International Standard ISO 5013

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Refractory products — Determination of modulus of rupture at elevated temperatures

Produits réfractaires — Détermination du module de rupture par flexion à températures élevées

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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Refractory products — Determination of modulus of rupture at elevated temperatures

1 Scope and field of application

This International Standard specifies a method for the determination of the modulus of rupture of refractory products at elevated temperatures, under conditions of a constant rate of increase of stress. A method for determination of the same property at ambient temperature is given in ISO 5014.

2 References

ISO 5014, *Refractory products — Determination of modulus of rupture at ambient temperatures.* [1)]

ISO 5022, *Shaped refractory products — Sampling and acceptance testing.*

3 Definitions

3.1 modulus of rupture: The maximum stress that a rectangular test piece of specified dimensions can withstand when it is bent in a three-point bending device.

3.2 test temperature: The temperature at the mid-point of the tensile face of the test piece (see 5.3).

4 Principle

4.1 Test pieces taken from items (bricks) are heated to the test temperature. After being maintained at this temperature until a specified temperature distribution is reached, the test pieces are loaded at a constant rate of increase of tensile stress until failure occurs.

4.2 The method relates primarily to shaped and fired refractories. If it is to be applied to chemically bonded or tar-bonded bricks, or to unshaped refractory products, they will usually require some form of preliminary heat treatment. This preliminary treatment shall be as agreed between the interested parties and shall be stated in the test report.

5 Apparatus

5.1 Loading device

5.1.1 The loading device shall have two bearing edges to support the test piece and one for the application of the load. The three bearing edges shall be parallel to each other. For normal test pieces, the distance between the bearing edges supporting the test piece shall be 125 ± 2 mm, with proportionate separations for other test piece lengths (see 6.2). The loading bearing edge shall be placed centrally between the two supporting bearing edges with an accuracy of ± 2 mm (see the figure).

5.1.2 The bearing edges and test pieces shall be free from any reaction on contact at the test temperature.

5.1.3 The bearing edges shall have a length not less than 5 mm greater than the breadth of the test pieces and a radius of curvature of 5 ± 1 mm.

NOTE — Since the bearing edges become flattened with use, they shall be examined periodically to ensure that their radii remain within these limits.

5.1.4 The distance between the two supporting bearing edges (see the figure) shall be measured at room temperature to an accuracy of ± 0,5 mm (this value is taken into account in the calculation of the modulus of rupture).

5.1.5 The loading device shall be capable of applying a load uniformly across the centre of the test piece and of increasing it

1) At present at the stage of draft.

Dimensions in millimetres

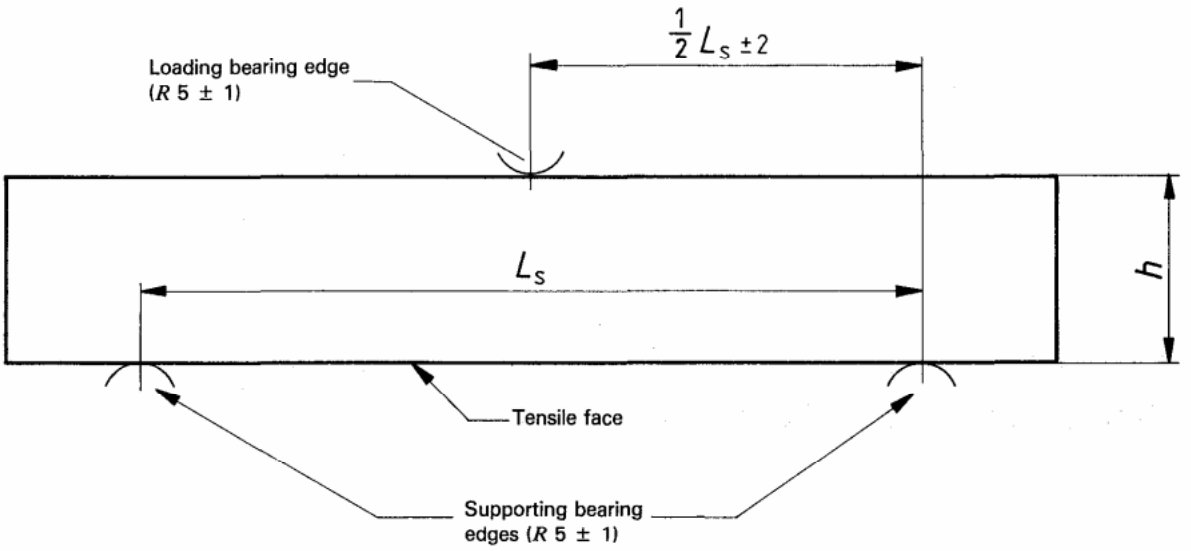

Figure — Arrangement and dimensions of test piece and bearing edges of loading device

at a constant rate. Means shall be provided of recording or indicating the load at failure with an accuracy of ± 2 %.

5.2 Furnace

5.2.1 The furnace shall be one of the following types:

a) batch type, in which a number of test pieces are heated to the test temperature together and tested in turn;

b) sequential type, in which the test pieces are heated to the test temperature one after another as they pass through the apparatus.

5.2.2 In either case, the furnace shall be capable of providing the overall heating of both the bending device and the test pieces, and shall be so designed that at the moment of test the temperature distribution in the test piece is uniform within ± 10 °C.

5.2.3 The atmosphere in the furnace shall be air or some other specified gas, as agreed between the parties concerned in the test.

5.3 Temperature measuring device

5.3.1 The temperature shall be measured by a calibrated thermocouple in the proximity of the midpoint of the tensile face of the test piece.

5.3.2 The relationship between the measured temperature and the temperature at the midpoint of the tensile face shall first be established and shall be checked periodically in accordance with the procedure set out in the annex.

5.3.3 During the test, the furnace shall be maintained at such a temperature that the midpoint of the tensile face of the test piece is nominally at the required test temperature.

6 Number, shape, size and preparation of test pieces

6.1 Number

6.1.1 The number of items (bricks) to be tested shall be determined in accordance with ISO 5022 or another standard sampling method agreed between the interested parties.

6.1.2 The number of test pieces to be tested for each item (brick) at each test temperature shall be agreed between the interested parties and shall be the same for each item; it shall be stated in the test report.

6.2 Shape and size

6.2.1 Unless otherwise agreed, the test piece shall be a rectangular bar with a cross-section of 25 ± 1 mm × 25 ± 1 mm and a length of about 150 mm. The longitudinal faces of each test piece shall be parallel to each other within a tolerance of ± 0,2 mm and the sides of a cross-section of the test piece shall be parallel to each other within a tolerance of 0,1 mm. Care shall be taken to ensure that the test pieces have smooth surfaces and clean edges. If other sizes of test piece are to be used, the dimensions shall be altered in steps of 5 mm, with a minimum of 100 mm for the length and a minimum of 10 mm for the width and for the height.

NOTE — The formula given in 8.1 is only valid for test pieces that are of a slender shape. It is therefore recommended that the ratio of the

height and width of the test piece and the ratio of the height of the test piece to the distance between the supports should be the following[1]:

$$\frac{h}{L_s} \leqslant \frac{1}{4} \quad \text{and} \quad \frac{h}{b} \geqslant \frac{1}{3}$$

6.2.2 The breadth and height of the cold test piece shall be measured at its midpoint with an accuracy of ± 0,1 mm (these values are taken into account in the calculation of the modulus of rupture).

6.3 Preparation

6.3.1 If the direction in which the brick was pressed is known, each test piece shall be cut out of the brick in such a way that the upper longitudinal face in the testing position (the face in compression) coincides with or was parallel to one of the original faces of the brick perpendicular to the direction of pressing. No other longitudinal face of a test piece shall include the original skin of the brick.

NOTE — Cutting with a continuous rim diamond wheel is recommended.

If a wheel with a serrated rim is used, the edges of the cut where the wheel emerges are often frayed. It is therefore recommended that in such a case the wheel should enter the face of the brick piece that is to form the tensile faces of the test pieces during the test.

6.3.2 The direction of pressing, if known, shall be marked on each test piece.

6.3.3 The test pieces shall be dried at 110 ± 5 °C to constant mass.

7 Test procedure

7.1 Heating

7.1.1 The test temperature shall be as agreed between the interested parties. It is recommended that multiples of 100 °C should be used (e.g. 1 000 °C, 1 100 °C, ...), but if necessary multiples of 50 °C may be used.

7.1.2 The test pieces shall be heated to the test temperature ± 10 °C with a mean rate of heating between 2 °C/min and 10 °C/min and preferably between 4 °C/min and 6 °C/min.

7.1.3 When the test temperature is reached, the test piece shall be maintained at this temperature for sufficient time[2] for the temperature distribution in it to become uniform within ± 10 °C. The time allowed for this shall be stated in the test report.

7.1.4 The temperature measured by the thermocouple near the midpoint of the tensile face of the test piece shall not vary during the time of testing by more than ± 2 °C.

7.2 Loading

7.2.1 Place a test piece on the lower bearing edges so that it rests symmetrically across them. If a longitudinal face of a test piece coincides with an original face of the brick, that face shall be the face in compression.

7.2.2 Apply the load vertically on the test piece half-way between the supports in the direction of pressing of the brick, with a constant rate of increase, until failure occurs. The rate of increase of the load shall be calculated, using the formula given in 8.1, so that the rate of increase of tensile stress in the test piece is as follows:

a) for a dense-shaped refractory product:
0,15 $N \cdot mm^{-2} \cdot s^{-1}$ ± 10 %;

b) for an insulating refractory product:
0,05 $N \cdot mm^{-2} \cdot s^{-1}$ ± 10 %.

7.2.3 Record the load at which failure of the test piece occurs (F_{max}).

8 Calculation and expression of results

8.1 The modulus of rupture (σ_F) is the ratio of the bending moment at the point of failure (M_{max}) to the moment of resistance W (the section modulus), and is calculated from the following equation which is derived from Hooke's Law for elastic materials[3]:

$$\sigma_F = \frac{M_{max}}{W} = \frac{3}{2} \times \frac{F_{max} L_s}{bh^2}$$

where

F_{max} is the maximum force exerted on the test piece;

L_s is the distance between the points of support of the test piece;

b is the breadth of the test piece;

h is the height of the test piece.

8.2 The result shall be expressed in newtons per square millimetre (meganewtons per square metre, megapascals).

1) These are empirical values that have resulted from a study of several publications describing the influence of the dimensions of the test piece on the determination of the modulus of rupture.

2) About 15 to 30 min for normal test pieces of fired bricks. For unfired bricks or unshaped refractories, a pre-treatment or soaking time and temperature shall be agreed between the interested parties.

3) Refractory materials do not always obey Hooke's Law exactly.

9 Test report

The test report shall include the following information:

a) the testing establishment;

b) the date of test;

c) a reference to this International Standard, i.e. "Test in accordance with ISO 5013";

d) designation of bricks (manufacturer, type, shape, batch no., etc.);

e) the number of items (bricks) tested;

f) the pre-treatment given to the test pieces (see 7.1.3 and its footnote);

g) number of test pieces per brick;

h) dimensions of the test pieces (mm);

j) position of the test pieces in the brick;

k) distance between supports (mm);

m) heating rate (°C/min);

n) atmosphere (see 5.2.3);

p) test temperature (°C);

q) time for which the test temperature was maintained for each test piece (min);

r) nominal rate of increase of tensile stress for each test piece ($N \cdot mm^{-2} \cdot s^{-1}$);

s) individual values and the median and mean values of the modulus of rupture of each brick.

Annex

Measurement of temperature distribution in the test piece

(This annex forms an integral part of the Standard.)

A.1 Preliminary measurements shall be carried out at each test temperature to determine the following:

a) the temperature distribution in the test piece;

b) the time required for the temperature distribution in the test piece to reach the specified degree of uniformity (see 5.2.2 and 7.1.3);

c) the relation, at equilibrium, between the temperature indicated by the test thermocouple and the temperature at the midpoint of the tensile face of the test piece (see 5.3.1 and 5.3.2).

A.2 These data can be determined under test conditions using the test thermocouple, additional thermocouples and special test pieces provided with borings for the additional thermocouples. The test pieces shall have the same dimensions as the test pieces to be used (see 6.2) and be of material having nearly the same thermal conductivity as the material to be tested.

A.3 The measurements shall be carried out on each new furnace and whenever the test conditions have been altered (e.g. after replacement of the heating elements or the test thermocouple).