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SCANDINAVIAN PULP, PAPER AND BOARD
TESTING COMMITTEE

Paper and board

Z-directional toughness

0 Introduction

This SCAN-test Method has been developed in order to specify the conditions for determining the toughness in terms of the energy per unit area to rupture the material in the z-direction of paper and board.

The terminology for the strength in the z-direction is not well defined. Terms such as z-directional tensile strength, Scott Bond, Internal bond strength, Internal fibre bond strength, Ply adhesion and Ply bond strength are used, depending on the measurement procedure, on the type of sample tested and on the purpose of the measurement.

In SCAN-P 90, the Z-directional toughness is evaluated by means of fracture mechanics theory from the maximum force that a test piece of a defined shape can withstand when loaded perpendicular to the plane in a tensile testing apparatus.

1 Scope

This SCAN-test Method describes a procedure for measuring the Z-directional toughness of paper and board.

The method is applicable to paper and board having a grammage exceeding 60 g/m^2.

> *Note* – Paper having a grammage lower than 60 g/m^2 may be tested provided that it can be shown that the tape does not reinforce the paper.

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)
SCAN-P 9	Paper and board – Identification of machine and cross direction
ISO 536	Paper and board – Determination of grammage (EN ISO 536)

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 *Note* – SCAN-test has withdrawn a number of test methods and refers instead to the corresponding EN and/or ISO standards.

3 Definition

For the purpose of this Method, the following definition applies:

3.1 *Z-directional toughness* – The incremental work needed to achieve unit incremental growth in area of a test piece when the test piece is loaded in the z-direction, under the conditions described in this Method.

4 Principle

A test piece, attached by double-sided adhesive tape between two flexible beams of specified geometry and pressed together under a given pressure for a given time, is loaded to break in the z-direction, using a tensile machine that records the maximum tensile force.

5 Apparatus

5.1 *A pair of flexible beams*. Each beam shall be made of polycarbonate and shall have the dimensions given in *Figure 1*. The width shall be (25 ± 0,1) mm. Each beam shall have a hole for load application. At a distance of (52,00 ± 0,05) mm from the centre of the hole, the height of the beam shall be (10,05 ± 0,05) mm. From that point, to a point (118,00 ± 0,05) mm further along the beam, the height shall increase according to the expression:

$$h = \left(\frac{3\,L^2}{8}\right)^{1/3} \qquad [1]$$

where
h is the height, in millimetres;
L is the distance from the point of load application, in millimetres.

From the last-mentioned point over a distance of (30,00 ± 0,05) mm to the end of the beam, the beam shall have a constant height of (21,12 ± 0,05) mm.

Note – The complicated shape of the beam makes it necessary to use a numerically controlled milling machine to obtain sufficient precision in the beam dimensions.

5.2 *Tensile testing apparatus* having a tensile force measuring device, with an accuracy of ±2 % of the scale reading within the range from 10 N to 200 N and having a loading device which loads the test piece at an elongation rate of (12 ± 8) mm/s.

Warning – To avoid gravity effects on the measurement results, the measurement is preferably carried out, as shown in *Figure 2*, by loading the beams horizontally. However, vertical loading is possible with special arrangements.

5.3 *Self-adhesive tape*, double sided.

Note 1 – A suitable tape is Duplocoll 310, supplied by Stokvis Tapes AB, Box 769, SE-601 17 Norrköping, Sweden, tel +46 11 28 04 00.

Note 2 – The quality of the tape is affected by ageing. Follow the tape manufacturer's recommendation for storage.

5.4 *Punch or cutter*, for preparation of the test pieces. The punch or cutter shall produce test pieces with a width of (25 ± 0,1) mm and a length of at least 150 mm.

5.5 *Press*, for bonding the tape to the test piece and to the beams.

The press shall press the beams together with a compression force of (20 000 ± 4 000) N (≈ (5 ± 1) MPa).

The press shall have press blocks that follow the shape of the beams over the distances 118 mm + 30 mm according to *Figure 1*. The pressure shall be applied evenly over this distance. To achieve an even pressure, a thin film of hard rubber is usually necessary between the beam and the press blocks.

6 Calibration

Calibrate the tensile testing apparatus according to the instructions given by the manufacturer.

The calculation of Z-directional toughness relies upon the elastic modulus of the beams and the geometry. The manufacturer of the beams is responsible for the accuracy of the dimensions, and for the calculation of

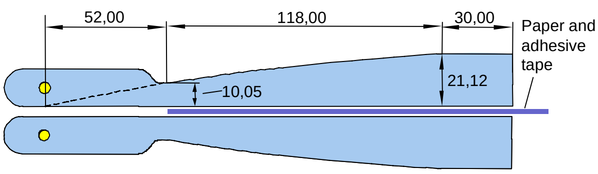

Figure 1. A pair of flexible beams. The dimensions, in millimetres, are theoretical values given with two decimals. For sufficient precision, a tolerance of ±0,05 mm of these figures is considered to be enough.

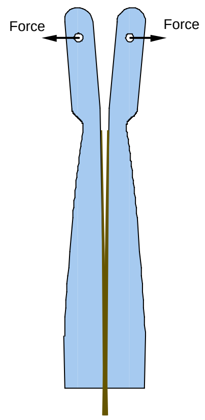

Figure 2. Measurement carried out by loading the beams horizontally.

the elastic modulus of the beams according to Eq. [A.1] (see Annex).

7 Sampling and conditioning

The sampling procedure is not covered by this method. Make sure that the test pieces taken are representative of the sample received.

Condition the specimens as specified in ISO 187 (EN 20187). Keep them in the prescribed conditioned atmosphere throughout the test.

This test, like other mechanical tests, is sensitive to changes in the moisture content of the test piece. Handle the test pieces carefully and never touch with the bare hand the region of the test piece to be tested. Keep the test pieces away from moisture, heat and other influences that may change their moisture content.

8 Procedure

8.1 Sample preparation

Carry out the test in the atmospheric conditions under which the samples were conditioned. The sample shall be undamaged paper or board avoiding watermarks, folds and wrinkles.

Remove the protective liner from the tape (5.3) on one side and apply tape on both sides of the sample to be tested. From the sample cut by using a punch or a cutter (5.4) test pieces having a width of 25 mm and a length of at least 150 mm.

> *Note 1* – It is easier to remove the tape from the beams after the test, if the test piece has a length exceeding 170 mm.

Remove the protective liner from the tape on the test pieces and fasten the test piece to one of the beam pairs (5.1). The test piece shall be placed so that it starts at a distance of 52 mm from the hole and stretches at least to the end of the beams, preferably protruding 20 mm outside the beams. Put the beam with the test piece in one of the press blocks of the press. Put the other beam in the other press block of the press (5.5). Activate the press for 30 seconds and remove the sandwich after pressing.

> *Note 2* – For weak papers sheets, damage may occur when the protecting liner is removed. If so, reject the test piece. In this case, it is recommended to fasten the tape on the beams first and then fasten the test piece.

8.2 Measurement

Place the sandwich in the tensile testing apparatus (5.2) where the tester grips the holes in the beams according to *Figure 2*. Run the tester at a constant rate of elongation of (12 ± 8) mm/s until the sandwich is split into two parts. After testing, ensure that the test piece is still attached to the beams and that the rupture occurs within the paper. Record the maximum force.

Carry out at least 10 measurements and calculate the mean maximum force F_m. Normally the Z-directional toughness is equal in MD and CD. If not, carry out at least 10 measurements in each direction and report the results separately.

> *Note 3* – If the surfaces of the beams are touched when the tape is removed, clean the surfaces with a solvent (ethyl alcohol or similar) and dry them.

9 Calculation

Calculate the Z-directional toughness from the expression:

$$G_{Ic} = c \cdot F_m^2 \qquad [2]$$

where

G_{Ic} is the Z-directional toughness, in Joules per square metre;
c is a constant depending on the geometry and the material property of the beams and the area of the test piece.
F_m is the mean maximum tensile force, in Newton.

> *Note* – The constant c is calculated according to the procedure described in the Annex.
> Here c is 0,02084 $(\mathrm{Nm})^{-1}$.

Report the Z-directional toughness to three significant figures.

Calculate and report the coefficient of variation of the result.

10 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 of the material tested;
(c) the Z-directional toughness, in J/m^2, either as a mean value for both directions or as mean values for the two directions separately;
(d) if required, the standard deviation of the Z-directional toughness;
(e) if the tape quality stated in 5.3 is not used, report the manufacturer and trade name of the tape used;

(f) any departure from the procedure described in this Method and any other circumstances that may have affected the result.

11 Precision

11.1 Repeatability

One laboratory tested three samples of paperboard and linerboard under normal laboratory conditions using test pieces from the same gross sample. The results were as follows:

Paper type		Mean, J/m^2	Within-lab CV, %
Paperboard, 240 g/m^2	CD	67,5	5,8
Kraft paper, 80-100 g/m^2	CD	238	8,3
Linerboard	CD	171	5,8

CV is the coefficient of variation.

11.2 Reproducibility

Five laboratories tested three samples under normal laboratory conditions using test pieces from the same gross sample. The results were as follows:

Paper type		Mean, J/m^2	Between-lab CV, %
Paperboard, 240 g/m^2	CD	69,2	6,9
Kraft paper, 80-100 g/m^2	CD	244	4,4
Linerboard	CD	172	4,9

CV is the coefficient of variation.

12 Literature

12.1 Lundh, A and Fellers, C. The Z-toughness method for measuring the delamination resistance of paper. Nordic Pulp and Paper Research Journal 16:*4*, p. 298-305 (2001)

Annex
Determination of the constant *c*

A.1 Procedure

Fasten the beam in a clamp over the 30 mm area in Figure 1, clause 5.1. Place a weight corresponding to a force (F) of about 100 N in the hole of the beam, as illustrated in *Figure A.1*. Wait 10 seconds. Then measure the deflection (δ) of the beam at the point 52,00 mm from the hole.

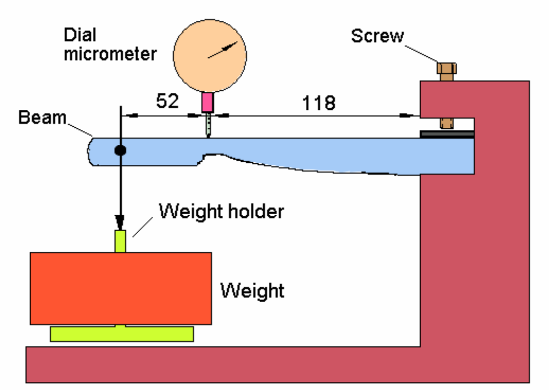

Figure A.1. An illustration of the calibration procedure.

Use the force and deflection values to calculate the elastic modulus as described in A.2.

A.2 Calculation of the elastic modulus of the beam

Calculate the elastic modulus using the following expression:

$$E = k\frac{F}{\delta} \qquad \text{[A.1]}$$

where
F is the force, in Newtons;
δ is the deflection, in millimetres;
E is the elastic modulus, in megapascals;
k is 77,6 mm^{-1} (see 12.1).

A.3 Calculation of the constant *c*

Calculate the constant, c, in equation [2] using the following equation:

$$c = \frac{32000}{E\,b^2} \qquad \text{[A.2]}$$

where
32000 is a constant referring to the geometry of the beams (12.1);
b is the width of the beam, in millimetres (here 25 mm).

A.4 Experimental example

In one investigation, using a number of polycarbonate beams, the following value for the elastic modulus, E, was obtained:

E = 2457 MPa

This gives c the value 0,02084 $(Nm)^{-1}$.

SCAN-test Methods are issued and recommended by KCL, PFI and STFI-Packforsk for the pulp, paper and board industries in Finland, Norway and Sweden.
Distribution: Secretariat, Scandinavian Pulp, Paper and Board Testing Committee, Box 5604, SE-114 86 Stockholm, Sweden.