
**Paper and board — Determination
of tensile properties —**

**Part 3:
Constant rate of elongation method
(100 mm/min)**

Papier et carton — Détermination des propriétés de traction —

Partie 3: Méthode à gradient d'allongement constant (100 mm/min)



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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 1924-3 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 2, *Test methods and quality specifications for paper and board*.

ISO 1924 consists of the following parts, under the general title *Paper and board — Determination of tensile properties*:

- *Part 2: Constant rate of elongation method*¹⁾
- *Part 3: Constant rate of elongation method (100 mm/min)*

Part 1: (*Constant rate of loading method*) was withdrawn in 2004 as it was considered obsolete.

1) In Part 2, a constant rate of elongation of 20 mm/min is used.

Introduction

This part of ISO 1924 has been developed in order to specify the conditions for determining the tensile properties of paper, including tensile stiffness and tensile stiffness index, using a higher rate of elongation than specified in ISO 1924-2, which is the most commonly used part where tensile strength, stretch at break, tensile energy absorption and modulus of elasticity are measured. In ISO 1924-2, the tensile properties are measured at a constant rate of elongation of 20 mm/min at a test span of 180 mm. For the measuring of tensile stiffness in this part of ISO 1924, a higher accuracy in the recording of elongation, compared to ISO 1924-2, is also required.

This part of ISO 1924 specifies the fastest of the two methods. In addition to the properties measured in ISO 1924-2, the tensile stiffness is also measured. The tensile properties are measured at a constant rate of elongation of 100 mm/min at a test span of 100 mm, and the elongation is recorded with a higher accuracy than the accuracy in ISO 1924-2.

This part of ISO 1924 differs from existing standards for testing tensile properties in that the test span, i.e. the distance between the clamping lines, is 100 mm irrespective of the kind of sample to be tested. The rate of elongation has been increased to 100 mm/min in order to reduce the testing time, thus making it possible to test a greater number of samples within a given time period.

NOTE The results of tensile tests depend on the rate of elongation applied and the test span. The rate dependence and the effect of test span may vary with paper grade and are different for tensile strength, strain at break, tensile energy absorption and tensile stiffness. In a study within SCAN-test, comparing the results achieved using ISO 1924-2 and this part, the tensile strength increased by 5 % to 15 % when the rate of elongation was increased from 20 mm/min (at a test span length of 180 mm) to 100 mm/min (at a test span length of 100 mm).

It is not possible to predict the exact relationship between the results for any particular paper whose tensile properties are determined using ISO 1924-2 and this part of ISO 1924. This relationship may only be determined by laboratory experimentation.

In this part of ISO 1924, the same terminology and symbols are used as in general literature concerning physics and mechanics of materials.

Paper and board — Determination of tensile properties —

Part 3: Constant rate of elongation method (100 mm/min)

1 Scope

This part of ISO 1924 specifies a method for measuring the tensile strength, strain at break, tensile energy absorption and tensile stiffness, using a testing machine operating with a constant rate of elongation (100 mm/min). This part of ISO 1924 also specifies equations for calculating the tensile index, the tensile energy absorption index, the tensile stiffness index and the modulus of elasticity.

When tensile stiffness is to be determined, a greater accuracy is required in the elongation measurement than when the other tensile properties are to be determined. If the elongation is determined with the lower accuracy, the tensile stiffness value obtained is not in accordance with this part of ISO 1924.

This part of ISO 1924 is applicable to all papers and boards, including papers of high extensibility, such as creped papers and extensible sack papers, but with the exception of low-density papers such as tissue papers and tissue products for which ISO 12625-4^[2] is recommended.

2 Normative references

The following referenced documents are indispensable for the application 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 536, *Paper and board — Determination of grammage*

3 Terms and definitions

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

3.1

tensile strength

maximum tensile force per unit width that paper and board will withstand before breaking under the conditions defined in this standard test method

3.2

tensile index

tensile strength divided by the grammage

3.3

elongation

increase in length of a test piece

3.4

strain

ratio of the elongation of a test piece to the initial test length

NOTE The initial test length of the test piece is the same as the initial span between the clamping lines.

3.5

strain at break

strain at the maximum tensile force

3.6

tensile energy absorption

amount of energy per unit surface area (test length \times width) of a test piece when it is strained to the maximum tensile force

3.7

tensile energy absorption index

tensile energy absorption divided by the grammage

3.8

tensile stiffness

maximum slope of the curve obtained when tensile force per unit width is plotted versus strain

3.9

tensile stiffness index

tensile stiffness divided by the grammage

3.10

modulus of elasticity

tensile stiffness divided by the thickness

4 Principle

A test piece of given dimensions is strained to break at a constant rate of elongation using a testing machine that automatically records both the tensile force and the elongation. From the recorded data, the tensile strength, the strain at break, the tensile energy absorption and the tensile stiffness are calculated.

5 Apparatus

5.1 Tensile testing machine, including means of determining the force (i.e. a load-cell), the elongation and the area between the force-elongation curve and the elongation axis. The testing machine is designed to strain a test piece at a constant rate of elongation of $100 \text{ mm/min} \pm 10 \text{ mm/min}$, and to record both the tensile force and the elongation.

NOTE 1 The true elongation rate is less than the rate of movement of the moving clamp due to the deflection of the load-cell and the testing machine. This rate difference has, however, normally a negligible effect on the strength values.

The testing machine shall have two clamps for holding the test piece. Each clamp shall be designed to grip the test piece firmly, but without damage, along a straight line across the full width of the test piece (the clamping line), and have a means of adjusting the clamping force.

NOTE 2 The clamping line is the contact zone resulting from gripping the test piece between a cylindrical and a flat surface or between two cylindrical surfaces whose axes are parallel. For certain grades of paper, "line contact" clamps may not be appropriate and it may be necessary to replace them with another type of gripping surface. Other types of clamps may be used, provided no slippage of, or damage to, the test piece occurs during the test.

When the test piece is clamped, the clamping lines shall be parallel to each other within an angle of 1° , see Figure 1. During the test, the angle between the clamping lines shall not change by more than $0,5^\circ$ in the plane of the test piece. The centre-line of the test piece shall be perpendicular to the clamping lines within an angle of 1° .

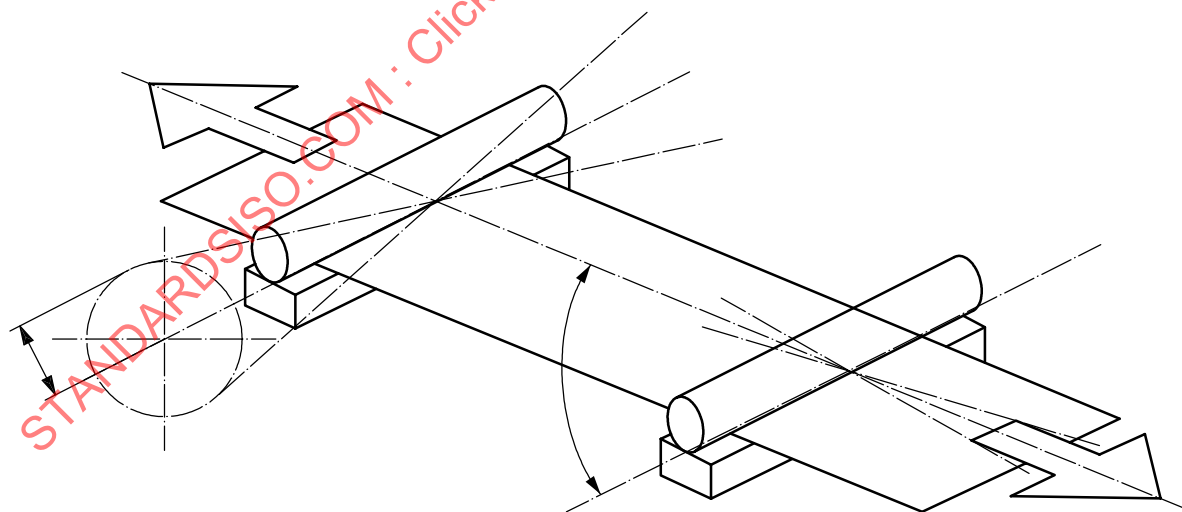
If there is any suspicion that the test piece slips, a test with different clamping forces shall be carried out. If the clamping force influences the strain at break, this means that the test piece may be slipping in the clamp. If the strain at break is independent of the clamping force, then no slipping in the clamps occurs.

The applied tensile force shall be parallel to the test piece centre-line, in the direction of the test piece, within an angle of 1° . The distance between the clamping lines (the test span) shall be $100 \text{ mm} \pm 0,5 \text{ mm}$.

The apparatus shall have means of recording the elongation and the force as follows:

| Property | Elongation | Force |
|---------------------------|---|---|
| Tensile strength | — | to an accuracy of 1,0 % of the true force |
| Strain at break | to an accuracy of 0,1 mm | |
| Tensile energy absorption | to an accuracy of 0,1 mm | to an accuracy of 1,0 % of the true force |
| Tensile stiffness | to an accuracy of 0,01 mm, in the range 0 to 1 mm | to an accuracy of 1,0 % of the true force |

The elongation shall be calculated from the change in distance between the clamps, or by the use of an extensometer.



Clamping lines parallel to each other within an angle of 1°

Centre-line of test piece perpendicular to clamping line within an angle of 1°

Tensile force parallel to the test piece centre-line within an angle of 1°

Figure 1 — Clamping line and test piece relationship

NOTE 3 If the elongation is calculated from the movement of the moving clamp, the deflection of the load-cell and of the testing machine must be taken into consideration and adjusted for.

5.2 Device for cutting test pieces to the dimensions required (see 7.3).

6 Calibration and adjustment of apparatus

The apparatus shall be calibrated according to the instructions given by the manufacturer. Ensure that the criteria stated in the Table in 5.1 are fulfilled.

Position the clamps so that the test span is $100 \text{ mm} \pm 0,5 \text{ mm}$. Check the test span by measuring the two impressions produced by the clamps when strips of, for example, thin aluminium foil are clamped.

Adjust the rate of separation of the clamps to $100 \text{ mm/min} \pm 10 \text{ mm/min}$. Adjust the clamping force so that there is neither slipping of, nor damage to, the test piece.

7 Sampling and preparation of test pieces

7.1 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 test pieces are representative of the sample received.

7.2 Conditioning

Condition the specimens of paper and board as specified in ISO 187. Keep them in the conditioning atmosphere throughout the test.

This test, like other mechanical tests, is very sensitive to changes in the moisture content of the test piece. Handle the test pieces carefully, and avoid touching with a bare hand the part of the test piece to be placed between the clamps. Keep the test pieces away from moisture, heat and other influences that may change their moisture content.

7.3 Preparation of test pieces

If the tensile index, tensile stiffness index or tensile energy absorption index is required, determine the grammage of the specimens as described in ISO 536. If the modulus of elasticity is required, determine the thickness as described in ISO 534.

From specimens of undamaged paper and board, cut test pieces with a width of $15,0 \text{ mm} \pm 0,1 \text{ mm}$ and long enough to be clamped in the clamps. Avoid touching with a bare hand the part of the test piece to be placed between the clamps, avoiding 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, parallel to within $\pm 0,1 \text{ mm}$ over the total clamping length, 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).

NOTE Several test pieces can be cut simultaneously, provided that the test pieces obtained fulfil the requirements specified above and that the test pieces obtained give the same result as test pieces cut one at a time.

A test width of $25,0 \text{ mm} \pm 0,1 \text{ mm}$ or $50,0 \text{ mm} \pm 0,1 \text{ mm}$ is also permitted, but this shall be reported.

8 Procedure

Ensure that the testing machine is calibrated as described in Clause 6. Place the test piece in the clamps without straining it and so that any observable slack is eliminated. Avoid touching the test area between the clamps with the fingers. Align and tightly clamp the test piece and perform the test.

Test at least 10 test pieces in each direction of interest (machine direction, cross direction). Reject all readings for test pieces that break within 2 mm of the clamping lines.

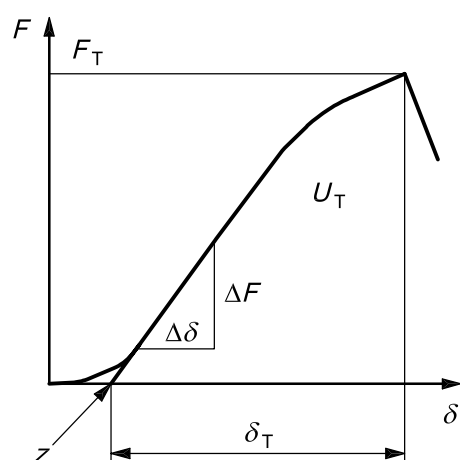
NOTE If more than 20 % of the test pieces break within 2 mm of the clamping lines, inspect the apparatus for conformity with the specifications and take the appropriate remedial measures. Accept the results if the apparatus conforms to the specifications in 5.1. Otherwise, reject all the readings obtained for that particular specimen.

9 Calculation and report

Calculate and report the results separately for the machine and cross directions.

In order to specify the kind of result reported, the suffixes MD and CD shall be used to express the machine and cross direction, respectively. As an example, $\sigma_{T,MD}^w$ is used for the tensile index in the machine direction, $\sigma_{T,CD}^w$ is used for the tensile index in the cross direction and $\sigma_{T,GM}^w$ is used for the geometric mean tensile index.

A typical force-elongation curve is shown in Figure 2.



Key

- F tensile force, in newtons
- δ elongation, in millimetres
- z point where the tangent to the curve, with a slope equal to the maximum slope of the curve, intersects the elongation axis
- F_T maximum tensile force, in newtons
- δ_T elongation at break, in millimetres
- U_T area under the tensile force-elongation curve, in millijoules

For other symbols, see Equation 6.

Figure 2 — Measured quantities for calculation of tensile properties

9.1 Tensile strength

Evaluate the maximum tensile force for each test piece. Calculate the mean maximum tensile force and then the tensile strength from the expression:

$$\sigma_T^b = \frac{\bar{F}_T}{b} \quad (1)$$

where

σ_T^b is the tensile strength, in kilonewtons per metre;

\bar{F}_T is the mean maximum tensile force, in newtons;

b is the width of the test piece, in millimetres (normally 15 mm).

Report the tensile strength to three significant figures.

9.2 Tensile index

Calculate the tensile index from the expression:

$$\sigma_T^w = \frac{1\,000\sigma_T^b}{w} \quad (2)$$

where

σ_T^w is the tensile index, in kilonewton metres per kilogram;

σ_T^b is the tensile strength, in kilonewtons per metre;

w is the grammage, in grams per square metre.

Report the tensile index to three significant figures.

9.3 Strain at break

All elongation values shall be calculated from the point, z , where the tangent to the curve, with a slope equal to the maximum slope of the curve, intersects the elongation axis, see Figure 2.

Evaluate the elongation at break for each test piece from the force-elongation curves from the point z up to the elongation corresponding to the maximum tensile force, see Figure 2. Calculate the mean elongation at break and then the strain at break from the expression:

$$\varepsilon_T = \frac{100\bar{\delta}_T}{l} \quad (3)$$

where

ε_T is the strain at break, as a percentage of the initial test length;

$\bar{\delta}_T$ is the mean elongation at break, in millimetres;

l is the initial test length of the test piece, in millimetres (100 mm).

If the higher accuracy of the elongation measurement is used, the strain at break shall be reported with two decimals. If the lower accuracy of the elongation measurement is used, report the strain at break with one decimal.

9.4 Tensile energy absorption

For each test piece, determine the area under the force-elongation curve from the point z up to the point of maximum tensile force, see Figure 2. Calculate the mean area, and then the tensile energy absorption, from the expression:

$$W_T^b = \frac{1\,000\bar{U}_T}{bl} \quad (4)$$

where

W_T^b is the tensile energy absorption (TEA), in joules per square metre;

\bar{U}_T is the mean area under the force-elongation curve, in millijoules;

b is the initial width of the test piece, in millimetres (normally 15 mm);

l is the initial test length of the test piece, in millimetres (100 mm).

Report the tensile energy absorption to three significant figures.

9.5 Tensile energy absorption index

Calculate the tensile energy absorption index from the expression:

$$W_T^w = \frac{1\,000\ W_T^b}{w} \quad (5)$$

where

W_T^w is the tensile energy absorption index, in joules per kilogram;

W_T^b is the tensile energy absorption, in joules per square metre;

w is the grammage, in grams per square metre.

Report the tensile energy absorption index to three significant figures.

9.6 Tensile stiffness

With the aid of a computer, for each test piece, determine the maximum slope of the force-elongation curve by preferably linear regression analysis over a number of corresponding force and elongation values, see Figure 2.

$$S_{\max} = \left(\frac{\Delta F}{\Delta \delta} \right)_{\max} \quad (6)$$

where

S_{\max} is the maximum slope of the force-elongation curve, in newtons per millimetre;

ΔF is the force increment, in newtons;

$\Delta \delta$ is the elongation increment, in millimetres.

Choose an elongation increment, $\Delta \delta$, of 0,1 mm. The linear regression analysis shall contain at least 10 force-elongation values.

Calculate the mean maximum slope, \bar{S}_{\max} , and then the tensile stiffness from the expression:

$$E^b = \frac{\bar{S}_{\max} l}{b} \quad (7)$$

where

E^b is the tensile stiffness, in kilonewtons per metre;

\bar{S}_{\max} is the mean maximum slope, in newtons per millimetre;

b is the initial width of the test piece, in millimetres (normally 15 mm);

l is the initial test length of the test piece, in millimetres (100 mm).

Calculate and report the tensile stiffness to three significant figures.

NOTE Since the stiffness (in the plane of the paper) is the same in tension and compression, the subscript T is omitted in Equation 7.

9.7 Tensile stiffness index

Calculate the tensile stiffness index from the expression:

$$E^w = \frac{E^b}{w} \quad (8)$$

where

E^w is the tensile stiffness index, in meganewton metres per kilogram;

E^b is the tensile stiffness, in kilonewtons per metre;

w is the grammage, in grams per square metre.

Report the tensile stiffness index to three significant figures.

9.8 Modulus of elasticity

Calculate the modulus of elasticity from the expression:

$$E = \frac{E^b}{t} \quad (9)$$

where

E is the modulus of elasticity, in megapascals;

E^b is the tensile stiffness, in kilonewtons per metre;

t is the thickness, in millimetres.

Report the modulus of elasticity to three significant figures.

10 Precision

10.1 Repeatability

Results from repeated measurements, under normal laboratory conditions using test pieces from the same gross sample, have a coefficient of variation for tensile strength and tensile stiffness of the order of 3 % to 5 % depending on the paper grade, whereas the coefficient of variation for the tensile energy absorption is of the order of 5 % to 10 %.

10.2 Reproducibility

Seven laboratories (within the Scandinavian Pulp, Paper and Board Testing Committee) tested the same papers and boards. The tensile stiffness was evaluated according to Equation (7). The reproducibility is shown in Table 1.