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WI _____ 180308.02 _____

T _____ 836 _____

DRAFT NO. _____ 3 - SARG _____

DATE _____ October 7, 2020 _____

WORKING GROUP
CHAIRMAN _____ Ben Frank _____

SUBJECT _____ Fiberboard Shipping
CATEGORY _____ Container Testing _____

RELATED
METHODS _____ See "Additional Information" _____

CAUTION:

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

**Bending stiffness, four point method
(Five-year review of T 836 om-13)
(changes approved on Ballot 2 and editorial changes
incorporated)**

1. Scope

This procedure specifies the method of determining the bending stiffness, also called flexural rigidity, in the machine and cross directions, of corrugated board using four-point loading. The procedure may also be used for solid boards and paperboard. The method is applicable to boards with a bending stiffness of 0.5 - 200 Nm (4.4 - 1770 lbf • in.).

2. Summary

2.1 A rectangular test specimen is clamped at each end with a clamping pressure P over the length s , leaving a free span l in the center (see Fig. 1).

2.2 Each clamp can be turned around a rotation axis r . A force F is applied at each clamp at a distance h from the rotation axis. The bending moments $F \cdot h$ cause the test specimen to bend, and maximum deflection from the plane through the rotation axes (the distances δ_B in Fig. 1) is measured.

2.3 The bending stiffness is calculated from the bending moment, the width of the test specimen, the free span and the deflection. The time from the application of the force to the measurement is 10 ± 3 s (see Fig. 2).

3. Significance

It has been shown that the top-to-bottom compression strength of corrugated boxes is partly dependent on the load-carrying ability of the central panel areas. The ability of these central areas to resist bending under load will increase the stacking strength of the box. The difference in box compression strengths between boxes of identical size made from the same components but of different flute sizes (if the load is applied parallel to the flutes) is primarily due to differences in the bending stiffness of the box panels. Bending stiffness measurements of the combined board when used with the edge crush test and box dimensions, can accurately predict the top-to-bottom compression strength of a box.

4. Definitions

4.1 *Bending stiffness*, the bending moment per unit width of a rectangular specimen, divided by the curvature according to the expression:

$$S^b = \frac{M}{kb} \quad (1)$$

where

S^b	=	bending stiffness
M	=	bending moment
k	=	curvature (the inverted value of the radius of curvature)
b	=	width of the specimen

5. Apparatus

5.1 Use either an instrument specially designed for the measurement of bending stiffness or a universal testing machine having suitably designed attachment. The apparatus shall meet the following requirements:

5.2 The specimen shall be clamped firmly over its full width at both ends. Each clamp shall be 50 mm (2 in.) deep and at least 100 mm (4 in.) wide. The clamping pressure at right angles to the plane of the specimen shall be 14 ± 4 kPa (2 ± 0.6 psi).

NOTE 1: For certain board grades, other clamping pressure may be needed. Boards with low strength properties in the thickness direction may need a lower clamping pressure, and boards with high strength properties may need a higher clamping pressure to ensure that the test specimen surface is plane.

NOTE 2: Make sure that the clamping force is adapted to the width of the specimen to give the standardized clamping pressure.

5.3 The clamps shall be free to move to allow for changes in free span at larger deflections.

5.4 The deflections δ_B (see Fig. 1) shall be measurable to an accuracy of $\pm 2\%$ of the reading down to 0.5 mm (0.02 in.) deflection or better. The sum of any deflection indicator and rotation moment of the clamps shall not impart to the specimen an additional bending force greater than 1% of the total bending force.

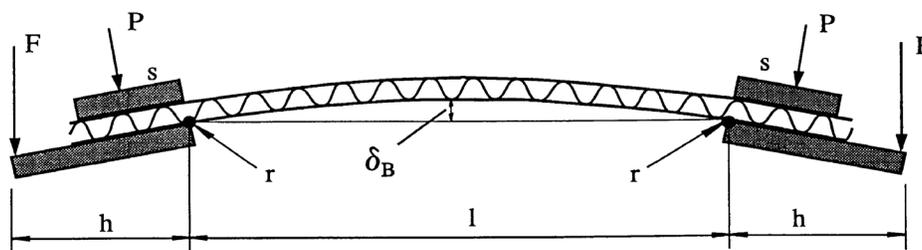


Fig. 1. The four-point test configuration (testing corrugated fiberboard in machine direction). Fig. legends: F = force; h = moment arm; l = free span; δ_B = deflection; r = rotation axis; P = clamping pressure; s = clamping length.

5.5 The bending force F shall be applied at right angles to the plane of the specimen at the beginning of the test (assuming that the specimen is perfectly flat). The bending force shall be known to an accuracy of 2% or better.

5.6 The rotation axes of the clamps shall be perpendicular to the long side of the specimen.

5.7 The free span shall be adjustable in three steps length: 150, 200 and 300 mm (5.9, 7.8 and 11.8 in.). The free span l and the distance h shall be known to an accuracy of $\pm 1\%$ or better. The free span is defined as the distance between the rotation centers of the clamps (Fig. 1).

5.8 Table 1 lists the free spans and widths to be used for corrugated fiberboards of different types. For other board types the thickness range given in Table 1 determines the free span. The 50-mm (2-in.) width is recommended for boards with a thickness above 10 mm (0.4 in.).

NOTE 3: The spans indicated in Table 1 are the recommended spans for referee testing. Other spans may also be suitable, and may be required particularly in situations including testing on small boxes where the available material free of scores is not long enough to meet the requirements of Table 1. Available test data indicates that using spans shorter than those listed in Table 1 may result in similar stiffness values or higher stiffness values than the recommended spans. Measurement variation increases as span decreases.

5.9 The strain in the liners shall be in the range of 0.03 to 0.05%. The deflection δ_B (Fig. 1) and the strain ε in the outer liners of a corrugated fiberboard or multi-layer board are related as given by the equation:

$$\delta_B = \frac{\varepsilon \cdot l^2}{400 \cdot t} \quad (2)$$

where:

δ_B	=	deflection of the specimen, mm (in.)
ε	=	strain in the outer liner, %
l	=	free span used, mm (in.)
t	=	corrugated board thickness, mm (in.)

It is recommended to check the allowable deflection before testing unknown samples. In a preliminary test, apply a force, record the deflection δ_B and calculate the strain ε from the expression:

$$\varepsilon = \frac{400 \cdot \delta_B \cdot t}{l^2} \quad (3)$$

to confirm that for a given load, ε is in the range 0.03% to 0.05%.

NOTE 4: While bending stiffness should be independent of strain, excessive loads producing high strains result in lower bending stiffness test values given the mechanics of the equipment and/or the methodology of the test. Low loads can result in strains that are very low, with an increase in the variation in the measurement. It is thus important to assure that the strain during the measurement process remains approximately within the indicated range. Table 2 provides guidance with regard to allowable deflections for boards of different thickness to remain in the recommended range.

Table 1. The free spans and the widths to be used when testing corrugated fiberboards of different thickness. (See also Note 3.)

<i>Type of corrugated fiber board</i>	<i>Test specimen width, mm (in.)</i>	<i>Free span, mm (in.)</i>	<i>Approximate thickness</i>
Single-wall F-,E-flute	100 (3.9)	150 (5.9)	0.5 - 2.29 (0.02 - 0.09)
Single-wall B-,C- and A-flute	100 (3.9)	200 (7.9)	2.30 - 5.99 (0.1 - 0.24)
Double-wall	100 (3.9)	300 (11.8)	6.00 - 20.00
Triple-wall	50 (2.0)		(0.24 - 0.79)

Table 2. Allowable deflections for corrugated fiberboards at an allowable strain of 0.03% to 0.05%.

<i>Corrugated fiberboard thickness mm (in.)</i>	<i>Allowable deflection at free span</i>		
	<i>Free span 150 mm (5.19 in.) mm (in.)</i>	<i>Free span 200 mm (7.9 in.) mm (in.)</i>	<i>Free span 300 mm (11.8 in.) mm (in.)</i>
0.75 (0.30)	2.2-3.7 (0.087 – 0.146)		
1.0 (0.039)	1.7–2.8 (0.067 – 0.110)		
1.5 (0.059)	1.1–1.9 (0.043 – 0.075)		
2 (0.079)	0.8–1.4 (0.031 – 0.055)		
3 (0.12)	1.0–1.7 (0.039 – 0.067)		
4 (0.16)	0.8–1.3 (0.031 – 0.051)		
5 (0.20)	0.6–1.0 (0.024) – 0.039)		
7.5 (0.30)	1.0–1.6 (0.039–0.063)		
15 (0.59)	0.5–0.8 (0.020–0.031)		

6. Calibration

Calibrate and if necessary adjust the following components to meet the requirements specified in Section 5: clamping pressure; deflection; bending force; free span; alignment of the clamps. Follow apparatus manufacturer recommendations.

7. Sampling

Sample in accordance with TAPPI T 400 “Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product.”

8. Test specimens

8.1 From each test unit of the sample, cut at least 10 test specimens in each principal direction. Ensure that the longer side is parallel to the machine or the cross direction. Ensure that the long edges are undamaged and

perpendicular to the plane of the sheet. If the test specimens are to be taken from corrugated shipping containers, take them from areas removed from scorelines, joints and closures. Do not take the specimens from obviously damaged areas or areas not representative of the container as a whole.

8.2 Cut the specimen widths with an accuracy of better than 1%. Typical nominal widths used include 100mm, 4.0 inches (101.6mm) and 50mm. While other widths can be used (and input for the calculations of equations (1) and (4)) as long as the width is known with sufficient accuracy, a minimum nominal width of 50mm (approximately 2 inches) is recommended. Cut the length so that it exceeds by 110–140 mm (4.3–5.5 in.) the free span selected.

9. Conditions

Precondition and condition the specimens and test in the atmosphere specified in TAPPI T 402 “Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products.”

10. Procedure

10.1 Select the appropriate free span with the aid of the recommendations in Table 1 and adjust the instrument accordingly.

10.2 Clamp the test specimen in the apparatus so that the full width of the test specimen is covered by the clamps. Set the deflection indicator to zero.

10.3 Apply the force F slowly to avoid large deflection vibrations in the test specimen (see Fig. 2). (This should occur provided the lowering speed of weight lifters is set correctly.) Wait 10 ± 3 s and read the deflection δ_B . Check that the strain ϵ is in the allowable region (see section 5.9).

10.4 Carry out 5 tests with the top side of the board on the outside of the bend and 5 tests with the top side on the inside of the bend.

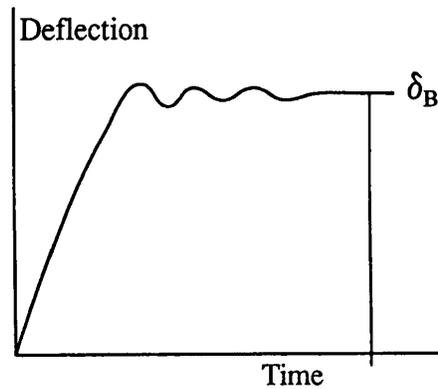


Fig. 2. Deflection versus time.

11. Calculations

11.1 For each test specimen calculate the bending stiffness from the equation

$$S^b = \frac{F}{\delta_B} \cdot \frac{hl^2}{8b} \quad (4)$$

where

S^b	=	bending stiffness, Nm (lbf • in.)
F	=	bending force, N (lbf)
δ_B	=	deflection after 10 ± 3 s, m (in.)
l	=	free span, m (in.)
h	=	moment arm, m (in.)
b	=	width of the test specimen, m (in.)

11.2 Calculate the mean bending stiffness separately for the machine and cross directions, as required.

Report the results with three significant figures.

NOTE 5: Bending Force is normally applied as a load to the ends of the sample as shown in Fig. 1. This load must be converted to force. For metric (N), it is load (grams)/1000 * 9.80665. To convert to English (lbf.) it is load (grams)/453.592.

NOTE 6: With reference to Fig. 1, it should be understood that the equation parameters for Bending Force (F) and Moment Arm (h), are intended to be only one F and only one h.

12. Report

12.1 For each test unit, report:

12.1.1 Date and place of testing.

12.1.2 Span used for testing.

12.1.3 Sample width.

12.1.4 The mean results as specified in section 11.2.

12.1.5 The number of replicate determinations made.

12.1.6 The standard deviation of the result.

12.1.7 The statement that the test was conducted in compliance with this test method and a description of any deviations.

13. Precision

13.1 In 2019 the TAPPI working group undertook a revision of the precision statement with a round robin among seven instruments in seven different labs worldwide. Each lab tested ten specimens each in the MD and CD direction of three different materials. Typically, the RMS bending (the square root of the product of the two independent directions) is used, for example in the McKee equation for estimation of Box Compression Strength. To obtain an estimate of the variation in RMS values, each MD result was multiplied by the average of the ten CD results, and each CD result was multiplied by the average of the ten MD results, to obtain twenty values for each laboratory. The average repeatability and reproducibility of the materials individually, and in the MD and CD directions, is summarized in Table 3.

13.1.1 RMS Repeatability (within a laboratory) = 7.9%.

13.1.2 RMS Reproducibility (between laboratories) = 12.7%.

Repeatability and reproducibility are estimates of the maximum difference (at 95% confidence) that should be expected when comparing test results for materials similar to those described below under similar test conditions. These estimates may not be valid for different materials and testing conditions.

Table 3- Detailed results of the 2019 repeatability and reproducibility study

Material	Mean (N-m)			Repeatability r and %r			Reproducibility R and %R		
	MD	CD	RMS	MD	CD	RMS	MD	CD	RMS
32ECT C Flute	11.3	5.9	8.2	1.1, 10.1%	1.1, 18.6%	0.6, 7.0%	1.5, 13.0%	1.4, 23.7%	0.9, 11.1%
44ECT C Flute	16.7	9.3	12.5	2.0, 11.8%	2.2, 23.8%	1.2, 9.7%	2.4, 14.2%	2.7, 29.1%	1.8, 14.4%
32ECT B Flute	5.6	3.1	4.2	0.9, 15.4%	0.4, 13.0%	0.3, 6.8%	1.1, 20.0%	0.5, 15.9%	0.5, 12.5%

14. Keywords

Corrugated boards, Fiberboards, Paperboard, Bend strength, Bending, Stiffness

15. Additional information

15.1 Effective date of issue: to be assigned.

15.2 The precision statement was updated in 2019 through a formal round robin. As well, further clarification of Span and Strain limitations for Tables 1 and 2 were included in the method, with updates to notes 3 and 4 and section 8.2. Information supporting these changes is on file at TAPPI.

References

1. Fellers, C. and Carlsson, L., "Bending Stiffness with Special Reference to Paperboard," *Handbook of Physical and Mechanical Testing of Paperboard*, Vol. 1, Ed. R. Mark, Marcel Dekker, 1983.
2. Carlsson, L., Fellers, C., and Jonsson, P., "Die Biegesteifigkeit von Wellpappe unter besonderer Berücksichtigung assymmetrischer und mehrlagiger Konstruktion," *Das Papier* **39** (4): 149-156 (1985).
3. SCAN Method P 65:91 "Bending Stiffness: Four-Point Method," Nov. 1991.
4. TAPPI T 820 "Flexural Stiffness of Corrugated Board."

Appendix A.1 Theory

A.1.1 For small deflections of a beam subjected to a bending moment at its ends (see Fig. 1) the curvature k may be evaluated from the expression.

$$k = \frac{8 \delta_B}{l^2} \quad (5)$$

where

- k = curvature ($1/\text{radius of curvature}$)
 δ_B = deflection in the center of the free span
 l = free span

A.1.2 The bending stiffness is defined by

$$S^b = \frac{M}{kb} \quad (6)$$

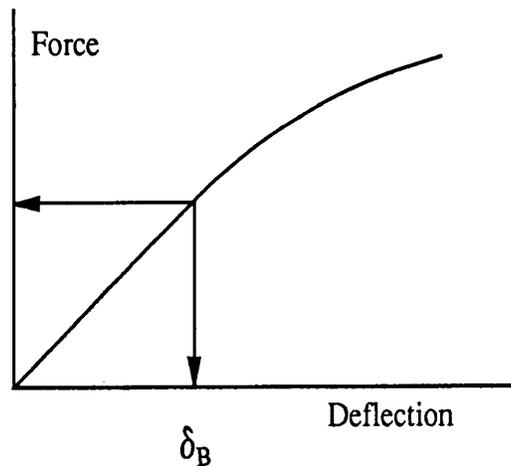


Fig. 3 Force versus deflection; ideal response.

where

- S^b = bending stiffness
- M = bending moment
- k = curvature (the inverted value of the radius of curvature)
- b = width of the specimen

A.1.3 A bending moment $M = F \cdot h$ is applied at the ends of the beam by applying force F with a moment arm h to the clamps at the end of the beam (Fig. 1).

A.1.4 The bending stiffness is thus

$$S^b = \frac{F}{\delta_B} \cdot \frac{hl^2}{8b} \quad (7)$$

A.1.5 For a small curvature the deflection δ_B is ideally a linear function of the force, as shown in Fig. 3.

A.1.6 Consequently, when using equation 7 to calculate the bending stiffness, it is sufficient to record the deflection δ_B caused by the Force F , within the elastic range.

A.1.7 At large deflections, the material becomes plasticized and there is no longer any linear relation between deflection and force.

Appendix A.2 Practical consideration

A.2.1 In practice, sheet materials like corrugated fiberboard are slightly twisted and deformable in the thickness direction. Their properties are also time dependent like those of all polymeric materials. In the method these factors have been considered. Any slight twist is removed by the clamping arrangement. By distributing the clamping force over a large area, undesirable deformation in the thickness direction is avoided.

A.2.2 The time dependence is handled by applying the force F slowly to minimize vibrations and by waiting a specified time before recording the deflection δ_B (Fig. 2).

Appendix A.3 Calculation of the bending stiffness from the E-modulus

A.3.1 The bending stiffness of a paper or board consisting of one or several layers may be calculated from the theory of elasticity by the equation:

$$S^b = \frac{\Sigma EI}{b} \quad (8)$$

where

- E = modulus of elasticity, for each ply, in the direction of loading (machine or cross direction)
 I = moment of inertia of the cross sectional area for each ply, and is dependent on the position of the ply in the sheet
 b = width of the test strip

In the calculations it is necessary to consider the non-homogeneous structure of corrugated fiberboard.

A.3.2 The modulus of elasticity is the same in tension as in compression. The bending stiffness in a given principal direction of the sheet is therefore independent of the direction in which the material is bent, provided that the boards are free from excessive curl.

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