed to be rotated backwards by the elasticity of the paper. The extent of this back rotation is a measure of the elasticity of the paper.

Preliminary experiments on the stretch of esparto printing papers were carried out by placing papers (having two lines exactly ten inches apart, the weight of the papers being known) between damp sheets of blotting-paper for 12-hours, after which the distance between the two lines was measured and the weight of the wet strips determined. No conclusion could be reached as to the relation of the esparto content and the amount of expansion.


A brief description is given of the Schopper apparatus which is designed to measure the stretch of paper when moistened and its shrinkage when dried.


The test result includes not only both the elastic and the inelastic stretch of the paper up to failure but also the small distance through which the broken strip will elongate during the test while being held together by protruding fibers, as this factor prevents the indicating mechanism from being released at the reading when the break starts. For this reason, the test may be termed more correctly "the percentage elongation of a strip of paper up to, and partly including, rupture under tension." Details are given of the apparatus, calibration, and procedure for making the test.
TAPING AND JOINT TEST

654. National Association of Purchasing Agents, Inc. Corrugated
fibresboard shipping containers. No. 19, 1934. 8 p.

Taping and Joint Test. There is no established procedure for
testing manufacturer's joints. If a taped joint, the quality and appli-
cation of the tape should be determined by a careful inspection. If
any doubt arises as to the quality of tape used, separate samples of
unused tape should be secured, identified as the same as that of the
manufacturer's joint, and tested for tearing strength as hereinafter
provided.
TEARING STRENGTH


When assessing the quality of a paper for general strength, it is usually just as important to know the tearing strength as the bursting and tensile strengths. The main uses of the tearing resistance test are: (1) For controlling the quality of the product on a machine. Since a single operation on a sample tears several inches of paper, a reliable result can be obtained with fewer tests than is the case with bursting and tensile testers. (2) For investigating the effect of beating and furnish on the average fiber length of paper. (3) For specifying the quality of a paper, particularly where toughness rather than a hard crease is required. The limitations are: (1) The moisture content of the paper may affect the test results more than in the case with tensile and bursting tests. (2) The number of sheets torn together in a test may affect the calculated result for a single sheet. This may be caused by the friction of torn edges over each other, altered conditions of stress, or variations in the rate of tearing. With readings of 20 to 60, the variations are not appreciable. (3) Instruments of the Elmendorf type do not measure the initial force required to start a tear but only that required to continue a tear. Resistance of the starting of a tear appears to involve a combination of tensile strength and stretch. (4) The necessity of checking the zero setting of the instrument regularly, preferably before each test. (5) The stiffness of the material affects the results; this is a serious limitation when dealing with material such as boxboard. The Thwing-Elmendorf tester is much easier for cutting and inserting specimens but the Marx-Elmendorf appears to be more likely to give accurate and reproducible results over a long period. The factor given by the makers of the Marx-Elmendorf for calculating the gram-weight per single tear from the actual reading is twice what it should be. It is suggested that the unit should be ongs and not grams-weight. The ratio of the Marx/Thwing readings (in the range between 15 and 70) varied from 0.99 to 1.09 for the machine direction and from 0.94 to 1.11 for the cross direction.


This is similar to TAPPI Standard T 414.
Tearing strength. Tearing strength is a property of the inner structure of the sheet, but surface treatment sometimes affects the values to a marked degree. Moisture content of paper has a large effect on its tearing strength. Tearing strength is an empirical property, and is also in the class defining manufacture of paper. This is in part due to the fact that the test is of long standing and widely used; hence it serves a useful purpose as a mill control test. The tear test can sometimes be interpreted to reflect the general nature of the fiber present in the paper as well as the beater treatment to which it has been subjected. For example, the test will usually provide some indication of fiber length and cementing action. Ordinarily, a dense sheet gives a lower tear than a bulky one of the same material and same basis weight; and long fibers offer greater resistance to tear than short ones. The test has great significance in the requirements of paper which is to be subjected to tearing strains in conversion or in actual use. This would include paper used for bags, boxes, building papers, wrapping, tissue (except creped), and many specialized industrial fields. As a rule, converters of paper in these industries rely more heavily on tearing strength than on any other single property. Among users of paper in sheets ordered to specifications in the converting trades, the tear test will be used more often than most other standard tests, with the exception of the all-important basis weight and the venerable bursting strength test.


After briefly discussing the general principles according to which dynamic tearing testers (such as the Thwing-Elmendorf and the Poller-Elmendorf instruments) work, brief reference is made to the calibration method of J. d'A. Clark [No. 668] which enables a correction factor (determined from a table or graph) to be applied to each observed value. A simpler procedure of sufficient accuracy for most practical purposes is outlined, which is based upon the adjustment of the tearing distance of the sample sheets, so that the instrument will yield approximately correct values for an ordinary working range. A graph is prepared for
Tearing Strength

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each tester in which the readings on the scale are plotted against the calculated tearing distance for the range 3.9 to 4.9 cm. of the specimens. This yields a rather flat curve for the higher readings. From this graph it is then possible to select the proper tearing distance to use so as to give approximately correct results over the chosen working range. According to the TAPPI Standard, enough sheets must be torn at one time that all readings on the scale lie within the limited range of 20 to 40 grams, which is advantageous in this method of calibration. The author suggests that, rather than use the standard tearing distance for testers of this type, each instrument should be calibrated and the correct tearing distance calculated for each individual tester.


It seems reasonable to suppose that a method of estimating the mechanical condition of paper depending upon the measurement of the energy required to tear a given length, rather than the force required to rupture a given width, is likely to be more consistent. It will be less influenced by local variations, since it essentially consists in the measurement of an integrated effect. The apparatus consists of a double pair of flat clamps which hold the sample; it is passed through a wire loop or stirrup which is free to move in the space between the clamps. The loop is connected by means of a flexible cord to the lower end of a pendulum, which is raised to a horizontal position and which, on being released, draws the wire loop through the paper. The pendulum swings with negligible friction on a horizontal axis. The connecting cord is so attached that, after the loop has torn through the paper, it becomes detached from the pendulum and the latter is free to continue its swing; it rises to a height which will vary according to the amount of energy which has been expended in tearing the paper. The amount of energy expended will also depend upon the breadth and thickness of the strip. Tests show that this energy is closely proportional to the width torn through over a fairly wide range. In a series of comparative tests, it is advisable to use paper which is originally of the same thickness. The values are expressed in millions of ergs. The apparatus has been used for the estimation of the extent of deterioration that takes place in the paper dielectric of an electric cable.


A new instrument is described in which the sheet is torn by a plunger operated by a lever. It permits tearing the sample in and across the machine directions simultaneously and records the initial tear and the tear-through. It is claimed that the new device corrects some of the faults of the Elmendorf tester. In general the results obtained with the two machines are the same. The time for ten tests with the Elmendorf was 7.5 minutes, for the new tester 3.25 minutes (with practice as little as 1.5 minutes).
Tearing Strength


The manual initial tear and the through-tear (ripping) tests are two fundamentally different testing procedures. The results are not identical and they cannot be substituted for each other. The mathematical treatment of the tests is given and the mechanics of the tearing resistances obtained is illustrated by several diagrams.


A method of calibration of the Pellular-Elmendorf tester, based on the operating characteristics and estimation of friction losses, is described; the results agree closely with those of the Clark method (Paper Trade J. 91, no. 1:33 [1932]). When a number of sheets are torn together, the starting cut is not the same in all, because of poor design of the knife; there is a marked tendency for the outer sheets to split, an abnormally high tearing force being required; the friction between the torn edges increases the tearing resistance abnormally. The errors from these sources are separately evaluated, and shown to reach 15% or more. Also, the relation of tearing resistance to weight of sheet is not linear. To obtain reasonably concordant and useful results, the instrument should be calibrated often and enough sheets torn to give a scale reading of at least 20 grams; the weight of the sheets should be quite constant; and the weight and number of sheets torn should be reported. Not enough is known as yet about the mechanism of this complex test to permit its use as a measure of fiber shortening in the manufacturing process.


A machine direction tearing test involves the tearing of paper so that the tear proceeds across the fibers which lie in the machine direction—that is, so as to rupture the machine direction fibers. It would seem illogical to speak of the machine-direction tearing strength when tearing paper so as to rupture the cross-direction fibers. Most people designate the direction as that in which the tear proceeds, a practice which is in conformity with engineering practice as applied to the shearing strength of wood. To make the analogy complete, one should speak of the "resistance of tearing along the machine direction." The proposition of designating direction in connection with the tearing strength of paper is open to question.

If the Elmandorf tearing tester, a sector-shaped pendulum carries a clamp which is in fixed alignment with a fixed clamp when the pendulum is in its initial position of maximum potential energy during a test. A specimen of paper is fastened in the two clamps, a slit is made in the paper between the clamps as a starting point for the tear, the pendulum is released, and the specimen is torn in two as the moving clamp moves away from the fixed one. As the paper is torn, work is done upon it, which is measured by the difference in potential energy at the beginning and the end of the swing. Dividing the work done on the paper by the distance the paper is torn (which is constant for all tests) gives the result as a force—the average tearing force. Since the initial displacement angle of the pendulum is fixed, the work done is a function of the final displacement angle—or the angle between the vertical and the line from the center of gravity perpendicular to the axis of rotation. The calibration of the instrument is accomplished by means of a formula derived from the behavior of the pendulum. Friction in the instrument, most of which is in the friction groove of the pointer, somewhat complicates the calibration. The derivation of the formula is given. The determination of the instrumental constants is illustrated. A simple procedure for the periodic adjustment of the instrument is described. The precision of the tester is probably not better than 1%, because of irregular variations in the instrument friction. A method is given by which the capacity of the tester was doubled. This was accomplished by means of a brass insert which was made to fit snugly in the open sector, and was fastened in place by means of lugs placed symmetrically with respect to the center line. The weight of the insert was 2501 grams. The use of the calibration equation in designing the modified tester is discussed. The tester has been used in testing roofing felts. Some suggested improvements in the tester are given.


Twelve strips, 1 by 2.5 inches, are cut from the sample to be tested, six with the long dimension parallel to the grain of the paper and 6 across the grain. A quarter-inch slit is made in one end of the paper. The apparatus consists of a method of clamping the strip and water is allowed to flow into a bucket attached to one end of the strip until the paper breaks; the weight of the water in the bucket in grams is taken as the tearing resistance. If a tearing distance of more than 0.25 inch is used, the peeling effect will have more influence upon the results. Satisfactory results cannot be obtained by clamping the strip in a Schopper tensile machine and measuring the load required to separate the two pieces. The exact rate of flow of the water is not important. The following advantages are cited: The comparative length of the fiber and the peeling qualities of the stock are shown in the result. Sizing does not increase the tearing resistance to such an extent as it does other tests. The apparatus is simple and is applicable to both light and heavy papers. The amount of grain in the paper is shown. The load is applied with an unchanging rate of increase. However, the testing is tedious and there is a wide variation in the results on a given sample. In this it resembles the Schopper folding machine.

A photograph of the Thwing tearing tester is given, with a very brief description of its method of operation.


The instrument is leveled and adjusted on a level sheet of plate glass and a known weight (W grams), the center of gravity of which is marked with a punched dot, is clamped to the radial edge of the sector beneath the jaws. The sector is raised and set as for proceeding with a tearing test and by means of a surface gage or other convenient means the height of the center of gravity of the weight above the glass plate is measured (h cm.). The sector is then released, allowed to swing, and the pointer reading noted. Without touching the pointer, the sector is raised until the edge of the pointer just meets with its stop, in which position the height of the center of gravity of the weight above the glass plate is again determined (H cm.). The work done is \( W(H - h) \) g.-cm. If \( f \) is the average force in grams to tear a single sheet of paper through 4.3 cm. (d) in the case of the Thwing instrument or 4.4 cm. in the case of the Marx instrument, then the work done is \( 2fd \). Thus \( W(H - h) = 2fd \), or \( f = W(H - h)/2d \) grams. If the instrument is designed to tear a single sheet, \( f \) should equal the pointer reading \( r \). However, the Thwing instrument is calibrated so as to read the force required to tear 16 sheets at one time through a distance of 4.3 cm. or a total tearing distance of 68.8 cm.; thus, \( r \) should equal \( W(H - h)/137.6 \) grams. With the Marx instrument it is \( W(H - h)/52.8 \) grams. The differences in results given by the two instruments are discussed; the Marx instrument at present is not calibrated so as to give grams force to tear a single sheet when 6 double tears are made, as recommended by the makers, but half that number; thus, six single tears should be made to obtain a direct reading.


Bursting and tensile tests may be carried out in what may be termed either a static or ballistic manner. Previously the question of static vs. ballistic conditions of testing has not been important in the case of tensile tests because static conditions can be approximated and are invariably used. However, with tearing testers of the type of the Elmendorf, in which the test is completed in about 0.1 second and, therefore, these instruments test the tearing strength under conditions approximating to ballistic conditions and may be termed "ballistic tearing testers." The ballistic condition of testing gives higher results than the static condition; this has been investigated by Carson [No. 56] and an explanation has been offered. The apparatus for determining the tensile test of paper can be adapted to carry out a
tearing test (Bureau of Standards, Circ. 107); this method operates practically under static conditions. However, the ordinary tensile tester is not sufficiently sensitive for this purpose. The author has designed and described an instrument for carrying out the static tearing test; the tear is carried out at a very slow and gradual rate—i.e., under practically ideal static conditions; the variations of the tearing force can be determined easily every few seconds. Contrary to the case of the bursting and tensile tests, the static tearing test produces the higher results (about 20%). The reason appears to be that, when the paper is torn slowly, splitting is much more marked than when the paper is torn at a rapid rate. The ballistic tearing testers do not measure directly tearing resistance but the energy in tearing a certain length of paper. Elmdorf and Marx have two definitions of tearing resistance, which has resulted in two systems of calibration. However, the Elmdorf definition, which is identified with the resistance opposed to the tearing force acting on one portion of the paper, brings it into relation with tensile strength. From a discussion of the application of the tearing test to various types of papers, it is concluded that, with the exception of tissue and possibly a few other papers, the tearing test per se is of little or no value as a criterion of the ability of paper to stand up to its commercial use. However, the test may give the paper manufacturer information regarding his manufacturing processes, such as conditions of beating, drying, etc. Its future value will depend on whether tearing strength is an effect of one or at least a very few factors, or whether it is a composite effect of several. If the latter, its use is very limited and will eventually disappear as soon as methods are evolved of measuring directly the individual factors themselves.


After briefly explaining the difference between absolute and relative resistance to tear, the different terms used in the English, Swedish, and German languages for defining this property and methods for calculation are described. A chart for correlating the values of tearing strength, tear factor, tear ratio, tear, g./lb./ream, and "Einrostläch" is included.


Paper falls more often by tearing than in any other manner; the tearing strength value, which measures toughness and durability, is of vital interest to every manufacturer. The tests were conducted at a relative humidity of 45 to 48%. Data are given for Kraft paper, with and against the grain, for eight basis weights from 20 to 90 pounds (24 x 56-500), for 16-, 20-, and 24-pound bond paper (17 x 22-500) and for 24- and 28-pound (17 x 22-500) ledger papers. It is stated that these data furnish a basis for judging the value or durability of a paper by the manufacturer or purchaser.
Toering Strength


Measuring the tearing strength of paper by determining the force required to rupture the fibers in pulling them apart has so many disadvantages that none of the devices that have been proposed has even been extensively adopted. These difficulties, which are discussed, result from the very nature of the paper itself. What must be determined is the average pull throughout the length of the tear--i.e., the pull across all fibers, strong, weak, and of medium strength. The author started from the premise that a machine for determining true tearing strength would have to depend upon the relation between force, distance, and work, and finally adopted the idea of a swinging pendulum provided with clamps for holding the paper. If a pendulum is swung to one side, away from its neutral or lowest position, it possesses a certain amount of potential energy by virtue of its position; this is measured by the product of the weight of the pendulum and the distance through which its center of gravity has been raised vertically. After having made a tear in a sheet of paper, the pendulum will not sweep through as large an angle on the opposite side of its neutral position as on the starting side; its potential energy is measured in the same way. Formulas are given to show that the angle at the end of the swing (between the pointer and the vertical) is the only variable quantity and that, when this is known, the average tearing force can be read from a properly graduated segment. Thus, although the instrument is based on the relation between work and average tearing force, and it measures the work done during the tear, it is calibrated to read the average tearing force in grams because the length of tear is kept constant in all cases. The force is applied by gravity and the rate of tearing is practically the same in all tests. This makes it possible to test 16 sheets of tissue or 1 sheet of heavy kraft paper on the same instrument.


A description is given of an early model of the Elmendorf tearing tester; a more recent model is described in No. 672. The instrument was designed to overcome the difficulties listed by Wells [No. 720]. Results of numerous tests are reported. The tearing strength across the machine direction is usually appreciably higher than that in the machine direction. The tearing strength per pound increases with the weight of the paper. Although the tearing strength increases with atmospheric humidity in the cases tested (kraft, wrapping, yellow writing), the change is most pronounced with the kraft wrapping paper, for which the tearing strength at 95% relative humidity was about twice that at very low humidity. This is probably the result of the greater toughness from improved cohesion between the fibers at the higher moisture contents.
A pendulum with a pointer attached is swung to its extreme left position. While in this position, the paper to be tested is placed in the jaws of the instrument, one of which is fixed to the frame and the other to the pendulum. On releasing the pendulum, the paper is torn for a length of exactly two inches and the work done decreases the distance to which the pendulum swings to the right, which is automatically measured by the pointer. If the dial is graduated in degrees, the work can be calculated from the weight of the pendulum, the distance of the axis of rotation to the center of gravity, and the initial and final angles which the pendulum makes with the vertical; or the dial may be graduated to read the work done directly. The difference in the two patents resides essentially in the design of the pendulum and jaws. In the first patent the pendulum consists of a weighted arm attached to a wheel and in the second it consists of a sector of a circle which is suitably graduated.

The Finch edge-tear stirrup consists of a metal plate, roughly Y-shaped and about 6 inches long. This serves as the suspension bar and sides of the stirrup. The transverse member is a metal plate 0.025 inch thick and cut in a shallow V at the top. The upper edges of this V are recessed and short lengths of 25-nil rod are inserted to give the sides of the V a smooth cylindrical surface that will not cut the material under test. A 1-inch strip of paper is passed through the stirrup and its ends bent down and fastened to the lower jaw of any convenient form of tension testing machine. The suspension bar of the stirrup is fastened to the upper jaw of the testing machine and force is applied. Because of the V across which the test strip lies, the force is applied to the strip at its two edges. As the force is increased, the strip ultimately tears from the edges toward the center and this force is used as a measure of the tear resistance.

This is a German translation of a part of the article by Elmendorf (No. 672).

The Marx-Elendorf tearing tester (the British modification of the original tester) enables one to tear papers under constant conditions and express the tearing resistance in terms of force of so many grams weight. The apparatus consists of a heavy segment of a circle (made of metal 3/32 inch thick); which is free to oscillate pendulum-wise about a pivot. The paper sample is held between two clamps. The pendulum is held in position by means of a catch, which may be released by pressing a knob. A scale is engraved at the circumference of the segment, over which a pointer moves, from the position of which after the test the tearing strength of the specimen may be calculated.

When the catch is depressed, the pendulum descends of its own weight and in so doing tears the paper across; when it has come to rest the position of the pointer is read on the scale. The manner in which the testor works is described, as well as the method of cutting the test samples. A piece of paper (100 x 62 mm.) is cut at two points, each 25 mm. from the edge, the cuts extending 18 mm. into the sheet, thus leaving 44 mm. to be torn by the testor. The action of the instrument is to hold the two 25-mm. wide portions firmly and tear out the middle part of the paper by the flag which is 50-mm. wide. Specimens are most conveniently cut by means of a small guillotine fitted with stops at the required distances or by means of a special knife which cuts the whole specimen in one action. If the reading of the pointer is less than 25% of the full scale reading, the results are liable to be inaccurate. Therefore, a preliminary tear is made, from which can be determined the number of sheets, torn together, which will give a reading between 25 and 95% of the full scale reading. By definition, the tearing strength of the sample, in grams, is given by multiplying the actual reading of the scale by three and dividing by the number of sheets torn simultaneously. The tearing resistance is taken as the mean of at least five readings and, for most papers, six sheets are torn together.


The through-tear testor of Brocht and Inset was found suitable for evaluating the strength properties of paper. Variations in the stock mixture and the beating operation are indicated by the results. Simplicity and speed are claimed for the new instrument.


Results of tests of 138 samples of paper, comprising 10 kinds of paper, 55 brands, and 69 weights from 24 manufacturers are reported. The papers included bonds, krafts, tag, book, ledger, writing, etc. It is claimed that the Elendorf paper testor is the only instrument that gives the necessary information about paper quality; the figures are sound and dependable and truly representative of the paper under test. Four to sixteen narrow strips are torn in making the tests and
Tearing Strength

One sample is torn four or more times. The test is given, without the data, in Pulp Paper Mag. Canada 20, no. 16:320 (April 20, 1922).


The first part of this paper gives results showing that it is necessary to cut test samples the same size in order to compare the tearing strength of papers. Three sizes were used: 1 x 8 inches, 2-3/4 x 1-1/8 inches, and 4 x 10 inches. If the test samples are cut the same size, very good check results are obtained. From a study of the action of the paper as it was torn, it was evident that each fiber in the path of the tear receives assistance from all the adjoining fibers as far as the edges of the test samples. The larger the test sample, the greater the amount of this assistance, provided that the beginning of the tear was always the same distance from the end of the test sample and just halfway across the width of the test sample. This is used as an explanation of the fact that the larger the test samples the greater the values of the tearing strength. Three instruments were used in this study; one was a tensile strength instrument; the second was the Thwing tearing tester (termed a recording instrument); the third was a nonrecording instrument. The Thwing instrument is concluded to be neither delicate, sensitive, nor accurate, since the amount of friction in the pin-slot bearing and the friction between the pen point and the paper chart do not allow careful accurate calibration. Because the test results obtained by using different factors will not check, there appears to be a defect in the mechanism of the instrument. The paper sample is cut by means of a die in such a way as to give five initial tears and a curve showing the maximum and minimum tear. There is great doubt whether the five peaks in the curve actually represent five initial tears. The fibers very near the edge of an angular slit in the test sample (or perhaps halfway between two angular slits between which the paper is torn) may be stronger than those fibers at the very edge. In such a case the result would be a rising curve and the peak would not represent the initial tear but the tearing strength of the fibers near the edge, or halfway between two slits of the paper. The nonrecording type consists of a beam balancing on a knife edge (the two arms of the beam being equal). One end of the beam holds a 500-cc. glass into which water as the load may be poured from a 500-cc. burette until the paper tears. At the other end of the beam one half of one slitted end of the test sample is clamped; the other half and the other end of the test sample are clamped against a vertical plate opposite. A special die is used for cutting a slit and eyeclot hole at each end of the middle of the test sample. The force at the tearing end of the beam is equal to the weight of water in the glass. This instrument gives merely the maximum tearing strength of the paper. The error caused by the beam position and that resulting from the impact of the water are discussed. It is believed that the second instrument will give results within a 5% error on the majority of papers. Because better comparative results are obtained by tearing paper in the machine direction, it would seem that all tearing tests should be made in this direction. Further, because
most papers are much stronger in the cross direction, the direction of tear as a rule turns to the machine direction soon after the beginning of the tear.

682. Houston, Paul L. A supplementary study of commercial instruments for determining the tearing strength of paper. Paper Trade J. 74, no. 10:43-45 (March 9, 1922); C. A. 16:4059.

Supplementing the work reported in Technologic Paper No. 194 of the Bureau of Standards, a study has been made of the Elmendorf tearing strength tester. A brief description is given of the instrument and a formula is developed for the calculation of the tearing strength, and also for the calibration of the instrument. The particular instrument studied was found to be graduated correctly. Tests indicated that there was a slight variation in friction in the ball bearing which might result from imperfect balls. However, any error that might be caused by slight variations in friction in ball bearing or indicator sleeve would be too small to be considered in an instrument of this type, which is not a precision instrument. Tests with writing and bag papers indicated that check readings could not be obtained by using different plies; 1 to 32 plies were studied. It would seem necessary to recommend the number of plies to be used for certain grades and weights of paper. The manufacturer has recommended that readings be taken between 10 and 20 on the scale; this range is small enough to allow the use of not more than two different numbers of plies. In the case of some papers (ledger in this study) both one and two plies gave readings between 10 and 20. The tests with the majority of the papers showed that one ply gave higher results than the other plies. Therefore, it might be well to eliminate the use of one ply where it is possible, even though it should give an initial reading between 10 and 20. It is concluded that the instrument is built on sound principles of mechanics, is calibrated correctly, and will perform satisfactorily provided certain recommendations are made mandatory.


The improvement appears to be the addition of a knife for cutting the slit which starts the tear after the specimen is in place. A simple moisture content indicator has been devised from which the percentage of contained moisture may be read. This consists of a balance, graduated to read from 0 to 20; comparison of the sample is made with a sheet of known moisture content. Data are given showing that at moisture contents of 0, 0.06, 0.10, 0.13, and 0.16%, the tearing strength of a bond paper was 60, 76, 88, and 105 grams, respectively. With a kraft paper of moisture content of 0, 0.06, 0.09, and 0.15, the values were 300, 400, 416, and 500 grams.
Elmendorf's method of testing paper for tearing strength satisfied a long-felt need in a very simple and effective manner. However, since the advent of this satisfactory method for measuring tearing strength, many data on this property have been obtained which are not well understood. Many practical facts regarding the behavior of tearing strength are known, such as: the negative correlation between tear and tensile or burst; the usefulness of tear in controlling beating and other refining, as regards cutting, when considered in conjunction with tensile or bursting strength; similarly, the usefulness of tear in comparing different types of beating actions. Very little work appears in the literature on the theory of tearing strength. If a theory is to be useful and comprehensive, it must account for such facts as: the variation of tearing strength with degree of beating (slight initial rise to a narrow maximum followed by a decline); the dependence of tearing strength on fiber length (positive correlation); the increase in tearing strength accompanying a decrease in bonding strength brought about through the use of material added to the furnish, and the inverse effect. A new theory is presented, by means of which a careful analysis is made of the manner in which the energy expended in tearing a sheet is dissipated in the paper. When a sheet is torn, $m$ fibers are ruptured in tensile failure and $n$ fibers are pulled intact from the mesh of contiguous fibers. The average work required to break a fiber is ordinarily insignificant in comparison with the work required to pull a fiber intact from the mesh, the force involved in the latter case being somewhat less. Since the average tearing force is equal to the sum of these two works divided by twice the length of line of tear, discussion of tearing phenomena with theory reduces to consideration of the effects of various treatments and pulp properties on (a) the relative numbers of fibers ruptured in tension and pulled intact from the fiber mesh, and (b) the average work required to pull a fiber from the mesh. The initial rise in the tearing strength-beating time curve is due to the fact that, in the initial stages of beating, the "frictional drag work" increases by virtue of tighter enmeshment caused by slightly increased bonding, during which time only a negligible number of fibers fail in tensile rupture. As the beating continues, however, more fibers fail in tensile rupture and, therefore, fewer fibers are pulled intact from the mesh. Since the frictional drag work per fiber is very much greater than the rupture work, this decrease in the number of fibers pulled intact from the mesh causes the tearing strength to decrease. Similarly, the addition of a material which reduces bonding strength will increase the tearing strength by increasing the number of fibers pulled intact from the sheet, and it is frequently observed that the addition of a bonding agent will cause a decrease in tearing strength. The positive correlation between tearing strength and fiber length is due to the fact that the frictional drag work depends directly on the average fiber length, being theoretically proportional to this length. The Elmendorf-Thwing instrument is based on a uniquely simple, straightforward, and intrinsically accurate method. Excepting certain obvious realizations which could be noted by any observant operator, this instrument should remain in accurate calibration after having been carefully
checked and calibrated. A theoretical error arising in the manner of allowing for friction in the pointer mechanism and bearing has been studied, and it is shown that this is of no real significance, provided, of course, that the pointer stop adjustment is properly made. An error due to multiplicity of specimens simultaneously tested is briefly described.

The Thwing initial tear tester was designed to measure the force required to start a tear on the edge of a specimen, which approximates a failure frequently occurring under use conditions. From a consideration of the mechanics involved, a tear should be caused by a force which is pure shear. In other words, the forces acting on the specimen at the point of rupture should be perpendicular to the surface, resulting in a compression on one side of the sample and an opposed compression on the other side. In testing a specimen, such as heavy paper or light board, the stiffness of the specimen is not sufficient to result in pure shear, so that some tension will be set up in the sample. The farther apart the jaws holding the specimen, the greater will be the tensile resultant of the forces applied. Under such conditions, the test becomes more of an edge tensile than an initial tear. The Thwing Initial tear tester has two jaws, each with a surface \( \frac{3}{4} \) by 2 1/2 inches, mounted one inch apart on horizontal shafts held in a rigid supporting framework. The jaws are so mounted that their surfaces are horizontal and one edge lies along the center line of the shafts. The back of each jaw is three fourths of an inch from this center line, allowing specimens to be inserted accurately before applying pressure by means of the tightening nuts. A ratchet is attached to the shaft supporting the rear jaw, and a crank and pawl mechanism is provided to act upon this ratchet. In the starting position, a metal pin on the ratchet rests on the framework. The shaft carrying the other jaw supports a weighted pendulum and is connected by means of gears to a needle mounted on a dial at the front of the instrument. These gears amplify the motion of the pendulum so that the needle travels through a greater arc than that through which the pendulum passes. Riding on a small shaft of the gear assembly behind the dial is a strip of spring metal which, through friction, holds the needle in any given position. A stop engages the pendulum in a vertical position before each test, allowing the needle to be returned to the zero reading. The specimen to be tested is clamped firmly in the jaws. The pendulum stop is released, and the crank is turned at a uniform speed, causing the rear jaw to rotate. Through the connecting test strip, the front clamp and the pendulum are also caused to rotate. The indicating needle moves until at the instant of failure, the pendulum recedes toward the vertical position, the needle remaining at the position of maximum displacement. A reading is taken, the ratchet returned to the starting position, the stop inserted in the pendulum, and the needle moved back to the zero mark. The following conclusions are drawn from a study of this instrument:
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The Thwing initial tear tester gives reproducible results. The magnitude of the results, in general, is increased by increasing the width of the specimen. Within reasonable limits, the rate of loading does not appear to have a significant effect on the results. Inconsistent results are obtained by testing several strips simultaneously. Initial tearing strength correlates in a general way with Elmondorf tearing strength and with tensile strength. Initial tearing strength as determined by the subject method is largely dependent upon tensile strength and stretch, the nature of the dependence being such that an increase in tensile strength and/or stretch causes an increase in initial tearing strength. The following changes are recommended.

1. The adoption of a means of loading at a more uniform rate.
2. The calibration of the dial in terms of actual pounds of force exerted on the specimen.
3. The installation of a wing-tipped pointer on the dial to reduce error in reading the scale.
4. The provision of variable pendulum weights with corresponding dial calibrations to expand the range of the instrument to cover lighter and heavier materials than those covered by the present range.
5. The design of supporting members so rigid as to ensure constancy of separation of the two pairs of jaws.


The ratios of the breaking length of paper samples with and across machine direction are given for strips of length 0, 1, 2, 5, and 180 mm.; the values for a kraft wrapping paper are 0.55, 0.57, 0.57, 0.56, and 0.53. The percentage adhesion is defined as the breaking length with 180 cc. free length divided by that at 0 mm. times 100.

687. Jacobsen, P. M. H. Strength tests on paper. Papier-Febr. 23, no. 45:717-718 (Nov. 8, 1925); Wochbl. Papierfabr. 56, no. 48:1445-1456 (Nov. 22, 1925); T. S. 82:501; 83:52.

The so-called zero breaking length (at 0 mm. free length) of paper rapidly increases at the beginning of the beating process and then slowly decreases. Possible reasons for this are discussed.


A comparison between the values of the Thwing-Elmondorf, the Marx-Elmondorf and the Brocht-Impact instruments for determining the tear-through strengths of papers has been carried out at Ooststrand. For beaten papers, the instruments are of equal value; for unbeaten samples, the Thwing-Elmondorf values are considerably higher. The Brocht-Impact apparatus permits accurate testing with a single paper sheet.
The initial step is to determine the first moment of the pendulum or sector about its axis; the next step is to determine the effect of friction in the instrument and the law which it follows. The difference in the angle at the conclusion of various half swings was found to be due to energy becoming stored in the pointer. The method of graduating the sector is outlined. The operation of the instrument depends primarily on the time period of the sector when swinging freely and the friction of the pointer. It is therefore possible to formulate the following two conclusive tests for its correct operation which are sufficiently accurate for all practical purposes: (1) The sector when allowed to swing freely from its initial position should make not less than 180 complete swings before coming to rest. (2) The sector when allowed to swing from its initial position but with the pointer held securely against the stop should make not less than 12 complete swings before coming to rest.

A brief description is given of the principle of the Elmendorf tester as modified by Marx.

The tearing test is especially valuable in showing the extent to which the fibers have become shortened in processing. The same pulp beaten to 65 degrees Schopper slowness in beaters with stone and with iron tackle gave, respectively, 190 and 111 grams tear. In general, tensile strength and tear vary inversely. Calendering decreases the tear, whereas normal moisture variations have no definite effects. The basis weight and the number and width of the strips torn affect the results. Data are given to substantiate these conclusions.

Tearing Strength (Elmendorf) Test. This test is only applicable to individual sheets of linerboard and corrugating medium and to pieces of unused tape. Test specimens should be cut from unwrinkled, uncreased, and unblemished stock, four each with the grain running the long and short way of the specimens (in the case of cloth tape, the long or the cross threads). The specimens shall be not less than 6.3 cm. (2.5 inches) in length (on samples cut along the cross threads of two-inch tape such length is acceptable) and of such width that the distance from the apex of the starting cut to the top edge of the specimen in position in the tester shall be exactly 4.3 cm. (1.69 inches). The
specimen shall be placed in the jaws of the tester with the bottom edge resting upon the bottom plates and so that not less than 2.5 cm. (1.0 inch) of the specimen extends into the movable jaws, the initial slit made, and the pendulum arc released tearing the specimen. Tests in which the tear deviates more than 6.3 cm. (0.25 inch) from the line of the initial cut shall be disregarded. The tearing strength shall be calculated in grams by multiplying the readings on the instrument by 16. Not more than one of the four tests in each direction may fall below the specification, with the average of the four tests meeting the requirement, for compliance. However, if the initial tests in either or both directions fail to comply, a series of 12 re-tests of either or both (according to the failure) shall be made, of which not more than three tests may fall below, with the average of all 12 tests complying with the specification, for acceptance.


The samples of paper to be tested are about 5 inches square and two parallel cuts, about 1.5 inches deep and about 2.5 inches apart, are made on one edge. The resulting center tongue is then turned up at right angles and the paper is clamped to the base of the machine with the tongue projecting vertically along the side of the flat metal clamp. The tongue is then gripped by means of the "Ever Handy" letter clip, from which a wire runs up over the wheel. The counter weight on the other end of the wire balances the weight of the clip. The wheel, which is graduated in degrees, is mounted upon a ball-bearing bicycle wheel hub and a lever is connected to the near side of the shaft. This lever, which is much in the nature of a pendulum, is provided with an adjustable weight. When the pendulum is released, it swings downward, carrying with it the wheel and the wire, thus pulling the letter clip upward and tearing the sheets of paper. This is an early form of the Elmendorf tester.


The Thwing tearing tester consists of a support from which is suspended a pendulum that swings on a ball bearing. On the right arm is a clamping jaw. On the supporting frame is a similar jaw, at the same level as the one on the pendulum arm, when the latter is in a raised position. The paper to be torn is inserted into these jaws and, to start the tear, a slit is made in the paper by raising a knife edge which is attached to the frame. The pendulum, when released from its raised position by lifting a simple catch, tears the paper until the resistance offered by the tearing paper brings the pendulum to rest. This resistance is designated in grams on a large dial, by a needle pointer which is actuated by a pinion in mesh with a larger gear wheel which rotates with the swing of the pendulum. The needle pointer travels almost completely around an 8-inch dial, for the full swing of the pendulum, making the scale reading very accurate. The most valuable characteristic that the machine has is its sensitiveness in tearing one sheet of paper at a time, whether tissue or ledger, thus allowing the paper to tear as naturally as when torn between the fingers, in which case more than one sheet is never torn to determine tearing quality.
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A test strip of paper is secured at two areas, which are spaced apart along its straight free edge and which are preferably semi-circular in shape with their centers at the free edge of the paper; progressively increasing tensile stress is applied along the marginal edge of the paper between the centers of the secured areas until initial tearing takes place; the centers and/or torn edge are then separated by causing or permitting the secured areas to rotate about their centers at a substantially uniform rate. Means are provided for measuring and recording the tensile stresses applied throughout the operation.


The Marx-Elmondorf tearing tester was studied. One disadvantage of the tearing test is the fact that some papers "skin" during the test; this is especially true of thick papers. Another point about the tearing tester is the fairly frequent alteration of the zero; in two sets of 50 tears, the zero altered four times in one set and three times in the other and the maximum alteration was two points on the actual graduations, or an error of about 7% on one of the sets of results. In these tests the average tear was 57.8 and 30.3; maximum deviation 5.2 and 7.25%; average deviation 1.6 and 3.4%; maximum zero alteration 2 in each case; tears which skinned 24 and 15%. The result of tearing two sheets of a paper together is not always double the single sheet tear. Results prove that the tearing tester is more accurate when the reading registers above 20 or over than when it is 10 or under. If four or more sheets are torn together, very consistent results are obtained (data for 1 to 10 sheets). Readings above 70 are not very reliable. The one large variable in the tearing tester is the pointer.


Specifications are given for the tearing test, using the Marx-Elmondorf tester. These include the preparation and dimensions of the test sample, the checking and adjustment of apparatus, and the operation of the instrument. The tearing test is most significant for those papers which, in actual use, are subjected normally to folding and twisting and in which the rupturing forces involved are relatively small and are not very variable; these include cigarette papers, waxed tissues, envelope
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and ledger papers, and the like. Otherwise, the tearing test as a
criterion of the use value of paper is of only minor importance. It
is impossible at present to define tearing resistance satisfactorily.
The basic difficulty is that of defining a tear or tearing resistance.
The manner in which a tear takes place is dependent not only on the
tearing tester and the means used for starting a tear but it also
varies, among other things, with the nature of the paper. The exact
direction of the tearing forces at the point of application, the extent
to which the stiffness of the paper is contributing to the energy
required to tear the paper, the area over which the forces are operating,
and other contribute their quota to the "tearing resistance" as
measured by instruments at present available. The effect of the
location of the starting slit is discussed as an example of the diffi-
culties encountered in an attempt to arrive at a definition. The
lack of such a definition has given rise to two methods of calibrating
tearing testers, resulting in two different values for tearing
resistance. The committee has decided that tearing resistance shall
be the resistance opposed to the tearing forces exerted on only
one portion of the paper, which brings the test into line with the
tensile test. Experiments are reported to support the following
conclusions:

The preliminary slit in the tearing test has no
influence on the true tearing strength of the paper. The effect of the
cross-slit is not considerable but it definitely has some influence
and, therefore, for accurate work, any fraying of the ends of the slit
must be avoided. Improper leveling of the instrument will give low
results (17.5% in one test). There is a negligible effect observed
when the pendulum is stopped after the completion of the first half-
swing: Provided the tear of a single sheet reads 30 or over on the
scale, similar results are obtained whether single or multiple sheets
are torn; if the reading is below 30, two or more sheets should be
torn—preferably a sufficient number to give a reading of about 50.
The average of the tearing results of the sheets cut together is
very similar to that obtained when the sheets are cut separately or
when the sheets are torn two together. There is no appreciable
difference between the results obtained with the test pieces fixed
tightly or slackly. A comparison is given of the Marx-Elmendorf (used
in Great Britain) and the Poller-Elmendorf (used on the continent).

698. Pott, T. Provor. Notes on the resistance of paper to
tearing. World’s Paper Trade Rev. 79, no. 3:362, 364, 366, 368; no.
6:444, 446, 489 (Feb. 2, 9, 1923); Paper-Maker 65, no. 2:167-168
(Feb., 1923); Paper Makers’ J. 61, no. 2:69-71 (Feb., 1923); Proc.
Tech. Section, Paper Makers’ Assn. Grt. Britain Ireland 4, part 1:
67-71; discussion, 71-75 (Sept., 1925).

A description of the design, method of use and theory of the
Marx-Elmendorf tearing tester. The discussion brings out a comparison
of the new tester with a Schopper machine and a curve illustrates
the effect of humidity on the tearing strength as determined on the
Marx-Elmendorf tester.
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A method is described for adapting the Schoppor tensile tester to measure the initial tearing resistance of paper, boards, and films. The Marx-Elmendorf and the Thwing-Elmendorf testers measure the force required to continue a tear which has already been started in the material under test; this is usually termed the tearing resistance but should properly be called the internal tearing resistance. These instruments do not reproduce the condition when the break or tear starts from the edge of the sheet. The ratio of the initial to the internal tearing resistance is not constant for different materials but varies with the extensibility and structure. The Schoppor tester (selected because the pendulum system can be used to record the tearing resistance) has been modified by the addition of a clamping unit to act as an initial tear tester. Two clamps are used; the left-hand clamp is fixed to the base of the unit, whereas the other is mounted on ball races and is free to rotate about an axis along the front edge of the clamps. Details are given of the method of operation of the instrument and of carrying out the test. The fixed clamp can be adjusted to give distances of 1/10, 1/4, 1/2 and 1 inch between the clamps. The depth of the paper held in the clamp can be adjusted to 1/4, 1/2, or 3/4 inch by positioning pins. Friction in the clamp bearing is compensated by setting the pendulum zero for each range. The force measured is not simply related to a fundamental property of the material but depends upon its tensile strength, extensibility, and rigidity, and also upon the distance between the clamps and depth of material clamped. Although increase in the distance between the clamps has the same general effect on all materials tested, the magnitude varies so that tests made with a 1/10-inch spacing may grade the materials in a different order from those made with a 1-inch spacing. The same is true of the depth of material in the clamp. Over the practical range of the instrument, the tearing resistance is independent of the rate of tearing. This test is empirical and the results depend upon the test conditions.

Data are given for cotton fabric, vegetable parchment, filter paper, and several plastic films.


Tearing strength. The Elmendorf tester is used. This test is applicable to individual sheets of paperboard. Samples must not be less than 2.5 inches in length. The width of the sample may be explained by saying that an initial or starting cut is made in the sample, and the width must be such that the apex of the starting cut is exactly 1.69 inches from the opposite side of the sample. The specimen is placed in the jaws of the tester with the bottom edge resting upon the bottom plates, so that not less than 1 inch of the specimen extends into the movable jaws. The initial slit is then made and the pendulum arc released which tears the sample. Tests are ignored in which the tear deviates more than 1/4 inch from the line of the initial cut.

The relative humidity, upon which the moisture content of the paper is dependent, is of great importance in paper testing. In passing from 5.8 to 9.1% moisture content there is a difference of 25% in the tearing strength.


A brief illustrated description is given of the instrument built by the Thwing Instrument Co., consisting of a support from which is suspended a pendulum that swings on a ball bearing. On the right arm of the pendulum is a clamping jaw and on the supporting frame is a similar jaw at the same level as the one on the pendulum arm when the latter is in a raised position. The paper to be torn is inserted into these jaws and then to start the tear, a slit is made in the paper by raising the knife edge which is attached to the frame. The mechanism is extremely simple and sensitive to slight differences in the tearing strength of the paper. It can be used equally well for testing tissues or ledgers and a single sheet can be used for the test in either case.


The instrument used was a modified Schopper tensile strength tester. The test as applied is to allow the lower arm to swing from a definite raised position after there is clamped between the jaws a piece of paper, no slit that one end fastens to the upper and the adjacent end in the lower jaw, and the strip is brought to a test condition by the hand wheel, tearing it slightly—a distance of about 1/8 inch. The lower arm is then released from its fixed position and the resistance in tearing offered by the paper prevents the arm from falling its total distance, making it come to rest at that point on the scale where the tearing resistance balances the force of the falling arm. A wooden arm was substituted for the metal arm of the machine and was so weighted that, when it is allowed to fall from the 30 mark, it will swing to rest at zero on the scale. The method of calibration is indicated. Results are given for 100% rag bond, artificial parchment, M. F. printing, Manila wrapper, kraft wrapper, and newsprint. An average of 5 tests will give a practical working value and, for more accuracy, 10 or more tests may be averaged.


The invention consists of two jaws for gripping the paper, one being fixed to the frame and the other to a movable element (preferably in the form of a weighted swinging lever) which moves under the action of gravity until the resistance offered by the paper to tearing balances
the pull of gravity. Three forms of instrument embodying the principle are described. In each one the two portions of the paper remain in the same plane during tearing, thus ensuring equal tension throughout the operation. The theory of the instrument is outlined. The scale can be graduated to give the tearing resistance directly in grams. The range of the instrument can be made to embrace papers having either high or low tearing resistance by changing the weight or by adjusting its position on the lever arm.


The well-known theory of the sliding or rolling weight upon an inclined plane is the basis of the invention and by this novel design all difficulties encountered through machine design and construction in other models have been overcome. An iron base supporting two side frames contains the entire mechanism. Two bearings mounted upon the top of the side frames carry a walking beam or inclinable plane upon which rest two round weights connected together by a ball-bearing carriage. Fastened to a cross bar in this carriage is a chain which passes over a screw and is adjustable for different lengths of the specimen. The inclined plane is operated by sliding across hands on either side which in turn are lowered by means of a vertical screw upon which a worm gear, acting as a nut, revolves. The worm driving this gear is operated by a train of change gears driven from the mechanism below. The machine is fitted with a chart, the vertical lines denoting strength and the horizontal lines stretch. The chart moves horizontally from right to left and the pen, supported from the rider on the scale, moves upward as the specimen elongates. Advantages of this type of tester are pointed out.


The tearing strength of paper produced from a mixture of chemical and mechanical pulps depends on the tearing strength of the two component pulps. It is possible to decrease the contents of chemical pulp in the composition of paper without impairing its mechanical properties by a more efficient beating of the chemical pulp or by improving the quality of the mechanical pulp.


The official method for determining the breaking length is given.

The work was performed upon samples of unbleached sulfite, representing the average output from a number of digesters. Each handsheet was cut in two on the diagonal and half tested in 5 places for bursting strength with a 140-pound Ashcroft tester. From the other half strips 2.5 inches wide were cut and all four were tested together in the Elmendorf tester, six tears being made on each sample. The tests were not made under controlled conditions but it was assumed that the relative humidity varied from 15 to 40%. Results are given for 76 samples. The bursting and tearing tests both rise and fall in 27 cases, whereas in 41 cases one test rises while the other falls. Eight samples showed no change in strength in one or the other of the tests. There is no definite relation between the magnitude of the changes; sometimes the change in tearing strength is greater and sometimes that of the bursting strength. On the whole there seems to be a slight preponderance of evidence that the tearing test rises as the bursting test falls, and vice versa, but there are so many exceptions to this rule that it is absolutely impossible to predict one test after having made the other. Tests were made also on 9 samples after the pulp was beaten in a pebble mill for 0.5, 1, 1.5, and 2 hours. The bursting test shows a continual increase as the time of beating is lengthened. The Elmendorf tearing test is practically a constant and is independent of the time of beating; this throws doubt on the value of the Elmendorf tester. If this instrument measures the work done in tearing the sample, it is evident that, for a given fiber, the work is practically the same whether it is expended in causing the partially beaten fibers to slip over each other or in actually breaking the highly hydrated fibers of the stock beaten for a longer period. It seems that there is still a certain quality in connection with the tearing of paper which is not taken into account by the Elmendorf tester.

709. Sutlemoister, Edwin. The tearing test of paper as affected by humidity. Papier Ind. 7, no. 2:231-233(June 9, 1925); World's Paper Trade Rev. 83, no. 24:1934(June 12, 1925); T. S. 81:246; C. A. 19:2128.

Results are given for 7 grades of paper, with and across the grain, for relative humidities of 11-15, 26-29, 42-45, 67-75, and 87-89%. They show that the tearing strength increases quite uniformly as the humidity rises and that the increase in strength is nearly the same in both directions. Apparently 100-lb. paper of grade 1 increases in strength more than the others but this is merely because it is stronger to start with; if the increase is calculated on a percentage basis, it is found to be practically the same as the others. A chart shows that if standards are established under winter conditions--about 13% relative humidity--the same paper may be as much as 50% stronger in the damp days of the summer. Tearing tests, therefore, unless the conditions under which they were made are stated, are very likely to be misleading and complaints based on such tests are very apt to be unjust to either the maker or the consumer of the paper. These tests were made on an Elmendorf tester.
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With reference to an earlier study by Reitäl, the authors show that neither tearing strength nor elongation (stretch) alone defines the quality of a paper or its resistance to mechanical stresses, but that both factors are required for determining these properties. They illustrate their theory by graphs and equations.


This method is adapted for determining the average force in grams required to tear a single sheet of paper after the tear has been started. This is distinguished from the initial or edge tearing resistance. The Thwing-Elnendorf tester is used.


Includes the Knife edge method developed by A. D. Little, Inc., the Witham and Case testers, the Schoppor tester and the Elnendorf tester.


This is a reply to the article by Elnendorf which appeared in the July and August issues of this journal, in which the author disagrees with the viewpoint that the tearing strength is the most important property of wrapping and bag papers. It is pointed out that the consumer of paper is more interested in the initial tear than in the continuance of that tear.


The instrument is designed to give an accurate indication of the torsional strain applied to paper or cardboard at the moment of initial tear. The construction is such that the graduations of the scale are spaced so as to provide larger spaces at those portions at which initial tear ordinarily occurs, and the indication of the pointer on the scale is maintained after recession of the drive shaft during the tearing operation.

This apparatus, known as the Elmendorf tearing tester, has been developed for the paper industry and is used to measure and indicate in grams the resistance to tearing of fabricated materials. An attachment to augment the capacity of the apparatus, so that it will accommodate stronger materials, has recently been perfected. It measures the actual work done in effecting a tear; the personal element does not come into play and no calculations are required. Its chief structural details are described and illustrated.


A brief description is given of the Elmendorf tearing tester and its theory. This does not give values comparable with the Schopper apparatus, because the latter gives a minimum value with a strip 18 cm. wide.


A brief description (page 18-20) of a modified tensile testing machine, in which the weights have been removed to give it more sensitivity.


A hook is substituted for the pan of the balance and the tearing is accomplished by adding weights to the other pan. The author suggests the concept "tear surface," meaning the surface of the paper being tested whose weight is the same as the force needed to tear the paper. He also suggests "longitudinal tear surface," "cross tear surface," and "average tear surface." It is more difficult to obtain accurate figures for cross tearing than for longitudinal tearing.


Results obtained by 16 testing stations (14 with Elmendorf, 1 with Witham, and 1 with Eastern Manufacturing Co. testers) on 12 sets of samples are tabulated. The factors influencing the tests seem to be related more to variations in the paper than in the instruments. Wherever more than two sheets were tested, the results checked very closely and a deviation from the average of more than 10% was exceptional. The mean deviation is usually less than 2%, indicating the regularity of the instrument. The fact that the mean deviation for the station averages usually greatly exceeded the mean variation of the individual tests would indicate variations in the instruments or in their setup or operation. The following causes
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are suggested: Movement of the instrument on the table after having been properly leveled and the zero point adjusted. Interference of the paper in the clamps with the end of the index arm. Fluctuations in the relative humidity of the testing room. Excessive friction of the spring plunger in the index arm bearing and the bearing itself. The influence exerted by splitting of the sheet was to increase the test in most instances. The splitting occurs only with the tougher papers. A test made of the best stock carefully drawn out in the beater and is a valuable indication of quality. The following recommendations seem pertinent: No pains should be spared in the calibration of the instrument before leaving the factory. Tests should be made under constant humidity conditions as far as possible. The instrument should be level and adjusted for zero reading frequently. Interference of the movement of the pointer by the paper in the clamps should be avoided. Movement of the pointer should be kept as free as possible and the same number of sheets per test chosen to give approximately the same end point. With the exception of where 1 or 2 sheets are used, tests in which splitting occurs should be discarded. All tests should be discarded which deviate more than 20 degrees from the intended direction. When 4 or more sheets are used per test, 5 tests in each direction are sufficient. When 2 sheets are used 10 tests should be made in each direction. When 1 sheet is used 20 tests in each direction are sufficient. A lighter instrument should be available for use in testing tissue paper and a heavier instrument for use in testing board and strong, heavy paper.


Tests were carried out with the Schopper tensile strength tester in which the following modifications were made: The weight was removed and only the arm and milled screw were used, with the small pawl held out of action by an elastic band. The load applied at any reading could be ascertained by the formula \( y = 1000(x - 1.9)/5.93 \), where \( x \) is the reading in kg., and \( y \) is the force applied in grams. Several sheets were torn together and the sheets were arranged so that half were in the machine and the other half across the machine direction. By using several sheets the extreme variations of a single sheet were equalized; for papers of common weight, 6 sheets were used. The speed at which the sheet was torn was very slow; a speed of 1.5 inches per minute was found to be satisfactory. Observations were made every five seconds. At speeds of 1.5-3 inches per minute, the change in tearing strength caused by speed is small. No relation was found between the bursting strength and the tearing strength. The tearing strength shows up characteristics not shown by the tensile, stretch, or folding tests. A reliable test can be obtained if conducted under standardized conditions but a smaller and cheaper machine should be built for this purpose.
721. Wells, S. D. Tearing tester. French patent 509,276(Aug. 12, 1920); Canadian patent 223,809(Sept. 19, 1922); Paper 29, no. 6:23 (Oct. 12, 1921); T. S. 75:280.

The clamped paper is pressed against the apex of a triangular shaped piece, the apex being pointed to pierce the material and the sides rounded to tear rather than cut the paper. The tearing device is supported on a resilient member, the displacement of which measures the force required to tear the paper. Means are provided for indicating the movement of the paper in relation to the force necessary to tear it, which gives a measure of the work done in tearing.


Elmendorf Tear Tester. The Elmendorf tearing tester is used rather extensively for testing the tearing resistance of both cloth and paper tape, and despite some uncertainty about the interpretation of the results, is currently acclaimed as the most suitable device available for the purpose. In this machine, a sector-shaped pendulum carries a clamp which is in alignment with a fixed clamp, when the pendulum is in its initial position of maximum potential energy. A specimen of paper or cloth tape is fastened in the two clamps, a slit is made in the specimen between the clamps as a starting point for the tear, the pendulum is released and the specimen torn in two as the moving clamp moves away from the fixed one. As the specimen is torn, work is done upon it, which is measured by the difference in potential energy at the beginning and at the end of the swing. The scale which is attached to the pendulum is so graduated that a pointer indicates the average tearing force directly. While the machine is generally conceded to be rather accurate in its results, still experience has shown that the very best readings will always be made when the average tearing force comes between 30 and 70 points on the scale. Wherever a single specimen will not reach this point on the scale another test is made with sufficient test pieces placed together to read around 50. The graduations of the scale can be quickly converted into grams tearing force by multiplying by a factor which takes into account the number of pieces used in the test. If only one piece is used, the conversion factor is 16, if two pieces are used the multiplier is 8. In short, the multiplier is always 16 divided by the number of pieces tested. The specimen to be tested measures 6.35 cm. (2.499 inches) in width and has a slit cut in the lower edge after clamping in the jaws 0.79 inch high, leaving a width of 1.70 inches to be torn. A small cutter is used in conjunction with the Elmendorf tester that cuts the samples to the desired width uniformly, insuring accurate results. Considerable importance is attached to the necessity of seasoning the test pieces before placing them in the tester since any deviation from the point of equilibrium represented by 65% relative humidity and 70°F would affect the final results to such an extent as to make them useless.
The instrument is of the pendulum type and consists of a revolving drum mounted on ball bearings with a suitable stand, with accurately counterbalanced pointer not rigidly attached to the drum but moved forward by contact with a pin projecting from the back of the drum. The load is applied through a similar revolving drum directly attached to a motor, which through a reducing gear applies load at the rate of 1 r.p.m. The two ends of the sample (1 inch wide) are attached to the revolving drums by placing the sample in slots and folding over ends by means of a spring clip arrangement, which holds the sample firmly in place. The load is applied by a pressing switch; as the pendulum weight rises, the needle is moved forward over a graduated scale until tearing takes place. This reading may be taken as initial tear, but the test may be continued to determine the presence of hard spots which will advance the needle slightly further. This measures the tearing resistance of the sample in grams direct pull and not by the indirect method of indicating the absorbed energy of a falling weight. The results obtained are somewhat lower than with the conventional method of measuring tear. However, when this direct-weight method is checked by lifting a known dead-weight attached to one end of a slit test sample, the results indicate that tear tests measured by the direct method, although lower, give a more accurate indication of actual tearing resistance, because the other methods of measuring tear involve a certain amount of tensile strain as well as pure tearing resistance.

The number of sheets torn at one time in an Elmdorf tearing tester has an effect on the final results. The instructions "enough sheets shall be torn at one time so that the reading on the scale shall be not less than 20 grams nor more than 40 grams" provide a too large working range. A modification is suggested to read that all tests shall preferably be made on single samples, except in those cases where such values are too low for accuracy. In no case should sheets be doubled to give a value of over 30 on the scale.

A paper tester comprises means for supporting a strip of paper, means for fastening one side of one end of the strip to the support, a weighted lever provided with means on one side of its fulcrum for engaging the other side of the paper, means for adding weights to the opposite side of the lever, and means for indicating the force required to perform the tearing operation.
TENSILE STRENGTH


The main uses of the tensile strength tester are: (1) For separating the various factors contributing to the general strength measured by the burst tester. (2) For obtaining information concerning the shake, draw tensions, and beating, by studying such details as the ratio of strengths in the two directions of the sheet, the amount of stretch in relation to substance and strength, and the uniformity of results. (3) For paper specifications in absolute units. The instrument can be driven at a sufficiently constant speed by power to give very reliable results. It can be checked for strength accuracy by hanging weights on it, and for stretch accuracy by using engineers' inside calipers. The width and length of the strip to be tested and the speed of applying the load affect the results to some extent and should be standardized. The main limitations are: (1) Both the time and size of sample required for a test are large in comparison with most testing methods. At least ten strips should be tested. (2) The cutting of strips for test involves careful work. Strips must be put over the clamps carefully, so as to be equally tight all over. (3) The stretch-recording apparatus is apt to develop errors through wear in the clamp guides and automatic release device. Stretch calibration is best readily made by stopping the instrument at intervals up to the expected break of a strip. Measurements of the original clamp-to-clamp strip length and also its length at the various stopping points will give figures for the percentage stretch at those points, which are compared with those recorded by the instrument.


Tensile strength. Tensile strength belongs to that group of paper properties associated with paper manufacture since it is largely influenced by the kind, quality, and treatment of the fiber constituents and by the way the sheet of paper has been formed on the paper machine. Although tensile strength is a fundamental property and the determination is reasonably precise, the arbitrarily chosen conditions of loading and size of the specimen influence the numerical values obtained. The test results are usually reported in kilograms per 15 mm. of width of specimen, sometimes in pounds per inch of width. Results expressed in pounds per inch of width may be converted to kilograms per 15 mm. of width by dividing by 3.73. Tensile strength is indicative of the durability and serviceability of many papers, such as wrapping, bag, gummed tape, and cable wrapping, which are subject to
Tensile Strength

Tensile strength measurements indicate the potential resistance to breaking when subjected to strains during travel from the roll through the web press mechanism in the process of printing. In general, tensile strength tests rate papers in the same order as the bursting strength tests, which depend upon both tension and stretch. One advantage of tensile strength over bursting strength is that the strength of the sheet in the tension test can be measured and reported for each direction, thereby detecting any abnormal differences between the two directions. In mill control work the tensile strength test may be used for determining the general strength properties of paper, but it is not as convenient nor as rapid as the bursting strength test. Although the tensile strength test does not usually give such a good indication of the practical "strength" of paper as the bursting strength test does, it fills a special need in the testing of paper subjected to tensile stresses in use.


Three types are listed: portable dial type 269, bench dial type 270, pendulum bench dial type 271, and precision motor driven type 250. Types 250 and 270 are illustrated. Type 271 is constructed in accordance to the TAPPI Standard T 404.


A general discussion of the effect of hydrometric conditions on the breaking length of writing and printing papers.


A discussion is given of the factors affecting the tensile strength of paper, of the precautions to be taken in using the Schopfer tensile tester, and of the strength tests to be applied to various grades of paper.


Reference is made to the paper testing machine manufactured by Goodbrand and Co. for determining the breaking strength and elongation of all classes of paper. The apparatus is described and illustrated.

Theories of paper strength are discussed. The strength of paper reaches a maximum at 50° C. and decreases with further heating. At a constant temperature of 20° C. the maximum is attained at 1-2% moisture. At constant temperature elasticity is practically independent of the moisture of the paper. When a load is applied in the Schöpper tester, the strip shows permanent elongation or slip before rupturing. This slip does not increase with time. Paper heated for some time at 100° C. will not recover its original moisture content. The higher the heating temperature, the less moisture is reabsorbed. This permanent loss of moisture is accompanied by a permanent loss of strength.


An instrument is described for making tensile and elongation tests and automatically registering the force-elongation diagram; the technique for its use, together with the precautions to be observed and the method of calculating the quality, is explained. A triangular rule has been devised for facilitating the measurement of the area of the diagram and the calculation of the quality of the paper.


The Bosco tester operates on a strip of paper rolled into a cylindrical shell. The two circular edges are fastened in two ring-shaped clamps, exactly concentric and located vertically above one another. If one of these clamps be turned slowly in one, the other just as slowly in the opposite direction, the paper is subjected to a torsion strain, which is strongest in the center of the cylinder. The result of this turning is a strain on the paper from every direction. The device is so constructed (along the lines of the Schopper strength tester) that the direction of revolution of the clamps can be reversed and the rotation in opposite directions is continued until the paper tears. This figure comes very close to the power of the paper to withstand crumpling.


Mean breaking lengths are given as follows: Writing paper of bleached pulp 50 to 100 grams per square meter; wrapping paper of unbleached pulp, glazed on one side, 18 to 100 grams; Kraft paper, either unglazed or glazed on one side, 40 to 100 grams. Average values for writing papers range from 3000 to 5000 meters, for wrapping papers 4000 to 6000 meters and pure Kraft papers 6000 to 7500 meters. The tests were carried out with a Schoppner tester at 65% relative humidity.

Tensile strength is measured in either the machine or cross machine direction of the paper web but very little is known about this property in the third direction—in the direction perpendicular to the plane of the sheet. Paper samples, 20 mm. in diameter, were glued between two wooden blocks of identical size and the adhesive was allowed to set for three hours. After this period, the blocks were clamped in a Schopper tensile tester and the breaking strength was determined. When the two wooden blocks were glued together without a paper sheet in between, the bonding strength of the adhesive was so great that the blocks could not be separated in the largest model for board testing with a maximum breaking load of 150 kg. The tear always occurred within the fibers and never within the adhesive layers. The strength perpendicular to the plane of the sheet is always extremely low. Of the ten samples tested blotting paper with values of 108, 59 and 2.3 for machine, cross machine, and perpendicular to plane of the sheet, and glassine with 1090, 600 and 24 for the same direction represented the lowest and highest values. Slack-sized papers from free pulps gave consistently lower strength figures than stronger and hard-sized papers from slow-beaten pulps.


Following the technique of the Shirley Institute for measuring the tensile strength of single cotton fibers, similar measurements were made on wood fibers. Difficulty was encountered in mounting the wood properly. Ruhlenman (Paper Trade J. 82:168(April 1, 1926)) gives as the breaking load of wood fiber, around 13 grams.


This is practically the same as TAPPI Standard T 404 m-41.


A discussion is given of the proposed revision of the TAPPI method under the headings: Dimensions of specimens, rate of testing, and report.


Tensile strength is discussed on p. 15-16. The Schopper tester is mentioned. Relationship of other strength properties is illustrated.
Tensile Strength


The present TAPPI method with a given speed of the stressing jaw limits the scale to the region between 10 and 90% of its total capacity and permits the use of different pendulum weights. It is obvious that a range of 9:1 is allowed in the rate of application of the load. As the leverage of the pendulum is not specified, if this factor varies, the range of rate of application of the load may easily be 20:1. In some cases a much smaller ratio may cause significant changes, especially in pulp testing. In a sulfite ledger paper, the increase in tensile and stretch with lighter speeds were 3.1 and 5% and in the cross direction 7.3 and 3.8%. It is recommended that the strip be 180 mm long and 15 mm wide and that the time to break the strip be from 10 to 30 seconds but for precise work the time should be as near 20 seconds as practicable.


The fundamental alteration to the method for determining tensile strength is requiring that the fraction be made in 20 ± 10 seconds from the time that the load is applied, in place of the old specification requiring a definite speed of the lower jaw of 12 inches per minute. Unless the pendulum weight and its leverage together with the speed of the stressing jaw are all specified, the rate of loading of the specimen, which is the important thing, is not defined. The width of the strip suggested is 15 mm and the distance between jaws 120 mm. For the pulp test a strip length of 100 is probably more suitable.


In the discussion of waterproof papers on page 157, it is stated that tensile strength and stretch shall be determined simultaneously with a pendulum type of instrument having a device for indicating the amount of stretch. The stretch shall be recorded at the instant of rupture of the paper under the tensile stress. When stretch is to be determined, care must be taken to apply no more initial tension to the test strip before clamping it than is required to straighten it. Strips 2 inches wide and not less than 5.5 inches between jaws shall be used for these tests. The test values are divided by 2 to obtain the values for tensile strength per inch width.
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Four machines were used. Two of these were of the inclineable balance type, operated on the deadweight principle and best suited to test strips of paper about 4 inches long and 1 inch- or 15 mm.-wide. A third machine was hand-propelled and tested strips 1 inch wide and 4 inches long. The fourth machine was best fitted to test strips of paper about 2 inches long and 15 mm. wide; it was operated by a hand lever. Twelve lots of paper were tested, the average of 10 tests being taken to determine the tensile strength of each sample; duplicate tests were made in each case; 1900 tests were made in all. Considering the amount of variation between individual tests made on the sample, two of the machines gave results superior to those obtained with the other two. All four machines gave good results as regards comparison-of average obtained for duplicate tests on the same machine. That is, as regards duplicate determinations made on the same machine, very close checks may be obtained. When the average results obtained by the different machines are compared, however, there is quite a wide variation. This is due, probably, not only to differences in the mechanical accuracy of the machines, but also to differences in the size of the paper strip tested and the rate of the application of the load. It is apparent that tensile testers of different types cannot be used for strictly comparative results and therefore, in reporting results of tensile tests, the kind of machine used should be specified.


The rapid paper tester is described. The strip to be tested is 50 mm. (2 inches) long and 10 mm. (3/8 inch) wide. The methods of testing the strength scale, the expansion scale and the defects in the mechanical construction are discussed. The values for the tearing length agree fairly well with the larger apparatus (30 kg.) but the expansion values are higher.


Tensile strength at rupture in p. a. 1. of original cross section is calculated from the breaking load on a sample of known dimensions. Solid fraction by volume is defined as the ratio of the volume of solid fiber in the sheet to the volume of the sheet. The value of fiber was calculated from the sheet weight and an assumed density of 1.5 for fiber substance; the volume of the sheet was derived from its measured dimensions. The general procedure was to prepare a number of sheets under rigidly standardized conditions, employing the most advanced technique available. These sheets were subjected to different wet pressures, dried, conditioned in a humidity room, and the solid fraction and tensile strength accurately determined. The solid fraction range studied was 0.15 to 0.5. The following conclusions are drawn.
from the data presented. Tensile strength increases in a regular manner with increase in solid fraction in the test sheet, the relation approaching a power function. The curves of tensile strength plotted against solid fraction change in an orderly and rational manner when a pulp is beaten or when it is dried, the two treatments producing changes in opposite directions. Tearing and bursting strength and folding endurance in an unbeaten pulp vary with solid fraction in the same way that they vary with time or freeness on beating. The beating process may be divided into two parts, one in which strength increases are due to an actual change in the surface conditions of the fibers, and the other in which such increases are due partly to solid fraction increases dependent upon increased shrinkage and, therefore, upon decreased fiber particle size. The second of these effects can be duplicated by wet pressure but the first cannot. A means is thus provided for studying separately the effects of freeness in beating and of some other factor approximating true hydration. The regular nature of the changes observed supports the hypothesis that this sheet strength is a function of sheet structure and fiber properties, which can be expressed mathematically.


In seeking an explanation of the fact that the breaking length of paper (ordinarily used as a measure of ultimate tensile strength) is not proportional to basis weight but, on the contrary, reaches a maximum as basis weight is increased from a low value, a series of test sheets of several basis weights, wet pressed at several pressures in order to produce various fractions for each basis weight, have been prepared and analyzed. The variation of ultimate tensile strength with solid fraction at constant basis weight and with basis weight with constant solid fraction and the variation of solid fraction with basis weight at constant wet pressure were studied. The results indicate that the commonly observed relation between breaking length and basis weight is governed by uncontrolled combinations of the three variables considered. Variation with basis weight is due primarily not to variation of basic weight as such but rather to fiber orientation as a manifestation of the variation in consistence when sheets of different basis weights are made, using equal volumes of stock. The following conclusions may be applied to paper sheets in general. Sheets of constant basis weight show a mathematically regular increase in tensile strength with increase in solid fraction; the increase in solid fraction is obtained by increase in wet pressure. Sheets of the same solid-fraction values show a regular decrease in tensile strength with increase in basis weight when the volume of stock used in their formation is kept constant and, consequently, the consistency is varied in proportion to the basis weight; this strength decrease is primarily a result of the consistence change rather than of the weight change. Sheets made up under constant wet pressure show a continuous increase in solid fraction with increase in basis weight, as a consequence of greater shrinkage on drying. As a result of the two effects just noted, sheets made up under constant wet pressure and with a constant volume (variable consistence) of stock
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first increase and then decrease in tensile strength when basis weight is increased from a low value. The relations involved may be expressed as \( S = kC^m \), where \( k \) is a characteristic of the pulp that is designated "fiber strength at unit consistency," and \( m \) and \( n \) may or may not be characteristic. Sheets of low basis weight (e.g., 21.5 pounds) show an anomalous behavior that may be either specific or an effect of inaccuracy in thickness measurements. The various effects of basis weight appear to be explainable from the standpoint of the fiber arrangement, particularly the concept of orientation of fibers perpendicular to the surface of the sheet.


Two unbeaten pulps—a spruce and a black gum sulfite—were separated by wet screening into long-fibered and short-fibered portions; the fractions passing a 60-mesh screen and that retained on the 32-mesh screen were used. These two fractions, as well as the whole pulp, were made into sheets which were subjected to various pressures while they were wet and the tensile strength and solid fraction values of the dry sheets were determined. The mean fiber lengths of the short fibered portions of the spruce and gum pulps were 0.2 and 0.07 mm; of the long-fibered fraction, 2 and 1.5 mm. The mean lengths of the whole pulps were 1.3 and 1.1 mm. Sheets made under any given pressure while wet from the short-fibered portion are from 25 to 200% stronger than those from the long-fibered fraction. The short-fibered fraction gives a sheet of higher solid fraction and, therefore, of greater strength than one of the long-fibered pulp. However, fiber length does not have a very great influence upon the strength of sheets at any given solid fraction. There is a fundamental difference in the internal structure of sheets made of fibers of different lengths, manifested in this work by the porosity test, that may be more evident by strength tests other than tensile strength. There are also differences in shoot-producing properties between pulps that cannot be explained by fiber length differences alone; possibly these are attributable to the chemical nature of the material.


When cutting out a test strip for the determination of tensile strength, the edges of the strip are mutilated and therefore weakened. The results of the test, therefore, are too low and represent the actual strength of the original paper less the decrease resulting from the mutilation along each edge of the strip. As the latter is independent of the width of the strip, the results obtained with wide strips are proportionally higher than with narrow strips, up to a certain width,
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above which the results are practically proportional to the width.

As the construction of instruments with wide jaws offers certain difficulties, Fournier proposes that the instruments at present in use be retained but that the strips be at least twice and preferably three or four times as wide as the jaws (15 mm.). The test would be simplified (less care required in preparing the strips), the results would be higher and would more truly evaluate the quality of the paper under the conditions of use.

Fournier, after briefly discussing the shortcomings of the instrument generally used for measuring the tensile strength of paper (Schopper), advises using a machine which could take a much wider strip—e.g., 15 cm. instead of 15 mm. This would necessitate the use of forces up to about 300 kg. and Schopper type instruments of this capacity would be too heavy, cumbersome, and expensive. A simple and efficient hydraulic type of instrument is described, in which the tension is exerted by means of a piston displaced by screwing a rod into the cylinder carrying the piston.


The test would be simplified (less care required in preparing the strip), the results would be higher and would more truly evaluate the quality of the paper under the conditions of use.

Goodbrand & Co. Ltd. Goodbrand tensile testing machine for paper. Circular with no number or date.

Three types are illustrated. See also World’s Paper Trade Rev. 112, no. 2:2438, 1438 (Dec. 1, 1939).


TAPPI Standard T 404-n specifies that the stressing Jaw shall be operated at a speed of 12 inches per minute and that the testing instrument shall be of such capacity that the tensile strength of the paper tested will not be greater than 90 nor less than 10% of its capacity. Clark has proposed that the break shall occur within 10 to 30 seconds from the time the load is applied. Using a Schopper tensile machine (power driven), a series of tests was made in the machine and cross directions of seven samples. When the TAPPI method was employed, only four of 11 groups of strips tested gave results outside the time limits of 10-30 seconds proposed by Clark. Of the 11 groups of duplicate tests, the average deviation was 2.8%; in only 2 cases was it over 5%. When all 11 groups were run within the proposed time (10-30 seconds), the average deviation was 2.0%. The tests indicate that rapid application of the load tends to give somewhat higher tensile strengths. The quantitative effect, however, apparently varies with the type of paper. From present data, there do not seem to be sufficient advantages in the proposed modification to warrant incorporating into the standard procedure, except as a suggestion. It is suggested that the method require the recording for each break the time in seconds from the application of the load until the break occurs.
Tensile Strength


The breaking length of sheets made from certain pulps and of various commercial papers was determined by the use of the "runther zero clamp" on strips of zero length. The zero-breaking length values of pulps change only slightly between 30 to 80 degrees Schopper, but from 90 and above it begins to decrease. The zero-breaking length of pulps is independent of the basis weight of the test sheet. By shortening the length of the strips of paper tested, the breaking length increases. By means of these tests, the actual felting properties of the fibers can be separately determined.


In a discussion of Oliver's paper, Harrison gave figures on the tensile strength for strips 1 inch and 15 mm. wide and calculated the strength of a strip 15 mm. wide from the values for the inch strip. The data confirm the results of Houston that decreasing the width of the strip increases the relative strength, yet this applies only to tests carried out on papers cut in the machine direction. With cross direction strips a decrease in the width of the strip causes practically no difference (in one sample of unglazed kraft a decrease of 11.3% was observed when the narrow strip was used). There is no general agreement on the effect of the length of the test strip. The rate of movement of the lower jaw of the Schopper tester is mentioned but no data are given.


The Patra laboratories use the Schopper tensile strength tester. The samples are 5/8 inch in width and not less than 8 inches long. Tests are made in both machine and cross directions. The method of making the test is reported in detail. The procedure follows the recommendations of the Paper Testing Committee of the Technical Section, Paper Makers' Association. It is recommended that the driving handle of the apparatus should be turned at the rate of 150 r.p.m. when the smaller weight is in use and at 30 r.p.m. with the larger weight. The average of ten readings is taken. Thin or weak papers may have several strips broken together.


This is a brief discussion of the work of Doughty (Nos. 746-748).
Tensile Strength


The apparatus used consisted of a heavy (7.5 kg.) iron roller (150 mm. diameter) provided with a central flange fitting exactly into a grooved rail, along which the roller runs. A strip of paper, 15 cm. wide, likewise exactly fitting the groove, is folded back upon itself, laid in the groove, and the roller run over it, in both directions. After removal the paper is tested for tensile strength. The difference between these numbers and those obtained with the original unfolded sample expressed in percentage of the latter gives the "loss in breaking strength" and "loss in stretching power" of the paper on folding. Some 87 papers were examined. The loss in stretching power was greater, both in machine and cross direction, than the loss in breaking strength. The loss in breaking strength in the machine direction is greater than in the cross direction. The loss in stretching power in most cases obeys the same law. The lowest mean loss in breaking strength observed was 4.7% and the greatest was 48.7%. The lowest loss in stretching power was 14.3% and the greatest was 78.7%.


Breaking strength, stretch and folding numbers of paper vary according to the direction in which the test is made on the paper. A comparison of tests made in machine direction with those in the cross directions in breaking length gives ratios from 100:18 to 100:31 between the two directions in breaking length, from 100:290 to 100:435 in stretch and from 100:21 to 100:1.5 in double folding tests on certain Manila papers. Herzberg advocates classifying papers, not on the average of tests made in both directions, but on the lower value found in either direction.


This study was made of a breaking strength machine of the inclinable type with a capacity of 50 kg. Ten different lots of paper were tested; samples were cut 0.25, 0.5, 0.75 and 1 inch in width and of such length that the distance between the jaws of the machine was 50, 90, 100, 150, and 180 cm. The machine was so set that the lower jaw descended at a speed of 6 inches per minute. The test results vary when different lengths of the same width specimen are used; however, this variation
was never greater than 1.5 kg., which is comparable with the experimental error of the machine. The percentage elongation varied with both the width and the length of the specimens. The elongation is highest for the 0.25-inch strip and lowest for the 1-inch strip—i.e., in the inverse order of the width; the same is true of the length. This is explained by the fact that there is a difference in stressed area as well as fiber adjustment to stresses. The rate of stress per unit area decreases as the stressed area decreases.

It is concluded that the length of test specimen is not important when only the breaking length is desired. However, if the percentage elongation is desired, the length and width must be controlled and standardized. It is suggested that a length of 3.5 inches (about 90 mm.) and a width of 1 inch (about 25 mm.) be adopted as a standard.


The apparatus employed was a 50-kg. breaking strength machine and a Mullen tester with an attachment for measuring deflection. Jaws for the breaking strength machine were made to use test specimens one inch in width. The attachment for the Mullen tester consisted of a drum which was geared to the hand wheel. A recording pen was attached to a very small rod in such a way that it could move up and down and describe a curve on a chart clamped to the drum. A thickness gage was also fastened to the Mullen tester. Determinations were made of the breaking strength, elongation, and bursting strength. As the bursting strength was determined, the increasing deflection of the paper was recorded on the chart, from which the elongation at the breaking point was calculated. Results are reported for eight kinds of paper. These show that the percentage variation of ratio of breaking strength to elongation and of ratio of bursting strength to elongation from the mean value is very small for each grade of paper (this can be explained by experimental errors in the initial test readings). Thus, it appears that there is a direct relationship between breaking and bursting strengths. If the relation (breaking strength)/elongation = (bursting strength)/elongation can be checked, it might be used as a possible means of calibrating the Mullen tester and creating a standard bursting strength machine.


The tensile strengths of papers, 24, 45, and 92 g./sq. cm., were 2390, 3470 and 3810 meters, respectively. In the second article values for paper of sp. gr. 1.225, 1.300, 1.360, 1.160, 1.120 and 1.103 were 4604, 4735, 3233, 2809, 2831 and 2464.
Tensile Strength

Tensile-testers are classified according to the method of loading the specimen. Following this classification, pendulum, inclined-plane, hydraulic, and spring types of instruments are described. The dead-weight method of calibrating the several types of instruments is discussed. It is shown that pendulum-type testers should not be calibrated by allowing the test weight to ride down on the lower clamp because the follow-through of the loaded pendulum causes a serious error, particularly at small loads and high clamp speeds. Calculation of the follow-through of the pendulum of a typical instrument in the actual testing of a specimen shows the follow-through to be much smaller than that of the pendulum loaded with the dead weight and to be negligible except when weak papers are tested at high speeds. The effects of rate of loading, specimen length, and specimen width are reviewed and additional data are presented. Tensile strength increases as the rate of loading increases and decreases as the specimen length increases. It appears that the relative tensile strength (tensile strength per unit width of specimen) should be independent of specimen width for wide specimens but that it should decrease rapidly for widths less than approximately half an inch. Data are given for rates of loading of 3, 6, 9, 12, 15, and 18 inches per minute, for specimens 2, 4, 6, 7, 9, and 8 inches in length, and for speeds of the stressing clamp of 3, 6, 9, 12, 15, and 18 inches per minute.


The instrument is of the pendulum type and has two ranges, 0 to 55 pounds, and 0 to 110 pounds, with scales graduated in half pounds and pounds, respectively. The lower range is effective when only the fixed weight is used on the pendulum and the higher range is effective when an auxiliary weight is added to the pendulum. The tensile scales are marked on a circular dial whose indicator is coupled to the pendulum through gears. The lower clamp is fastened to a threaded rod which is motor driven through a gear box and a variable speed pulley. The speed of this lower clamp may be varied continuously from 3 to 20 inches per minute. The upper clamp is connected to the pendulum by a chain passing around and anchored to a pulley which in turn is fastened to the pendulum and is coaxial with the bearing of the pendulum. The jaws are equipped with interchangeable anvils of 1- and 3-inch widths.
The instrument is equipped with a recording mechanism for tracing load-elongation curves. The chart carriage is drawn downwards by a gear train coupled to the lower clamp, thus assuring that the chart moves at speed proportional to the speed of the lower jaw. The pen carriage moves horizontally and is connected to the pendulum by a rod.
The particular instrument studied is in error at a number of points along its scale. For many applications to control testing this error is not serious. For many other applications it is serious. In addition, friction causes errors of as much as 1.5 pounds. Neither source of error is due to faults in fundamental design and both could be eliminated by the manufacturer.


The instrument is of the pendulum type and has three ranges: 0 to 200 pounds, 0 to 50 pounds, and 0 to 15 pounds with scales graduated in pounds, quarter pounds, and tenth pounds, respectively. The ranges are changed by changing the weights on the pendulum. The three scales are marked on a quadrant concentric with the axis of the pendulum, and the load is indicated by a pointer fastened to the pendulum which moves over the scale. The upper specimen clamp is connected by means of a chain to a sprocket on the shaft which supports the pendulum. The lower specimen clamp is connected to a threaded rod, called a spindle, which is motor driven through a belt, clutch, and gear box.

In this particular instrument, the lower clamp is driven at a constant speed of 12 inches per minute. The jaws of the clamp are one inch wide. The complete instrument, including the motor, is mounted upon a common base. The pendulum swings in a plane perpendicular to the front of the instrument. When a specimen breaks, the pendulum is held at its position of maximum displacement by pins which engage teeth on the quadrant which also bears the scales. The lower jaw is brought back to its starting position by moving the operating lever to its upper position. This starting position may be set at any desired point by adjustment of the stop on the rod which controls the clutch. For specimen lengths less than six inches the upper clamp must be lowered by shifting its chain on the sprocket. The spindle projects below below the level and in front of the base during part of its motion, so that the instrument must be set with its base flush with the edge of the table. Two screws are provided at the back of the instrument base to permit levelling the instrument in the plane in which the pendulum swings. The instrument is equipped with a device for indicating the elongation of the specimen. The dial of this device bears two scales, one giving the elongation in inches, the other giving the stretch in percentage for a six-inch specimen. The calibration of one presumably typical instrument was studied; the greatest error found by dead-weight loading was 0.5%, but measurements of the small divisions indicate errors up to about 0.7% of full-scale load. This error is not serious in most applications of the instrument. It appears that the errors in the calibration are due to inaccurate divisions of the scale and are matters that can be taken care of by the manufacturer.
The instrument is of the pendulum type and has two ranges: 0 to 15 pounds and 0 to 75 pounds with scales divided to 1/32 pound and 1/4 pound, respectively. The upper specimen clamp is fastened to a chain which passes around and is anchored to a quadrant coaxial with the bearing of the pendulum. The lower specimen clamp is fastened to a rod which is drawn downward by means of the motor-driven gear box. The speed of the lower clamp is continuously variable from 2 to 20 inches per minute. These clamps afford rates of loading varying approximately from 0.6 to 6 pounds per second on the 75-pound scale and approximately from 0.12 to 1.2 pounds per second on the 15-pound scale. The separation of the clamps is adjustable to distances of 2, 4, 6, and 8 inches. In this particular instrument extra holes were drilled in the rod which holds the lower clamp to permit a specimen test length of 7.09 inches (180 mm.). The scales are marked on a quadrant which also bears teeth which engage the pawls fastened to the pendulum to hold the pendulum in its position of maximum displacement after the specimen breaks. The lower clamp is returned to its starting position by moving the operating lever to its upper position. The complete instrument, including the motor, is mounted upon a base. Errors were found in the calibration of one instrument, presumably typical. These errors are not serious in many control problems, but they might be serious in other cases. The error appears to be due to inaccuracy in division of the scale and not to a fundamental fault in design of the instrument; therefore, it could be corrected by the manufacturer.


In the apparatus described, a strip of cardboard 1 by 10 cm. is supported on knife edges exactly 50 mm. apart, so that 25 mm. project at either end. A graduated lever, pivoted at one end, carries a third knife edge by means of which the load is applied to the middle of the test strip. The weight of the lever and knife edge is balanced by means of an adjustable counterpoise and the load is varied by means of a rider on the lever arm. The method of calculating the elasticity is given.

Isnard describes a home-made apparatus for testing the tensile strength of cardboard, which may be made to indicate the elongation if desired. It is not as accurate as the instruments at present on the market, but it is sufficiently accurate for the purpose and is cheap and simple.
Tensile Strength


Suggestions are given for the construction of a simple bursting and tensile strength testing instrument of sufficient accuracy for practical operation when only comparative results are required.


The product of breaking length and stretch of paper as a measure of its capacity to absorb work is discussed.


Strips 15 mm. and 9 mm. were tested with 3 kinds of papers; the results with the 9-mm. strips were 2.3, 3.7, and 35.5% less than the calculated values.


Seven samples of commercial papers were tested for uniformity in tensile strength, fifty tests being made in each direction on adjoining portions of the sheet. Under those conditions the maximum difference in 50 tests varied between 9.4 and 33.4%, the average deviation from the mean being + 1.8 and + 6.1%, and the probable error of the mean between + 0.23 and + 0.74%. Samples taken from different sheets might be expected to show greater divergence than this. There appears to be no definitely greater uniformity in one direction than in the other in the samples tested.


The number of twists under a definite load up to the point of rupture decreases as the paper thickness increases. However, no marked differences were shown by papers ranging from 32 to 92 grams per square meter. Differentiation of such papers is more easily carried out by determining the load of rupture in the machine direction.
This paper is an exploration of certain fundamentals of paper structure. It is postulated that all the physical characteristics of a sheet of paper must be related to (a) the primary valence linkages in the cellulose chain molecule, (b) the forces of molecular cohesion between chains, and (c) conjugated surfaces. When a sheet of paper is ruptured in any physical test, the felted fibers must be twisted or compressed to destroy the conjugated surfaces. When a tensile stress is applied to a sheet, the fibers will first slip where the conjugations are disrupted; it will then shear along the lines of cohesion parallel to the fiber, and finally break at the atomic linkages across the fiber.

Using cotton pulps, it is shown that the tensile strength is higher for the pulp having a greater viscosity; the tear shows the opposite tendency. Two pulps, with viscosities of 626 and 129 seconds and freenesses of 695 and 715 cc., had tensile strengths of 8.5 and 4.0 and tears of 114 and 141. A rag sheet from a pulp of high viscosity and beaten for 30, 90, and 180 minutes (freenesses of 695, 205, and 130 cc., respectively) had tensile strengths of 8.50, 21.56 and 29.12; the tears were 114, 128, and 137; this represents an increase of 244% on beating. A similar change is produced by the action of zinc chloride on a sheet of waterleaf paper. Thus a sheet with a tensile strength of 15, on treatment with 68 or 71% zinc chloride for 1 minute at 60° or 120° C., had a tensile strength of 21.1 or 44.1; the tears were 67, 80, and 129, respectively. Other experiments show that the tensile strength is increased in the direction of the tension, values for the machine direction being much higher than in the cross direction. There is a theoretical discussion of the results, especially of the hydration theory.

A description is given on an improved model of the Leunig paper tester. The tester is fitted with a graphic recorder which enables the operator to determine the proportion between load and elongation at any moment of the test. The recorder can be applied to the motor- or hand-driven instrument. The standard strip is 15 mm. wide and 180 mm. long. The English strip, 5/8 inch wide and 12 inches long, is the nearest equivalent.

Six types of testers were studied; these are described briefly, but the names of the manufacturers are not given. In addition to such mechanical details as ruggedness of construction and ease of calibration, a good tensile tester should fulfill two requirements: The results obtained by testing duplicate specimens of the same sample should check reasonably well and the average (checked) results should be reasonably near the truth.
The results can hardly be expected to check each other within about 5%; this figure may be taken as a measure of the heterogeneity of the paper. None of the instruments showed any appreciable change of accuracy in different parts of the scale, within the limits examined. An instrument may give results which check each other closely, and yet all the results may be far from the truth.

The Schopper tester was introduced into England as the Leunig tester. The principle of using dead weight to apply the breaking load, as used today, is exactly the same as in the first machine. Certain improvements are detailed. Experiments have shown that the results of tensile strength tests depend on the speed at which the load is applied to the test sample. A means of determining the correct speed and checking its constancy is provided in Alt’s diaphragm apparatus; it can be used as a recorder to register the actual testing speed or as an apparatus for predetermining the speed at which the test should be carried out. The graphic recorder, fitted to a paper tester, records along the horizontal axis the breaking strength and along the vertical axis the elongation. The breaking length is that length of a strip of paper of any uniform width and thickness which, if suspended freely at one end, will break by reason of its own weight, at the point of suspension. This method of expression indicates the specific tensile strength of the sheet, irrespective of the width of the test strip. The breaking length can be calculated from the breaking strength and the substance of the sheet; it is generally expressed in meters. If $G$ is the weight in grams of a strip 180 mm. long and the breaking strength in kg., then the breaking length is $0.18G/P$ m. The Leunig tester is graduated in the British system of weights and measures.

A chart is given from which can be calculated the tearing length when the weight per square meter and the tearing load are known.

This tester is built on the inclination balance principle with the pendulum having a maximum angular swing of 45 degrees. The load is balanced by the inclination of the lever and is reflected directly to the quadrant scale. The pulling clamp is attached to the upper end of a guide tube which gets its uniform linear speed of 12 inches per minute through a chain and sprocket driven by the motor through the speed reduction unit. This unit consists of a double set of worm gears running in heavy annular ball bearings, in an oil bath. A feature of the motor-driven unit is the sealed mercury-to-mercury contact switch through which the current is fed. The operation of the tester is described.
Tensile Strength Test. This test is only applicable to individual sheets of linerboard and corrugating medium—it cannot be applied to combined board or finished boxes. Test specimens shall be cut from un-wrinkled, uncreased and unblemished sheets, four each with the grain running the long way and the short way of the specimens. The specimens must be cleanly and accurately cut, with parallel opposite edges, not less than 12.7 mm (0.5 inch) nor more than 25.4 mm (1.0 inch) wide, and of such length that when clamped in the tester the distance between the jaws shall be not less than 5 times nor more than 12 times the width of the sample, but in no case shall they be less than 140 mm (5.5 inches) long. The exact size shall be determined according to the tester and its convenience in operation. The specimen shall be firmly and squarely clamped in the jaws of the clamps and the stressing clamp then operated at a constant speed of 30.5 cm. (12 inches) per minute until the specimen breaks under the tension. Tests in which the specimen breaks at or in one of the clamps shall be disregarded. The tester shall be of such capacity that all tests will fall within the range from 10 to 90% of its capacity. The breaking load shall be recorded to the nearest 2% of the total indicated reading and shall be calculated in kilograms per 15 mm. width of the specimen. Not more than one of the four tests in each direction of the stock may fall below the specification, with the average of the four tests meeting the requirement, for compliance. However, if the initial tests in either or both directions shall fail to comply, a series of 12 re-tests of either or both (according to the failure) shall be made, of which not more than three tests may fall below, with the average of all 12 tests complying with the specification, for acceptance.

The test for tensile strength shall be as follows: From each sample specimen 2 inches wide and not less than 10 inches long shall be clean cut parallel to the longest direction of the board and at right angles thereto. The distance between clamps shall be not less than 6 inches. Results on specimens under test that break within 0.5 inch of the jaws shall be disregarded. The machine speed shall be set for the openings between the clamps at the rate of 2 inches per minute. The specimens before being placed in the testing machine shall be measured for width and thickness to the nearest 0.01 inch. The tensile strength shall be taken as the average of three specimens from each direction of the board.

A brief discussion of tensile strength is given on pages 15-17, with an illustration of the apparatus.
The Perkins tensile tester is of the vertical type, hydraulically operated. The cylinder is filled with a liquid which is compressed by a solid metal plunger, which fits the cylinder with a very accurately ground and lapped fit. This plunger is attached to the upper or stationary clamp by means of a stirrup which brings the pull in a straight vertical line without cramping and without side pull. The lower or moving clamp is attached to a vertical screw which is operated by means of a handwheel on the side of the machine. The pressure is indicated on a specially made standard gage which is acted on by hydraulic pressure from the cylinder. Removable and interchangeable stop gages are provided which automatically separate the clamps 1, 2, or 4 inches apart, as desired, so that strips of these lengths may be tested easily. The operation of the tester is described.


The Schubert puncture dynamometer is used in the textile industry for strength testing of fabrics, the test being a puncture of the sheet by a plunger or bolt of definite dimensions. The authors compare the application of the new instrument and of the Schoppor tensile tester to papers and pulps of various beating degrees. Unbeaten stocks show greater fluctuations in results with the Schubert tester; however, uniform results are obtained in the use of well-beaten stocks. Tables showing results with the two testers on papers of various compositions are given.


The electrically driven Schoppor tensile tester was studied. The makers stipulate 100 cm. per minute downward movement of the moving jaw. The instrument is capable of adjustment to four different lengths of strips; weights are supplied for readings up to 14 and 70 pounds, respectively. A strip 5 cm. long gave higher results (5.2, 5.5, 15.1) than one 18 cm. long (5.1, 7.5, 13.3). The use of different weights for testing papers with a tensile strength of less than 14 pounds gives rise to small differences in the results; the large weight gave slightly higher results. In a series of tests on kraft paper the maximum deviations were 5.6, 2.0, and 7.3% and the average deviations were 2.2, 1.2, and 2.0%, respectively.

Specifications are given for the tensile test using the Schopper tester. The tensile strength test gives a general indication of the quality of paper rather than definite information as to its suitability for any specific purpose. It is not necessary to base the test on any fundamental considerations or relate it to methods used for the tensile testing of other materials. The immediate requirements for a satisfactory specification are that it shall be convenient to apply, allow of reasonable speed of testing, be of suitable sensitivity, and give consistent results. The testing conditions (e.g., rate of loading) should either be the same for different breaking loads or else continuously variable. The factor most difficult to specify is the rate at which the load shall be applied. The time may be shortened by using a heavier weight (and correspondingly more rapid rate of loading) for papers over 14 pounds, the ratio being 1:5. The effect of the change in rate is not very clearly known but published results indicate that a definite change in strength can be introduced. In the present specification, the ratio of rates of loading is 3:5 (that is, the weight is five times greater but the speed is reduced to a third). A change of rate of loading with the normal type of instrument can be obtained in the following ways: By using one clamp speed and different positions of the weight on the arm; by using a constant speed and a greater range of weights (e.g., in the ratio of 1:2:3:4:5); by using a single weight and different speeds; or by a combination of weights and speeds. These are discussed. Results are given which show the tendency of the strength to rise when measured on a shorter strip; they are not sufficient, however, to establish a correction factor and, in any case, varying uniformity in the paper may be expected to affect the relationship. Similar results are obtained from single strips and folded strips, the magnitude of errors being of the same order in either case. Substantially the same results are obtained whether single or multiple sheets are used in the case of tissue paper. Present data indicate that small variations in the rate of loading do not affect the results. The results are expressed as pounds breaking strain, kilogram breaking strain (calculated for 1 inch or 1 cm. width) or breaking length in meters.


The tensile strength of paper is the load required to break a parallel strip of a stated width (usually 15 mm). The arbitrary conditions accepted as standard are: (1) that the test be carried out at 70° F. and 65% relative humidity on strips previously conditioned in that atmosphere. (2) That both ends of the strip for test be clamped in jaws such that the strip, including the clamped ends, lies in one plane. (3) That the tensile load be applied along the center line and in the plane of the strip. (4) That the distance between the edges of the jaws, or the actual length of strip under test, be 100 mm. (For pulp sheets, 100 mm). (5) That the tensile load be gradually increased at a practically uniform rate till fracture occurs. (6) That the load be applied at such a rate that fracture occurs in about 20 seconds. The tensile test measures a less complex set of properties than most other tests; the
result depends primarily upon, and is almost proportional to, the basis weight of the sheet; it also depends upon the degree of bonding between the fibers; to a minor extent upon the average fiber length, and to a minor extent upon the flexibility of the fibers and fibrous structure. The test strips must be cut accurately parallel and with clean edges. For an accurate test at least 10 strips should be cut from both machine and cross directions of 10 sample sheets of paper. There are four types of instruments: spring balance indicator, load applied by lever; hydraulic diaphragm and gage indicator, load applied by screw; inclined plane; pendulum (standard) type. This first type is represented by the Schopper portable instrument; the second type is the Perkins instrument; the inclined plane type (developed for textiles) has been adapted for paper testing by the Scott Co. The test is particularly adapted to the graphical drawing of the stress-strain curve and fatigue curves. A homemade apparatus is described also.


The construction and operation of the apparatus (Noss and Sadler, Wochbl. Papierfabr. 64:360-363(1933)) are briefly criticized. By making certain (not stated) changes in design and taking proper account of the deflections, the results obtained with either strip or round samples may be calculated to tensile strength with reasonable accuracy. The sample must have negligible stiffness.


Tensile strength. This test is applicable only to single pieces of paperboard. The samples are 0.5 to 1.0 inch wide and of such a length that, when clamped in the tester, the distance between the jaws will not be less than 5 times nor more than 12 times the width of the sample. The sample is clamped squarely between the jaws of the tester and a stressing force of 12 inches per minute is exerted; the point at which failure occurs is recorded. Tests in which the sample breaks at or in one of the jaws are disregarded.


The Rühlemann apparatus for determining the tensile strength and elasticity of single fibers photographically is described.


An apparatus for testing the tensile strength of flexible materials by inflation, comprising means for supplying gas under pressure to one side of the part under test and exchangeable means of geometrically similar configuration for holding said part.
Experiments were carried out with a Schopper torsional strength tester. A square test sheet is subjected to torsional strain, operating at the two outer edges, through two balanced forces which are vertical to the axis of the test sheet and which effect a marginal tear. This results in a torsional moment (termed the "marginal moment") which is automatically measured by a recording device. From this the marginal strength of the sheet can be computed. No attempt was made to calculate the specific marginal strength, since it is not known whether sheet thickness taken alone or considered in conjunction with the angle of torsion lends itself to such calculations. Since the value for marginal strength includes stiffness of the test sheet, the concept of "through-tear" has been avoided.


An illustrated description is given of the rapid paper tester and its operation.


A Mullen-type tester is provided with an elongation indicator consisting of a pointer mounted on the shaft of a pulley around which passes a thread, one end of which is connected to a plate resting on a test piece and the other end of which is connected to a counterweight. Electrical or mechanical means are provided to apply a brake to the pulley when the test piece bursts so as to automatically arrest the indicating pointer.

Schopper's strength tester as a rapid testing apparatus. Papierfabr. 12, no. 17:481-482(April 24, 1914); cf. no. 20: 577(May 15, 1914); Pulp Paper Mag. Canada 12, no. 12:375(June 15, 1914).

A complete strength test with the Schopper apparatus occupies considerable time in many cases. The following rapid method affords a sufficiently exact test. Cut only one strip from each direction of the paper to be tested, add the two breaking loads (in lbs.) and divide by three times the weight per square meter in grams. In order to obtain the breaking strength in meters, the number obtained must be multiplied by 100,000. Possible errors can arise owing to only one strip instead of five being used, and thereby obtaining an average which is not sufficiently exact. In addition, the percentage of moisture in the paper is not taken into consideration. Since the moisture at 65% relative humidity is between 7 and 10%, the results of the tests will be about 5% too low. The formula on which the above test is based is given.
A description is given of an electrically driven dynamometer in which the local strength of fabrics, paper, etc., is determined. The theory and practical value of the test and the calculation of the results are further discussed.

The fabric is weighted by a bolt producing a fissure of only a few mm. The new process is rapid and exact; it is very economical on account of the small size of the fissures, thus enabling one to do numerous tests with a small amount of material. Cf. Radegger, Wochbl. Papierfabr. 64:585 (1933).

The principle of the invention consists in cutting a hole in the material to be tested, held under tension in all directions, in the main testing direction at both sides of and close to the sides of a pressure tool, and subsequently allowing the tool to operate on the severed piece secured against sliding. The test is carried out with a pressure tool of rectangular cross section, which is provided with cutting edges extending beyond the end of the tool and corresponding in width to the size of the pressure tool. The test piece is placed in a special clamp which is mounted in place of the bottom clamp of a tensile-strength tester, and the pressure tool is suspended from the chain of the upper clamp.

The combination tester for paper, etc., is built on the "dead weight" principle. The pendulum swings on ball bearings. The force exerted through the sample raises the pendulum, the pull in pounds being indicated by the pointer on the dial. The toothed rack is one inch wide with teeth spaced 12 per inch. Six gravity pawls travel on this rack and hold the pendulum in the position at break until released by raising the pawls and returning the pendulum to the vertical position. The stretching screw operates smoothly and passes through the gear box without revolving. This obviates the possibility of the yarn becoming entangled in the moving parts. The machine is operated by two levers, one for starting and the other for reversing and stopping. The automatic reversing and stopping of the machine is accomplished by means of an arm attached to the stretching screw and sliding on the reverse stop rod between two adjustable collars. The jaws may be set at any desired distance apart and after each test the machine will automatically reverse and stop at the original starting position.
The most accurate method of testing fatigue, tensile, elongation, or other pulling stresses is by applying load to the specimen itself at a constant and uniform rate; the older machines, however, applied the tension to the sample in varying amounts per unit of time. The incline plane principle used in the new testing machines applies a definite amount of load per unit of time, regardless of whether the sample is long or short, elastic or rigid, ductile or plastic. Greater accuracy and simplicity are claimed for machines of this type.

The attachment comprises a weight adjustable on the balance arm of the tensile testing machine, making possible a direct reading on the dial in accordance with correction factors of any predetermined table.

Using a standard Leunig machine, tensile strength results were obtained of a writing paper (16.5-lb. damy) by testing from 1 to 10 strips at the same time. The results calculated for one strip from the observed results were: 7.5, 7.25, 6.67, 6.45, 7.2, 7.1, 7.2, 7.1, 6.8, and 7.2. The results seem to indicate that the strength readings are proportional to the number of strips; the average of all readings is 7.05 pounds, whereas that for a single strip is 7.5 pounds. The gradual addition of one strip for each succeeding experiment does not appear to create any serious difficulty in manipulation, as the average readings with the greater number of strips are fairly constant. The second article shows that similar results are obtained with a wood pulp paper (6-lb. damy); the breaking weight of the paper found by testing a number of single strips was 3.9, whereas the average of all the readings was 3.82. In the third article the effect of stretch is discussed. If two strips of equal length and width are inserted in the Leunig machine, one being taken from the machine direction and the other from the cross direction, it is clear that, when the tension is gradually applied to both, the machine-direction strip, though stronger, will break first because it stretches less than the other. The weight necessary to break the former is largely used in merely stretching the cross-direction strip.

With reference to an earlier study by Reid, the authors show that neither breaking strength nor elongation alone defines the quality of paper or its resistance to mechanical stresses, but that both factors are required for determining these properties. They illustrate their theory by graphs and mathematical formulas.

804. TAPPI. Tensile breaking strength of paper and paperboard. TAPPI Standard T 404 m-44, 1 p. Paper Trade J. 83, no. 11:53-54 (Sept. 9, 1925); 86, no. 8:213 (Feb. 23, 1928); 102, no. 8:133 (Feb. 20, 1936); 112, no. 6:33-34 (Feb. 6, 1941); Tech. Assoc. Papers 19:271 (June, 1936).

805. TAPPI. Tensile tester testing board. TAPPI Special Reports No. 181-82 (1926).

The question discussed related to the use of tensile testers for coarse boards, such as jute linens. Of the nine mills replying, only one used the tensile tester; this mill stated that the test was of value in determining differences between machine and cross direction; however, the test is inconvenient and slow to perform. It is doubtful if the tensile test is as useful as the Mullen for the routine and control testing of boards. Another mill reported the use of the Perkins tensile tester for comparing the strength of various boards from 0.2 to 0.5 inch but did not use it for mill control because the desired information was obtained with the Mullen tester. The tensile tester was used for dry felts for the manufacture of prepared roofings.

806. Tensile paper tester (Marshall). World's Paper Trade Rev. 75, no. 5:68 (Feb. 4, 1921); Paper Trade J. 73, no. 3:40.

The machine depends for its action on the compression of the liquid contained in the diaphragm, the pressure being produced in the diaphragm by means of a tensile force applied through the paper by a hand wheel. The pressure is registered on a dial in terms of the weight applied to the strip of paper under test and the tensile strength is expressed in the number of pounds pull which the strip of paper supports up to the point of break; an important advantage of the machine is that the tensile strength in both the machine and cross direction can be determined with equal ease and certainty; another advantage is that the width and length of the strip may be varied at will, the machine being capable of dealing with strips up to 12 inches long and 2 inches wide. The stretch of the paper under tension is indicated on a graduated scale under the left-hand screw clip, from the reading of which the percentage of stretch may be readily ascertained.


Of 46 mills having tensile testers, 19 used the Standard Schopper graduated in kg. and 14 in pounds; 2 used the Rapid Schopper (pounds); 7 used the Perkins tester (pounds); 10 the Scott (pounds); 1 the Nickel (pounds); and 1 had its own make. The paper is primarily a discussion of the question of graduation in pounds or kilograms. For commercial or mill work the pound was greatly favored.
Tensile Strength

806. Tensile testing machine for cellophane, transparent paper, etc. Silk & Rayon 13, no. 6:68 (June, 1939); B. I. P. C. 9:487.

An illustrated description is given of a testing instrument for accurately determining the breaking strength and elongation of cellophane, transparent paper, and similar material. The machine is of the inclination balance type with a roller for the weight lever housed in fine ball bearings and in which the medium from the upper grip to the indicating motion is a flexible steel tape.


Illustration and very brief discussion.


Tensile Tester. The tensile test, despite the several conditions specified, is one of the least arbitrary tests for the strength of paperboard and measures a less complex set of properties than most other tests in common use. The results depend primarily upon, and are almost proportional to, the basis weight of the sheet. They also depend upon the bonding between the fibers; to some extent, on the average fiber length, and, to a minor extent, upon the flexibility of the fibers and fibrous structure. In general, the test results parallel those from the Mullen test, but the latter, in addition to the factors mentioned, are also greatly influenced by the ability of the paperboard to stretch during the test. The tensile strength of paperboard is the load or weight, usually expressed in kilograms (1 kg. = 2.2 lbs.), required to break a parallel strip of a stated width, generally 15 mm. (19/32 inches). The arbitrary conditions accepted as standard are: (1) That the test be carried out at 70° F. and 50% relative humidity on strips previously conditioned in that atmosphere; (2) That both ends of the strip for test be clamped in jaws such that the strip, including the clamped ends, lies in one plane; (3) That the tensile load be applied along the center line and in the plane of the strip; (4) That the distance between the edges of the jaws, or the actual length of strip under test, be 180 mm., except for pulp test sheets, for which 100 mm. is the standard distance; (5) That the tensile load be gradually increased at a practically uniform rate until fracture occurs; (6) That the load be applied at such a rate that fracture occurs in about 20 seconds. The tensile test is very widely used to define the "strength" of paperboard. Although it takes longer to perform and requires, as a rule, a more expensive piece of apparatus than the Mullen or Cady test, it is better defined, is less empirical, and is a more reproducible test. As most tensile testers also incorporate a mechanism for determining the percentage stretch of the paperboard before rupture, at the same time the tensile test is made, a knowledge of both may be gained without appreciable additional work. Much more information is then available than from the bursting strength test only; more especially if the two
properties of tensile strength and stretch are determined in both the machine (grain) and cross directions of the board. There is no information given by the bursting test which may not be deduced from the tensile strengths and stretch tests; consequently, for scientific work, the latter tests are more preferred. The ratio between the tensile tests in the machine and cross directions gives useful information regarding the manner in which the sheet of paperboard has been made, and occasionally this ratio is used as a control test for board made on cylinder machines, or with a Fourdrinier, for adjusting the shade and other factors controlling the uniformity of strength in both directions.

Wet Tensile Strength


A preliminary report is given of a method for determining the wet strength of pulp test sheets. The sheet is made on the English sheet machine and pressure is applied at any one point on the sheet. The suction built up by the resistance of sheet is measured on a manometer. As soon as a sufficient suction is built up, the sheet bursts; the pressure at that point represents the breaking point of the sheet. The maximum reading on the manometer indicates the strength of the sheet. No further information about this test seems to have been published.


A strip of paper is looped under a horizontal rod in an assembly which is held by the lower jaws of a paper testing machine. The two ends of the loop are clamped in the upper jaws. Below the rod is a container filled with water which can be raised so as to immerse the paper. The apparatus gives reliable results in wet strength tests on weak specimens such as absorptive paper and also on very thin paper like that of condenser tissue, which is only 0.0003 inch in thickness. The test is important in the case of paper used for making phenol fiber.


The wet strength is determined by breaking a strip of a definite width, after it has been immersed in water at a constant temperature for a definite period of time. A Schopper tensile strength machine is used. The jaws of the clamps should open in front, so that the ends of the wet strip may be inserted without injury, and are set 10 cm. apart, so a short strip of wet paper can be handled more easily. The test strips are cut 15 cm.
wide and sufficiently long to allow for clamping in the machine. The strips are placed separately in a water bath at 70°F for 20 minutes. After the specified time they are removed one at a time and tested immediately. Care must be exercised in handling and clamping the wet strips to prevent injury to them. Data are given showing the effect of temperature of the bath (70, 65, 70, 75, and 100°F.) and of the time of wetting (10, 20, 30, 45, and 60 min.). The test was developed to study blueprint paper.

Wet strength is controlled by the combination of factors which influence other physical properties, such as fiber length, beating, kind and quality of sizing, and formation of the sheet, yet there is no direct relationship between the wet and dry strengths of paper.

81. TAPPI Committee on Paper Testing. [Tensile or breaking strength]. Paper Trade J., 75, no. 4:44-45 (July 27, 1922)

814. The Schopper tensile tester. Wet tensile strength is also discussed; the strips are immersed in water at 70°F. for 20 minutes and a speed of 6 inches per minute is applied to the lower jaw.


The ultimate wet strength means the strength of the material after complete saturation with a liquid. Normal wet strength means the strength of the material after it has been wetted to an extent comparable with normal use conditions. For certain materials, such as tissue and unsealed papers, the two may be the same. The apparatus consists of a tensile tester (cf. T 404-m) and a Finnish wet-strength device. The test is made according to TAPPI Standard T 404-m, using strips that have been wetted in liquids at 75 ± 2°C. The Finnish device (No. F12) is used for wetting papers that are difficult to handle when wet. For ultimate wet strength determine the required time of immersion by measuring test strips for various periods of time and determining their tensile strength at the end of each period until no further significant loss in tensile strength occurs. To obtain normal wet strength values, the time of immersion for paper towels shall be 15 ± 3 seconds and for blueprint and other photographic papers 20 ± 2 minutes, using water in each case.
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WATER ABSORPTION


Water Absorption. A specimen 12 x 12 inches shall be dried at 160°F for 24 hours and cooled to room temperature in a dry atmosphere. The thickness of the sample shall be measured and the volume calculated therefrom. The sample shall then be carefully weighed and submerged horizontally under 1 inch of distilled water maintained at 70 ± 5°F. After 2 hours of submersion, the sample shall be stood on end to drain for 10 minutes, at the end of which time the excess surface water shall be removed by hand with a blotting paper or paper towel and the sample immediately weighed, the volume of absorbed water calculated, and the water absorption expressed in percentage by volume based on the initial volume.


This method is the same as that given by the National Bureau of Standards.

818. TAPPI. Water absorptiveness of nonbibulous paper and paperboard. TAPPI Standard T 441 m-42. 1 sheet.

This method is based upon the method of Cobb and Lowe [Paper Trade J. 92, no. 12:43-46(March 22, 1934)] and Cobb [Paper Trade J. 100, no. 16:42-45(April 18, 1935)]. It is suitable for determining water penetration into paper and board 0.004 inch or more in thickness. In the test a definite area of one side of the specimen is wet uniformly at the moment that the count of time is begun. Penetration occurs only through the test area and no possibility exists of wetting the edges or other portion of the specimen other than the area under test. The absorption of water is stopped at the end of the test by removal of all surface water. An accurate weight of the specimen is obtained before and after exposure to the water. Loss of moisture between the expiration of the test period and the time of weighing is avoided. A suitable apparatus and procedure are described.
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