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An American National Standard

Standard Test Method for Folding Endurance of Paper by the M.I.T. Tester[1]

This standard is issued under the fixed designation D 2176; 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 M.I.T.-type folding apparatus for determining folding endurance of paper. The M.I.T. tester can be adjusted for papers of any thickness; however, if the outer fibrous layers of paper thicker than about 0.25 mm (0.01 in.) rupture during the first few folds, the test loses its significance. The procedure for the Schopper-type apparatus is given in Test Method D 643. This test method is the technical equivalent of TAPPI T 511.

1.2 *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 Products[2]

D 643 Test Method for Folding Endurance of Paper by the Schopper Tester[2]

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

D 1968 Terminology Relating to Paper and Paper Products[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]

3. Terminology

3.1 Definitions shall be in accordance with Terminology D 1968 and the *Dictionary of Paper.*[4]

4. Significance and Use

4.1 The folding endurance of a paper is frequently used to estimate the ability of the paper to withstand repeated bending, folding, and creasing, and may be encountered as a measure of the quality of bank note paper, or document paper.

4.2 Folding endurance has also been found useful in measuring the deterioration of paper upon aging.

5. Apparatus

5.1 *Folding Tester*, consisting of:

5.1.1 A spring-loaded clamping jaw constrained to move without rotation in a direction perpendicular to the axis of rotation of the folding head specified below and having its clamping surfaces in the plane of this axis. The load is applied by a spring attached to the jaw assembly which is easily adjustable to provide any desired tension on the specimen within range of 4.9 to 14.72 N (500 to 1500 gf). The deflection of the spring when loaded shall be at least 17 mm (0.67 in.) /9.81 N, which is achieved by using a weight of 1 kg mass.

5.1.2 An oscillating folding head supporting two smooth, cylindrical folding surfaces parallel to, and symmetrically placed with respect to, the axis of rotation. Each of the two folding surfaces shall have a radius of curvature of 0.38 mm (0.015 ± 0.001 in.) and a width of 19 mm (0.75 in. ± 0.04 in). The distance separating the folding surfaces is greater than the uncompressed thickness of the paper being tested by no more than 0.25 mm (0.010 in.). The position of the axis of rotation is midway between the common tangent planes of the two folding surfaces. The folding head is provided with a clamping jaw with its nearest edge not less than 9.5 mm (0.375 in.) beyond the axis of rotation. The rotary oscillating movement of the head is such as to fold the paper through an angle of 135° ± 2°, both to the right and to the left of the position of the unfolded specimen.

5.1.3 Various size folding heads are required for testing different thicknesses of paper. Heads available will accommodate thicknesses from 0 to 0.25 mm (0 to 0.01 in.), 0.25 to 0.50 mm (0.01 to 0.02 in.), 0.50 to 0.75 mm (0.02 to 0.03 in.), 0.75 to 1.02 mm (0.03 to 0.04 in.), and 1.02 to 1.25 mm (0.04 to 0.05 in.).

5.2 *Power Driven Device*, for imparting a rotary oscillating motion of 175 ± 25 cycles/min to the folding clamp.

5.3 *Counter*, for registering the number of double folds required to break the specimen and a device to stop the instrument when the specimen breaks.

5.4 *Strip Cutter*, to cut 15-mm wide parallel strips within ±0.02 mm with clean edges.

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[1] This test method is under the jurisdiction of ASTM Committee D06 on Paper and Paper Products and is the direct responsibility of Subcommittee D06.92 on Test Methods.

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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 the Technical Association of the Pulp and Paper Industry, P.O. Box 105113, Atlanta, GA 30348.

5.5 A means for controlling the temperature of the folding head so that, during folding, it does not increase more than 0.5°C. Temperature rises of this magnitude will reduce the relative humidity at the fold by more than 2 % and the number of folds by as much as 10 %. A common method for controlling the temperature of the folding head is by allowing an exhaust fan to draw conditioned room air from air rapidly over both the specimen and head. The fan should be of the centrifugal type not less than 50 mm in diameter, mounted so that its inlet is adjacent to the folding head. Other methods that prevent heating of the folding head within the tolerances specified are acceptable.

6. Sampling

6.1 *Acceptance Sampling*—Acceptance sampling shall be done in accordance with Practice D 585

6.2 *Sampling for Other Purposes*—The sampling and the number of test specimens depends upon the purpose of the testing. Practice E 122 is recommended

7. Conditioning

7.1 Condition the samples as required in D 685.

7.2 Folding endurance measurements are very sensitive to the moisture content of the paper. It is most important to observe all the requirements of Practice D 685 with regard to preconditioning from the dry side, conditioning, and maintaining the conditioned environment for testing when making folding endurance measurements.

8. Test Specimen

8.1 From each conditioned test unit cut ten specimens accurately and cleanly to a width of 15 ± 0.02 mm and a length of not less than 130 mm, and preferably 150 mm or longer in each of the principal directions of the paper. Test specimens must be cut from paper free of wrinkles or blemishes not inherent in the paper. The portion of the test specimen where folding will occur must be free of any portion of a watermark and have opacity and formation typical of the sample. Because the folding process occurs over a very short length of the total test specimen (that is, at the line of fold), data precision is heavily dependent upon the care taken in test specimen selection and preparation.

9. Instrument Maintenance and Calibration

9.1 The folding test results are very sensitive to tension, arc of fold, and radius of fold; therefore it is essential that regular calibration routines be established and followed.

9.2 Make sure that the folding edges are free from rust, nicks, dirt, and oil and that the counter operates properly.

9.3 Measure the plunger friction by determining the additional load required to move the plunger perceptibly under a load of 9.81 N or the load tension used for the testing. This shall not be greater than 0.245 N (25 gf).

9.4 The change in tension due to the eccentricity of rotation of the folding edges is measured as follows: Place a test specimen of strong paper of the proper thickness, cut in the machine direction, in the tester as for making a folding test, and apply a tension of 9.81 N or that to be used for the testing. Rotate the folding head slowly by hand throughout the entire folding cycle and measure the maximum change in displacement of the plunger with an accuracy of 0.1 mm (0.004 in.). This displacement shall not be greater than that produced by adding a weight equivalent to 0.343 N (35 gf).

NOTE 1—The displacement must be equally centered around the plunger position when the strip of paper is straight and the tension is 9.81 N, that is, when the slot in the following head is vertical.

9.5 The curvature of the folding edges can be measured by making casts, magnifying them in profile, and comparing them to true circles.

9.6 The two folding edges shall be at the same elevation when the slot head is vertical.

10. Procedure

10.1 Perform testing in an atmosphere in accordance with Practice D 685. Handle the test specimens only by the ends, taking care not to touch them in the region in which they will be folded.

10.2 Turn the oscillating folding head so that the opening is vertical. Turn the motor control switch to the off position. Place a 1-kg weight on the top of the plunger (equivalent to the tension desired on the specimen); tap the plunger sideways to minimize friction effects and lock it in position. Without touching the part of the strip to be folded, clamp the specimen lying wholly within one plane, that is, flat, and with the sides, parallel to, and not touching the oscillating jaw-mounting-plate. Remove the weight and unscrew the plunger lock to apply the specified tension to the test strip. If the reading of the load indicator changes, reclamp the specimen to give it its proper tension. Zero counter, then start motor.

NOTE 2—The number of the folds may vary by as much as the cube of the applied tension. Use a tension of 9.81 N (1 kgf), but if this gives an unreasonably high or low test result, use more or less tension: 14.72 N or 4.9 N (1.5 or 0.5 kgf) and state the actual tension used in a prominent position in the report.

10.3 Set the counter to zero and place the centrifugal fan so that its inlet is almost touching and is across the specimen and oscillating head. Start the fan and the instrument motor. Fold the strip at a uniform rate of 175 ± 25 double folds per minute until it breaks. Record the number of double folds made before fracture. If there is any appreciable delay between tests on successive specimens, keep the fan running to prevent the head warming by conduction from its shaft.

11. Report

11.1 For each test specimen record the number of double folds for the machine and cross directions. Convert the raw data to the logarithm (base 10). Calculate the mean of the logs and report as $\log_{10}$ MIT folding endurance for each direction separately, to two significant figures for the mantissa. State clearly if a tension other than 9.81 N (1 kgf) was used. Include the number of specimens tested, and the standard deviation of the $\log_{10}$ of the fold number obtained in each direction.

11.2 Alternate report permitted. Although the preferred method for reporting MIT folding endurance is that in 11.1, an alternate procedure of reporting the mean of the number of double folds and the standard deviation for the machine and cross directions of the paper separately is permitted.

11.3 Tests made on strips having their length in the machine direction are designated as being the "machine direction," and similarly for the cross direction.

12. Precision and Bias

12.1 *Precision*:

12.1.1 The repeatability standard deviation for folding endurance has been determined to be 20 % and the reproducibility standard deviation for folding endurance has been determined to be 28 %.

12.1.2 These estimates of precision are based upon an inter-laboratory study of one grade of printing paper tested in both machine direction and cross machine direction in eight laboratories conducted by a committee of TAPPI and reported in TAPPI Test Method T 511. The average machine and cross direction folding endurance values for the sample tested were 1.32 and 0.80, respectively.

12.1.3 The repeatability and reproducibility standard deviation for folding endurance reported in a previous revision of this test method were 6 and 19 %. The source of that precision study is unknown.

12.1.3.1 A note accompanying that precision estimate in the previous revision of the standard noted that the results of the test method are very susceptible to small errors in adjustment and calibration of the instrument and in the relative humidity of the test environment. It was estimated that limits twice those in 12.3 might be expected if all steps in the test method were not followed meticulously.

12.1.4 The repeatability and reproducibility of the test method may differ by being either greater or smaller than the values in either 12.1.2 or 12.1.3 for various types of paper.

12.2 *Bias*:

12.2.1 No information can be presented regarding the bias of fold endurance by the M.I.T. tester, as the measured value is defined by the procedure in the test method. No information is given regarding the bias between folding endurance as measured in this test method using the M.I.T. tester and that measured in Test Method D 643 using the Schopper Tester because the instruments apply folding stress to the test specimen in different ways and the relationship between results by the two procedures is not a constant value.

13. Keywords

13.1 fold number; folding endurance; paper