SCANDINAVIAN PULP, PAPER AND BOARD

TESTING COMMITTEE

Corrugated fibreboards and boards

Bending stiffness

Four-point method

1   Scope

This SCAN-test Method specifies the procedure for determining the bending stiffness, in the machine and cross directions, of corrugated fibreboard using four-point loading. The Method may also be used for solid board and paperboard.

2   References

ISO 187   Paper, board and pulps – Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples (EN 20187)

ISO 3034   Corrugated fibreboard – Determination of thickness

> *Note* – SCAN-test has withdrawn a number of test methods and refers instead to the corresponding ISO and/or EN Standards.

3   Definition

For the purpose of this Method, the following definitions apply:

3.1   *Bending stiffness* – The bending moment per unit width of a rectangular test piece, divided by the curvature according to the expression:

$$S_b = \frac{M}{c\,d} \tag{1}$$

where
S_b is the bending stiffness;
M is the bending moment;
c is the curvature (the inverted value of the radius of curvature);
d is the width of the test piece.

4   Principle

A rectangular test piece is clamped at each end with a clamping pressure p over a length s, leaving a free span *l* in the centre, see *Figure* 1.

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 $F\,h$ cause the test piece to bend, and the maximum deflection from the plane through the two rotation axes (the distance e in *Figure 1*) is measured.

The bending stiffness is calculated from the bending moment, the width of the test piece, the free span and the deflection.

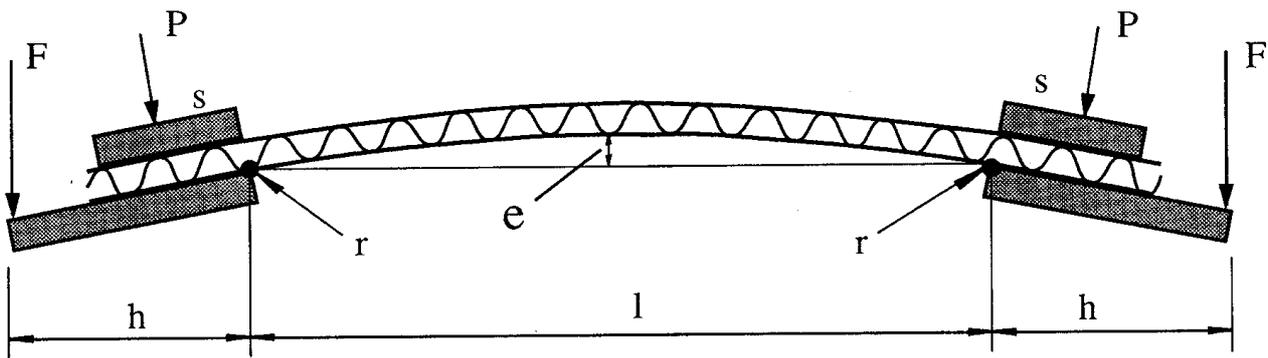The time from the application of the force to the measurement is 10 ± 3 s, see *Figure 2*.

Figure 1   The four-point test configuration (testing corrugated fibreboard in MD)

Figure legends: r= rotation axis
F = force   P = clamping pressure
H = moment arm   s = clamp length
L = free span
E = deflection

5   Apparatus

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

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

Note 1 − For certain corrugated fibreboard qualities other clamping pressures may be needed. Corrugated fibreboards with low strength properties in the thickness direction may need a lower clamping pressure to avoid crushing. Corrugated fibreboards with high strength properties may need a higher clamping pressure to ensure that the test piece surface is plane.

Note 2 − Make sure that the clamping force is adapted to the width of the test piece to give the standardized clamping pressure.

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

The deflection e (see Figure 1) shall be measurable to an accuracy of ± 2 % of the reading or better. The sum of any deflection indicator and rotation moment of the clamps shall not impart to the test piece an additional bending force greater than 1 % of the total bending force.

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

The rotation axes of the clamps shall be perpendicular to the long sides of the test piece.

The free span shall be adjustable in three steps lengths; 150, 200 and 300 mm. The free span l and the distance h shall be known to an accuracy of ± 1 % or better.

Note 3 − The free span is defined as the distance between the rotation centres of the clamps (Figure 1).
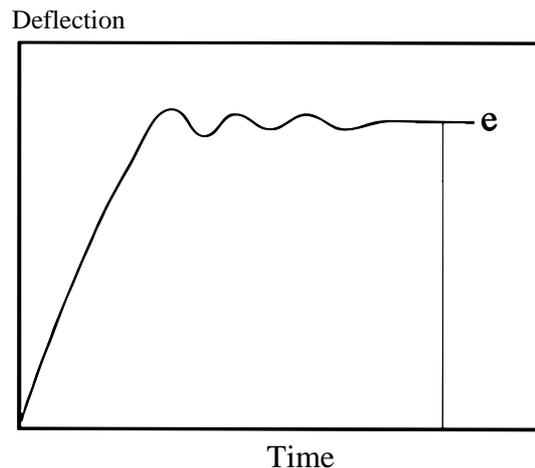
Deflection

Time

Figure 2   Deflection versus time

6   Allowable deflections and free spans

Table 1 lists the free spans and widths to be used for corrugated fibreboards of different types.

For other samples the thickness range given in Table 1 determines the free span. The 50 mm width is recommended for samples with a thickness above 10 mm.

Table 1   The free spans and the widths to be used when testing corrugated fibreboards and boards of different thickness.

Type of corrugated fibreboard	Test piece width mm	Free span mm	Approximate thickness range mm
Single-wall E-flute	100	150	0,50–2,29
Single-wall B-, C- and A-flute	100	200	2,30–5,99
Double-wall Triple-wall	100 50	300	6,00–20,00

Table 2   Allowable deflections for corrugated fibre boards at an allowable strain of 0,03 to 0,05 %.

Corrugated fibreboard thickness mm	Allowable deflection (mm) at free span:		
	150 mm	200 mm	300 mm
1,5	1,1–1,9		
2	0,8–1,4		
3		1,0–1,7	
4		0,8–1,3	
5		0,6–1,0	
7			1,0–1,6
15			0,5–0,8

The strain in the liners shall be in the range of 0,03 to 0,05 % .The deflection *e* (in *Figure 1*) and the strain E in the outer liners of a corrugated fibreboard or multi-layer board are related as given by the equation:

$$e = \frac{\varepsilon l^2}{400\, t} \qquad [2]$$

where

e   is the deflection of the test piece in millimetres;
ε is the strain in the outer liner as a percentage;
l   is the free span used in millimetres;
t   is the corrugated fibreboard thickness in millimetres.

> *Note* − Check the allowable deflection before testing unknown samples. In a preliminary test, apply a force, record the deflection *e* and calculate the strain e from the expression:
>
> $\varepsilon = 400e\ t/l^2 \qquad [3]$
>
> to check that ε is in the range 0,03 to 0,05 %.

Furthermore, if the corrugated fibreboard crushes during bending, the strain must be reduced.

Table 2 gives guidance with regard to allowable deflections for corrugated fibreboards at different thickness at an allowable strain of 0,03 to 0,05 %.

7   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

8   Sampling and preparation of test pieces

Select or cut specimens of the corrugated fibreboard from reasonably flat and undamaged areas. Avoid scores or crushed areas.

Condition the specimens at 23°C and 500 % relative humidity as specified in ISO 187. Keep specimens and test pieces in the conditioning atmosphere throughout the test.

Measure the thickness as described in ISO 3034. Cut test pieces (100 ± 0,5) mm wide (50 ± 0,5 mm for triple-wall corrugated fibreboard) and with a length that exceeds by 110–140 mm the free span selected. The longer side shall be parallel to the machine or the cross direction. The long edges must be undamaged and perpendicular to the plane of the sheet.

> *Note* – The result of this test is very sensitive to changes in the moisture content of the test piece. Handle the test pieces carefully and never touch them in the area between the clamps. Keep them away from moisture, heat, direct illumination, expiration air and other influences that may change their moisture content.

Prepare at least 10 test pieces for each direction. Mark them to identify machine direction and the top side.

9   Procedure

The procedure depends on the design of the test instrument.

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

Clamp the test piece in the apparatus. The full width of the test piece shall be covered by the clamps. Set the deflection indicator to zero.

Apply the force *F* slowly to avoid large deflection vibrations in the test piece, see *Figure 2*, wait (10 ± 3) s

and read the deflection *e*. Check that the strain ε is in the allowable region (see Section 6).

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.

10 Calculation

For each test piece calculate the bending stiffness from the equation

$$S_b = \frac{F}{e}\;\frac{h\,l^2}{8000\,d} \qquad [4]$$

where

S_b	is the bending stiffness in newton metres;
F	is the bending force in newtons;
e	is the the deflection after 10 ± 3 s in millimetres;
l	is the free span in millimetres;
h	is the moment arm in millimetres;
d	is the width of the test piece in millimetres.

Calculate the mean bending stiffness separately for the machine and cross directions, as required. Report the results with three significant figures.

11 Test report

The test report shall include reference to this SCAN- test Method and the following particulars:

(a) date and place of testing;
(b) identification mark of the sample tested;
(c) the mean results as specified in Section 10;
(d) the number of replicate determinations made;
(e) the coefficient of variation of the results;
(f) any departure from the procedure described in this SCAN-test Method and any other circumstances that may have affected the test results.

12 Precision

Five laboratories tested pre-cut test pieces from the same corrugated fibreboard samples under normal laboratory conditions. The reproducibility and repeatability, calculated as the coefficient of variation between and within laboratories respectively, was as follows:

Type of sample (corrugated fibreboard)		Mean bending stiffness Nm	CoV* within labs %	CoV* between labs %
Single-wall A	MD	17,9	6,3	2,5
	CD	8,17	2,7	3,4
Single-wall C	MD	10,2	6,3	1,6
	CD	4,12	1,7	2,7
Single-wall B	MD	5,14	6,6	2,1
	CD	2,22	3,2	3,2
Single-wall E	MD	1,61	5,6	1,9
	CD	0,81	4,9	4,9
Double-wall	MD	19,9	8,2	2,5
	CD	14,8	4,2	5,3
Triple-wall	MD	112	5,4	2,8
	CD	62,7	1,8	2,9

* Coefficient of Variation

The fact that the coefficient of variation within laboratories for some samples exceeds that between laboratories indicates that the variability of the sample is great in comparison with the variability of the means reported by the different participating laboratories.

13 References

13.1 *Fellers, C. and Carlsson, L.*: Bending stiffness with special reference to paperboard. Handbook of physical and mechanical testing of paper and paperboard, Vol. 1, Ed. R. Mark, Marcel Dekker 1983.

13.2 *Carlsson, L., Fellers, C. and Jonsson, P.*: Die Biegesteifigkeit von Wellpappe unter besonderer Berucksichtigung assymmetrischer und mehrlagiger Konstruktionen. Das Papier 39 (1985):4, 149-156.

Annex

A.l Theory

For small deflections of a beam subjected to a bending moment at its ends (see Figure 1) the curvature c may be evaluated from the expression

$$c = \frac{8e}{l^2} \qquad [A.1]$$

where
c is the curvature (I/radius of curvature);
e is the deflection in the centre of the free span;
l is the free span.

The bending stiffness is defined by

$$S_b = \frac{M}{c\,d} \qquad [A.2]$$

where
S_b is the bending stiffness;
M is the bending moment;
d is the width of the test piece.

A bending moment $M = F\,h$ is applied at the ends of the beam by applying forces F with a moment arm h to the clamps at the end of the beam *(Figure 1)*.

The bending stiffness is thus

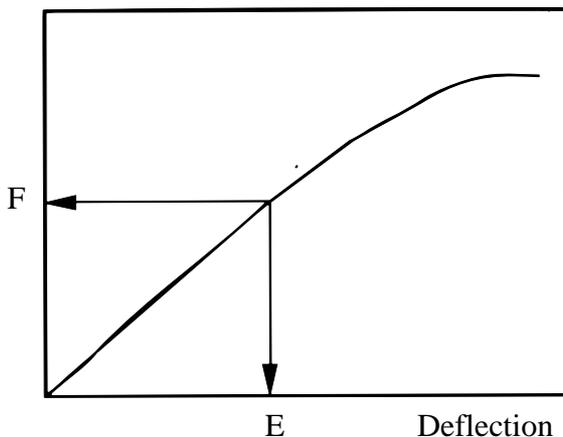$$S_b = \frac{F\,h\,l^2}{d\,8\,e} \qquad [A.3]$$

Force

Figure 3 Force versus deflection. Ideal response.

For a small curvature the deflection e is ideally a linear function of the force, as shown in *Figure 3*.

Consequently, when using equation 7 to calculate the bending stiffness, it is sufficient to record the deflection e, caused by the forces F, within the elastic range.

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

A.2 Practical considerations

In practice, sheet materials like corrugated fibreboard are slightly twisted and deformable in the thickness direction. Their properties are also time dependent like those of all polymeric materials. In this Method these factors have been considered.

Any slight twist is removed by the clamping arrangement. By distributing the clamping force over a large area, any undesirable deformation in the thickness direction is avoided.

The time dependence is handled by applying the force F slowly to minimize vibrations and by waiting a specified time before recording the deflection e *(Figure 2)*.

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

A3.1 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:

$$S_b = \frac{\Sigma\, EI}{d} \qquad [A.4]$$

where

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

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

A3.2 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.