Designation: D 6125 – 97 (Reapproved 2002)

An American National Standard

Standard Test Method for Bending Resistance of Paper and Paperboard (Gurley Type Tester)[1]

This standard is issued under the fixed designation D 6125; 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 determines the bending resistance of paper, paperboard, and other flexible flat-sheet materials by measuring the force required to bend a specimen under controlled conditions. The instrument described allows for a wide variation in specimen length, width and applied force.

1.2 This test method is not recommended for soft, limp or creped materials. Materials such as tissue or toweling would not normally be tested by this procedure and materials with a pronounced degree of curl would give erroneous results. Products with a bending resistance below 1.39 Gurley Units (or products not able to give a deflection between 1 and 7 on the scale when using the lightest weight) should not be tested by this procedure.

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.*

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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]

2.2 *TAPPI Standards:*[3]

T 543 Bending Resistance of Paper

T 1200 Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility

3. Terminology

3.1 *Definitions:*

3.1.1 *bending resistance*, *n*—a material attribute quantified by the magnitude of an applied force which produced deflection of a specimen having specified dimensions.

3.1.2 *stiffness, of paper and paperboard*, *n*—a synonym for bending resistance.

3.1.3 *machine direction bending resistance*, *n*—the bending resistance of a test specimen, clamped with the machine direction of the paper perpendicular to the specimen clamp.

3.1.4 *cross direction bending resistance*, *n*—the bending resistance of a test specimen, clamped with the cross direction of the paper perpendicular to the specimen clamp.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *Gurley stiffness*, *n*—stiffness or bending resistance of paper and paperboard determined using measurements made with a specific instrument patented by W& L.E. Gurley Co.

3.2.2 *Gurley units*, *n*—the units assigned to represent the force required to bend the specimen. Traditionally the results have been reported in terms of milligrams of force (mgf) which are identical to the now preferred term of Gurley units. In terms of force units (milliNewtons) the following applies:

$$\text{Force, mN} = 9.807 \times 10^{-3} \text{ (Gurley units)} \quad (1)$$

3.2.3 *Taber stiffness*, *n*—stiffness of paper and paperboard determined using measurements made with a specific instrument patented by Taber Industries.

4. Significance and Use

4.1 The bending resistance of paper affects many converting operations and most end-users. The bending resistance of paperboard is basic to many of the uses into which this material is placed. It is necessary to have a convenient, reproducible test method to measure this fundamental characteristic.

5. Apparatus

5.1 *Bending Resistance Tester*:

5.1.1 The instrument, shown in Fig. 1, consists of a balanced pendulum or pointer, pivoted at its center of gravity, mounted in jewel bearings, and provided with holes for attaching weights at a distance of 25.4 mm (1 in.), 50.8 mm (2 in.), and 101.6 mm (4 in.) below the center pivot. In non-digital instruments, the lower end of the pendulum is pointed and moves parallel to a scale mounted on the base of the instrument. The scale is graduated, in both left and right directions,

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

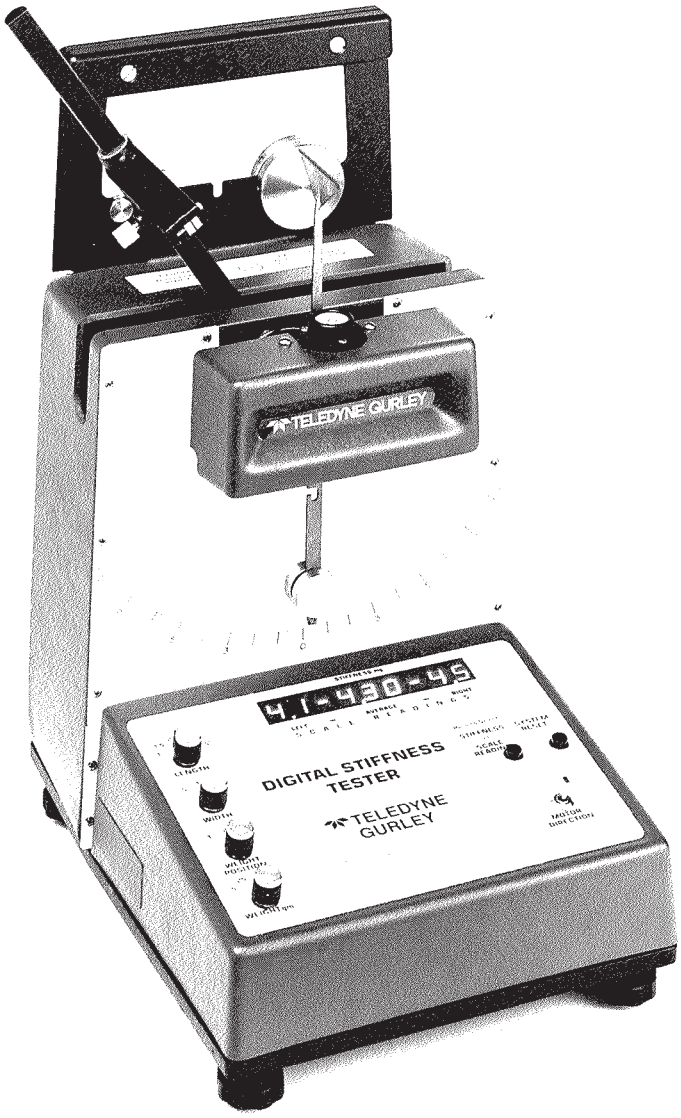

FIG. 1 Bending Resistance Tester

from zero to 8 units (corresponding to 10 times the sine of the angle produced by the pendulum) and is subdivided into five divisions, permitting readings to 0.1 unit. Newer versions employ optical encoders and microprocessors to measure the pendulum angle and compute the bending resistance automatically.

5.1.2 The upper end of the pendulum terminates in a triangular vane, 50.8 mm (2 in.) wide at the upper edge. The specimen presses against the vane causing the pendulum to deflect when the test is conducted. The upper edge of the vane is parallel to a specimen clamp, which is mounted upon an arm that rotates about the same geometrical center as the pendulum. The specimen clamp is movable upon the arm and may be positioned so that a gap (test length) of 12.7 mm (0.5 in.), 25.4 mm (1 in.), 50.8 mm (2 in.), 76.2 mm (3 in.), or 101.6 mm (4 in.) separates the clamp jaws from the top edge of the pendulum vane. The arm carrying the clamp is rotated left and right through approximately 20° by means of a reversible gear-motor at 2 rpm and contains recesses that automatically position the specimen clamp to the gaps referred to previously.

5.1.3 Weights of 5, 25, 50, and 200 g are provided. The tolerance on these weights is ±0.1 %. They are attachable to the lower end of the pendulum at distances of 25.4 mm (1.0 in.), 50.8 mm (2.0 in.), and 101.6 mm (4.0 in.) from the pivot.

5.1.4 The instrument is mounted upon a base that is provided with a spirit level (identical to those used with surveying instruments), leveling screws and a reversing switch for operating the motor.

5.1.5 The instrument provides 150 different combinations of specimen size and loading, encompassing a bending resistance range of 1.39 to 56 888 Gurley units.

5.2 *Paper Cutter*, See 7.1.1.

6. Sampling

6.1 Obtain a sample of paper or paperboard in accordance with Practice D 585.

6.2 Select test units free from watermarks or unusual flaws or creases that might subsequently affect the test results.

6.3 Avoid unnecessary handling of the test units prior to testing.

7. Test Specimen

7.1 From each test unit cut specimens, shown in Fig. 2, 63.5 ± 0.4 mm (2.5 ± 1/64 in.) long and 50.8 ± 0.4 mm (2 ± 1/64 in. wide). The nominal length of 50.8 mm (2.0 in.) plus an extra 12.8 (0.5 in.) is to provide 6.4 mm (0.25 in.) for clamping and 6.4 mm (0.25 in.) for the vane overlap. Ten specimens should be cut, five in the machine direction and five in the cross direction.

7.1.1 The length of the strip is very critical. An error of 1 % in the length of the 63.5 mm strip can cause an error of 4 % in the bending resistance reading. Therefore, it is required that the strips be cut with a 63.5 mm (2.5 in.) double knife cutter such as that used for the Elmendorf tearing resistance test. The specimens should be cut one at a time to avoid the burs produced by cutting several sheets at one time. For all size specimens, a suitable cutter should be used to ensure accurate specimen preparation.

7.1.2 Although the length of 63.5 mm (2.5 in.) and width of 50.8 mm (2 in.) should be used wherever possible, either the test specimen length or width, or both, may be varied to provide a test reading between 1 and 7 on the scale. Specimen widths between 12.7 mm (0.5 in.) and 50.8 mm (2 in.) can be used. If a width other than the preferred width of 50.8 mm is used, this should be reported with the results. Specimen length can be selected from the following:

Cut Length	Test Length	Length Ratio, L_R
25.4 mm (1.0 in.)	12.8 mm (0.5 in.)	0.167
38.1 mm (1.5 in.)	25.4 mm (1.0 in.)	0.333
63.5 mm (2.5 in.)	50.8 mm (2.0 in.)	0.667
88.9 mm (3.5 in.)	76.2 mm (3.0 in.)	1.000
114.2 mm (4.5 in.)	101.6 mm (4.0 in.)	1.333

The cut length refers to entries in the conversion factor table; the test length and length ratio are used in evaluating Eq 1.

8. Conditioning

8.1 Condition and test the specimens in an atmosphere in accordance with Practice D 685.

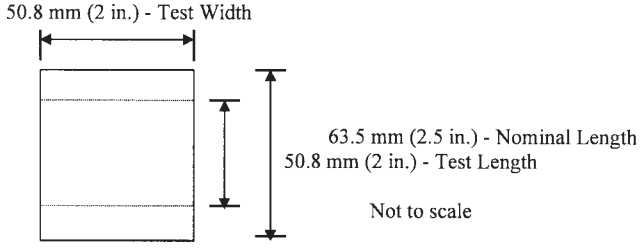

FIG. 2 Test Specimen

9. Procedure

9.1 Select an appropriate weight, mounting position and specimen size to give a deflection between 1 and 7 on the scale. Level the base of the instrument so that the pendulum pointer will indicate zero after attachment of the required weight. Note that the pointer is on jeweled bearings. If the pointer loses sensitivity, wipe it clean with a lint-free cloth. Do not oil these bearings.

9.2 Fasten the specimen strip in the specimen clamp in such a manner that 6.4 ± 0.2 mm (0.25 ± 0.01 in.) will be held in the jaws. Set the specimen clamp at a position so that the test strip will overlap the top of the pendulum by exactly 6.4 ± 0.2 mm (0.25 ± 0.01 in.). Note that the specimen should be brought up close to the pendulum vane before applying force to avoid oscillation in the early stages of deflection.

9.3 Press the reversing switch to cause the clamp arm to bring the specimen in contact with the top of the pendulum. Record the reading to the nearest 0.1 unit at the point where the specimen clears the pendulum.

9.4 Reverse the motor and load the test specimen against the pendulum from the opposite side. Record the scale reading in this direction. Average the results of the two readings.

9.5 Repeat the test with four more specimens.

9.6 There are now digital machines that work as described above. The left and right readings are automatically captured and stored. The average is also calculated and displayed as well as the actual bending resistance value.

10. Calculations and Theory

10.1 *Calculation of Bending Resistance*—Bending resistance is calculated in three ways:

10.1.1 Direct lookup via the table of conversion factors provided with each instrument (see Table 1).

10.1.2 Computation via the equation upon which the lookup table is based.

$$S = 1000 \frac{R\,D\,M\,L_R^2}{10\,V\,W_R} \quad (2)$$

where:

S = bending resistance or stiffness, Gurley units,
R = scale reading,
D = distance from weight to pivot, mm,
V = distance from tip of vane to pivot = 127.0 mm,
M = weight, g,
L_R = length ratio = $L_{test}/L_{standard}$,
$L_{standard}$ = 76.2 mm,
W_R = width ratio = $W_{test}/W_{standard}$, and
$W_{standard}$ = 25.4 mm.

NOTE 1—The size specimen used in Eq 2 was the size specimen that was selected when the instrument was developed. It must not be confused with the preferred testing size given in 7.1.2.

10.1.3 *Automatic Digital Computation*—Newer models of the Gurley tester incorporate optical encoders and microprocessors. The left and right scale readings are automatically averaged and displayed. Conversion to Gurley bending resistance units are also automatically displayed.

TABLE 1 Factors for Converting Scale Reading of Gurley Bending Resistance Tester (Reading to Milligrams with Gurley Bending Resistance Tester)

NOTE 1—Multiply Average Scale Reading by Conversion Factor Based on Instrument Settings:

Size of Sample			***Width ½ in.***		
Actual length, in.:	1	1½	2½	3½	4½
5 Gram Weight:					
Distance from center, 1 in.	5.56	22.2	88.9	200	356
Distance from center, 2 in.	11.1	44.4	178	400	711
Distance from center, 4 in.	22.2	88.9	356	800	1422
25 Gram Weight:					
Distance from center, 1 in.	27.8	111	444	1000	1778
Distance from center, 2 in.	55.6	222	889	2000	3556
Distance from center, 4 in.	111	444	1778	4000	7111
50 Gram Weight					
Distance from center, 2 in.	111	444	1778	4000	7111
Distance from center, 4 in.	222	889	3556	8000	14222
200 Gram Weight					
Distance from center, 1 in.	444	1778	7111	16000	28444
Distance from center, 2 in.	889	3556	14222	32000	55888
Size of Sample			***Width 1 in.***		
Actual length, in.:	1	1½	2½	3½	4½
5 Gram Weight:					
Distance from center, 1 in.	2.78	11.1	44.4	100	178
Distance from center, 2 in.	5.56	22.2	88.9	200	356
Distance from center, 4 in.	11.1	44.4	178	400	711
25 Gram Weight:					
Distance from center, 1 in.	13.9	55.6	222	500	889
Distance from center, 2 in.	27.8	111	444	1000	1778
Distance from center, 4 in.	55.6	222	889	2000	3556
50 Gram Weight:					
Distance from center, 2 in.	55.6	222	889	2000	3556
Distance from center, 4 in.	111	444	1778	4000	7111
200 Gram Weight:					
Distance from center, 2 in.	222	889	3556	8000	14222
Distance from center, 4 in.	444	1778	7111	16000	28444
Size of Sample			***Width 2 in.***		
Actual length, in.:	1	1½	2½	3½	4½
5 Gram Weight:					
Distance from center, 1 in.	1.39	5.56	22.2	50	88.9
Distance from center, 2 in.	2.78	11.1	44.4	100	178
Distance from center, 4 in.	5.56	22.2	88.9	200	356
25 Gram Weight:					
Distance from center, 1 in.	6.94	27.8	111	250	444
Distance from center, 2 in.	13.9	55.6	222	500	889
Distance from center, 4 in.	27.8	111	444	1000	1778
50 Gram Weight:					
Distances from center, 2 in.	27.8	111	444	1000	1778
Distance from center, 4 in.	55.6	222	889	2000	3556
200 Gram Weight					
Distance from center, 2 in.	111	444	1778	4000	7111
Distance from center, 4 in.	222	889	3556	8000	14222

10.2 *Additional Information*—In Eq 2, the term $R/10$ is exactly the sine of the pointer angle at which the vane clears the specimen, and the term $1000\ [(R/10)(D/V)]M$ is the corresponding force on the specimen. The term L^2_R/W_R accounts for the fact that, for a given scale reading R, longer samples are stiffer by the square of their length, and wider samples are less stiff, in proportion to their width.

10.3 *Taber Equivalency*—Gurley bending resistance (S_G) can be converted to Taber stiffness (S_T) by the equation:

$$S_T = 0.0146\ S_G + 0.053, \text{ where } S_G < 300 \text{ milligrams.}$$
$$S_T = 0.01478\ S_G + 0.0588, \text{ where } S_G > 300 \text{ milligrams.} \quad (3)$$

11. Report

11.1 *Report the following information*:

11.1.1 Bending resistance reading in Gurley units,

11.1.2 Scale reading,

11.1.3 Distance from weight to pivot in mm (in.),

11.1.4 Weight used in grams, and

11.1.5 Test length and test width as defined in Section 7.

12. Precision

12.1 *Precision*—Based on data obtained from National Bureau of Standards (NBS) - TAPPI Collaborative Reference Program Number 25 through 51 (August 1973 through January 1978). The range of test results of Gurley bending resistance covered is 76 Gurley units to 870 Gurley units.

12.2 *Repeatability (between laboratory)*—The repeatability is 5.4 % of the test results. The range of all calculations of repeatability is 3.7 to 9.6 %. The range of the central 90 % of the calculations is 3.9 to 8.7 %.

12.3 *Reproducibility (between laboratory)*—The reproducibility is 19.2 % of the test results. The range of all calculations of reproducibility is 6.4 to 45.4 %. The range of the central 90 % of the calculations is 12.2 to 25.5 %.

13. Keywords

13.1 Gurley stiffness; Gurley units; stiffness

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL TEST DATA

X1.1 Data shown in Table X1.1 are taken from four reports of Collaborative Testing Services (CTS) Analysis 336 (Gurley stiffness - standard Gurley units). These figures are based on ten test determinations per sample and calculated as defined in TAPPI T 1200. The reader should be cautioned that this analysis is based on actual mill/laboratory bending resistance with instruments or procedures that may not conform with this test method. This information is given as a guide as to the potential variation in Gurley bending resistance evaluation that may exist across the industry.

TABLE X1.1 Data Showing Estimates of Precision

Statistic	Sample SH19[A] (Report 130S)	Sample SH17[B] (Report 129S)	Sample SH11[C] (Report 126S)	Sample SH05[D] (Report 123S)
Grand mean	130.0	205.7	278.1	374.9
Number of labs included	43	46	37	39
Between - lab standard deviation	21.2	35.8	19.8	29.4
Repeatability standard deviation	9.9	13.0	17.2	20.9
Reproducibility standard deviation	23.3	38.1	26.1	35.5
Repeatability limit	27.4	36.0	47.6	57.9
Reproducibility limit	64.6	105.6	72.3	98.3
Coefficient of variation, %	16.3	17.4	7.1	7.8

[A] 50 # Offset.
[B] 60 # Offset.
[C] 24 # Bond.
[D] 70 # Offset.