Designation: C 1548 – 02

Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio of Refractory Materials by Impulse Excitation of Vibration[1]

This standard is issued under the fixed designation C 1548; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of the fundamental resonant frequencies for the purpose of calculating the dynamic Young's modulus, the dynamic shear modulus (also known as the modulus of rigidity), and the dynamic Poisson's ratio of refractory materials at ambient temperatures. Specimens of these materials possess specific mechanical resonant frequencies, which are determined by the elastic modulus, mass, and geometry of the test specimen. Therefore, the dynamic elastic properties can be computed if the geometry, mass, and mechanical resonant frequencies of a suitable specimen can be measured. The dynamic Young's modulus is determined using the resonant frequency in the flexural mode of vibration and the dynamic shear modulus is determined using the resonant frequency in the torsional mode of vibration. Poisson's ratio is computed from the dynamic Young's modulus and the dynamic shear modulus.

1.2 Although not specifically described herein, this method can also be performed at high temperatures with suitable equipment modifications and appropriate modifications to the calculations to compensate for thermal expansion.

1.3 The values are stated in SI units and are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 71 Terminology Relating to Refractories[2]

C 215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens[3]

C 885 Test Method for Young's Modulus of Refractory Shapes by Sonic Resonance[2]

C 1259 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration[2]

3. Summary of Test Method

3.1 The fundamental resonant frequencies are determined by measuring the resonant frequency of specimens struck once mechanically with an impacting tool. Frequencies are measured with a transducer held lightly against the specimen using a signal analyzer circuit. Impulse and transducer locations are selected to induce and measure one of two different modes of vibration. The appropriate resonant frequencies, dimensions, and mass of each specimen may be used to calculate dynamic Young's modulus, dynamic shear modulus, and dynamic Poisson's ratio.

4. Significance and Use

4.1 This test method is non-destructive and is commonly used for material characterization and development, design data generation, and quality control purposes. The test assumes that the properties of the specimen are perfectly isotropic, which may not be true for some refractory materials. The test also assumes that the specimen is homogeneous and elastic. Specimens that are micro-cracked are difficult to test since they do not yield consistent results. Specimens with low densities have a damping effect and are easily damaged locally at the impact point. Insulating bricks can generally be tested with this technique, but fibrous insulating materials are generally too weak and soft to test.

4.2 For quality control use, the test method may be used for measuring only resonant frequencies of any standard size specimen. An elastic modulus calculation may not be needed or even feasible if the shape is non-standard, such as a slide gate plate containing a hole. Since specimens will vary in both size

[1] This test method is under the jurisdiction of ASTM Committee C08 on Refractories and is the direct responsibility of Subcommittee C08.01 on Strength.
Current edition approved Nov. 10, 2002. Published July 2003.

[2] *Annual Book of ASTM Standards*, Vol 15.01.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

and mass, acceptable frequencies for each shape and material must be established from statistical data.

4.3 Dimensional variations can have a significant effect on modulus values calculated from the frequency measurements. Surface grinding may be required to bring some materials into the specified tolerance range.

4.4 Since cylindrical shapes are not commonly made from refractory materials they are not covered by this test method, but are covered in Test Method C 215.

5. Apparatus

5.1 *Electronic System*—The electronic system in Fig. 1 consists of a signal conditioner/amplifier, a signal analyzer, a frequency readout device, and a signal transducer for sensing the vibrations. The system should have sufficient precision to measure frequencies to an accuracy of 0.1 %. Commercial instrumentation is available which meets this requirement.[4]

5.1.1 *Frequency Analyzer*—This consists of a signal conditioner/amplifier to power the transducer and a digital waveform analyzer or frequency counter with storage capability to analyze the signal from the transducer. The waveform analyzer shall have a sampling rate of at least 20 000 Hz. The frequency counter should have an accuracy of 0.1 %.

5.1.2 *Sensor*—A piezoelectric accelerometer contact transducer is most commonly used, although non-contact transducers based on acoustic, magnetic, or capacitance measurements may also be used. The transducer shall have a frequency response in the range of 50 Hz to 10 000 Hz, and have a resonant frequency above 20 000 Hz. The sensor shall have a mark identifying the maximum sensitivity direction so that it can be properly oriented for each vibration mode.

5.2 *Impactor*—Because refractory materials are tested with specimens of various sizes, it is not feasible to specify an impactor with a specific size, weight, or construction method. However, hammer style impactors which have light weight handles with the impacting mass concentrated near the end are preferred to dropping vertical impactors. Steel hammer style impactors, with head weights between 0.3 and 3 % of the specimen weight, are recommended. To avoid damaging the surface of insulating bricks or other weak materials, plastic or rubber shapes should be substituted for the steel impactors.

5.3 *Specimen Support*—The support shall permit the specimen to vibrate freely without restricting the desired mode of vibration. For room temperature measurements, soft rubber or plastic strips located at the nodal points are typically used. Alternately, the specimen can be placed on a thick soft rubber pad. For elevated temperature measurements, the specimen may be suspended from support wires wrapped around the specimen at nodal points and passing vertically out of the test chamber.

6. Test Specimen

6.1 *Preparation*—Test specimens shall be prepared to yield uniform rectangular shapes. Normally, brick sized specimens are used. Although smaller bars cut from bricks are easily tested for flexural resonant frequencies, it is more difficult to obtain torsional resonance in specimens of square cross-section. Some pressed brick shapes are dimensionally uniform enough to test without surface grinding, but specimens cut from larger shapes or prepared by casting or other means often require surface grinding of one or more surfaces to meet the dimensional criteria noted below.

6.2 *Heat Treatment*—All specimens shall be prefired to the desired temperature and oven dried before testing.

6.3 *Dimensional Ratios*—Specimens having either very small or very large ratios of length to maximum transverse dimensions are frequently difficult to excite in the fundamental modes of vibration. Best results are obtained when this ratio is between 3 and 5. For use of the equations in this method, the ratio must be at least 2.

6.4 *Dimensional Uniformity*—Rectangular specimens shall have surfaces that are flat and parallel to within ± 0.5 % of the nominal measured value.

6.5 *Weight (or Mass) and Dimensions*—Determine the weight (or mass) to the nearest ± 0.5 %. Measure each dimension to within ± 0.5 %.

7. Measurement of Impulse Resonant Frequencies

7.1 *Transverse Frequency*:

7.1.1 Support the specimen so that it may vibrate freely in the fundamental transverse mode. In this mode the nodal points (where the displacement is zero) are located at 0.224L from

4 Equipment found suitable is available from J. W. Lemmons, Inc., 3466 Bridgeland Drive, Suite 230, St. Louis, MO 63044-260.

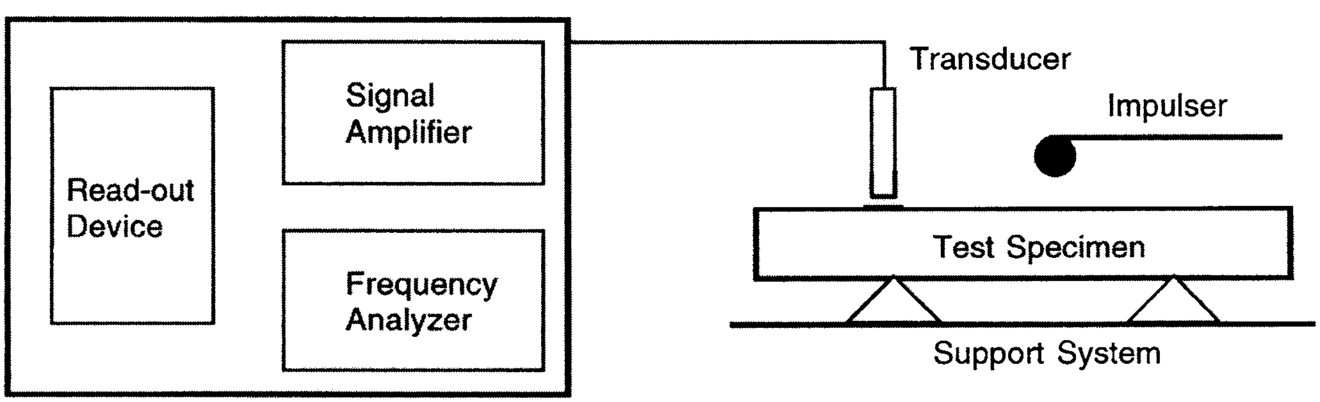

FIG. 1 Diagram of Test Apparatus

each end, where L is the specimen length. Vibrational displacements are a maximum at the ends of the specimen and about 3/5 maximum at the center. The nodal points are shown in Fig. 2 along with recommended impact points and sensor locations. If the specimen does not have a square cross-section, support the specimen on its largest face such that it vibrates perpendicular to its thinnest dimension.

7.1.2 Turn on the electronic system and warm it up according the manufacturers instructions.

7.1.3 Position the sensor on the side face of the specimen at mid length, with the sensor oriented such that the most sensitive pick-up direction coincides with the vibration direction. In Fig. 2, the dot on the sensor indicates the most sensitive pickup direction of the sensor and it is pointed upward toward a top-center impact point. The sensor is typically held against the specimen with very light hand pressure, but some types could be temporarily attached to large specimens.

7.1.4 Select an impact hammer with a head weight 0.3 to 3 % of the specimen weight and lightly tap the top center of the specimen perpendicular to the surface. Note the reading displayed by the electronic system, allow a few seconds for existing vibrations to dampen in the specimen, and repeat the

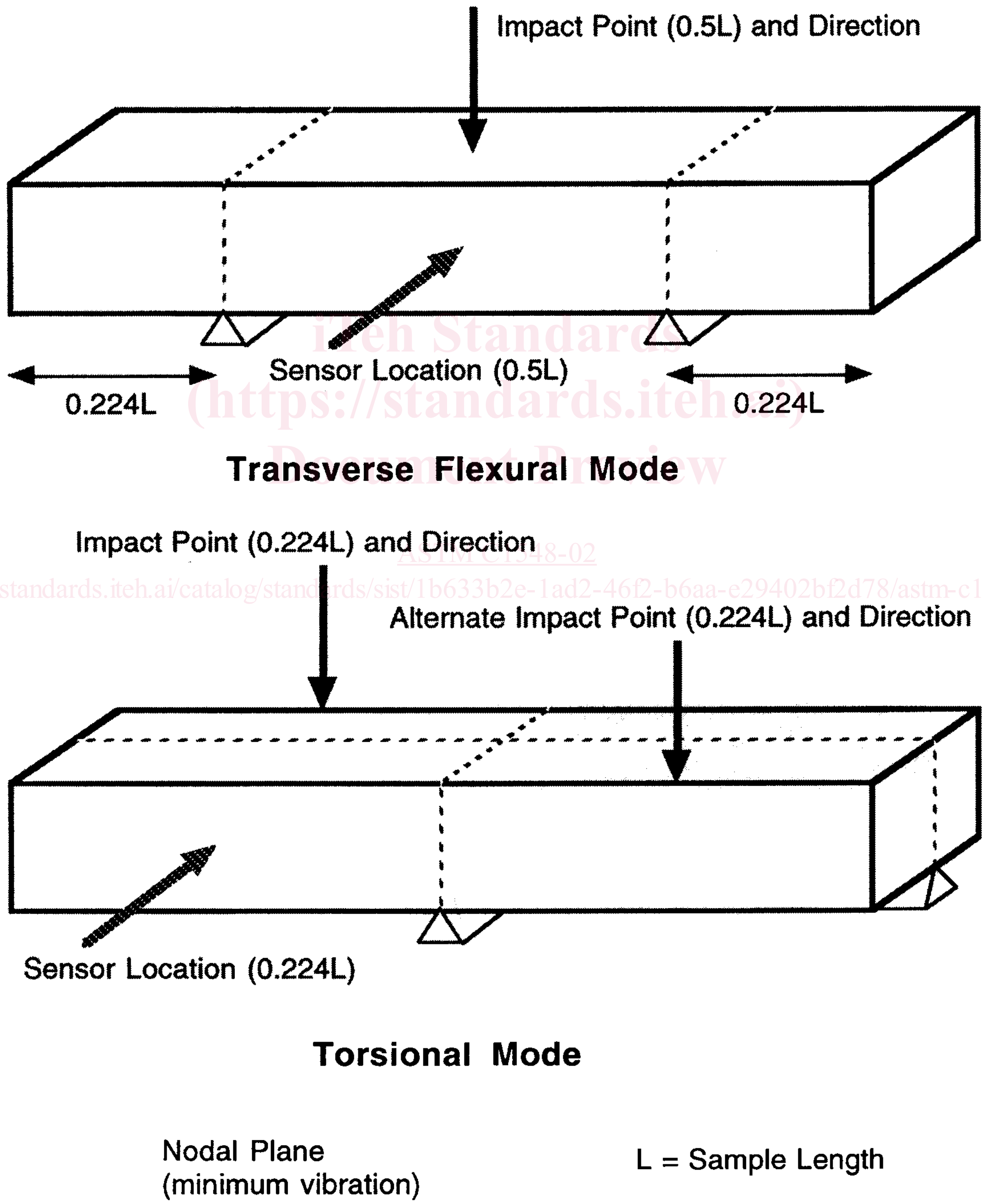

FIG. 2 Impact Points and Transducer Locations