WI 120808.19

T 511

DRAFT NO. 2

DATE Fall 2013

WORKING GROUP
CHAIRMAN John Walkinshaw

SUBJECT
CATEGORY Physical Properties

RELATED
METHODS See "Additional Information"

Folding endurance of paper (MIT tester)
(Revision of T 511 om-08)
(underscores and strikeouts indicate changes from Draft 1)

1. Scope

1.1 This method describes the use of the MIT-type apparatus for the determination of the folding endurance of paper. An exhaust fan arrangement maintains the folding head at room temperature.

1.2 The MIT tester is suitable 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.

1.3 The procedure for the Schopper-type apparatus is given in TAPPI T 423 "Folding Endurance of Paper (Schopper-Type Tester)."

Approved by the Standard Specific Interest Group for this Test Method
TAPPI

2. Significance

2.1 Folding endurance tests have been used to estimate the ability of paper to withstand repeated bending, folding, and creasing.

2.2 Folding endurance has also been useful for measuring the deterioration of paper upon aging.

3. Definitions

3.1 *Folding endurance*, the logarithm (to the base 10) of the number of double folds required to break the paper when a strip of paper 15 mm (0.59 in.) wide is tested under a standard tension of 9.81 N (1 kgf).

3.2 *Double fold*, one complete oscillation of the test piece, during which it is folded first backwards then forwards about the same line.

4. Apparatus

4.1 *Folding tester*[1] consisting of:

4.1.1 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 the range of 4.9 - 14.72 N (500 - 1500 gf). The deflection of the spring when loaded shall be at least 17 mm (0.67 in.) per 9.81 N, which is achieved by using a weight of 1 kg mass.

4.1.2 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 ± 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.

4.1.3 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.), 1.02 to 1.25 mm (0.04 to 0.05 in.).

4.2 *Power driven device*, for imparting a rotary oscillating motion of 175 ± 25 cycles/min to the folding clamp.

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

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[1] Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list in the set of TAPPI Test Methods, or may be available from the TAPPI Quality and Standards Department.

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

4.5 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 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 which prevent heating of the folding head within the tolerances specified are acceptable.

5. Calibration

5.1 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.

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

5.2.1 Measure the plunger friction by determining the additional load required to move the plunger perceptibly under a load of 9.81 N (1kgf) or the load tension used for the testing. This shall not be greater than 0.245 N (25 gf).

5.3 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 (1kgf) 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, i.e., when the slot in the folding head is vertical.

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

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

6. Test specimen

Obtain a sample of the paper to be tested in accordance with TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Products." From each test unit of the paper obtain 10 representative specimens in each principal direction of the paper (condition paper prior to cutting) cut accurately to a width of 15 ± 0.02 mm and a length of not less than 130 mm. A 150-mm or longer strip is preferable to provide easier insertion in the clamps. Select specimens that are free from wrinkles or blemishes not inherent in the paper and make 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. The long edges shall be clean cut and parallel.

7. Conditioning

Condition and test the paper in an atmosphere in accordance with TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products."

8. Procedure

8.1 Turn the oscillating folding head so that the opening is vertical. Turn 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; remove the weight. Without touching the part of the strip to be folded, clamp the specimen lying wholly within one plane, i.e., flat, and with the sides, parallel to, and not touching the oscillating jaw-mounting-plate. 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.

8.2 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.

9. Report

9.1 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.

9.2 Alternate report permitted. Although the preferred method for reporting MIT folding endurance is that in 9.1, 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.

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

10. Precision

10.1 The following estimates of precision are based on an interlaboratory study with one grade of printing paper, tested in both the machine and cross machine direction, in eight laboratories. Results are reported in accordance with TAPPI T 1200 "Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility." For the grade of printing paper tested, the average number of double folds is 121 in the machine direction and 63 in the cross direction.

10.2 Repeatability (within a laboratory) = 92% of double folds, or 20% of $\log_{10}$ double folds.

10.3 Reproducibility (between laboratories) = 131% of double folds, or 28% of $\log_{10}$ double folds.

10.4 Repeatability and reproducibility are estimates of the maximum difference (at 95%) which should be expected when comparing replicate measurements for materials similar to those described above under similar test conditions. These estimates may not be valid for different materials or testing conditions.

NOTE 3: This method is very susceptible to small errors in adjustment and calibration of the instrument and in the relative humidity of the test room. Limits as much as two times those shown may be expected if the instructions are not followed meticulously. The repeatability of the measurement is also sensitive to small differences in the radius of the folding edges.

11. Keywords

Paper, Folding endurance, MIT folding testers

12. Additional Information

12.1 Effective date of issue: to be assigned.

12.2 The 1996 revision included a revised precision statement. The 1988 revision consisted of the following: The definition of the folding endurance was revised to reflect the reporting of the results as the log 10 of the number of double folds required to break the specimen under the test conditions. The report was changed to permit the results to be reported as the log 10 MIT folding endurance or number of double folds. The method was also put into current format for TAPPI Test Methods. ~~This~~ The 2008 revision resulted from an early review designed have a safer way to preload the plunger that will reduce the possibility of causing the 1-kg weight to fall; changes to Section 8.1 were made.

12.3 The rationale for reporting the log 10 fold is as follows:

12.3.1 The greatest source of test variability is that the folding stresses are applied to a very small area of paper. Failure occurs at this point and not, as in normal tensile test, at the weakest point in the test strip. Thus, "within-sample" variability is great. In addition, the fold test operates cumulatively, the reduction in strength at the test point being approximately exponential. Therefore, it is possible for two test pieces of similar initial tensile strength at the test points and with identical rates of loss of strength with folding to give very different folding numbers. It is thus unfortunate that the number of double folds has been used to represent folding endurance. A suitable fractional power of the fold number of the log 10 of the fold number provides a much more realistic and less misleading result.

12.3.2 Van Nederveen and Van Royan *(1)* found that the loss in strength of paper due to repeated folding is a linear function of the logarithm of the number of folds. Krohnstad *(2)* reported a linear relationship between the load applied during folding and the logarithm of the number of folds. Andersson *(3)* showed that folding endurance data expressed as the logarithm of the number of folds are normally distributed and thus, amenable to further statistical analysis. Naoumof *(4)* and Korn *(5)* supported the view that the log of the fold number is a better measure of the folding endurance of paper than the fold number itself.

12.4 The reporting of the log fold is supported by ISO/TC6/SC2/W5 (Secretariat-2) June 8, 1968 and ISO 5626 dated November 15, 1993.

12.5 Related methods: ~~ASTM 2176;~~ Canadian PAPTAC D.17P ~~PAPTAC D.17P~~; AS/NZS/1301.423; ~~British BSI 4419;~~ ISO 5626.

Literature cited

1. Van Nederveen, G., and Van Royen, A.H.H., *Papierwereld* **6**(5): 41 (1951).
2. Krohnstad, W., *Norsk Skogind* **10**(2): 58 (1956).
3. Andersson, O., *Svensk Paperstid*. **54**(17): 591 (1951).
4. Naoumof, R., *Papier Ztg*. **30**(74): 2802 (1905).
5. Korn, R., *Papier Fabrik* **35**(5): 33 (1937).

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1. Snyder, L.W., and Carson, F.T., *Paper Trade J*. **96**(22): 276 (1933).
2. Reitz, L.K., and Sillay, F.J., *Paper Trade J*. **126** (17): 54 (1948).
3. Brecht, W., and Wesp, A., *Das Papier* **6**(11): 443 (1952); 6(12): 496 (1952).

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department. ■

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T 511

DRAFT NO. 1

DATE December 4, 2012

WORKING GROUP
CHAIRMAN to be determined

SUBJECT
CATEGORY Physical Properties

RELATED
METHODS See "Additional Information"

Folding endurance of paper (MIT tester)
(Five-year review of T 511 om-08)

1. Scope

1.1 This method describes the use of the MIT-type apparatus for the determination of the folding endurance of paper. An exhaust fan arrangement maintains the folding head at room temperature.

1.2 The MIT tester is suitable 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.

1.3 The procedure for the Schopper-type apparatus is given in TAPPI T 423 "Folding Endurance of Paper (Schopper-Type Tester)."

Approved by the Standard Specific Interest Group for this Test Method
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2. Significance

2.1 Folding endurance tests have been used to estimate the ability of paper to withstand repeated bending, folding, and creasing.

2.2 Folding endurance has also been useful for measuring the deterioration of paper upon aging.

3. Definitions

3.1 *Folding endurance*, the logarithm (to the base 10) of the number of double folds required to break the paper when a strip of paper 15 mm (0.59 in.) wide is tested under a standard tension of 9.81 N (1 kgf).

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4. Apparatus

4.1 *Folding tester*[1] consisting of:

4.1.1 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 the range of 4.9 - 14.72 N (500 - 1500 gf). The deflection of the spring when loaded shall be at least 17 mm (0.67 in.) per 9.81 N, which is achieved by using a weight of 1 kg mass.

4.1.2 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 ± 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.

4.1.3 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.), 1.02 to 1.25 mm (0.04 to 0.05 in.).

4.2 *Power driven device*, for imparting a rotary oscillating motion of 175 ± 25 cycles/min to the folding clamp.

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

5.2.1 Measure the plunger friction by determining the additional load required to move the plunger perceptibly under a load of 9.81 N (1kgf) or the load tension used for the testing. This shall not be greater than 0.245 N (25 gf).

5.3 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 (1kgf) 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, i.e., when the slot in the folding head is vertical.

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8.1 Turn the oscillating folding head so that the opening is vertical. Turn 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; remove the weight. Without touching the part of the strip to be folded, clamp the specimen lying wholly within one plane, i.e., flat, and with the sides, parallel to, and not touching the oscillating jaw-mounting-plate. 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.

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11. Keywords

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12. Additional Information

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12.3.1 The greatest source of test variability is that the folding stresses are applied to a very small area of paper. Failure occurs at this point and not, as in normal tensile test, at the weakest point in the test strip. Thus, "within-sample" variability is great. In addition, the fold test operates cumulatively, the reduction in strength at the test point being approximately exponential. Therefore, it is possible for two test pieces of similar initial tensile strength at the test points and with identical rates of loss of strength with folding to give very different folding numbers. It is thus unfortunate that the number of double folds has been used to represent folding endurance. A suitable fractional power of the fold number of the log 10 of the fold number provides a much more realistic and less misleading result.

12.3.2 Van Nederveen and Van Royan *(1)* found that the loss in strength of paper due to repeated folding is a linear function of the logarithm of the number of folds. Krohnstad *(2)* reported a linear relationship between the load applied during folding and the logarithm of the number of folds. Andersson *(3)* showed that folding endurance data expressed as the logarithm of the number of folds are normally distributed and thus, amenable to further statistical analysis. Naoumof *(4)* and Korn *(5)* supported the view that the log of the fold number is a better measure of the folding endurance of paper than the fold number itself.

12.4 The reporting of the log fold is supported by ISO/TC6/SC2/W5 (Secretariat-2) June 8, 1968 and ISO 5626 dated November 15, 1993.

12.5 Related methods: ASTM 2176; Canadian PAPTAC D.17P; AS/NZS/1301.423; British BSI 4419; ISO 5626.

Literature cited

1. Van Nederveen, G., and Van Royen, A.H.H., *Papierwereld* **6**(5): 41 (1951).
2. Krohnstad, W., *Norsk Skogind* **10**(2): 58 (1956).
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References

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