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Paper and board — Determination of fracture toughness — Constant rate of elongation method (1,7 mm/s)

Papier et carton — Détermination de la résistance à la rupture — Méthode à gradient d'allongement constant (1,7 mm/s)

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Foreword

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The committee responsible for this document is ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 2, *Test methods and quality specifications for paper and board*.

Introduction

The essence of fracture mechanics theory is that the material parameter fracture toughness is determined by controlled laboratory testing before it is used to predict the fracture properties of structures or structural components containing defects. This Technical Specification describes a laboratory test method for determination of the fracture toughness of paper materials and a numerical method to predict the fracture strength and fracture strain of notched paper webs for a given reference paper web geometry called ISO paper web geometry. The specified methods are based on nonlinear fracture mechanics theory (J-integral theory).[1] [2] [3]

The experimental procedure for determining the fracture toughness of this Technical Specification consists of two material tests: tensile testing and fracture toughness testing. Both these tests are performed following ISO 1924-3, with the exception that 50 mm wide test pieces containing 20 mm-wide centre notches are used in the fracture toughness test.

For material ranking and material development purposes, it is advantageous to define a notched reference geometry for predictions of fracture strength (stress at break) and fracture strain (strain at break). Such notched reference geometry makes it easier to compare fracture properties of different paper materials and to communicate results in reports and articles. The main application of fracture mechanics to paper materials is related to breaks in continuous web handling operations, such as in manufacture, winding, and printing. The characteristic dimensions of paper webs in such operations generally are in the order of metres, while defects in the paper webs commonly have a characteristic size in the order of millimetres. Furthermore, the most severe defects from a web break perspective are located in the region of the edges of the paper web. In this Technical Specification, a 2 m long and 1 m wide paper web, containing a 10 mm edge notch, is used as the notched ISO paper web geometry for predicting and ranking of the fracture properties of paper materials. The terms ISO fracture strength and ISO fracture strain are used to indicate that the fracture properties are determined for this particular notched ISO paper web geometry following this Technical Specification. A successful experimental validation of the procedure for determining the fracture properties for the assigned ISO web geometry has been performed.[1] [2] [3]

NOTE 1 The determined fracture toughness may also be utilized to predict fracture properties of paper webs and paper products that have different dimensions and shapes than the introduced ISO paper web geometry. The procedure for such predictions is given in References [1], [2], and [3].

NOTE 2 The fracture toughness alone does not constitute sufficient information to determine the fracture behaviour of structures or structural components. Consider the stress/strain curves for two materials, A and B, obtained by tensile testing of notched test pieces (see Figure 1). The exemplified materials have *equal fracture toughness* but *different fracture strengths and fracture strains*. Materials A and B, which have different stress/strain behaviours, could for instance originate from machine direction (MD) and cross-machine direction (CD) of a particular paper grade or could be two papers of different origin. Clearly, materials A and B are expected to behave very differently in converting operations, although they have equal fracture toughness. This example illustrates that the fracture toughness cannot be used to rank the fracture properties of papers that show different stress/strain behaviour. However, the ISO fracture strength and ISO fracture strain, according to this Technical Specification, can be used to accurately rank the fracture properties of materials A and B.

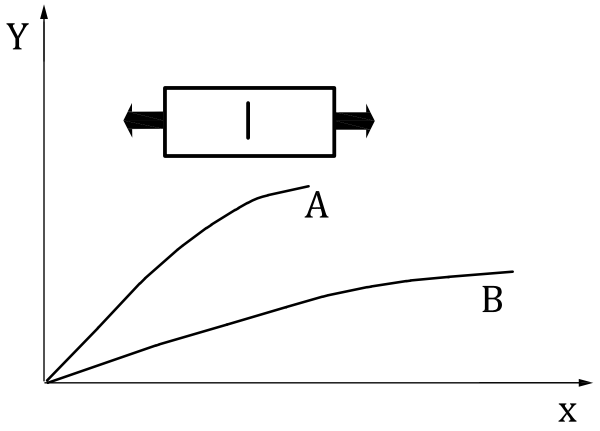


Figure 1 — Stress/strain curves for two materials, A and B, obtained by tensile testing of notched test pieces

Paper and board — Determination of fracture toughness — Constant rate of elongation method (1,7 mm/s)

1 Scope

This Technical Specification describes a method for determining the fracture toughness of paper and board using a tensile testing machine operated with a constant rate of elongation. This Technical Specification also describes the determination of the fracture strength and fracture strain of a notched paper web with an assigned standard web geometry. This information is used to rank the fracture properties of paper materials.

This Technical Specification is applicable to all kinds of paper and paperboard, except for certain special grades, such as creped paper and other paper materials that significantly deviate from exhibiting monotonically decreasing tangential stiffness during tensile testing. This Technical Specification does not apply to corrugated fibreboard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 536, *Paper and board — Determination of grammage*

ISO 1924-3, *Paper and board — Determination of tensile properties — Part 3: Constant rate of elongation method (100 mm/min)*

3 Terms and definitions

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

3.1
tensile stiffness
E^b
maximum slope of the curve obtained when tensile force per unit width is plotted versus strain

[SOURCE: ISO 1924-3:2005, definition 3.8]

3.2
tensile strength
σ_T^b
maximum tensile force per unit width that paper and board will withstand before breaking under the conditions defined in this Technical Specification

[SOURCE: ISO 1924-3:2005, definition 3.1]

3.3
tensile energy absorption
W_T^b
amount of energy per unit surface area (test length × width) of a test piece when it is strained to the maximum tensile force

[SOURCE: ISO 1924-3:2005, definition 3.6]

3.4
strain at break
ε_T
strain at the maximum tensile force

[SOURCE: ISO 1924-3:2005, definition 3.5]

3.5
strain-hardening exponent
N
mathematically determined exponent describing the non-linear part of the stress/strain curve of the test material

Note 1 to entry: The strain–hardening exponent is dimensionless.

3.6
strain-hardening modulus
E_0^b
mathematically determined modulus describing the non-linear part of the stress/strain curve of the test material

Note 1 to entry: The strain–hardening modulus is expressed in newtons per metre (N/m).

3.7
apparent tensile strength
σ_{cr}^b
tensile strength of the centre-notched fracture toughness test piece

Note 1 to entry: The apparent tensile strength is reported in newtons per metre (N/m).

3.8
apparent strain at break
ε_{cr}
strain at break of the centre-notched fracture toughness test piece

Note 1 to entry: The apparent strain at break is dimensionless and usually reported as a percentage.

3.9
fracture toughness
J_{cr}^b
energy release rate at structural instability of notched paper or board panels under in-plane tensile loading

3.10
ISO fracture strength
σ_{ISO}^b
tensile strength of the edge-notched ISO paper web geometry used in this Technical Specification

3.11
ISO fracture strain
ε_{ISO}
strain at break of the edge-notched ISO paper web geometry used in this Technical Specification

4 Principle

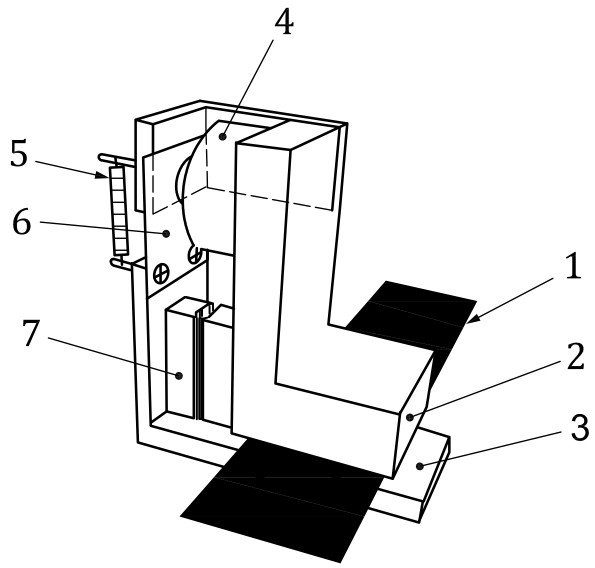
Two different kinds of test pieces, un-notched and notched, of given dimensions are subjected to constant rate of elongation using a tensile testing machine recording the tensile force and elongation. From the recorded data of the un-notched test pieces, the tensile strength, strain at break, tensile energy absorption, and tensile stiffness are determined. From the recorded data of the notched test pieces, the apparent tensile strength and apparent strain at break are determined. The parameters of the un-notched test pieces in combination with the parameters of the notched test pieces are used to calculate the fracture toughness of the material. The required calculations are treated in Clause 9.

5 Apparatus

5.1 Tensile testing machine, as described in ISO 1924-3. The tensile testing machine shall be capable of testing both 15 mm wide and 50 mm wide test pieces.

5.2 Anti-buckling guide, used to keep the notched region of the fracture toughness test piece flat during the fracture toughness test. The anti-buckling guide shall consist of two supports with parallel, flat, smooth low-friction surfaces, preferably made of steel or aluminium that shall cover the total width of the test piece and a length of 15 mm on each side of the notch. A compression force of (0,6 ± 0,2) N shall be applied to the fracture toughness test piece by the supports, before the separation of the supports is fixed. The fixed separation of the supports shall then be retained during the reminder of the fracture toughness test.

One possible solution to prevent out-of-plane buckling of the fracture toughness test piece is shown in Figure 2. The paper test piece (1) is placed between a stationary upper support (2) and a movable lower support (3). The lower support, which is free to slide vertically on roller bearings (7), is brought into contact with the test piece. The specified compression force is applied by the spring (5) to the paper test piece via the lower support. The position of the lower support is then fixed by the pneumatic cylinder (4) via the thin metal blade (6).



Key

1 paper test piece
2 upper support
3 lower support
4 pneumatic cylinder
5 spring
6 thin metal blade
7 roller bearings

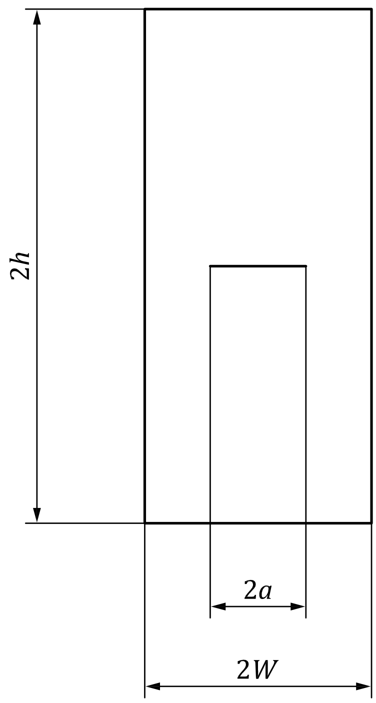
Figure 2 — Illustration of one possible solution to achieve anti-buckling

5.3 Computer, means for numerical calculation of fracture toughness and predictions of fracture strength and fracture strain, in accordance with the formulae given in this Technical Specification.

5.4 Cutting device(s), used for cutting tensile and fracture toughness test pieces. The cutting device(s) shall be able to cut (15 ± 0,1) mm wide tensile test pieces and (50 ± 0,1) mm wide fracture toughness test pieces (2W), respectively.

5.5 Device for making a notch, used to manufacture a centre-notch in each fracture toughness test piece. The device shall be able to produce a (20 ± 0,1) mm long straight centre-notch (2a). The notch shall be oriented perpendicular to the loading direction with a precision of ± 5 and have a central location with respect to both the width and the length of the test piece. The end of the notch shall be situated (15 ± 0,1) mm from the edge of the test piece. The position of the notch in the length direction shall be (50 ± 5) mm (h) from each clamp in the testing apparatus. A description of the test piece is given in Figure 3.

NOTE One possible device that is able to cut the notch with the required precision consists of a sharp razor blade mounted in a punch press.



Key

2*h* test piece length between clamps

2*a* notch length

2*W* test piece width

Figure 3 — The characteristic geometry of the fracture toughness test piece

6 Calibration and adjustment of apparatus

The tensile testing machine (5.1) shall be calibrated according to ISO 1924-3 and instructions given by the manufacturer of the testing apparatus.

The proper function of the anti-buckling guide shall be checked before the fracture toughness testing. Ensure that the anti-buckling guide is applying a compression force of (0,6 ± 0,2) N to the fracture toughness test piece before the separation of the supports is fixed. A calibration weight or a force measurement instrument may be used for controlling the compression force. If necessary, adjust the applied force.

7 Sampling and preparation of test pieces

7.1 Sampling

If the tests are being made to evaluate a lot, select the sample in accordance with ISO 186. If the tests are made on another type of sample, ensure that the specimens taken are representative of the sample received.

7.2 Conditioning

Condition the samples at (23 ± 1) °C and (50 ± 2) % relative humidity (r.h.) as specified in ISO 187.

These tests, like other mechanical tests, are very sensitive to changes in the moisture content of the test pieces. Handle the test pieces carefully and never touch the part of the test pieces to be placed between the clamps with bare hands. Keep the test pieces away from moisture, heat, and other influences that may change their moisture content.