INTERNATIONAL

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Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)[1]

This standard is issued under the fixed designation C1550; 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 determination of flexural toughness of fiber-reinforced concrete expressed as energy absorption in the post-crack range using a round panel supported on three symmetrically arranged pivots and subjected to a central point load. The performance of specimens tested by this method is quantified in terms of the energy absorbed between the onset of loading and selected values of central deflection.

1.2 This test method provides for the scaling of results whenever specimens do not comply with the target thickness and diameter, as long as dimensions do not fall outside of given limits.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C125 Terminology Relating to Concrete and Concrete Aggregates

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *central deflection*—the net deflection at the center of the panel measured relative to a plane defined by the three pivots used to support the panel; this is a conditioned deflection that excludes extraneous deformations of the load train and local crushing of the panel at the point of load application and points of support.

3.2.2 *compliance*—a measure of the tendency of a structure to deflect under load, found as the inverse of stiffness or deflection divided by the corresponding load.

3.2.3 *load train*—those parts of a testing machine that experience load and undergo straining during a mechanical test, including the actuator, frame, support fixtures, load cell, and specimen.

3.2.4 *toughness*—the energy absorbed by the specimen equivalent to the area under the load-deflection curve between the onset of loading and a specified central deflection.

4. Summary of Test Method

4.1 Molded round panels of cast fiber-reinforced concrete or fiber-reinforced shotcrete are subjected to a central point load while supported on three symmetrically arranged pivots. The load is applied through a hemispherical-ended steel piston advanced at a prescribed rate of displacement. Load and deflection are recorded simultaneously up to a specified central deflection. The energy absorbed by the panel up to a specified central deflection is representative of the flexural toughness of the fiber-reinforced concrete panel.

5. Significance and Use

5.1 The post-crack behavior of plate-like, fiber-reinforced concrete structural members is well represented by a centrally loaded round panel test specimen that is simply supported on

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard three pivots symmetrically arranged around its circumference. Such a test panel experiences bi-axial bending in response to a central point load and exhibits a mode of failure related to the *in situ* behavior of structures. The post-crack performance of round panels subject to a central point load can be represented by the energy absorbed by the panel up to a specified central deflection. In this test method, the energy absorbed up to a specified central deflection is taken to represent the ability of a fiber-reinforced concrete to redistribute stress following cracking.

NOTE 1—The use of three pivoted point supports in the test configuration results in determinate out-of-plane reactions prior to cracking, however the support reactions are indeterminate after cracking due to the unknown distribution of flexural resistance along each crack. There is also a change in the load resistance mechanism in the specimen as the test proceeds, starting with predominantly flexural resistance and progressing to tensile membrane action around the center as the imposed deflection is increased. The energy absorbed up to a specified central deflection is related to the toughness of the material but is specific to this specimen configuration because it is also determined by the support conditions and size of the specimen. Selection of the most appropriate central deflection to specify depends on the intended application for the material. The energy absorbed up to 5 mm central deflection is applicable to situations in which the material is required to hold cracks tightly closed at low levels of deformation. Examples include final linings in underground civil structures such as railway tunnels that may be required to remain water-tight. The energy absorbed up to 40 mm is more applicable to situations in that the material is expected to suffer severe deformation *in situ* (for example, shotcrete linings in mine tunnels and temporary linings in swelling ground). Energy absorption up to intermediate values of central deflection can be specified in situations requiring performance at intermediate levels of deformation.

5.2 The motivation for use of a round panel with three supports is based on the within-batch repeatability found in laboratory[3] and field experience.[4] The consistency of the failure mode that arises through the use of three symmetrically arranged support pivots results in low within-batch variability in the energy absorbed by a set of panels up to a specified central deflection. The use of round panels also eliminates the sawing that is required to prepare shotcrete beam specimens.

5.3 The nominal dimensions of the panel are 75 mm in thickness and 800 mm in diameter. Thickness has been shown to strongly influence panel performance in this test, while variations in diameter have been shown to exert a minor influence on performance.[5] Correction factors are provided to account for actual measured dimensions.

NOTE 2—The target dimensions of the panel specimen used in this test are held constant regardless of the characteristics of aggregate and fibers used in the concrete comprising the specimen. Post-crack performance may be influenced by size and boundary effects if large aggregate particles or long fibers are used in the concrete. These influences are acknowledged and accepted in this test method because issues of size effect and fiber alignment arise in actual structures and no single test specimen can suitably model structures of all sizes. Differences in post-crack behavior exhibited in this test method can be expected relative to cast fiber-reinforced concrete members thicker than 100 mm. Because fiber alignment is pronounced in structures produced by shotcreting, and the maximum aggregate size in shotcrete mixtures is typically 10 mm, post-crack behavior in specimens tested by this method are more representative of *in situ* behavior when they are produced by spraying rather than casting concrete.

6. Apparatus

6.1 *Testing Machine*—A servo-controlled testing machine incorporating an electronic feed-back loop that uses the measured deflection of either the specimen or the loading actuator to control the motion of the actuator shall be used to produce a controlled and constant rate of increase of deflection of the specimen without the intervention of an operator. To avoid unstable behavior after cracking, the system stiffness of the testing machine inclusive of load frame, load cell (if used), and support fixture shall exceed that of the specimen. The system stiffness of the testing machine can be determined in accordance with the procedure described in Annex A1. Load-controlled test machines incorporating one-way hydraulic valves or screw mechanisms lacking an electronic feed-back loop for automatically controlling the rate of increase in displacement shall not be used. The load-sensing device shall have a resolution sufficient to record load to ±50 N.

NOTE 3—Although it is commonly believed that servo-controlled systems, incorporating a feed-back loop in which the measured central displacement of the specimen is used to control the motion of the actuator, are capable of overcoming the disadvantages of a structurally compliant testing machine, this will depend on the speed and sensitivity of the feed-back loop and the mechanical response rate of the loading apparatus. A more reliable configuration comprises a servo-controlled actuator in which the measured displacement of the actuator is used in the feed-back loop to control the motion of the actuator combined with a high load train stiffness. Experience has indicated that the redistribution of stress that occurs in fiber-reinforced concrete panels following cracking of the concrete matrix generally results in stable post-crack behavior provided a testing machine complying with the requirements of this section is used.

6.2 *Support Fixture*—The fixture supporting the panel during testing shall consist of any configuration that includes three symmetrically arranged pivot points on a pitch circle diameter of 750 mm (see Fig. A1.4 in Annex A1). The supports shall be capable of supporting a load of up to 100 kN applied vertically at the center of the specimen. The supports shall be sufficiently rigid so that they do not displace in the radial direction by more than 0.5 mm between the onset of loading and 40 mm central deflection for a test involving a specimen displaying a peak load capacity of 100 kN. The three supports must also not translate by more than 0.5 mm in the circumferential direction during a test. The pivots shall not restrict rotation of the panel fragments after cracking. The support fixture shall be configured so that the specimen does not come into contact with any portion of the support fixture apart from the three pivots during a test. A photograph of a suggested design is shown in Fig. 1. The contact between the specimen and each pivot shall comprise a steel transfer plate with plan dimensions of approximately 40 mm × 50 mm with a spherical seat of about 4 mm depth machined into one surface to accept a ball pivot (see Fig. 2). The distance between the surface of the panel and the center of the pivot shall be 20 mm ± 2 mm. The diameter of the pivot ball shall be 16 mm ± 2 mm. The radius to the center of each

[3] Bernard, E. S. "Correlations in the Behaviour of Fibre Reinforced Shotcrete Beam and Panel Specimens," *Materials and Structures*, RILEM, Vol 35, pp. 156–164, April 2002.

[4] Hanke, S. A., Collis, A., and Bernard, E. S., "The M5 Motorway: An Education in Quality Assurance for Fibre Reinforced Shotcrete," *Shotcrete: Engineering Developments*, Bernard (ed.), Swets & Zeitlinger, Lisse, pp. 145-156, 2001.

[5] Bernard, E. S. and Pircher, M., 2001, "The Influence of Thickness on Performance of Fiber-Reinforced Concrete in a Round Determinate Panel Test," *Cement, Concrete, and Aggregates*, CCAGDP, Vol 23, No. 1, pp. 27 –33, June 2001 .