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Paper and board — Determination of bending stiffness — General principles for two-point, three-point and four-point methods

Papier et carton — Détermination de la rigidité à la flexion — Principes généraux pour les méthodes à deux points, à trois points et à quatre points

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 2, *Test methods and quality specifications for paper and board*.

This third edition cancels and replaces the second edition (ISO 5628:2012), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

— in 6.4.2, a Note has been added to clarify the measurement of *F*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 in the bending stiffness of paper and board. For paper and board in the grammage range 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 limits with regard to the degree of deformation imposed upon the test piece. These limits depend on the dimensions of the test piece and on the test method used.

This document 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 document 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 document will be used as the basis for preparing detailed methods for determining bending stiffness, using particular instruments.

Paper and board — Determination of bending stiffness — General principles for two-point, three-point and four-point methods

1 Scope

This document specifies three test methods for determining the bending stiffness of paper and paperboard. The test methods differ in the type of loading mode, thus giving rise to the two-point, three-point and four-point bending test methods.

For paper and paperboard in a low thickness range, the two-point bending method and the three-point bending method are suitable.

For corrugated fibreboard and board with a higher thickness, the four-point bending method is recommended.

The measurement conditions are defined in such a way that the test piece is not subjected to any significant permanent deformation during the test, nor is the range of validity of the formulae for calculating the bending stiffness exceeded.

In these bending tests, the test pieces of paper and board are regarded as "beams" as defined by the science of the strength of materials, see Reference [2].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 187, *Paper, board and pulps — Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples*

ISO 534, *Paper and board — Determination of thickness, density and specific volume*

ISO 3034, *Corrugated fibreboard — Determination of single sheet thickness*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
bending stiffness
S_b
resistance that a test piece offers to bending, in the region of elastic deformation

Note 1 to entry: The theories used for the determination of bending stiffness are derived under the condition that the test piece is perfectly flat at the beginning of the test. In a real situation, the test piece always deviates from flatness. It is, however, not possible to give recommendations on the magnitude of such deviations (such as curl, twist, cockle or other deviations) that can be present and still produce a valid test.

4 Symbols and units

The following symbols are used for the formulae in this document.

Symbol	Unit	Meaning
b	mm	test piece width in the direction of the bending axis
E	MPa (N/mm^2)	modulus of elasticity
f	mm	linear deflection
F	N	force
f_{max}	mm	maximum linear deflection
I	mm^4	second moment of inertia
l	mm	bending length
l_1	mm	distance in the four-point method
l_2	mm	bending length in the four-point method
S_b	N·mm	bending stiffness
t	mm	test piece thickness
α	° (degree)	bending angle
α_{max}	° (degree)	maximum bending angle
ε	% (mm/mm)	strain
ε_{max}	% (mm/mm)	maximum strain

5 Theory

For a beam of a homogeneous material, with equal thickness and a constant modulus of elasticity in the plane of the paper or board, the bending stiffness S_b (per unit width b) may be derived from the product of the modulus of elasticity, E, and the second moment of inertia, I, of the test piece, divided by the width, b, of the test piece as shown in Formula (1):

$$S_b = \frac{E \cdot I}{b} \quad (1)$$

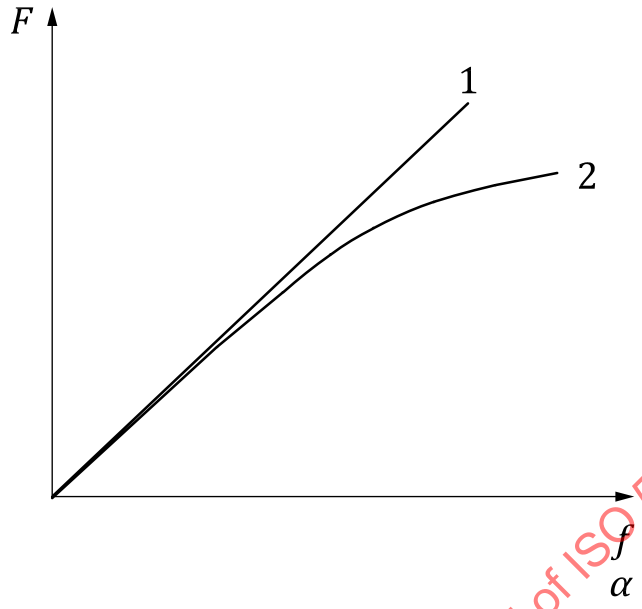
From a testing point of view, the bending stiffness, S_b, may be evaluated in three principally different ways:

a) From the maximum slope of the curve achieved from recording force versus linear deflection (F/f), or force versus angular deflection (F/α), see Figure 1[2]. The rate of testing shall be reported.

b) Applying a linear deflection or angular deflection and recording the force after a specified time[5]. This document gives suggestions for maximum allowable deflections for the various beam-bending methods. The time of application shall be reported.

c) Applying a force and recording the linear deflection or angular deflection after a specified time (References [3], [4], [5]). This document gives suggestions for maximum allowable deflections for the various beam-bending methods. The time of application shall be reported.

NOTE Suggestions for allowable deflections only apply to principles b) and c).



Key

1 maximum slope of curve

2 true curve

F force

f linear deflection

α angular deflection

Figure 1 — Schematic curve of force versus linear deflection or force versus angular deflection of a paper or board

6 Different bending test methods

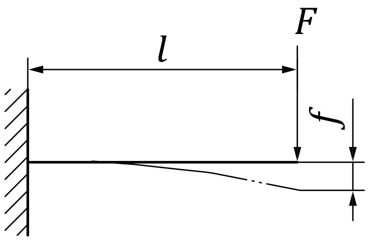
6.1 Two-point bending method

The two-point method is suitable for paper and low-thickness board. For corrugated board, the two-point method is not recommended.

The bending according to the two-point bending method can be performed in two ways.

In Figure 2, the beam-shaped test piece is clamped at one end and subjected to a force, *F*, acting perpendicular to the surface of the test piece at the start of the test, at a bending length, *l*, from the clamp. The linear deflection, *f*, of the test piece is the shift in the point of application of the force in the direction in which it acts.

In Figure 3, the beam-shaped test piece is clamped at one end in a clamp that rotates and is subjected to a force, *F*, acting perpendicular to the surface of the test piece at the start of the test, at a bending length, *l*, from the clamp. The bending angle, *α*, is the angle through which the clamp is rotated during the test.



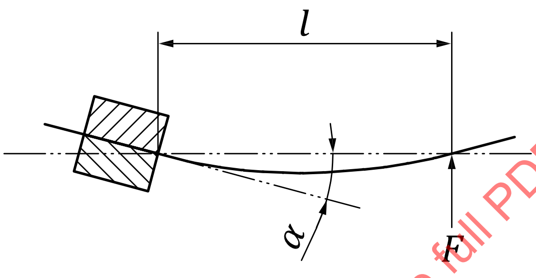
Key

F force (in newtons)

f linear deflection (in millimetres)

l bending length (in millimetres)

Figure 2 — Two-point method



Key

F force (in newtons)

l bending length (in millimetres)

α bending angle (in degrees)

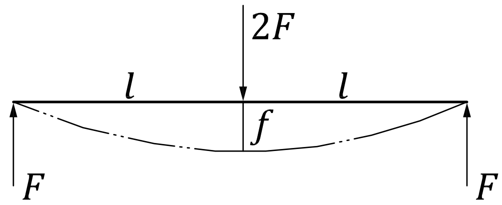
Figure 3 — Two-point method

6.2 Three-point bending method

The three-point method is suitable for paper and low-thickness board. For corrugated board, the three-point method is not recommended.

NOTE 1 It is possible to use the three-point bending method for corrugated board, if very long test pieces are used. The test method is not suitable for test pieces of recommended dimensions used for paper and board, due to the shear strain of the corrugated board[5]. The suitable dimensions depend on the material to be tested and no absolute values can be stated in this document.

The beam-shaped test piece is supported close to each end and is subjected to a force, 2*F*, in the centre perpendicular to the test-piece surface at the start of the test, see Figure 4.



Key

F force (in newtons)

f linear deflection (in millimetres)

l bending length (in millimetres)

Figure 4 — — Three-point method

The distance between the two supporting anvils is now twice the bending length, *l*. The linear deflection, *f*, is the shift in the point of application of the force in the direction in which it acts.

NOTE 2 The definitions of the force and bending length in the three-point test make the three-point test equal to two mirror images of the two-point test, thus making the calculation of bending stiffness and measurement conditions equal for these two tests.

6.3 Calculation of bending stiffness using the two-point and three-point methods

6.3.1 Bending stiffness determination

If the linear deflection, *f*, and the force *F* are measured during the bending test, the bending stiffness, S_b, is calculated according to Formula (2):

$$S_b = \frac{F}{f} \cdot \frac{l^3}{3b} \tag{2}$$

If the bending angle, α, and force *F* are measured during the bending test, the bending stiffness, S_b, is calculated according to Formula (3):

$$S_b = \frac{60}{\pi} \times \frac{F}{\alpha} \cdot \frac{l^2}{b} \tag{3}$$

6.3.2 Geometrical requirement

It is assumed in Formulae (2) and (3) that the bending occurs with negligible influence of inter-laminar shear strain. This strain depends theoretically on the ratio of inter-laminar shear stiffness to tensile stiffness and the ratio of the thickness to the bending length. In order to minimize the impact of inter-laminar shear strain on the result, the length *l* shall not be less than approximately 40 times the thickness of the test piece for paper and board, see Reference [5].

In this document, no particular requirement is stipulated for the width of the test piece. The choice of width has to be selected by the user and be suited for a particular testing equipment. The width shall be reported.

6.3.3 Allowable deflections and angles

The test piece shall not suffer any significant permanent deformation during the bending test. Furthermore, there are requirements for the maximum deflection according to the beam-bending theory[5]. To comply with these requirements, Formulae (4) to (7) apply.

The in-plane strain, ε, should not exceed approximately 0,2 % (ε_{max}) in the outer layers of the test piece, see Reference [2].

When linear deflections are recorded, Formulae (4) and (5) apply. The deflection f shall not exceed f_{max} according to either Formula (4) or Formula (5), whichever gives the lowest value.

$$f_{max} = \frac{2}{3} \times \frac{\varepsilon_{max}}{100} \cdot \frac{l^2}{t} \quad (4)$$

$$f_{max} = 0{,}132 l \quad (5)$$

When angles are recorded, Formulae (6) and (7) apply. The bending angle, α, shall not exceed α_{max} according to either Formula (6) or Formula (7), whichever gives the lowest value.

$$\alpha_{max} = \frac{120}{\pi} \times \frac{\varepsilon_{max}}{100} \cdot \frac{l}{t} \quad (6)$$

$$\alpha_{max} = 7{,}5^\circ \quad (7)$$

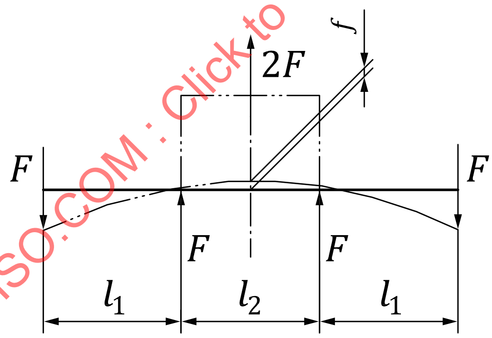
NOTE Bulking thickness and single sheet thickness give different results. Consequently, this will result in a difference in the calculation of the allowable deflection or bending angle.

6.4 Four-point bending method

6.4.1 Geometry

The four-point method is suitable for corrugated board and thick board (References [2], [3], [4], [5]).

The test piece is subjected to forces according to Figure 5. The outer forces act close to each end of the test piece.



Key

F force (in newtons)

f linear deflection (in millimetres)

l_1 bending length (in millimetres)

l_2 bending length in the four-point method (in millimetres)

Figure 5 — — Four-point method

The distance, l_1, is the measured distance between one of the outer supporting anvils and the point of application of the neighbouring force, F.

The bending length, l_2, is the distance between the points of application of the two inner forces and the two inner anvils.

The linear deflection, f, is the displacement of the point midway between the two inner forces in the direction of action of these forces.

6.4.2 Calculation of bending stiffness

The bending stiffness, S_b, of the test piece is calculated according to Formula (8).

$$S_b = \frac{F}{f} \cdot \frac{l_1}{8} \cdot \frac{l_2^2}{b} \tag{8}$$

NOTE Some testing devices deliver 2 F instead of F. This is because the load cell is submitted to 2 F (see Figure 5). F will be displayed correctly only if the software is adapted to the four-point bending method.

6.4.3 Measurement conditions

The test pieces shall not suffer any significant permanent deformation during the bending test.

The strain, ε, in the outer layers of the test piece should not exceed 0,05 % (ε_{max}) for corrugated board and 0,2 % (ε_{max}) for board, see Reference [2].

To comply with this requirement, care is required to ensure that the linear deflection, f, does not exceed the limit values f_{max}, calculated according to Formula (9) (References [2], [5]).

$$f_{max} = \frac{1}{4} \times \frac{\varepsilon_{max}}{100} \cdot \frac{l_2^2}{t} \tag{9}$$

NOTE Bulking thickness and single sheet thickness give different results. Consequently, this will result in a difference in the calculation of the allowable deflection or bending angle.

6.4.4 Geometrical and practical considerations

Suitable lengths and widths shall be selected. The lengths depend on the material to be tested and no absolute values can be stated in this document.

l_1 and l_2 shall be chosen as large as possible. As a rule of thumb, l_1 shall be equal to or larger than l_2.

In this document, no particular requirement is stipulated for the width of the test piece. The choice of width has to be selected by the user and be suited for a particular testing equipment. The width shall be reported.

The test equipment shall be constructed in such a way that small warp, twist or curl of the board does not interfere with the results.

Table 1 — Recommended lengths, l_2, for corrugated board[2]

Thickness mm	l_2 mm
< 3	150
3–15	200
> 15	300

Table 2 — Recommended lengths, l_2, for paper and board[2]

Thickness mm	l_2 mm
< 0,3	10
0,3–0,8	30
> 0,8	50

NOTE 1 In the four-point method, the result of measurement is not influenced by inter-laminar shear strain.

NOTE 2 The bending length is usually dictated by the measuring instrument that is employed.

NOTE 3 Recommendations for suitable lengths, l_1 and l_2, are given in References [2], [3], [4], [5].

7 Apparatus

7.1 Bending tester, designed and constructed in such a way that the bending lengths can be adjusted adequately with a precision of ± 1 % of the length. Preferably, using a measuring instrument that makes it possible to record force versus deflection or force versus angle, and having a means of evaluating the maximum slope of the curves.

7.2 Measuring device, making it possible to measure force, deflection or angle to within ± 2,5 % of the maximum value used to obtain the bending stiffness.

7.3 Supporting anvils, designed and constructed in such a way that their impact on the result of measurement is negligible.

8 Sampling and preparation of test pieces

8.1 Sampling

If the tests are being made to evaluate a lot, the sample shall be selected in accordance with ISO 186. If the tests are made on another type of sample, make sure that the specimens taken are representative of the sample received.

8.2 Conditioning

Unless otherwise specified, condition the specimens in accordance with ISO 187 and keep them in the conditioning atmosphere throughout the test.

8.3 Preparation of test pieces

From specimens of undamaged paper and board, cut test pieces with a desired width and length according to the recommendations given in 6.3.2 and 6.4.4. Avoid touching the test piece with bare hands. Avoid watermarks, folds and wrinkles. Ensure that the test pieces are representative of the sample to be tested. The long edges of the test pieces shall be straight, and parallel to within ± 1 % of the width over the total clamping length. The test pieces shall be cleanly cut and undamaged. Cut a sufficient number of test pieces to enable at least 10 tests to be made in each direction of interest (machine direction, cross direction).

Define one side of the specimens as the upper side.

9 Procedure

Prior to testing, determine the thickness of the test pieces in accordance with ISO 534 (for paper and board) or ISO 3034 (for corrugated board).

NOTE Bulking thickness and single sheet thickness give different results. Consequently, this will result in a difference in the calculation of the allowable deflection or bending angle.

Test one test piece according to the requirements of the type of test being conducted. Test the remaining test pieces to obtain at least five tests with the test piece deflected towards the upper side and five with the test piece deflected towards the lower side.

The test pieces shall be as flat as possible. Even slight pre-curvatures in the test pieces may cause force versus deflection or force versus angle, when bending towards the upper and lower sides, to differ. For