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Refractories — Determination of dynamic Young's modulus (MOE) at elevated temperatures by impulse excitation of vibration

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Foreword

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This document was prepared by Technical Committee ISO/TC 33, *Refractories.*

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Refractories — Determination of dynamic Young's modulus (MOE) at elevated temperatures by impulse excitation of vibration

1 Scope

This document specifies a method for determining the dynamic Young's modulus of rectangular cross-section bars and circular cross-section specimens of refractories by impulse excitation of vibration at elevated temperature. The dynamic Young's modulus is determined using the resonant frequency of the specimen in its flexural mode of vibration.

This document does not address the safety issues associated with its use. It is responsibility of the users of this standard to establish appropriate safety and health practices.

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

ISO 8656-1, *Refractory products — Sampling of raw materials and unshaped products — Part 1: Sampling scheme*

ISO 12680-1, *Methods of test for refractory products — Part 1: Determination of dynamic Young's modulus (MOE) by impulse excitation of vibration*

ISO 16835, *Refractory products — Determination of thermal expansion*

IEC 60584-1, *Thermocouples — Part 1: EMF specifications and tolerances*

IEC 60584-2, *Thermocouples — Part 2: Tolerances*

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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:

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

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

3.1
modulus of elasticity
MOE
ratio of stress to strain below the *proportional limit* (3.2)

3.2
proportional limit
greatest stress which a material is capable of sustaining without deviation form proportionality of stress to strain (Hooke's Law)

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3.3

homogeneous

uniform composition, density and texture

Note 1 to entry: A result of homogeneity is that any smaller specimen taken from the original is representative of the whole. In refractory practice, as long as the geometrical dimensions of the specimen are large with respect to the size of individual grains, crystals, components, pores and microcracks, the body can be considered homogeneous.

3.4

isotropic

condition of a specimen such that the values of the elastic properties are the same in all directions in the specimen

3.5

resonant frequency

natural frequencies of vibration of a body driven into *flexural vibration* (3.6)

Note 1 to entry: Resonant frequencies are determined by the elastic modulus, mass and dimensions of the specimen. The lowest resonant frequency in a vibrational mode is the fundamental resonant.

3.6

flexural vibrations

displacements in a *slender bar or rod* (3.11) in the plane normal to its length

3.7

nodes

location on a *slender bar or rod* (3.11) in resonance having a constant zero displacement

Note 1 to entry: For the fundamental flexural resonance of such a rod or bar, the nodes are located at 0,224L form each end, where L is the length of the specimen.

3.8

anti-nodes

locations, generally two or more, of local maximum displacement in an unconstrained *slender bar or rod* (3.11) in resonance

Note 1 to entry: For the fundamental flexural resonance, the anti-nodes are located at the two ends and the centre of the specimen.

3.9

out-of-plane flexure

flexural mode for rectangular parallelepiped geometry specimens in which the direction of the displacement is perpendicular to the major plane of the specimen

3.10

in-plane flexure

flexural mode for rectangular parallelepiped geometry specimens in which the direction of the displacement is in the major plane of the specimen

3.11

slender bar

slender rod

slender bar whose ratio of length to width is at least 3 and the ratio of length to thickness is at least 5

slender rod whose ratio of length to diameter is at least 5

Note 1 to entry: This applies to dynamic property testing.

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4 Principle

A test specimen of suitable geometry is heated up to the test temperature and allowed to stabilize at this temperature. It is then excited mechanically with a single elastic strike by an adequate impulse tool (Method A).

Alternatively, the test specimen is heated up (resp. cooled down) at a low heating rate (resp. cooling rate) to the test temperature, excited mechanically with a single elastic strike by an adequate impulse tool at regular intervals and the fundamental resonant frequency values are determined (Method B).

A vibration signal detector (e.g. non-contacting microphone or laser vibrometer) senses the mechanical vibrations in the specimen resulting from the excitation and transforms the vibrations into electrical signals. Specimen supports, impulse locations and signal pick-up points are selected to induce and measure a specific mode of transient vibrations, i.e. the flexural mode. The signals are analysed and a signal analyser that provides data about the frequency and/or the period of the specimen's vibration determines the fundamental resonant frequency. The appropriate fundamental resonant frequency, dimensions and mass of the specimen are then used to calculate the dynamic Young's modulus at this test temperature.

5 Significance and use

This test method may be used for refractory characterization, development and quality control purposes.

This test method is appropriate for determining the modulus of elasticity of refractory bodies that are homogeneous in nature.

This method addresses the determination of the dynamic moduli of elasticity of slender rectangular bars and cylindrical rods.

This test method is non-destructive in use, so it may be used on specimens prepared for other tests. The specimens are subjected to only minute strains; hence the moduli are measured at or near the origin of the stress-strain curve with a minimum possibility of specimen fracture.

The test provides options for variations in test specimen sizes and procedure to accommodate most refractory compositions and textures.

The impulse excitation test method utilizes an impact tool (hammer) and simple supports for the test specimen.

This test method is not suitable for specimens with major cracks or voids.

This test method is limited to determining moduli of specimens with regular geometries, such as rectangular parallelepipeds and cylinders, for which analytical equations are available to relate geometry, mass and modulus to the resonant vibration frequency.

The analytical equations assume parallel or concentric dimensions for the geometry of the specimens. Deviations in the dimensions of the specimens will introduce errors in the calculations and in the results of the test.

Uneven or excessively rough surfaces of as-formed specimens can have a significant effect on the accuracy of the determination. The dynamic modulus value is inversely proportional to the cube of the thickness, so the thickness variation is significant.

This test method assumes that the specimen is vibrating freely with no significant or impediment. Specimen supports should be designed and located so the specimen can vibrate freely in the proper mode.

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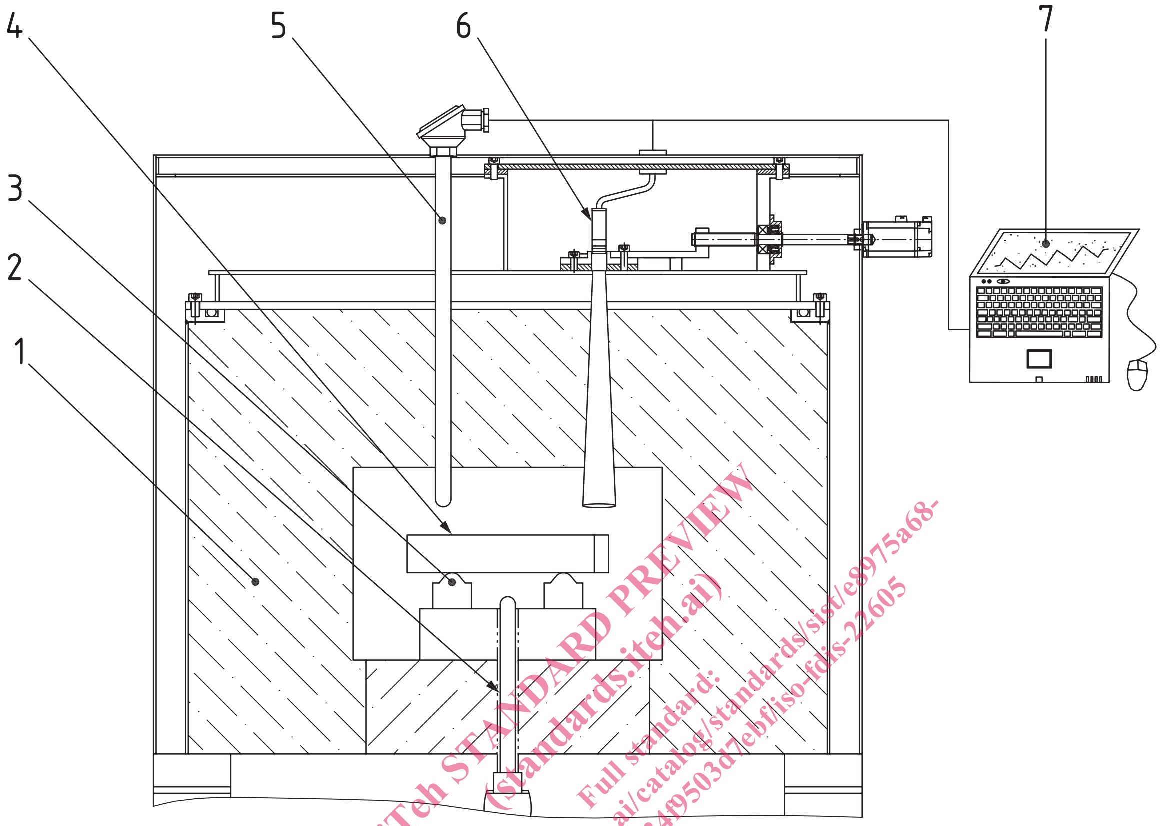
6 Apparatus

The equipment includes the furnace, the pulse excitation, measure device and the specimen support device. The structure principle of the equipment is shown in Figure 1.



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Key

1	lining
2	impulse excitation tool
3	specimen support device
4	specimen
5	thermocouple
6	vibration signal detector
7	signal analyser

Figure 1 — Structure principle of the equipment

6.1 Furnace

An electrical furnace can be used, capable of raising the temperature of the specimen to the test temperature at the specified rate (see 9.5.2) and shall be so designed that at the moment of test the temperature distribution in the test pieces is uniform within ±5 °C.

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

6.2 Impulse excitation measuring device

Including impulse excitation tool, vibration signal detector and signal analyser (see Figure 1). Used for excitation, detection, analysis and recording the natural frequencies of the specimens.

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6.2.1 The impulse excitation tool and the specimen should not occur any chemical reaction or deformation under the test temperature. The force of the impulse excitation tool should be adjustable to be able to make the specimen to produce the appropriate vibration amplitude but cannot cause physical damage to the specimen or cause the specimen to move.

6.2.2 Including vibration signal detector set-up suitable for high temperature measurements, the measuring range is at least 50 Hz to 20 kHz.

The frequency response of the vibration signal detector across the frequency range of interest shall have a bandwidth of at least 10 % of the maximum measured frequency before −3 dB power loss occurs.

NOTE The vibration signal detectors are commonly acoustic microphones. However laser, magnetic or capacitance methods to measure the vibration can also be used.

6.2.3 The frequency analysed by the signal analyser shall have an accuracy of 0,1 % or lower.

6.3 Specimen support device

The specimen is supported, preferably by lightweight materials, on sharp knife edges or cylindrical surfaces. Alternatively, a wire suspension system is used. The specimen should be positioned horizontally in the furnace.

The specimen support device should ensure that the specimen is free vibrating in the flexural vibration mode after the impulse excitation. At the test temperature, there should not be any chemical reaction or deformation. The supports should be examined periodically.

The supports are located at the nodes of the flexural vibration mode, which is 0,224*L* from the ends of the specimen.

6.4 Thermocouple, meeting the requirements of IEC 60584-1 and IEC 60584-2.

The thermocouple to measure the specimen temperature shall be positioned as close as possible to the specimen.

6.5 Vernier caliper, division values 0,02 mm.

6.6 Drying box, can control the temperature in (110 ± 5) °C.

6.7 Electronic balance, division values 0,01 g.

7 Sampling

The number of specimens to be tested shall be determined in accordance with ISO 5022 for shaped products or ISO 8656-1 for unshaped products or using a sampling plan agreed upon between the interested parties.

8 Test specimens

8.1 Specimen geometry

The specimens shall be simple beams or slender rods, either rectangular or circular in cross section. See 3.11.

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