
**Paper and board — Determination
of roughness/smoothness (air leak
methods) —**

**Part 3:
Sheffield method**

*Papier et carton — Détermination de la rugosité/du lissé (méthodes
du débit d'air) —*

Partie 3: Méthode Sheffield



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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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on 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 the following URL: 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 8791-3:2005), which has been technically revised.

The main changes compared to the previous edition are as follows:

- editorial changes have been made;
- precision data has been added as [Annex D](#).

A list of all parts in the ISO 8791 series can be found on the ISO website.

Paper and board — Determination of roughness/smoothness (air leak methods) —

Part 3: Sheffield method

1 Scope

This document specifies a method for the determination of the roughness of paper and board using the Sheffield apparatus.

This document is applicable to papers and boards which have Sheffield roughness values between 10 ml/min and about 3 000 ml/min. It is not suitable for soft papers which allow the lands of the test head to indent the surface, or for high air-permeance papers which allow a significant flow of air through the sheet, or for papers which will not lie flat during the test.

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*

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:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

Sheffield roughness

measure of the rate at which air flows between flat circular lands and the surface of a sheet of paper or board under specified conditions

Note 1 to entry: The roughness is expressed in millilitres per minute.

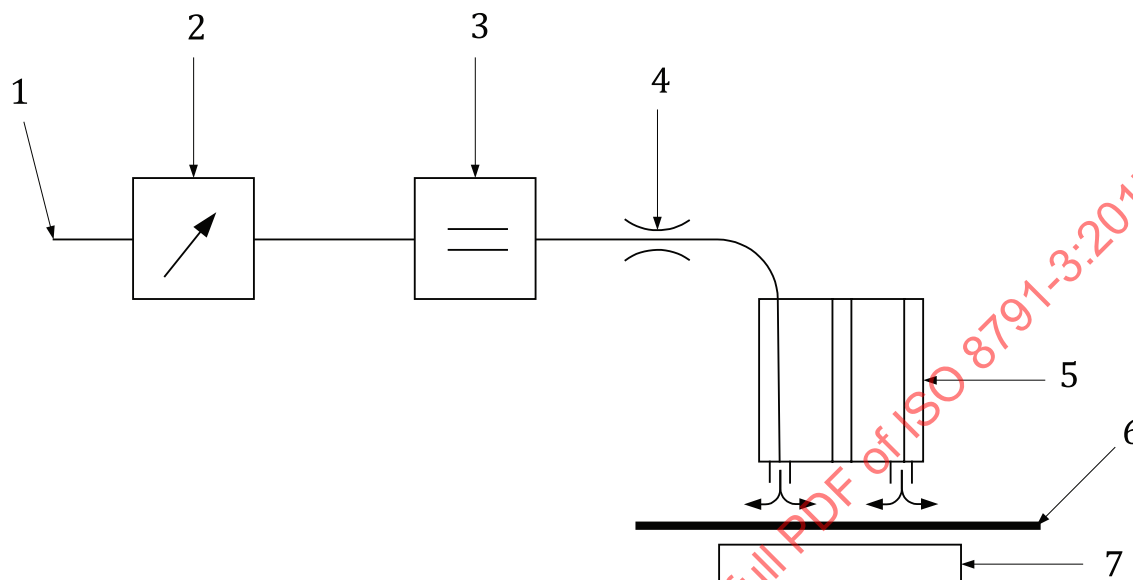
Note 2 to entry: The Sheffield unit is not defined, since it has been found that the scale units (Sheffield units) on different instruments can correspond to different air flows, and there is no precise physical definition. This document requires that the flowmeters be calibrated to give a flow rate in millilitres per minute.

4 Principle

A test piece is clamped between a flat plate and two flat concentric annular lands. Air is supplied at a specified pressure to the space between the two lands, and the rate of air flow between the lands and the test piece is measured. The air flow rate is a measure of the roughness of the test piece.

5 Apparatus

The apparatus, an example of which is shown in Figure 1, shall consist of an air supply (5.1), an air pressure control (5.2) and air flow-measuring device (5.4), a test assembly (5.5) which houses a measuring head (5.5.1) fitted with test lands, a flat plate (5.5.2), and a mechanical device for bringing the lands into contact with the flat plate under a defined load.



Key

- | | | | |
|---|-----------------------|---|---------------|
| 1 | air supply | 5 | test assembly |
| 2 | pressure regulator | 6 | test piece |
| 3 | flow-measuring device | 7 | flat plate |
| 4 | flow impedance | | |

Figure 1 — Example of Sheffield apparatus

5.1 Air supply, free of water, oil and other contaminants, at a pressure of 420 kPa to 950 kPa. A small compressor using laboratory air is preferred to external compressed air.

5.2 Pressure-regulating device, consisting of a primary regulator to reduce the pressure to between 205 kPa and 210 kPa, and another regulator to adjust the pressure at the measuring head to 10,3 kPa (variable-area flowmeters) or 9,85 kPa (electronic flowmeters).

5.3 Pressure manometer, with a range from 0 kPa to 20 kPa to enable the air pressure at the measuring head to be set to the specified pressure within 2 % of the nominal value.

5.4 Flow-measuring device, of either a variable-area or an electronic type. The air flow shall be measurable to an accuracy of ± 5 % of the measured value.

5.4.1 Variable-area flow-measuring device, consisting of three variable-area flowmeters, each having a tapered glass column containing a metering float suspended by the air flow in the column (see Reference [7]). The three columns shall be chosen such that they enable measurement to be made on a continuous scale of flow rate from 10 ml/min to 3 000 ml/min, with some overlap of scales between columns. Each column shall be provided with a means of adjusting the flow rate (float-position knob)

and a means of span calibration (calibrating knob). This type of instrument shall operate at a supply pressure of 10,3 kPa.

At air flow rates greater than 1 200 ml/min, the pressure drop in the Sheffield system is substantial and, to ensure the reproducibility of results, it is necessary that the tubing used to connect the flowmeter to the measuring head be carefully controlled with a length of $1,50 \text{ m} \pm 0,01 \text{ m}$ and an internal diameter of $6,25 \text{ mm} \pm 0,25 \text{ mm}$. For the same reason, openings in valves and other fittings on the instrument shall not be changed from those provided by the instrument manufacturer.

5.4.2 Electronic flow-measuring device, for measuring the air flow to the test assembly (measuring head). The inlet pressure to the measurement device shall be controlled at 9,85 kPa.

NOTE The 9,85 kPa pressure is the typical pressure measured downstream of variable-area flow tubes that have been calibrated using the zero and span adjustment air bleeds to atmosphere.

5.5 Test assembly.

5.5.1 The measuring head, together with a dead weight, shall have a mass of $1\,640 \text{ g} \pm 2 \text{ g}$, shall have two concentric annular lands made of, or coated with, a corrosion-resistant material and be designed to contact the test piece. The annular lands shall have a total area of $97 \text{ mm}^2 \pm 3 \text{ mm}^2$; each land shall have a width of $0,380 \text{ mm} \pm 0,010 \text{ mm}$. The outer diameters of the outer and inner lands shall be $47,70 \text{ mm} \pm 0,03 \text{ mm}$ and $34,37 \text{ mm} \pm 0,03 \text{ mm}$, respectively.

The test assembly, an example of which is shown in [Figure 2](#), shall include a detachable measuring head mounted so that it can be brought into contact with a test piece placed on an optically flat plate.

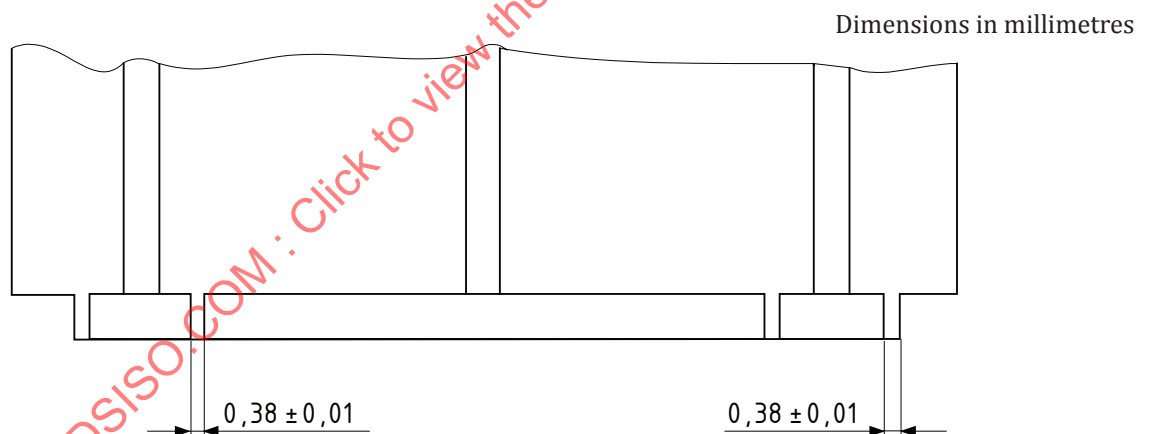


Figure 2 — Example of test assembly

The measuring head shall be connected to the air supply with an airtight seal and the air shall be fed into the gap between the two measuring lands through a narrow hole bored through the material of the measuring head. This can act as impedance in the measurement air line (see [Figure 1](#), Key 4). The central space inside the inner land shall be vented to the atmosphere.

The test assembly shall have a suitable coupling through which the chosen flowmeter is connected to the tube leading to the measuring head. The tube, connecting the measuring head to the instrument, and the tube connectors have internal diameters that provide resistance to the air flow. Alteration of these components from those provided by the manufacturer may change the calibration and operation of the instrument.

5.5.2 The flat plate is usually glass and shall be free from surface flaws. The measuring lands shall be machined and the supporting plate shall be sufficiently flat so that, when the measuring lands are in contact with the plate in the absence of any test piece, the air flow rate does not exceed 10 ml/min.

5.6 Calibration plate device, if the instrument employs an electronic flow-measuring device, the plate device will enable the test assembly to be connected to an external calibration system (see [Clause 9](#) and [Annex B](#)).

NOTE 1 Although this calibration plate is necessary only with electronic devices, it can also be used in instruments incorporating a variable-area flow-measuring device.

NOTE 2 Sheffield reference surface masters are available to check orifices for contamination and measuring heads for wear or damage, but these are not specified by this document.

6 Sampling

Sampling is not included in this document. If the mean quality of a lot is to be determined, sampling shall be in accordance with ISO 186. If the tests are made on another type of sample, make sure that the test pieces taken are representative of the sample received.

7 Conditioning

Condition the samples in accordance with ISO 187.

8 Preparation of test pieces

Cut at least 10 test pieces, each at least 100 mm × 100 mm for each surface to be tested, and identify the two sides (e.g. side one and side two). The test pieces shall be free from watermarks, creases, wrinkles, rubber marks and other defects. Do not handle that part of the test piece which will become the test area.

9 Calibration

9.1 Variable-area flow-measuring device

Calibrate the instrument against an external flow-measuring device as specified in [B.1](#), and prepare a calibration graph or chart as specified in [B.2](#).

Calibrate the instrument sufficiently frequently to ensure that the reading does not deviate at any time by more than ±5 % from the true value.

Care and maintenance of the test instrument shall be carried out as specified in [Annex A](#).

9.2 Electronic flow-measuring device

Carry out the internal adjustment of the flowmeter according to the manufacturer's instructions. Check the calibration of the instrument against an external flow-measuring device as specified in [B.1](#).

10 Procedure

10.1 Test atmosphere

Carry out all testing under the same atmospheric conditions as those used to condition the sample in accordance with ISO 187.

10.2 Determination of roughness

10.2.1 Ensure that the instrument is level on a surface free from vibrations. Check that the air pressure to the measuring head is correct ([5.4.1](#) or [5.4.2](#)). Check that the reading obtained against the glass plate ([5.5.2](#)) with no test piece present is less than 10 ml/min.

10.2.2 Place a test piece in the measuring gap and measure the roughness in accordance with the manufacturer's instructions. Record the result.

All papers are hygroscopic to some degree, and readings should be taken at the initial stabilization point to avoid any possible effect of the incoming air adding moisture to, or extracting moisture from, the test piece.

10.2.3 Repeat the measurement on the remaining test pieces.

11 Calculation and expression of results

11.1 If the instrument provides readings in "Sheffield units", convert each reading to an air-flow rate, in millilitres per minute, using the calibration chart or graph prepared as specified in [B.2](#).

See [Table C.1](#) for additional information of the conversion of the traditional Sheffield units (SU) to SI units.

11.2 Calculate the roughness, expressed as the mean flow rate, in ml/min, to three significant figures, for each side to be tested.

11.3 Calculate the standard deviation or coefficient of variation of the flow rate, to two significant figures, for each side to be tested.

12 Test report

The test report shall include the following:

- a) a reference to this document, i.e. ISO 8791-3;
- b) the date and place of testing;
- c) all information necessary for complete identification of the sample;
- d) the type of instrument used and, if appropriate, the flowmeter range used;
- e) the conditioning atmosphere used;
- f) the number of test pieces tested;
- g) the arithmetic mean result (see [11.2](#));
- h) the standard deviation or coefficient of variation (see [11.3](#));
- i) any deviation from the procedure specified in this document which may have affected the result.

Annex A **(normative)**

Care and maintenance of test instrument with variable-area flowmeters

Weekly, or more often if required, check the cleanliness of the working orifices by testing against a spare manifold.

Check each orifice of the calibration orifice manifold for contamination. If necessary, clean with a suitable solvent, for example, petroleum ether (boiling point 60 °C to 100 °C).

If the floats tend to stick in the air flowmeter columns, this may be due to dirt or static electrical charges. Clean as indicated in the instrument manual.

Renew the rubber gaskets in the hose couplings at least once a year.

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Annex B (normative)

Calibration of flowmeters

B.1 Calibration of flowmeters

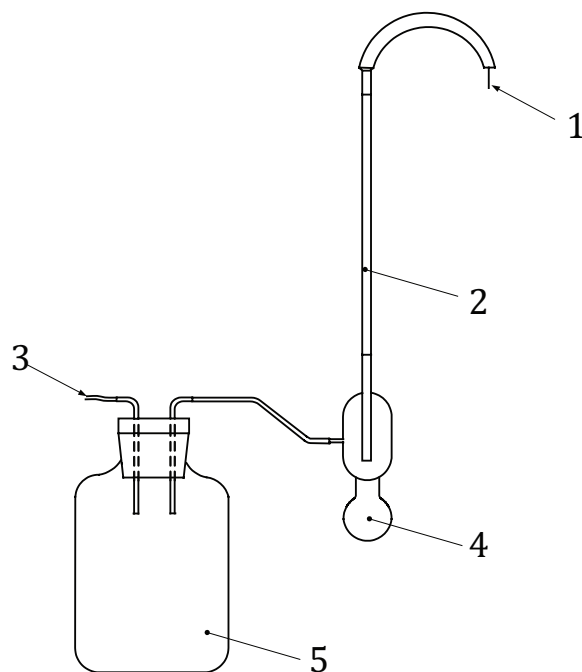
B.1.1 General

The flowmeters may be calibrated with any instrument and procedure which provides a calibration accuracy to within 1,2 %.

One procedure for calibrating variable-area flowmeters uses a soap-bubble meter, [Figure B.1](#), is described in ISO 11605. The method can also be used to calibrate electronic flow-measuring devices, provided a suitable attachment is available.

The principle of the method is that the movement of a soap bubble introduced into an air flow from the flow-measuring device being tested is timed between two marks in a volumeter, representing an accurately known volume, and the actual air-flow rate is calculated. This is repeated at other air flow rates until the whole flowmeter range of the instrument has been covered.

NOTE This method of calibration gives satisfactory accuracy from test atmospheric conditions which do not deviate appreciably from 101,3 kPa and 23 °C. For this reason, it is desirable, if possible, to choose a day for calibration when the meteorological conditions are favourable.



Key

- | | | | |
|---|------------------|---|------------------------------|
| 1 | needle valve | 4 | rubber bulb |
| 2 | volumeter | 5 | glass flask, of capacity 1 l |
| 3 | connection point | | |

Figure B.1 — Soap-bubble meter

B.1.2 Apparatus and materials

B.1.2.1 Soap-bubble meter, consisting of the following:

- glass flask or bottle, of capacity 1 l;
- volumetric tube, with graduation marks indicating 50 ml, 1 000 ml and 2 000 ml; the different ranges may be achieved with replaceable volumeters (suitable designs are described in Reference [8]);
- needle valve;
- glass and rubber tubing, of as large an internal diameter and as short a length as practicable to minimize pressure drop.

B.1.2.2 Stopwatch, capable of being read to 0,1 s.

B.1.2.3 Soap solution, 3 % to 5 % liquid detergent in distilled water.

B.1.2.4 Barometer, or other means of ascertaining the actual atmospheric pressure.

NOTE It may be sufficient to contact a local meteorological station to obtain information about the atmospheric pressure.

B.1.3 Procedure

B.1.3.1 Make sure that the instrument is level on a surface free from vibrations. Make sure that the internal adjustment of the flowmeter has been carried out according to the manufacturer's instructions.

B.1.3.2 Prior to performing the following calibration procedure, the variable-area flow tubes and the air leak adjustment valves on the older style instruments shall first be calibrated to Sheffield units using calibration orifices provided by the manufacturer. In operation, the instrument shall always be checked against the manufacturer's calibration orifices, prior to using the flow tube, to ml/min calibration graph or chart.

To calibrate a variable-area flow-measuring device, disconnect the test assembly from the downstream end of the rubber or plastic tubing and connect the soap-bubble meter in its place. Set the valves to deliver air through the flowmeter to be calibrated and then through the soap-bubble meter. Adjust the needle valve to give a conveniently measurable air flow and ensure that the flow rate remains constant. Rapidly squeeze the rubber bulb at the bottom of the volumeter so that a soap bubble enters the volumeter tube. The volumeter range should be chosen so that the time taken for the bubble to pass from the first to the second graduation is longer than 30 s.

Record the reading, x , on the flowmeter scale and record the time, t , in seconds for the soap bubble to pass through the volume, V .

Repeat the procedure at about six different air flow rates distributed over the upper 80 % of the flowmeter measurement range.

Record the atmospheric pressure, p .

NOTE A better calibration may be achieved by leaving the measuring head in position and using a calibration plate device such as that used with an electronic flow-measuring instrument, since this set-up includes the restriction within the measuring head.

B.1.3.3 To calibrate an electronic flow-measuring device, connect the soap-bubble meter to the calibration plate device (5.6) placed beneath the measuring head. Set the valves to deliver air through the flowmeter to be calibrated and then through the soap-bubble meter. Adjust the needle valve to give a conveniently measurable air flow and ensure that the flow rate remains constant. Rapidly squeeze the rubber bulb at the bottom of the volumeter so that a soap bubble enters the volumeter tube. The volumeter range should be chosen so that the time taken for the bubble to pass from the first to the second graduation is longer than 30 s.

Record the reading, x , on the flowmeter scale and record the time, t , in seconds, for the soap bubble to pass through the volume, V .

Repeat the procedure at about six different air flow rates distributed over the upper 80 % of the flowmeter measurement range.

Record the atmospheric pressure, p .

B.1.4 Calculation

For each determination, calculate the flow rate, q , in millilitres per minute using [Formula \(B.1\)](#).

$$q = \frac{60 \times V}{t} \quad (\text{B.1})$$

where

V is the known volume, in millilitres, between the two graduations on the volumeter;

t is the time, in seconds, taken for the soap bubble to go from the first to the second graduation.

If the actual atmospheric pressure differs by more than 5 % from the normal atmospheric pressure of 101,3 kPa, calculate the corrected flow rate, q_o , using [Formula \(B.2\)](#).

$$q_o = q \frac{(p+10,3)}{111,6} = 0,538 (p+10,3) \frac{V}{t} \quad (\text{B.2})$$

where

p is the actual atmospheric pressure.

NOTE The pressure of 111,6 kPa is the sum of the normal atmospheric pressure, 101,3 kPa, and the nominal operating pressure, 10,3 kPa, at 23 °C.

The air passing through the apparatus may pick up moisture from the walls of the soap-bubble meter, and the air flow can thus be overestimated. The error is, however, appreciably less than the inherent errors associated with the Sheffield instrument and it may therefore be ignored.

B.2 Construction of a calibration graph

Construct a graph by plotting the scale reading, x , against the calculated air flow, q or q_o , for each flowmeter. The graph should be a straight line which can be represented by [Formula \(B.3\)](#):

$$q = A + Bx \quad (\text{B.3})$$

where

A and B are constants;

x is the scale reading, in Sheffield units.

This graph or formula can be used for conversion of the data to air flow rates, in millimetres per minute.

Annex C (informative)

Conversion table

Table C.1 — Conversion of the traditional Sheffield units (SU) to SI units (derived from a survey of 12 instruments)

Tube No. 3	Air flow rate	Tube No. 2	Air flow rate	Tube No. 1	Air flow rate
SU	ml/min ^a	SU	ml/min ^a	SU	ml/min ^a
0	0	50	303	160	1 334
5	35	60	404	180	1 501
10	70	70	495	200	1 668
15	104	80	585	220	1 835
20	139	90	676	240	2 002
25	174	100	767	260	2 170
30	209	110	858	280	2 337
35	244	120	949	300	2 504
40	278	130	1 039	320	2 671
45	313	140	1 130	340	2 838
50	343	150	1 221	360	3 006
55	383	160	1 312	380	3 137
60	412	170	1 403	400	3 340
		180	1 493		
		190	1 584		
Sheffield tube		Recommended range		Conversion to SI units,	
No.		Sheffield units, SU		ml/min ^a	
3		0 to 56		ml/min = 6,96 SU	
2		56 to 170		ml/min = 9,08 (SU) - 141	
1		170 to 400		ml/min = 8,36 (SU) + 4	
^a Air flow rate is measured in millilitres per minute (ml/min), referenced to 21 °C and 101,3 kPa.					
NOTE See Reference [6].					

Annex D (informative)

Precision

In 2015, an international round-robin was performed, in which 20 laboratories from different countries participated.

Three different qualities were tested: white wrap, brown wrap and photo paper. The top and bottom sides were tested of all samples.

The data are presented in [Tables D.1](#) and [D.2](#).

The calculations were made according to ISO/TR 24498 and TAPPI T 1200[5].

The repeatability standard deviation reported in [Table D.1](#) 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.

The repeatability and reproducibility limits reported are estimates of the maximum difference, which should be expected in 19 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 1 The repeatability standard deviation and the within-laboratory standard deviation are identical. However, the reproducibility standard deviation is not the same as the between-laboratories standard deviation. The reproducibility standard deviation includes both the between-laboratories standard deviation and the standard deviation within a laboratory, viz.:

$$s_{\text{repeatability}}^2 = s_{\text{within lab}}^2 \text{ but } s_{\text{reproducibility}}^2 = s_{\text{within lab}}^2 + s_{\text{between lab}}^2$$

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