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Dense and insulating shaped refractory products — Determination of modulus of rupture at ambient temperature

Produits réfractaires façonnés denses et isolants — Détermination du module de rupture à température ambiante

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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 document 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 33, *Refractories*.

This fourth edition cancels and replaces the third edition (ISO 5014:1997), which has been technically revised.

The main changes are as follows:

— revised definitions;

— addition of a clause on significance and use;

— addition of an informative annex on precision and bias.

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.

Dense and insulating shaped refractory products — Determination of modulus of rupture at ambient temperature

1 Scope

This document specifies a method for the determination of the modulus of rupture of dense and insulating shaped refractory products at ambient temperature, under conditions of a constant rate of increase of stress.

Shaped refractories are those which have fixed geometry and dimensions when delivered to the user. This document is accordingly applicable to standard shape refractory bricks, but also special shapes refractory products and pre-cast products.

This document is also applicable to unshaped refractories (see ISO 1927-6) after preparation of test specimens according to ISO 1927-5.

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 13385-1, *Geometrical product specifications (GPS) — Dimensional measuring equipment — Part 1: Design and metrological characteristics of callipers*

ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

3 Terms and definitions

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

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

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

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

3.1
modulus of rupture
MOR
σ_F
maximum stress that a prismatic test piece of specified dimensions can withstand when it is bent in a *three-point bending* (3.2) device

3.2
three-point bending
means of bending a beamlike test piece whereby the test piece is supported on bearings near its ends, and a central force is applied

3.3
dense shaped refractory product
product with specific dimensions, having a true porosity of less than 45 % by volume, when measured in accordance with ISO 5017

3.4
shaped insulating refractory
shaped refractory having a true porosity of not less than 45 % by volume, when measured in accordance with ISO 5016

3.5
sample
representative collection of items that can be obtained by sampling according to a sampling plan agreed upon by the interested parties

Note 1 to entry: An example of an applicable sampling plan is given in ISO 5022.

3.6
item
refractory brick or shape

3.7
test piece
test specimen
piece of material extracted from an *item* (3.6) and suitably shaped and prepared for the test

4 Significance and use

This test is intended to be used for research, material development, manufacturing process control and design data acquisition purposes. The strength level determined by the test is calculated on the basis of linear elastic bending of a beam on the assumption that the material being tested is elastically homogeneous, isotropic and shows linear (Hookean) stress-strain behaviour.

The modulus of rupture can be significantly affected by a large number of factors associated with the microstructure of the material, the surface finishing procedure applied in preparation of the test pieces, the size and shape of the test piece, the orientation of the test piece during testing, the geometry and functions of the testing jig and the stress rate. Comparisons of the results between different determinations should accordingly not be made if one or more of these parameters differ between the two determinations.

As a consequence of the brittle nature of refractories, there is usually a considerable range of results obtained from a number of nominally identical test pieces. Caution in the interpretation of test results is hence required. For many purposes, and as described in this document, the results of the MOR test may be described in terms of a mean value and a standard deviation. Further statistical evaluation of results is required for design data acquisition and can be desirable for other purposes. In particular, any extrapolation of modulus of rupture data to other geometries of stressing, to multiaxial stressing, to other rates of stressing or to other environments should be viewed with caution.

This method places closely defined restrictions on the size and shape of the test piece and on the function of the test apparatus in order to minimize the errors that can arise as a consequence of the test method.

The method relates primarily to shaped and fired refractories. If it is to be applied to chemically bonded or carbon-bonded bricks, they will usually require some form of preliminary heat treatment. This preliminary treatment is a matter of agreement between the interested parties and shall be described in the test report.

This method can also be applied to unshaped refractories, more specifically on test pieces prepared according to ISO 1927-5 and ISO 1927-6.

5 Principle

Bending a prismatic test piece of the product to be tested at a constant rate of increase of stress until failure occurs, whereby the test piece is supported on bearings near its ends, and a central force is applied.

6 Apparatus

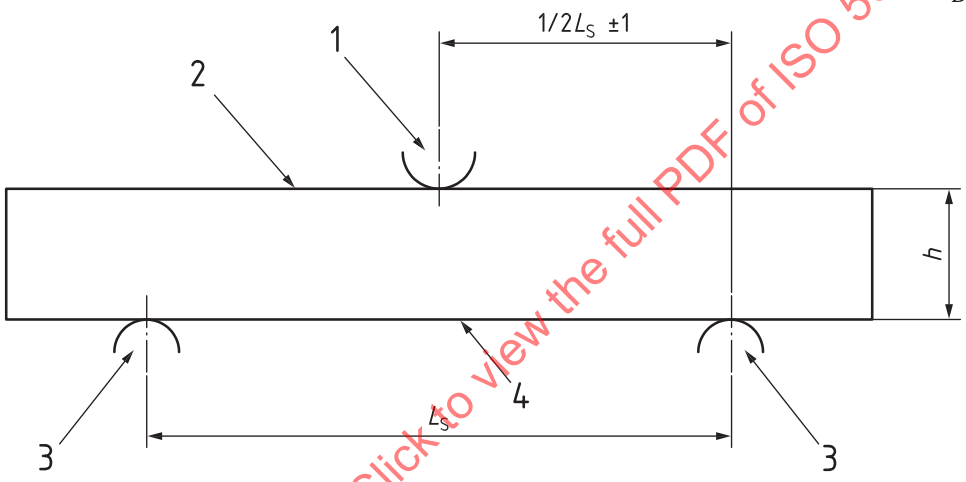
6.1 Test jig

The loading device shall have three bearing edges, two to support the test piece and one for the application of the load (see Figure 1). The three edges shall have a radius of curvature in accordance with the requirements given in Table 1 and shall be of length not less than 5 mm greater than the width (w) of the test piece (see Figure 2).

The contact lines of the three edges shall be parallel to each other in a direction perpendicular to the length and the plane of the width of the test piece. Two supporting edges shall rest on an intermediate bearing piece, cylindrical on its lower surface, so that each edge may rotate independently in a vertical plane to accommodate any slight twist in the test piece (see Figure 2). Alternatively, one supporting edge may be fixed, with the other supporting edge and the load-bearing edge being capable of rotating in a vertical plane.

The distance between the two supporting edges shall be in accordance with Table 1 and the load-bearing edge shall be positioned equidistantly, at $L_s/2 \pm 1$ mm from each supporting edge.

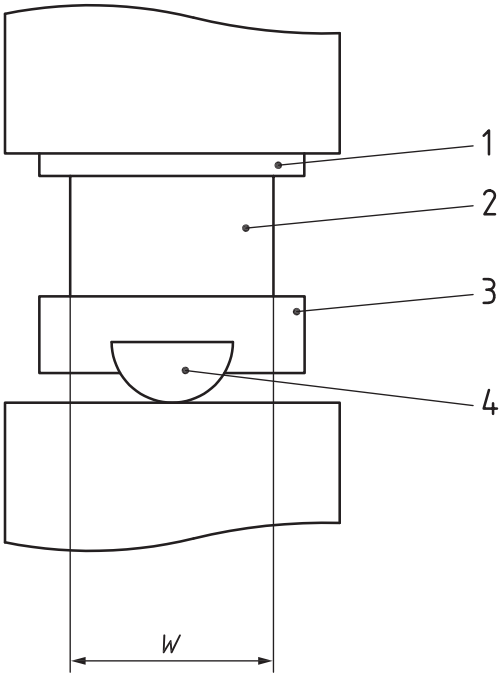
Dimensions in mm



Key

1	load-bearing edge	L_s	span, distance between the points of support of the test piece
2	compression face	h	height of the test piece
3	supporting edge		
4	tensile face		

Figure 1 — Arrangements and dimensions of test piece and bearing edges of the test jig; for tolerances, see Table 1



Key

1	load-bearing edge	*w*	width of the test piece
2	test piece		
3	supporting edge		
4	intermediate bearing piece		

Figure 2 — Diagrammatic representation of loading device - Intermediate bearing piece

6.2 Testing machine, capable of applying a force uniformly to the load-bearing edge in order to stress the test piece. The machine shall be capable of applying this force at a constant loading rate. The test machine shall be equipped for recording the peak load applied to the test piece. The accuracy of the test machine shall be in accordance with ISO 7500-1, Grade 2 (accuracy 2 % of indicated load), or better.

6.3 Drying oven, capable of being controlled at (110 ± 5) °C, or other device which has an equivalent heating effect.

For MgO containing products, it is recommended to dry the test pieces to constant mass at (150 ± 10) °C.

NOTE A fan-assisted oven with ventilation and an exhaust air damper would assist in attaining an even temperature distribution and efficient drying of the test pieces.

6.4 Calliper, which shall be in accordance with ISO 13385-1, of resolution 0,1 mm, or alternative calibrated device measuring to this resolution, for measurement of test piece dimensions.

7 Test pieces

7.1 Number of test pieces

7.1.1 A sample consists of at least four items, obtained by sampling according to a sampling plan agreed upon by the interested parties, e.g. ISO 5022**.**

7.1.2 The number of test pieces to be cut from each item is a matter of agreement between the interested parties and shall be stated in the test report (see Clause 10). In order to facilitate statistical analysis, the same number of test pieces shall be cut from each item.

NOTE If only one item is available, whenever possible, at least four test pieces will be taken in order to compose a representative sample.

7.2 Shape and size

7.2.1 Dimensions and tolerances of test pieces shall be in accordance with the values given in Table 1.

Table 1 — Test pieces dimensions and tolerances

Dimensions in millimetres

Test piece size L x b x h	Tolerance for the width w and height h	Tolerance for the parallelism of the cross- section sides	Tolerance for the parallelism of the top and bottom faces	Span L_s	Radius of curvature for the supporting and load-bearing edges
230 x 114 x 76 230 x 114 x 64	-	-	-	180 ± 1	15 ± 0,5
200 x 40 x 40	±1	±0,15	±0,25	180 ± 1	15 ± 0,5
150 x 25 x 25	±1	±0,1	±0,2	125 ± 1	5 ± 0,5

7.2.2 In the case of complex shapes or small items, test pieces similar in shape shall be cut from the item with the largest possible volume (see 7.2.3).

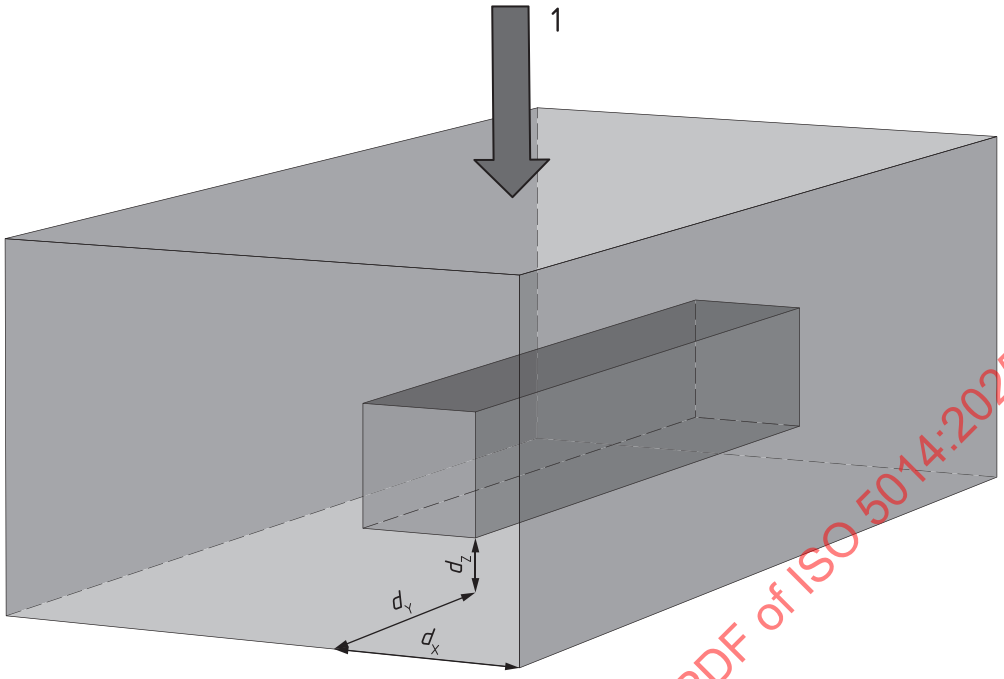
7.2.3 The relative ratio of the largest grain size to the smallest test piece dimension can significantly affect the obtained modulus of rupture value. Testing test pieces cut from larger items and containing large grains may result in MOR values significantly different from those obtained when testing the items from which they were cut. The smallest test piece dimension should at least be five times larger than the maximum grain dimension.

7.3 Preparation

7.3.1 Standard size bricks shall be tested as received.

7.3.2 If test pieces are prepared out of larger items (by cutting or grinding), it shall be done in such a way that, if the direction in which the brick was pressed is known, the longitudinal bearing faces of the test pieces are perpendicular to the direction of pressing. In order to avoid potential effect of remaining as-

sintered surfaces on the resulting modulus of rupture, the location of extraction shall be, whenever possible, at least 10 mm away from any original surface of the item (see Figure 3).



Key

1 pressing direction

Figure 3 — Diagrammatic representation of test piece extraction from larger item Coloured surfaces are longitudinal (test) surfaces; d_x, d_y and $d_z \geq 10$ mm

Cutting with a continuous rim diamond wheel is recommended. If a serrated rim wheel is used, the edges of the cut where the wheel emerges are often frayed; it is therefore recommended that such a wheel should enter the face of the brick that is to form the tensile face of the test piece during the test. Alternatively, any method involving the use of abrasives, such as a high-speed abrasion wheel, enabling the production of test piece of the correct dimensions without weakening their structure, may be used.

7.3.3 The direction of pressing, if known, shall be marked on the test piece.

8 Procedure

8.1 Record the ambient temperature of the test environment to the nearest 1 °C.

8.2 Dry the test piece to constant mass in the oven (5.3), controlled at (110 ± 5) °C, cooling it each time away from moisture. Store the test pieces under dry conditions till performing the test.

For MgO containing products, it is recommended to dry the test pieces to constant mass at (150 ± 10) °C.

8.3 Measure the width (w) and height (h) of each test piece at its mid-point to the nearest 0,1 mm.

8.4 Check the parallelism of the cross-section sides and of the top and bottom faces, and that it complies with the limits given in Table 1

8.5 Measure the distance between the lower supporting edges to the nearest 0,1 mm.

8.6 Ensure that the test jig is cleaned of fracture debris from previous tests, and that the rollers of the test jig are free from burrs and can rotate freely in the jig.

8.7 Position each test piece in turn in the test jig, ensuring that the test piece is positioned centrally across the supporting edges, that the rollers are in the correct starting position, and that the test piece is centralized under the loading axis.

When the test piece is a normal standard brick, the face bearing any brand mark, shall be in compression (i.e. shall be the upper face).

8.8 Select a loading rate depending on the material tested according to the requirements of Table 2.

For high-strength materials requiring longer than about 3 min to perform a test, preloading to one half of the anticipated failure load may be accomplished at any convenient rate exceeding the specified rate. Subsequently, the test pieces would be loaded at the standard rate specified in Table 2. Both the preload and the rate used to reach it would accordingly be given in the report.

Table 2 — Standard loading rates

Refractory type	Dimensions (mm)	Span (mm)	Stress rate (MPa/s)	Loading rate (N/s)
Dense shaped refractory	230 × 114 × 76	180	0,15 ± 0,015	366 ± 37
	230 × 114 × 64	180		259 ± 26
	200 × 40 × 40	180		36 ± 3,6
	150 × 25 × 25	125		13 ± 1,3
Shaped insulating refractory	230 × 114 × 76	180	0,05 ± 0,005	122 ± 12
	230 × 114 × 64	180		86 ± 8,6
	200 × 40 × 40	180		12 ± 1,2
	150 × 25 × 25	125		4 ± 0,4

8.9 Apply the test force at the chosen rate and record the peak load force (F_{max}) supported by the test piece at the instant of failure.

A graph of applied load against time is recommended for showing the results.

8.10 Inspect the test piece. If the onset of failure is located outside the range [midpoint - 10 % of the Span, midpoint + 10 % of the Span], discard the result of the test and repeat with a new test piece.

9 Expression of results

9.1 The modulus of rupture σ_F is calculated from Formula (1):

$$\sigma_F = \frac{3}{2} \times \frac{F_{max} L_S}{wh^2} \quad (1)$$

where

F_{max} is the maximum force exerted on the test piece at rupture, in Newtons (N);

L_S is the distance between the points of support of the test piece, in millimetres (mm);

w is the width of the test piece, in millimetres (mm);

h is the height of the test piece, in millimetres (mm).

NOTE It is recognized that this formula does not necessarily give the true fracture stress at the point of failure, but a nominal maximum effective stress experienced by the most highly stressed region in the test piece.

9.2 The result shall be expressed in megapascals (MPa), to three significant figures.

9.3 For bricks of standard size, the value obtained for a brick constitutes the result of that item.

9.4 For cut test pieces, record the individual values and the mean value for each item; these constitute the result for that item.

9.5 The precision that can be expected for the calculated values of modulus of rupture is discussed in Annex A.

10 Test report

The test report shall include the following information:

a) the name and address of the testing establishment;

b) the date of the test, unique identification of the report and of each page, the customer name and address, and signatory;

c) reference to this document, i.e. "Determined in accordance with ISO 5014:2025";

d) the designation of the product tested (manufacturer, type, shape, batch number);

e) the number of items tested;

f) the method of production of test pieces from supplied material, if appropriate;

g) the pre-treatment, if any, given to the test pieces (see clause 4);

h) the number of test pieces per item;

i) the dimensions of the test pieces;

j) the position of the test pieces in the item;

k) the character of the faces (that is, as-fired, cut, ground, as-pressed, as-cast, etc.);

l) ambient test temperature;

m) the test jig geometry used and the span size;

n) the test piece orientation during testing;

o) the nominal stress rate;

p) the preload, if any, and the stress rate used to reach it;

q) either:

   1) the individual values of modulus of rupture for each item (when whole bricks are used);

   2) the individual values of modulus of rupture for each test piece and the mean modulus of rupture value for each item (when more than one test piece is cut from each item – see 7.1.2);

r) the overall mean modulus of rupture value and the standard deviation for the sample;

s) details of any necessary deviations from this document, and any useful comments about the test or the test results.