Standard Test Method for Folding Endurance of Paper by the Schopper Tester[1]

This standard is issued under the fixed designation D 643; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes the use of the Schopper type of folding apparatus. It is suitable for papers having a thickness of 0.25 mm (0.010 in.) or less.

1.2 The procedure for the M.I.T.-type apparatus is given in Test Method D 2176.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Product[2]

D 685 Practice for Conditioning Paper and Paper Products for Testing[2]

D 776 Test Method for Determination of Effect of Dry Heat on Properties of Paper and Board[2]

D 1968 Terminology Relating to Paper and Paper Products[2]

D 2176 Test Method for Folding Endurance of Paper by the MIT Tester[2]

D 4714 Test Method for Determination of Effect of Moist Heat (50 % Relative Humidity and 90°C) on Properties of Paper and Board[2]

E 122 Practice for Calculating Sample Size to Estimate, with a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process[3]

2.2 *ISO Standard:*

ISO 5626 Paper Determination of Folding Endurance[4]

3. Terminology

3.1 *Definitions*—Definitions shall be in accordance with Terminology D 1968 and the *Dictionary of Paper.*[5]

4. Significance and Use

4.1 Folding endurance is not a measure of the foldability of paper, but a measure of the strength of paper. In many cases, it is a better measure of strength than the conventional tests for tensile strength, bursting strength, and tearing resistance. The uniqueness of the folding endurance tests leads to many special uses for this test method.

4.2 Folding endurance is determined by the number of times that the paper can be folded before it loses enough tensile strength to break under the conditions of the test. It is the only one of the four strength tests that uses a repetitive mechanical treatment to weaken the sheet. Therefore, it is the only one of the strength tests that measures the durability of paper subjected to repeated or rough handling. It is an important test for paper that will be subjected to continued folding and unfolding during use. Examples are maps and printed materials such as music, pamphlets, folded prints, and blueprints. It is also an important test for any paper that will be handled repeatedly or which might be subjected to rough treatment when it is being used.

4.3 The ratio between the machine direction and cross direction folding endurance is a good measure of the fiber orientation in the sheet. For most papers, the machine direction test will be higher than the cross direction test, and the more the fibers are oriented in the machine direction, the greater the difference will be. If the cross direction is higher than the machine direction, the paper has an unusually large number of fibers oriented in the cross direction. This information may also be obtained from tests for tensile strength and tearing resistance but the folding endurance test is much more sensitive to these differences than the other two tests.

4.4 Folding endurance is more sensitive to the flexibility in the paper than the other strength tests. Because flexibility is lost with aging, folding endurance is commonly used as an indicator of strength loss in accelerated aging tests.

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[2] *Annual Book of ASTM Standards*, Vol 15.09.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] Available from the Technical Association of the Pulp and Paper Industry, P.O. Box 105113, Atlanta, GA 30348.

4.5 The folding endurance test is made on a very small section of the paper (15 mm by approximately 1 mm). The test is sensitive to very small changes in the paper, and as a result there will be a significant variation in the tests made on the same sheet using these very small test areas. The better the formation, the smaller this variation will be. Therefore, the variation in individual fold numbers is an indirect indication of the uniformity of the formation.

4.6 Variability of data from tests made on the same sheet of paper has sometimes raised concerns regarding the value of the folding test. This variability comes in part from the sensitivity of the test to changes in the papermaking process, and in part from the very wide range of values that will be encountered for apparently similar papers. For example, low fold endurance papers may have values as low as two or three folds, while strong papers will withstand 5000 or more folds. Other strength tests might typically vary by an order of magnitude for strong and weak papers, but would not approach the 1000-fold differences sometimes seen for fold. A process or furnish change causing a 10 % change in fold might not be detected by another strength test such as tensile or tear. Folding endurance is a reliable measure of paper strength, particularly for the grades mentioned in 4.2; however, differences in the range of 10 % in fold numbers may not have practical significance.

4.7 The fact that a small difference between two fold numbers is not significant creates a problem as to what should be considered a significant difference. A difference of 30 between averages of 20 and 50 would be very significant, but a difference of 30 when the averages are 600 and 630 would be meaningless. To solve this problem, folding endurance is reported as the average of the logarithms of the individual fold numbers. For example, the fold numbers of 20 and 50 become folding endurances of 1.301 and 1.699 or a difference of 0.398, which would be a significant difference. The fold numbers of 600 and 630 would become folding endurances of 2.778 and 2.799, or a difference of only 0.021, which would not be a significant difference.

NOTE 1—To determine the difference that must be exceeded in order to consider the difference to be significant, follow the same procedure that would be used to calculate the precision of any other strength test. However, for other strength tests, the absolute value will usually increase as the average test value increases and as a result, the repeatability is expressed as a percentage. Because the folding endurance is expressed as the logarithm of the fold number, the absolute repeatability value may represent all levels of folding endurance. The value will vary depending upon the variability of the paper being tested, but it should not vary because of the magnitude of the folding endurance. The repeatability should be about the same for a fold number of 600 as it is for a fold number of 60.

5. Apparatus

5.1 *Folding Tester*, consisting of the following:

5.1.1 *Clamping Jaws*, two horizontally opposed and movable, which hold a specimen 100 mm (4 in.) long under variable tension during the folding cycle, while a slotted folding blade, sliding back and forth between four creasing rollers, folds the paper at 105 to 125 double folds/min. The clamps are supported from below on rollers, and while in motion, are freely suspended between tension springs. The folding blade is 0.50 ± 0.0125 mm (0.020 ± 0.0005 in.) thick, with a vertical folding slot 0.50 ± 0.0125 mm (0.020 ± 0.0005 in.) wide, the slot extending somewhat above and below the normal position of the test specimen. The vertical edges of the slot are cylindrical, with radius equal to half the thickness of the blade. The four creasing rollers, each 6 mm (approximately 0.25 in.) in diameter and 18 mm (approximately 0.75 in.) long, are arranged symmetrically about the midposition of the folding slot, and provided with antifriction or jeweled bearings.

5.1.2 *Counter*, to register the number of double folds and to stop the instrument when the specimen breaks.

5.1.3 *Motor*—A means of imparting approximate harmonic motion to the reciprocating blade at 115 ± 10 double folds/min.

5.2 *Cutter*, to provide test strips, 15.0 ± 0.1 mm (0.590 ± 0.004 in.) wide, with clean edges.

5.3 *Calibration Equipment*:

5.3.1 A device for applying a tension of 7.60 N (780 gf) on the spring loaded jaw as specified in the calibration instructions.

5.3.2 A device for measuring a variable tension on the spring loaded jaw ranging from 9.3 to 10.3 N (950 to 1050 gf) as specified in the calibration instructions.

6. Sampling

6.1 If the paper is being tested to determine the acceptance of a lot, obtain a sample in accordance with Practice D 585.

6.2 Where testing is for purposes other than acceptance, Practice E 122 may be used as an alternative for sampling purposes.

7. Test Specimens

7.1 From each conditioned sample, cut ten specimens in each principal direction of the paper, with each specimen having a width of 15.0 ± 0.1 mm (0.590 ± 0.004 in.) and a length of 100 mm (4 in.). Select specimens that are free from wrinkles or blemishes not inherent in the paper and be sure that the area where the folding is to take place does not contain any portion of a watermark and appears to be of average opacity.

7.2 Handle each specimen by an end and do not touch it with hands in the region in which it is to be folded.

8. Adjustment and Calibration

8.1 Test the clamps as follows:

8.1.1 Insert a specimen in place and alternately apply and release the tension a number of times. Then, with tension released, note whether the specimen remains smooth and straight as originally inserted. Buckling or waviness indicates a faulty clamp which has allowed the specimen to slip.

8.1.2 Inspect and correct the supporting rollers for worn surfaces and for bearing friction. Adjust the rollers so that they do not bind against the clamps in any position. With a feeler gage, check the four creasing rollers for parallelism and clearance. Also, make sure that the two edges of the folding slot are parallel with each other and with the creasing rollers. The distance between the folding blade and the two creasing rollers on each side is required to be 0.38 ± 0.05 mm (0.015 ± 0.002 in.), and the width between the rollers of the space occupied by the unbent specimen should be approximately 0.5

mm (0.02 in.). As a final test of alignment, fold a specimen somewhat short of failure, and inspect it for uniformity of wear along the crease. If the specimen seems weaker at one end of the crease than at the other, and the ends of the strip are satisfactorily clamped, this indicates faulty alignment of the rollers or the folding slot and will lead to low folding results.

8.1.3 Using a dead-weight load of 780 g, adjust the tension on the springs attached to the clamps so that the tension on the specimen during a test is 7.60 ± 0.1 N (780 ± 10 gf) when the clamps are farthest apart (when the specimen is straight and free). Instructions for making these adjustments are given in X1.3. These adjustments are preferably made *in situ*, with the aid of a calibrating device that automatically ensures that the two clamps are extended the proper distance. A device for making this measurement is described in X1.1 and X1.2. If such a device is not used, the operator should make sure that the clamps are extended the same distance and that this is the distance that they will be extended when a test specimen is in place ready for the test to begin.

8.1.4 After the minimum tension is properly set, tighten the small Allen setscrew on the barrel to lock the 7.60 N setting in place. For routine calibrations, the maximum tension does not need to be checked and the calibration is completed. When new springs are installed and occasionally during routine calibrations, check the maximum tension to determine whether both jaws are the same.

8.1.5 Instructions for measuring the maximum tension are given in X1.3.2. If the maximum tension of the two jaws differs by more than 0.5 N (50 gf), a new set of matched springs should be installed. If the variable weight specified in X1.3.2 is not available, a rough check may be made using the 1000 g weight to check the maximum tension. If both jaws check at 1000 gf, there is no need to make further measurements. However, if the maximum tension is not 1000 gf, do not adjust the minimum tension spring settings previously established. See Note 2.

NOTE 2—The minimum tension is the most important value and should be set as accurately as possible at 7.60 N (780 gf). The specimen always breaks at minimum tension because the change in the direction of the fold gives the specimen a shock that breaks it. The specimen never breaks at the maximum tension because there is no shock at that point, and the gradual increase in tension will not cause it to break. Therefore, the value of the maximum tension is not important, but the difference between the maximum tension of the two jaws is important because a difference in maximum tension is a definite indication that the springs are not matched.

8.1.6 Adjust and calibrate the instrument at least once a month if it is in continual use, or immediately before a test if not used on a regular basis.

9. Conditioning

9.1 Prior to cutting test specimens, condition the paper in an atmosphere in accordance with Practice D 685.

9.2 As folding endurance is very sensitive to the moisture content of the specimen, it is important to strictly observe the requirements for preconditioning from the dry side, for both conditioning and conditions during testing.

10. Procedure

10.1 Lock the vertical slot of the reciprocating blade in its central position. Without touching the center of the specimen, place it in the slot and fasten the ends firmly and squarely in the jaws with the surface of the specimens lying wholly within one plane.

10.2 Apply the specified tension and fold the specimen at a uniform rate of approximately 115 double folds/min until it breaks.

10.3 Record the number of double folds made before fracture.

11. Report

11.1 *Reporting Terminology*:

11.1.1 *fold number*—the number of double folds required to cause failure of the test specimen.

11.1.2 *folding endurance*—the logarithm to the base 10 of the fold number.

11.1.3 Specimens with their length in the machine direction are measuring the strength of the paper in the machine direction and are reported as machine direction fold numbers and machine direction folding endurance.

11.1.4 Specimens with their length perpendicular to the machine direction are measuring the strength of the paper in the cross direction and are reported as cross-direction fold numbers and cross-direction folding endurance.

11.2 For each test unit, report the following measurements separately for machine direction tests and cross direction tests:

11.2.1 *Fold Number*—For the direction of each test unit, report the average number of double folds prior to failure; the range of these fold numbers; the standard deviation of the individual fold numbers; and the number of specimens tested.

11.2.2 *Folding Endurance*—For the direction of each test unit, convert the individual fold numbers to the equivalent common logarithm (log to the base 10), using a table of common logarithms or a calculator. Determine the average, range, and standard deviation of these individual logarithms and report these values as the average, range, and standard deviation of the folding endurance.

11.3 As agreed upon between the users of this test method, only the fold number, or the folding endurance, or both values may be reported.

11.4 As agreed upon between the users of this test method, only the standard deviation or the range, or both may be reported.

NOTE 3—It is important that the folding endurance be determined by averaging the individual logarithms. The logarithm of the average fold number will not be the same as the average of the individual logarithms. The distribution curve of fold numbers will be skewed, and the conversion to logarithms reduces the skewness, giving a more realistic average. This also makes it possible to calculate the standard deviation of the folding endurance from the individual values.

12. Precision and Bias

12.1 *Precision (Fold Number)*:

12.1.1 *Repeatability*—The repeatability standard deviation and the 95 % repeatability limits for fold number, both calculated as the percent coefficient of variation (standard deviation divided by the mean value of the samples tested multiplied by

100 and 95 % repeatability limit divided by the mean value of the samples tested multiplied by 100, respectively) are 5 and 15 %.

12.1.2 *Reproducibility*—The reproducibility standard deviation and the 95 % reproducibility limits for fold number, both calculated as the percent coefficient of variation (standard deviation divided by the mean value of the samples tested multiplied by 100 and the 95 % reproducibility limit divided by the mean value of the samples tested multiplied by 100, respectively) are 14 and 40 %, respectively.

12.2 The results produced by the procedure in this test method are very sensitive to errors in adjustment and calibration of the instrument and to variations in relative humidity. Therefore, unless the instructions for adjustment and calibration in Section 8 and the instructions for conditioning in Section 9 are diligently followed, the precision may not be equal to that in 12.1.

12.3 *Bias*—No statement may be made about the bias of the procedure in this test method as folding endurance is defined only in terms of this procedure and test instrument. No statement may be made about the results in comparison to folding endurance measured, using other procedures or equipment such as that found in Test Method D 2176, where results may be the same, less than, or more than those in the procedure in this test method, depending upon the nature of the specific sample tested.

13. Keywords

13.1 blueprints; folded paper products; folding endurance; Schopper fold endurance

APPENDIX

(Nonmandatory Information)

X1. INSTRUCTIONS FOR USE OF CALIBRATING DEVICE

X1.1 Apparatus

X1.1.1 See Fig. X1.1.

X1.1.2 *Wire-Pulling Frame*.

X1.1.3 *Blocks*, two, with protruding limit guides (one for 1000 gf extension, the other for 780 gf extension).

X1.1.4 *Upright*, with free-turning pulley.

X1.1.5 *Weights*, 1000 and 780-g.

X1.1.6 *Brackets*, for use with the upright.

X1.2 Mounting

X1.2.1 Screw the upright brackets to each side of the base so that when the upright with the free-turning pulley is placed in the bracket cutout, the center of the pulley is exactly in line with the center of the barrels, the center of the jaws, the center of the bearing block, and the movement of the jaws.

X1.2.2 Place the wire-pulling frame over one of the barrel assemblies and central bearing blocks. Grip the flat metal tang of the frame in the jaw of the other assembly so that the top of the tang is flush with the top of the jaw.

X1.2.3 With the flywheel of the instrument in its locked position, place the block with protruding limit guides on the sliding mechanism, so that the sliding arm fits into the cutout of the block and that the protruding limit guides at the top of the block extend out over the wire-pulling frame. Insert the upright with free-turning pulley in its bracket. Hook the string attached to the weight to the center of the end section of the wire-pulling frame, and pass the string over the pulley to hold the weight vertically.

X1.3 Operation

X1.3.1 There are two sets of limit guides: one set to measure the minimum tension and the second to measure the maximum tension. With the minimum tension guide in position, pull the barrel mechanism to its outward position and gently release the suspended 780-g weight. When the spring of the jaw is correctly calibrated, the jaw will barely touch the edge of the protruding limit guide. If the jaw does not reach the protruding limit guide or if it touches and is stopped by it, loosen the small Allen setscrew on the rear side of the barrel and turn the knurled knob one way or the other, until contact is just barely made. Reset the Allen setscrew to lock the setting in place.

X1.3.2 *Determining Maximum Tension*—Determination of the maximum tension requires a device weighing less than 1000 g which is designed so that the weight can be increased by adding balance weights. Replace the minimum tension guide with the maximum tension guide, and replace the 780-g weight with the variable weight. Add weight until the jaw barely touches the maximum tension guide. Record the weight that was required. Do not make any adjustments in the spring tension.

X1.3.3 Apply the procedure outlined in X1.3.1 and X1.3.2 to the other jaw after reversing the position of the wire-pulling frame and the upright with the free-turning pulley.

X1.3.4 If the maximum tension of the two jaws differs by more than 50 gf, new matched springs should be installed.

X1.4 Other Fold Testing Instruments

X1.4.1 This test method is limited to the Schopper tester, but several other instruments have been developed to measure folding endurance. ISO 5626 covers the Schopper instrument, along with three other instruments. The general comments about folding endurance that are included in 4.1 apply to all four instruments but it should be recognized that the instruments differ in design and the numerical values obtained will not be the same. Although the numerical values will be different, the four instruments will usually rank a group of

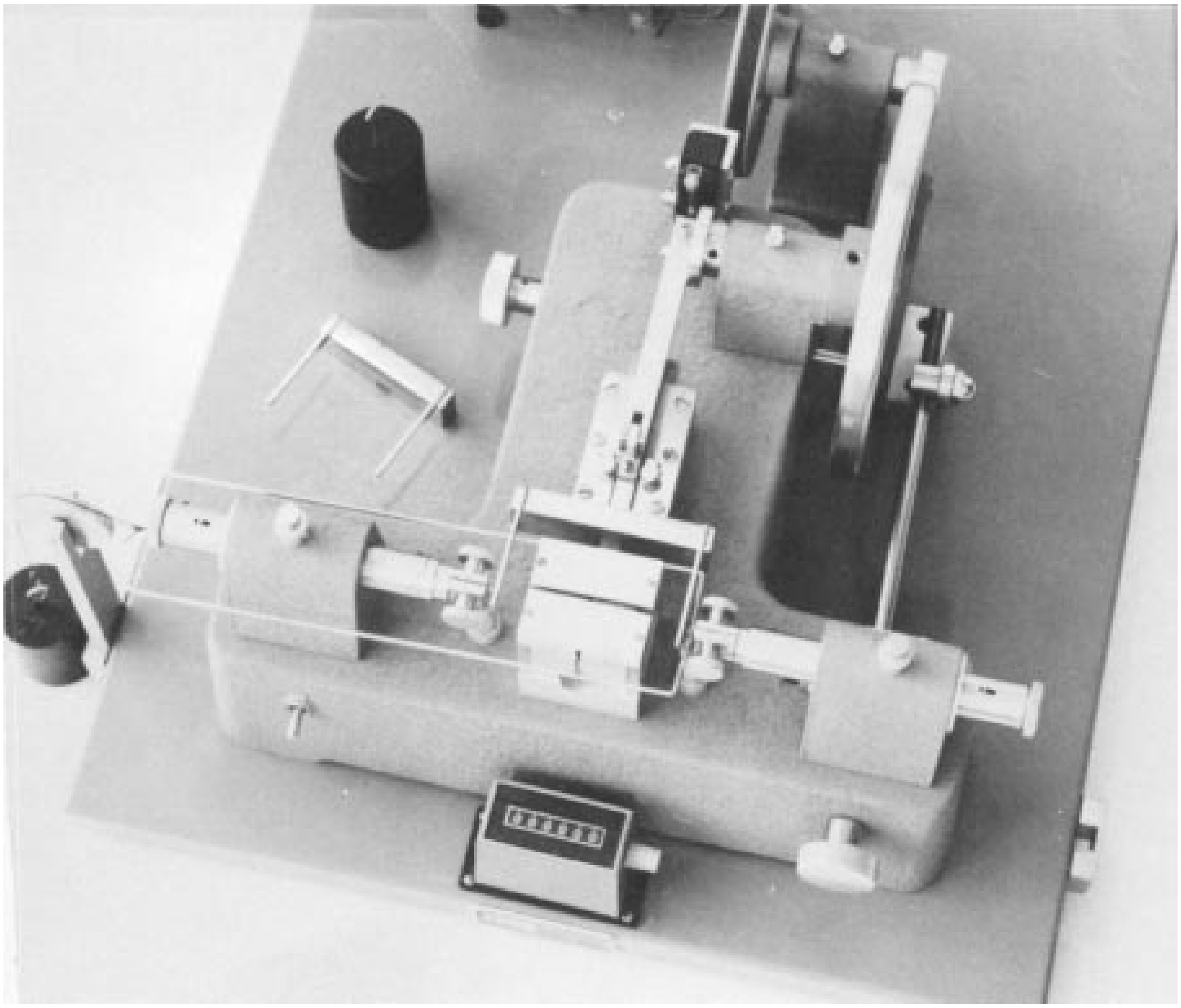

FIG. X1.1 Schopper-Type Tester Showing Calibrating Device in Place

papers in the same order. If the ranking is different, a knowledge of the difference in the design of the instruments could provide an indication of the characteristics of the papers which caused them to be ranked in a different order.

X1.4.2 The Lhomargy tester is the French version of the Schopper instrument. The folding is accomplished by a slotted blade and a set of rollers similar to those used in the Schopper. However, the tension is applied by weights instead of matched springs, keeping the tension constant throughout the test. The method provides the option of making the test at tensions of 4.01, 7.60, or 9.81 N.

X1.4.3 The MIT tester is covered by Test Method D 2176. The design of the MIT and Schopper instruments are different in many ways, but the most important difference is the method used to fold the paper. The slotted blade and the rollers are replaced by a rotating jaw. This eliminates the shock that occurs when the direction of the fold is reversed in the Schopper instrument and also eliminates the maximum and minimum tensions. The matched springs used in the Schopper instrument are replaced by a single spring that is automatically calibrated for every test. The standard tension is 1 kg, but other tensions may be used.

X1.4.4 The Kohler-Molin tester is more closely related to the MIT tester than it is to the Schopper tester. However, the tension is applied by a weight on the lower jaw instead of a spring on the upper jaw, and the upper jaw is the rotating jaw. A tension applied by use of an 800 g (7.95 N) weight is used.

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