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Paper and board — Determination of bending stiffness by static methods — General principles

Papier et carton — Détermination de la résistance à la flexion par des méthodes statiques — Principes généraux

Reference number
ISO 5628:1990(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 5628 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

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Introduction

Bending stiffness is regarded as an important property of paper and board, and a large number of test methods have been used for its determination. This is a result, in part at least, of the wide range of values obtained. For papers and board in a grammage range of 50 g/m^2 to 500 g/m^2, bending stiffness might vary by a factor of over 1 000. This wide variation is reflected in the design of instruments intended for the measurement of this property.

A second factor to be taken into account is that, in general terms, bending stiffness (as defined here) can only be determined with accuracy within certain limitations with regard to the degree of deformation imposed upon the test piece. These limitations depend, in effect, on the dimensions of the test piece and on the test method used.

This International Standard is intended to enable the bending stiffness (as defined here) to be measured and described in a consistent way despite the variations in material type and instrument design. It will be found that many commercially available instruments can be regarded as giving results in accordance with this International Standard for only part of the range of bending stiffness, or for only some of the materials, for which they were originally designed. It is intended, therefore, that this International Standard will be used as the basis for preparing detailed methods for determining bending stiffness, using particular instruments.

Attention is drawn to ISO 5629:1983, *Paper and board — Determination of bending stiffness — Resonance method*, which deals with a dynamic (resonance) method of bending stiffness measurement.

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Paper and board — Determination of bending stiffness by static methods — General principles

1 Scope

This International Standard specifies the general principles to be observed in the preparation of test methods for determining the bending stiffness of all types of paper and board using static methods, by applying line loading to which the mass of the test piece makes negligible contribution.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 186:1985, *Paper and board — Sampling to determine average quality*.

ISO 187:1977, *Paper and board — Conditioning of samples*.

ISO 534:1988, *Paper and board — Determination of thickness and apparent bulk density or apparent sheet density*.

ISO 2493:1973, *Paper and board — Determination of stiffness — Static bending method*.

3 Definition

For the purposes of this International Standard, the following definition applies.

bending stiffness, R: The moment of the resistance, per unit width, that a paper or board offers to bending within the limits of elastic deformation. It can be defined mathematically as

$$\frac{EI}{b}$$

where

E is the modulus of elasticity, i.e. Young's modulus;

I is the second moment of area (moment of inertia) of the cross-sectional area, about an axis through the centre of that area, in its plane, and perpendicular to the direction of bending;

b is the width of the cross-sectional area considered.

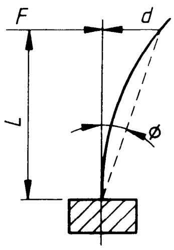
NOTE 1 It is noted that, in the case of multi-ply structures, this definition lacks precision, but for the purpose of this International Standard, it is sufficient to enable measurements to be made.

4 Principle

The bending stiffness of a material, which is proportional to the product of its elastic modulus (E) in the appropriate direction and its moment of inertia (I), can, in practice, be more readily determined as the ratio of the force per unit width applied at right angles to the test piece to the linear deflection that results from the application of this force. Three different loading methods can be considered and these are shown diagrammatically in figure 1 to figure 3. Two point loading is suitable for light materials and three point or four point loading is recommended for heavier materials.

Very flexible paper should be tested with the plane of the test piece vertical.

4.1 Two point loading



The force is applied to the test piece by movement of the deflecting probe.

L is the test length (bending length), i.e. the distance between the top of the clamp and the deflecting probe;

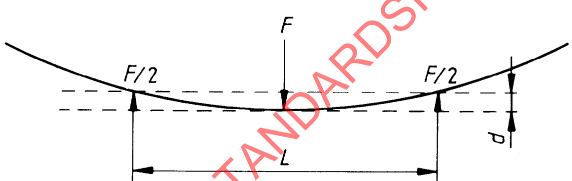
F is the bending force applied through the deflecting probe to the test piece;

d is the deflection and the movement of the deflecting probe;

ø is the arctan (d/L), i.e. the angular deflection.

Figure 1

4.2 Three point loading



The force is applied by movement of the supports relative to a probe located centrally between them.

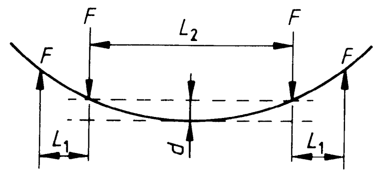
L is the distance between the two supports;

F is the bending force applied at right angles to the test piece and measured by the probe;

d is the deflection of the test piece midway between the supports.

Figure 2

4.3 Four point loading



The force is applied by movement of the outer pair of supports relative to the inner pair of supports.

L_1 is the distance between each outer support and its nearest inner support;

L_2 is the distance between the two inner supports;

F is the force at each of the supports in a direction normal to the undeflected test piece (on most instruments, the force measured will be $2F$);

d is the deflection of the test piece midway between the inner supports, measured from the line through the contact points of the inner supports and the test piece.

Figure 3

5 Apparatus

Any apparatus in accordance with this International Standard shall meet the following requirements.

NOTE 2 The apparatus may consist of an instrument specifically designed to measure bending stiffness or of an attachment or cradle used in conjunction with a suitable tensile tester or compression tester.

It should preferably be of a type that permits continuous recording of the force-deflection curve.

In some two point loading instruments, the bending angle may be measured rather than the linear deflection of the test piece, or a constant bending angle may be used.

In some two point loading instruments, the moment of force ($M = FL$) rather than the force (F) is measured.

5.1 Bending force measurement

The bending force applied shall be measurable to an accuracy of ± 2 % of the reading.

5.2 Deflection measurement

The deflection obtained shall be measurable to an accuracy of ± 2 % and shall not include any distortion of the force applicator.

The deflection indicator, where this is separate from the force applicator, shall not impart to the test piece an additional bending force greater than 1 % of the total bending force.

5.3 Measurement of test lengths

The test lengths L, L_1 and L_2 shall be known to an accuracy of $\pm$ 1 % or better because this dimension appears to the third power in calculating the results.

5.4 Deflecting force application rate

The rate of application of the deflecting force (rate of loading) shall not vary by more than 25 % of its maximum during a test.

5.5 Test piece clamps

Clamps (two point loading) shall grip the test piece firmly, but without excessively compressing it, over its full width and shall be at right angles to the length of the test piece.

5.6 Test piece supports and probes

Supports and probes should preferably give effective line contact with the test piece over its full width and shall be at right angles to the test piece. The area in contact with the test piece shall be rounded off to a radius that is appreciably less than the minimum radius of curvature of the test piece during a test. In the case of supports, the radius of curvature of the contacting surface shall be such that the test length does not change by more than 1 % of the undeflected length of the test piece during a test.

NOTE 3 With some instruments the deflecting probe does not contact the test piece over its full width.

6 Limitations on use of instruments

Stiffness measurements should be made over the limited range of deflection for which the load-extension relationship of the material is substantially linear. In those instruments which provide a plot of applied force against deflection, the initial slope of the curve may be used to give the term F/d used in the calculation of results. When the test is performed either by application of a set force and measuring deflection or by measuring the force to produce a set deflection, care must be taken not to exceed the limits of linearity. These limits will vary from material to material. The following limits have been evaluated assuming that linearity may be assumed up to 0,2 % strain. The limit on d_a, the maximum allowable deflection, is directly proportional to this value of limiting strain and so may easily be adjusted for materials where a different value is known.

a) Two point loading

$$d_a = \frac{1{,}3L^2}{t} ; \Phi_a = \frac{76L}{t}$$

b) Three point loading

$$d_a = \frac{0{,}33L^2}{t}$$

c) Four point loading

$$d_a = \frac{0{,}5L^2}{t}$$

where

d_a is the maximum allowable deflection, in millimetres;

L is the test length, in millimetres;

t is the test piece thickness, in micrometres;

Φ_a is the maximum allowable angular deflection, in degrees.

Two further limitations need to be considered in the cases of two point and three point loading. These are

a) Simple bending theory used in the calculation of results assumes that the first derivative of deflection by position is zero at all points in the test piece. This is not strictly true and to keep ensuing errors to less than 5 %, the following limitations need to apply:

1) Two point loading

$$d_a \ngtr 0{,}132L ; \Phi_a \ngtr 7{,}5°$$

2) Three point loading

$$d_a \ngtr 0{,}067L$$

b) The effect of shear in the test piece may invalidate the simple bending theory. To keep errors due to this effect below 5 % for both two point and three point loading, the bending length should be at least 40 times the thickness t of the test piece.

Further guidance on limits for deflection, rates of deflection and test piece dimensions will be included in the standards for specific tests.

NOTE 4 The origin of the limiting values given above is contained in the *Handbook of physical and mechanical testing of paper and paperboard*, vol. 1, chapter 7, pp. 323-347, ed. R.E. Mark (Dekker).

7 Sampling

Sample in accordance with ISO 186.

8 Conditioning

Condition the samples in accordance with ISO 187.

9 Preparation of test pieces

Carry out the test piece preparation in the standard atmospheric conditions used for conditioning the sample.

Prepare test pieces, in accordance with clause 6, from samples taken at random from those selected. No creases, obvious flaws, or watermarks shall be included in the test area and test pieces shall not include any part of the sample within 15 mm of the edge of any sheet or roll. If it proves necessary to include watermarks, this fact shall be noted in the test report.

Cut test pieces one at a time. The edges of the test pieces shall be straight, parallel, cleanly cut and undamaged. Mark the test pieces to indicate the direction of test and appropriate surface (see 10.5).

Care should be taken that the test pieces are not damaged during test piece preparation or later handling. Machine direction stiffness is measured when dimension L is in the machine direction. At least 10 test pieces should be cut in each direction.

10 Procedure

10.1 General

The procedure used depends to some extent on the design of the test instrument and on whether a continuous record of force and deflection is obtained during the test. Carry out the test in the standard atmosphere at which the sample was conditioned.

Measure the thickness of the test piece using an instrument in accordance with ISO 534.

Take care to ensure that the results are not affected by curling of the test piece, particularly when the axis of curvature of the test strip is in the direction in which the stiffness is to be measured.

NOTE 5 When adjustment of the instrument will not compensate for test piece curling and there are no flat samples available it may still sometimes be necessary to obtain a stiffness test result even at the cost of reduced accuracy. In such cases, draw the sample gently over a smooth edge, applied to the outside of the curved sheet, preferably prior to cutting and conditioning the test pieces. This operation can, however, result in a loss of stiffness and, if it has been performed, this should be clearly stated in the test report.

10.2 Two point loading

Select the most appropriate test length (bending length) and adjust the instrument accordingly.

Clamp the test piece and adjust the instrument so that the deflecting probe is just in contact with the test piece. No bending force should then be present.

10.3 Three point loading

Select the most appropriate test length and adjust the instrument accordingly.

Rest the test piece on the supports and adjust the instrument so that the stationary probe is just in contact with the test piece. No bending force should then be present.

10.4 Four point loading

Select the most appropriate test length and adjust the instrument accordingly. The application points are normally arranged such that $2L_1$ and L_2 will be approximately equal.

Rest the test piece on the lower pair of supports and, where possible, adjust the upper (inner) pair of supports to just touch the test piece. No bending force should then be present.

10.5 All methods

If the instrument has the means to obtain a continuous record of force and deflection, carry on the test until there is a marked divergence from linearity in the relationship between these two quantities. If no recording device is available, carry on the test until the required value of force or deflection is obtained and record the final force and deflection.

Carry out five tests, with each surface of the material forming the outside of the bend, and record the results separately. If the difference between the mean values for each surface is significant, report the mean and the coefficient of variation for each surface separately.

Verify that the limits on deflection and test length given in clause 6 and the elastic limits have not been exceeded. For this purpose, the amount of deflection shall be the sum of the deflection of the test piece under its own weight and that induced during the test.

For the calculation of results, the deflection induced during the test shall be used.

Carry out the tests with test pieces cut in both principal directions of the sample if this is required.

11 Expression of results

11.1 Force-deflection diagram

If during the test a force-deflection diagram is recorded, determine the slope of the straight portion of the relationship and thus determine F/d, F/Φ or M/Φ, as appropriate.

11.2 Two point loading

11.2.1 Where the deflection d of the test piece is measured

$$S = \frac{FL^3}{3db}$$

where

- S is the bending stiffness, in millinewton metres;
- F is the bending force, in newtons;
- L is the test length (bending length), in millimetres;
- b is the test width, in millimetres;
- d is the deflection, in millimetres.

11.2.2 Where the angular deflection, Φ, of the test piece is constant and known or is measured

$$S = \frac{19{,}1FL^2}{\Phi b}$$

where Φ is the angular deflection, in degrees.

NOTE 6 For instruments in which the moment of the force (M) about the clamp is measured, F should be calculated from

$$F = \frac{M}{L}$$

proper attention being given to units.

11.3 Three point loading

$$S = \frac{FL^3}{48db}$$

11.4 Four point loading

$$S = \frac{FL_1L_2^2}{8db}$$

where

- L_1 is the distance, in millimetres, between the outer support and its nearer inner support;
- L_2 is the distance, in millimetres, between the inner supports.

NOTE 7 Care should be taken to ensure that the value of force, F, inserted in this equation is as defined in 4.3. On many instruments, F is one-half the indicated force.

11.5 Values to be used

Values should be expressed in micronewton metres (µN·m), millinewton metres (mN·m), newton metres (N·m), or kilonewton metres (kN·m), as appropriate.

12 Precision

No general statement is possible with regard to the precision of this test as it will vary with the particular type of instrument used and the paper or board tested.

13 Test report

The test report shall include the following:

a) reference to this International Standard;

b) the date and place of testing;

c) the principle of the method used (i.e. two point, three point, or four point loading) and, for instruments that are commercially available, the name of the instrument manufacturer and the type of instrument;

d) the conditioning atmosphere used;

e) the test length (L) and the test piece width used;

f) the deflection obtained during the test; values corresponding to each principal direction being reported separately;

g) the maximum deflection permitted in accordance with clause 6;

h) the mean value of the bending stiffness in each direction tested;

i) the coefficients of variation of the measurements;

j) any divergencies from the specified test method.