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Paper — Determination of tearing resistance — Elmendorf method

Papier — Détermination de la résistance au déchirement — Méthode Elmendorf

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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 1974 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 fourth edition cancels and replaces the third edition (ISO 1974:1990), which has been technically revised. The specification for the tester has been moved from Annex A to Clause 5 and is given in more general terms so that this International Standard is applicable to a wider range of designs. In addition, new precision data have been inserted in Annex C.

Paper — Determination of tearing resistance — Elmendorf method

1 Scope

This International Standard specifies a method for determining the (out-of-plane) tearing resistance of paper. It can also be used for boards having a low grammage if the tearing resistance is within the range of the instrument.

This International Standard does not apply to corrugated fibreboard, but it may be applied to the components of such boards. It is not suitable for determining the cross-direction tearing resistance of highly directional paper (or board).

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 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
tearing resistance
mean force per sheet required to continue the tearing started by an initial cut in the test piece

NOTE 1 If the initial cut is in the machine direction, the result is given as the machine-direction tearing resistance; similarly, if the initial cut is in the cross-direction, the result is given as the cross-direction tearing resistance.

NOTE 2 The tearing resistance is expressed in millinewtons (mN).

3.2
tear index
tearing resistance of the paper (or board) divided by its grammage

NOTE The tear index is expressed in millinewton square metres per gram ($mN \cdot m^2/g$).

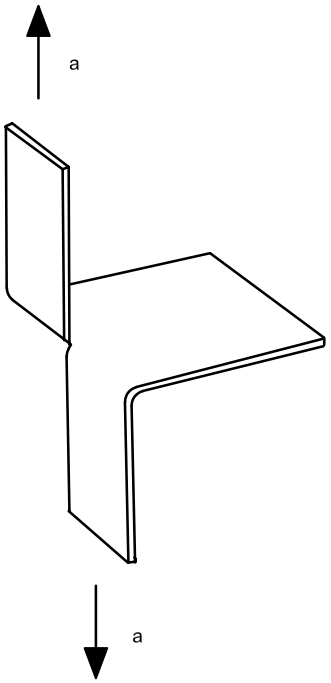
3.3
test piece
pack of four rectangular sheets of the same size

NOTE The dimensions depend on the design of the apparatus clamp used (see Clause 8).

4 Principle

An initial cut is made in a test piece (of four superimposed sheets), which is then torn out-of-plane through a given distance along one single tear line using a pendulum. The work done in tearing the test piece is measured as the loss in energy of the pendulum.

The mean tearing force of a single sheet is calculated by dividing the work done by the distance torn and the number of sheets in a test piece.



a Tearing force.

Figure 1 — Principle of the Elmendorf method

5 Apparatus

5.1 Elmendorf-type tear tester, of suitable capacity, consisting of the following parts.

5.1.1 Stationary frame, mounted on a rigid base and provided with a levelling device. The frame shall be held stationary during the measurement by its mass or by attaching the tear tester to a stable stand.

5.1.2 Pendulum, carried by the frame. The pendulum is formed, in principal, by a sector of a circle and is free to swing about a horizontal axis on low-frictional bearings.

To enable a wide range of tearing resistance to be measured, a set of interchangeable pendulums having different capacities (see Table 1), or one pendulum having interchangeable weights, may be used. The result shall fall within approximately 20 % to 80 % of the maximum reading.

Table 1 — Recommended pendulum capacities

Capacity mN
2 000
4 000
8 000
16 000

Pendulums that have other capacities, e.g. 32 000 mN, may exist. High-capacity pendulums may be used for testing very strong papers such as asphalt paper.

NOTE 1 High-capacity pendulums are, in many cases, used when more than one test piece, i.e. more than four sheets, are torn together. This is, however, not in compliance with this International Standard.

The pendulums shall have an arrangement for attaching calibration weights.

NOTE 2 The total work done by the pendulum includes the work done in tearing the test piece and also the work done in lifting and bending the test piece and overcoming friction between the torn edges of the test piece. With some instruments, the total work done also includes overcoming frictional forces due to the test piece rubbing on the pendulum during the test. This is a major source of error on such apparatus, and apparatus on which this occurs is not considered suitable for testing in accordance with this International Standard. Instruments modified by a suitable cut-out to avoid this problem are available.

5.1.3 Catch, which holds the pendulum when it is raised from its equilibrium position to the starting position and which can instantaneously be released.

5.1.4 Two clamping jaws, one stationary jaw attached to the frame, and one movable jaw attached to the pendulum. The jaws shall be mounted in such a way that the test piece does not touch the pendulum or the frame when bent due to the tearing force.

With the pendulum in its raised position, the jaws shall be separated by a distance of (2,8 ± 0,3) mm and so aligned that the test piece clamped in them lies in a vertical plane parallel to the axis of the pendulum. The clamping surface in each jaw shall be 25 mm ± 1 mm or 36 mm ± 1 mm wide and 15 mm ± 1 mm deep and the clamping surfaces shall be flat and parallel. The distance between the axis of the pendulum and the top edges of the jaws, which are in a horizontal line, shall be $102{,}7^{-0{,}5}_{+3{,}3}$ mm . The line between the axis and the top edges of the jaws shall make an angle of (27,5 ± 0,5)° with the vertical.

NOTE The asymmetric tolerance for the distance between the axis of the pendulum and the top edges of the jaws results from keeping a value consistent with the original Elmendorf, e.g. 102,7 mm, taking into account the different types of apparatus existing on the market while at the same time maintaining the value within the desired range.

The jaws shall clamp the test piece with a force large enough to prevent the test piece from slipping during the test.

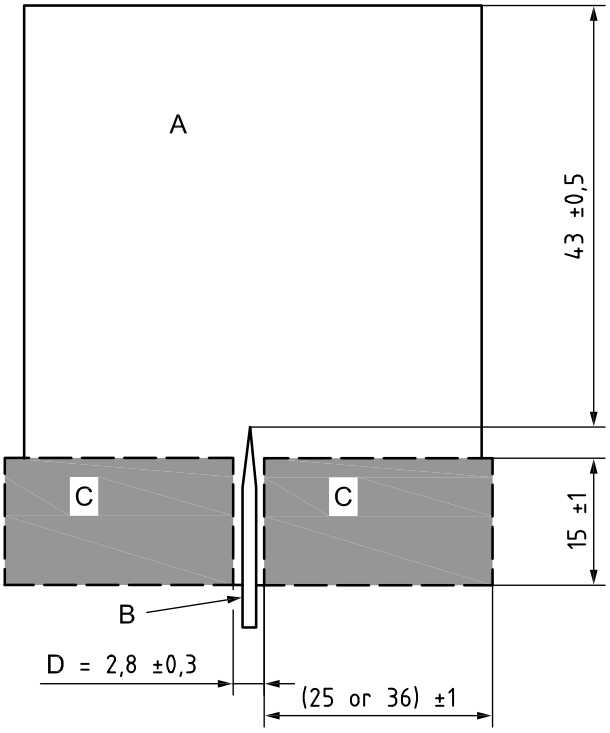
5.1.5 Cutting knife (see Figure 2), if applicable, centred between the clamping jaws and mounted on the frame so that, when a test piece is clamped with the pendulum in the raised starting position, an initial cut can be made in the lower part of the test piece.

The knife shall be adjusted so that the tearing length after cutting is (43,0 ± 0,5) mm when the lower edges of the test piece rest against the bottom of the jaws.

5.1.6 Means for registering the maximum arc [scale reading A in Equation (2)] through which the pendulum swings when released, e.g. a pointer assembly, or a means for direct reading of the tearing resistance [reading F in Equation (1)], e.g. transducer outputs.

5.2 Device for preparing the test piece, e.g. a suitable die, guillotine or template and knife, if applicable, with the required dimensions (see Figure 2).

Dimensions in millimetres



Key

A test piece
B knife
C clamp
D distance between clamps

Figure 2 — Important dimensions of the test piece, the knife and the clamps

6 Sampling

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

7 Conditioning

Condition the sample as specified in ISO 187. Keep the sample in the prescribed atmosphere throughout the test.

This test, like other mechanical tests, is very sensitive to changes in moisture content of the test piece. Handle the test pieces carefully and never touch with a 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 Preparation of test pieces

Prepare the test pieces in the same conditioning atmosphere used to condition the samples. If the tear index is to be calculated, determine the grammage of the sample in accordance with ISO 536.

The sample shall be free from folds, creases or other visible defects in the area from which the test piece is cut and the test piece shall not include any part of the sample that is less than 15 mm from the edge of the sheet or reel. If watermarks are present, this shall be stated in the test report.

Identify the two sides of the sample in a convenient way, for example, side one and side two, and with the same side up. From the sample, cut four rectangular sheets of the same size. The width of each sheet shall be (50 ± 2) mm or (76 ± 2) mm (depending on the size of the clamps, 25 mm or 36 mm) (see Figure 2). The edges of each sheet shall be parallel to the desired test direction and shall be of such a length that, after the initial cut has been made, either as part of the test piece preparation or by means of the integral knife (5.1.5), the untorn length is (43,0 ± 0,5) mm. The sheet length is the sum of the clamp depth, the initial cut length and the untorn length. Assemble the cut sheets into sets of four, with the same side uppermost, to make up the test pieces.

Alternatively, arrange four sheets of the sample with their machine directions parallel and the same sides facing the same way and cut the test piece simultaneously as described above. The untorn length shall be as specified above.

The edges of the sheets comprising the test piece shall be free and not stuck together.

Cut a sufficient number of test pieces, as defined in 3.3, to give a minimum of 10 valid readings in each required principal direction (i.e. a total of at least 40 sheets in each direction).

NOTE The apparent tearing resistance is dependent on the number of sheets torn simultaneously. With some papers, the difference in apparent tearing resistance when one and four sheets are torn simultaneously may exceed 20 %. Comparison between four sheets and two or more sheets (up to 16) shows smaller differences than between one and four sheets, but these differences may still be significant.

9 Adjustment and calibration of apparatus

Check the instrument as described in Annex A.

If necessary, calibrate the instrument as described in Annex B.

10 Procedure

Carry out the tests in the same conditioning atmosphere as that used to condition the sample.

Select the appropriate pendulum or the pendulum/augmenting mass combination so that the mean readings fall within the range of 20 % to 80 % of the maximum scale reading. Individual readings taken outside these limits shall be noted in the test report.

Raise the pendulum to its initial position and secure it with the pendulum release mechanism. Position the test piece (consisting of four sheets) in the clamps. If the slit is pre-made, it shall be positioned centrally between the clamp on the frame and the clamp on the pendulum. Tighten the clamps. Where applicable, operate the knife to produce the required slit. Set the pointer, if fitted, against its stop.

Sharply depress the pendulum release mechanism and hold it down. Gently catch the pendulum by hand on its return swing without disturbing the position of the pointer, if fitted. Record the reading given as the tear resistance or scaling reading.

Return the pendulum and, if fitted, the pointer to the initial position and remove the torn paper. Repeat this procedure for the other nine test pieces, orientating them so that one side faces alternately towards and away from the pendulum.

Check that the test pieces are completely torn. The path of the tear may deviate from the direction of the slit. If the deviation exceeds 10 mm in one or two out of 10 tests, reject these readings and carry out further tests to bring the number of satisfactory readings up to 10. If, in more than two of the test pieces, the deviation exceeds 10 mm, include the results and state the fact in the test report.

If, instead of tearing in the normal way, the sheets of any test piece peel apart so as to expose a wide band of torn surface (the effect known as “skinning”), apply the criteria in the preceding paragraph to the mean centre line of the torn band through the test pieces.

If the tearing resistance of the sample or the available pendulum or pendulum/augmenting mass combination is such that satisfactory results cannot be obtained using a test piece made up of four sheets, tests may be carried out using more or fewer sheets. State this deviation clearly in the test report.

If the sheets curl, ensure that they lean towards and not away from the pendulum, by bending them gently at the clamp. In doing so, avoid affecting the moisture content of the test areas.

11 Calculation and expression of results

11.1 Tearing resistance

Calculate and report the tearing resistance separately for the machine direction and cross-direction, as required.

11.1.1 For readings given as tearing resistance

For instruments where readings are stated directly as tearing resistance, calculate the mean reading. Then calculate the tearing resistance per sheet, F, in millinewtons, using Equation (1):

$$F = \frac{\bar{F}}{n} \tag{1}$$

where

$\bar{F}$ is the mean reading (normally ten readings), in millinewtons;

n is the number of sheets in each test piece (normally four).

Report the tearing resistance, in millinewtons, to three significant figures.

11.1.2 For readings given as scale readings

For instruments where readings are stated as scale readings, calculate the mean scale reading. Then calculate the tearing resistance, F, using Equation (2):

$$F = \frac{\bar{A}p}{n} \tag{2}$$

where

$\bar{A}$ is the mean scale reading;

p is the pendulum factor (commonly the value of this factor is 4, 8, 16 or 32).

Report the tearing resistance, in millinewtons, to three significant figures.

11.2 Tear index

If required, calculate and report the tear index separately for the machine direction and cross-direction, using Equation (3):

$$X = \frac{F}{g} \tag{3}$$

where

X is the tear index, in millinewton square metres per gram (mN·m^2/g);

g is the grammage, in grams per square metre (g/m^2), determined in accordance with ISO 536.

Report the tear index, in millinewton square metres per gram (mN·m^2/g), to three significant figures.

11.3 Coefficient of variation

Calculate the coefficient of variation from the tearing resistance or from the individual scale readings. Express it as a percentage (standard deviation × 100/mean).

12 Test report

The test report shall include the following information:

a) a reference to this International Standard;

b) the date and place of testing;

c) the conditioning atmosphere used;

d) a description and identification of the material tested, including grammage if the tear index is reported;

e) the number of replicate tests carried out, if other than ten;

f) the number of sheets torn simultaneously, if other than four;

g) the tearing resistance, separately for the machine direction and cross-direction as required, as stated in 11.1;

h) if required, the tear index, as stated in 11.2;

i) the coefficient of variation of the results, as stated in 11.3;

j) the pendulum (model number, pendulum factor) and/or pendulum capacity;

k) if any individual reading taken was outside the range of 20 % to 80 % of the maximum scale reading;

l) any deviation in tear exceeding 10 mm from the correct path, or whether extensive “skinning” occurred;

m) any deviation from this International Standard or any other circumstances that may have affected the results.

Annex A
(normative)

Adjustment and maintenance of Elmendorf-type tear testers

A.1 Inspection

Check the following items and make adjustments as necessary.

a) Check that the pendulum shaft is not bent.

b) Check that the distance between the clamps is 2,8 mm ± 0,3 mm and that the clamps are in alignment when the pendulum is in its initial position.

c) Ensure that the pointer is undamaged and rigidly attached to the sleeve, if applicable.

d) Where fitted, check that the knife fitting is secure and that the cutting edge is sharp and undamaged. The blade shall be midway between, and at right angles to, the top of the clamps. If sharpening is required, make sure that, after replacement, the length of the uncut portion is as specified in Clause 8.

e) For apparatus fitted with transducers, check mounting and operation in accordance with the manufacturer's instructions.

A.2 Levelling

Mount the instrument on a rigid bench and, if possible, attach it firmly to the bench.

With the pendulum clamp empty and closed, and the pendulum stop depressed, adjust the level of the apparatus so that the pendulum hangs vertically and the index marks on the pendulum and base coincide. Keep the pendulum stop depressed, displace the pendulum slightly and check that the index marks still coincide after it has come to rest.

The pointer should be turned vertically upwards during these operations, if applicable.

For digital read-out apparatus, level the apparatus according to the manufacturer's instructions.

A.3 Zero adjustment

After levelling, operate the apparatus several times with the pendulum clamp empty and closed. If the pointer does not register zero, adjust the pointer stop until zero is obtained, if applicable. Do not change the level to adjust the zero.

For digital read-out instruments, check and adjust the zero according to the manufacturer's instructions.

A.4 Pendulum friction

Make a reference mark on the pendulum release mechanism 25 mm to the right of the pendulum catch. Release the pendulum, turn the pointer, if fitted, so that it points vertically upwards and return the pendulum to its initial position. On releasing the pendulum and keeping the release mechanism depressed, the pendulum should make at least 35 complete oscillations before the edge of the pendulum, which engages the pendulum catch, no longer passes to the left of the reference mark. Otherwise, clean, oil or adjust the bearing as appropriate for the type of apparatus.

For digital read-out apparatus, it may be necessary to make a reference mark on something other than the pendulum release mechanism and also on the pendulum.

Some instruments (belt and encoder version instruments) have a “zero calibration” to eliminate the influence of the different kinds of friction involved. That means that the test is started by letting the pendulum swing without any test piece. (There is a connection between the pendulum and an incremental encoder.) The instrument stores this as a reference value in its internal memory. During normal paper testing with the instrument, the reference value is subtracted from the measured value. If the instrument is equipped with pneumatically activated grips, check that the tubing used does not hinder pendulum action.

A.5 Pointer friction (if applicable)

Check the zero setting as in A.3. Set the pendulum in its initial position with its clamp empty and closed and with the pointer on zero. Release the mechanism and stop the swing before the pendulum has completed its swing back to the left. Estimate the distance by which the pointer has been deflected from the zero mark. This should be within the range of four to eight scale divisions.

NOTE Do not oil the pointer bearing, but a drop of clock oil may be applied to the pointer friction pin plunger so that it will move freely up and down in its housing.

Too low a pointer friction is usually due to wear or compression of the linings and is remedied by roughening or replacing the lining.

After adjusting the pointer friction, check the instrument zero.

A.6 Tearing length

Check that the tearing length, i.e. the length after making the initial cut, is 43,0 mm $\pm$ 0,5 mm. If this is not the case, adjust the integral knife, if fitted, and the die, template or guillotine used.

Annex B
(normative)

Calibration of Elmendorf-type tear testers

B.1 Calibration by means of check masses

The calibration of wholly mechanical apparatus may be checked by measuring the work done by the pendulum in raising various attached check masses.

The indicated scale reading is then compared with the amount of work done. Many tear testers are provided with a threaded hole to assist in the attachment of check masses.

The position of the centre of gravity of the attached masses should be known.

Check the apparatus as specified in Annex A. With a check mass attached, operate the apparatus with the clamps closed and empty and determine the scale reading and height above a horizontal datum surface of the centre of gravity of the additional weight corresponding to this scale reading.

For apparatus graduated in millinewtons, calculate the correct scale reading, Y, from the following equation.

$$Y = \frac{9{,}81 \times m(h - H) \times 10^3}{0{,}086 \times p} \tag{B.1}$$

where

Y is the correct scale reading (scale units);

m is the mass, in kilograms, of the check mass;

h is the height, in metres, of the centre of gravity of the attached mass, above the horizontal datum line, with the pendulum in the position that gives the scale reading Y;

H is the height, in metres, of the centre of gravity of the attached mass, above the horizontal datum line, with the pendulum in the initial position;

p is the pendulum factor (see 11.1.2);

0,086 is the distance, in metres, of the pendulum clamp movement when a test piece is torn 43,0 mm.

Repeat with other check masses and prepare a graph of (h – H) for different scale readings.

For routine calibration checks, it is then only necessary to determine the scale reading for a given added check mass to read off the corresponding value of (h – H) and to calculate the error using this value.

Calculated and indicated scale readings should agree to within ±1 %. If they do not, the fault should, if possible, be found and remedied. Otherwise, prepare a correction chart and adjust the results accordingly.

Digital read-out apparatus are not always conveniently calibrated by the above method because of the electronic sensing systems. In such cases, alternative calibration methods specified by the manufacturer are acceptable, provided the validity of such methods can be demonstrated.

B.2 Calibration by means of check masses with tongues

Sets of check masses, calibrated to specific values and constructed with tongues to fit into the pendulum clamp, are available. When these are used, check the calibration of the apparatus as follows.

Set up the apparatus and check it as described in Annex A. Raise the pendulum to its initial position and fix a check mass in the clamp. Operate the apparatus and determine the scale reading. Repeat for other check masses in the set. The scale readings should agree with the specified values of the check masses to within ±1 %. If they do not, the fault should, if possible, be found and remedied. Otherwise, prepare a correction chart and adjust the results accordingly.

Annex C
(informative)

Precision

C.1 General

The following calculations have been made according to ISO/TR 24498[2] and TAPPI T 1200[3].

When data from CEPI-CTS, the Comparative Testing Service of the Confederation of European Paper Industries, are used, there is a need to recalculate the data to present the repeatability limits and reproducibility limits:

The repeatability limit, r, can be calculated from: $r = 1{,}96 \times \sqrt{2} \times s_{\text{within lab}}$.

The reproducibility limit, R, can be calculated as: $R = 1{,}96 \times \sqrt{2} \times \sqrt{s^2_{\text{within lab}} + s^2_{\text{between lab}}}$.

The repeatability standard deviation reported in Tables C.1 and C.2 is the “pooled” repeatability standard deviation; that is, the standard deviation is calculated as the root-mean-square of the standard deviations of the participating laboratories. This differs from the conventional definition of repeatability in ISO 5725-1[4].

The repeatability and reproducibility limits reported are estimates of the maximum difference that should be expected in 19 out of 20 instances, when comparing two test results for material similar to those described under similar test conditions. These estimates may not be valid for different materials or different test conditions.

Repeatability and reproducibility limits are calculated by multiplying the repeatability and reproducibility standard deviations by 2,77.

NOTE $2{,}77 = 1{,}96\sqrt{2}$, provided that the test results have a normal distribution and that the standard deviation, s, is based on a large number of tests.

C.2 Data from CEPI-CTS

In 2010, 17 laboratories from 14 European countries tested four samples. For each sample, 10 test pieces were tested. The data for tearing resistance has been obtained from CEPI-CTS, the Comparative Testing Service of the Confederation of European Paper Industries.

Table C.1 — Estimation of the repeatability (CEPI-CTS data)

Sample	Number of laboratories	Mean value	Standard deviation s_r	Coefficient of variation $C_{V,r}$	Repeatability limit r
		mN	mN	%	mN
Sample 1 [a]	15	356	15,5	4,4	43,0
Sample 2 [b]	17	895	16,4	1,8	45,5
Sample 3 [c]	17	1 299	30	2,3	83,2
Sample 4 [d]	16	1 828	58	3,2	160,8

[a] Indicative range 320 ÷ 370.

[b] Indicative range 750 ÷ 900.

[c] Indicative range 1 300 ÷ 1 500.

[d] Indicative range 1 700 ÷ 2 000.

Table C.2 — Estimation of the reproducibility (CEPI-CTS data)

Sample	Number of laboratories	Mean value	Standard deviation s_R	Coefficient of variation $C_{V,R}$	Reproducibility limit R
		mN	mN	%	mN
Sample 1 [a]	15	356	29,2	8,2	81,1
Sample 2 [b]	17	895	45,6	5,1	126,5
Sample 3 [c]	17	1 299	64,4	5,0	178,5
Sample 4 [d]	16	1 838	150,6	8,2	417,5

[a] Indicative range 320 ÷ 370.

[b] Indicative range 750 ÷ 900.

[c] Indicative range 1 300 ÷ 1 500.

[d] Indicative range 1 700 ÷ 2 000.

Bibliography

[1] Elmendorf, A. *Paper Trade Journal* **70** (1920) 16, p. 213

[2] ISO/TR 24498:2006, *Paper, board and pulps — Estimation of uncertainty for test methods*

[3] TAPPI T 1200, *Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility*

[4] ISO 5725-1:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*