Designation: C 1018 – 97

# Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)[1]

This standard is issued under the fixed designation C 1018; 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 evaluates the flexural performance of toughness parameters derived from fiber-reinforced concrete in terms of areas under the load-deflection curve obtained by testing a simply supported beam under third-point loading.

NOTE 1—Toughness determined in terms of areas under the load-deflection curve is an indication of the energy absorption capability of the particular test specimen, and, consequently, its magnitude depends directly on the geometrical characteristics of the test specimen and the loading system.

1.2 This test method provides for the determination of a number of ratios called toughness indices that identify the pattern of material behavior up to the selected deflection criteria. These indices are determined by dividing the area under the load-deflection curve up to a specified deflection criterion, by the area up to the deflection at which first crack is deemed to have occurred. Residual strength factors that represent the average post-crack load retained over a specific deflection interval as a percentage of the load at first crack are derived from these indices.

NOTE 2—Index values may be increased by preferential alignment of fibers parallel to the longitudinal axis of the beam caused by fiber contact with the mold surfaces or by external vibration. However, index values appear to be independent of geometrical specimen and testing variables, such as span length, which do not directly affect fiber alignment.

1.3 This test method provides for the determination of the first-crack flexural strength using the load corresponding to the point on the load-deflection curve defined in 3.1.1 as first crack, and the formula for modulus of rupture given in Test Method C 78.

1.4 Values of flexural toughness and first-crack flexural strength stated in inch-pound units are to be regarded as the standard. Values of toughness indices and residual strength factors are independent of the system of units used to measure load and deflection.

1.5 *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 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions[2]



## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *first crack*—the point on the load-deflection curve at which the form of the curve first becomes nonlinear (approximates the onset of cracking in the concrete matrix).

3.1.2 *first-crack deflection*—the deflection value on the load-deflection curve at first crack.

3.1.3 *first-crack strength*—the stress obtained when the load corresponding to first crack is inserted in the formula for modulus of rupture given in Test Method C 78.

3.1.4 *first-crack toughness*—the energy equivalent to the area under the load-deflection curve up to the first-crack deflection.

3.1.5 *toughness*—the energy equivalent to the area under the load-deflection curve up to a specified deflection.

3.1.6 *toughness indices*—the numbers obtained by dividing the area up to a specified deflection by the area up to first crack.

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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

NOTE 3—Values of 5.0, 10.0, and 20.0 for $I_5$, $I_{10}$, and $I_{20}$ respectively, as defined below, correspond to linear elastic material behavior up to first crack and perfectly plastic behavior thereafter (see Appendix X1).

3.1.6.1 *toughness index* $I_5$— the number obtained by dividing the area up to a deflection of 3.0 times the first-crack deflection by the area up to first crack.

3.1.6.2 *toughness index* $I_{10}$— the number obtained by dividing the area up to a deflection of 5.5 times the first-crack deflection by the area up to first crack.

3.1.6.3 *toughness index* $I_{20}$— the number obtained by dividing the area up to a deflection of 10.5 times the first-crack deflection by the area up to first crack.

3.1.6.4 *residual strength factor* $R_{5,10}$—the number obtained by calculating the value of 20 ( $I_{10} - I_5$).

3.1.6.5 *residual strength factor* $R_{10,20}$—the number obtained by calculating the value of 10 ( $I_{20} - I_{10}$).

## 4. Summary of Test Method

4.1 Molded or sawn beams of fiber-reinforced concrete are tested in flexure using the third-point loading arrangement specified in Test Method C 78. Load and beam deflection are monitored either continuously by means of an X-Y plotter, or incrementally by means of dial gages read at sufficiently frequent intervals to ensure accurate reproduction of the load-deflection curve. A point termed first crack which corresponds approximately to the onset of cracking in the concrete matrix is identified on the load deflection curve. The first-crack load and deflection are used to determine the first-crack flexural strength and to establish end-point deflections for toughness calculations. Computations of toughness and toughness indices are based on areas under the load-deflection curve up to the first-crack deflection and up to the specified end-point deflection.



## 5. Significance and Use

5.1 The first-crack strength characterizes the behavior of the fiber-reinforced concrete up to the onset of cracking in the matrix, while the toughness indices characterize the toughness thereafter up to specified end-point deflections. Residual strength factors, which are derived directly from toughness indices, characterize the level of strength retained after first crack simply by expressing the average post-crack load over a specific deflection interval as a percentage of the load at first crack. The importance of each depends on the nature of the proposed application and the level of serviceability required in terms of cracking and deflection. Toughness and first-crack strength are influenced in different ways by the amount and type of fiber in the concrete matrix. In some cases, fibers may greatly increase the toughness, toughness indices, and residual strength factors determined by this test method while producing a first-crack strength only slightly greater than the flexural strength of the plain concrete matrix. In other cases, fibers may significantly increase the first-crack strength with only relatively small increases in toughness, toughness indices, and residual strength factors.

5.2 The toughness indices and residual strength factors determined by this test method reflect the post-crack behavior of fiber-reinforced concrete under static flexural loading. The absolute values of toughness determined to compute the toughness indices are of little practical significance since they are directly dependent upon geometrical variables associated with the specimen and the loading arrangement.

NOTE 4—In applications where the energy absorption capability of a structural concrete element is important, it may be possible to obtain some indication of its performance by testing a specimen equivalent to the element in terms of size, span, and mode of loading.

5.3 In determining which toughness index is most appropriate as a measure of material performance for a specific application, the level of serviceability required in terms of cracking and deflection shall be considered, and an index appropriate to the service conditions shall be selected in accordance with the rationale described in 9.6 and in Appendix X1.

5.4 Values of toughness indices, residual strength factors, and first-crack strength may be used for comparing the performance of various fiber-reinforced concretes during the mixture proportioning process or in research and development work. They may also be used to monitor concrete quality, to verify compliance with construction specifications, or to evaluate the quality of concrete already in service.

NOTE 5—Values of toughness index at different ages may not be comparable.

5.5 Values of toughness indices, residual strength factors, and first-crack strength obtained using the 14 by 4 by 4 in. (350 by 100 by 100 mm) preferred standard size of molded specimen may not necessarily correspond with the performance of larger or smaller molded specimens, concrete in large structural units, or specimens sawn from such units, because of differences in the degree of preferential fiber alignment parallel to the longitudinal axis of the specimen. For molded specimens, they tend to increase as the degree of preferential fiber alignment increases.

5.5.1 Preferential fiber alignment is likely to occur in molded specimens when fibers in the vicinity of the mold surfaces tend to align in the plane of the surface, and is most pronounced in specimens of small cross-section containing long fibers.

5.5.2 In thin concrete sections, such as overlays and shotcrete linings, fibers tend to align in the plane of the section, so in-place performance is best evaluated using either molded or sawn specimens of depth equal to the thickness of the section. Consequently, toughness indices, residual strength values, and first-crack strengths for thin sections may differ from those for standard molded specimens of nominally identical concrete.

5.5.3 External vibration promotes preferential alignment of fibers parallel to the vibrating surface of the form or screeding device used, while internal vibration does not have this effect. Consequently, toughness indices, residual strength values, and first-crack strengths for identical concrete specimens prepared using the two kinds of vibration may differ.

5.5.4 Preferential fiber alignment is negligible in mass concrete because the aligning effect of mold surfaces is absent and because internal vibration is often used, so toughness indices, residual strength values, and first-crack strengths for standard molded specimens may differ from those for sawn specimens of nominally identical concrete.

NOTE 6—The degree of preferential fiber alignment may be less for fibers that are flexible enough to be bent by contact with aggregate particles or mold surfaces than for fibers rigid enough to remain straight during mixing and specimen preparation.

## 6. Apparatus

6.1 *Testing Machine*—The testing machine shall be capable of operating in a manner which produces a controlled and constant increase of deflection of the specimen. A testing arrangement where specimen net mid-span deflection is used to control the rate of increase of deflection using a closed-loop, servo-controlled testing system shall be used. Testing machines that use stroke displacement control or load control are not suitable for establishing the post-crack portion of the load-deflection curve. The loading and specimen support system shall be capable of reproducing third-point loading on the specimen without eccentricity or torque. The system specified in Test Method C 78 is suitable.

NOTE 7—Load-deflection curves produced from closed-loop testing systems may show substantial toughness for non-fibrous concrete in the post-crack deflection area up to a deflection of 5.5 times the first-crack deflection. Values of toughness indices $I_5$ and $I_{10}$ and residual strength $R_{5,10}$, should be used with caution, as they may not accurately reflect the contribution of fibers to post-crack toughness at these deflections.

6.2 *Deflection-Measuring Equipment*— Devices such as electronic transducers or electronic deflection gages shall be located in a manner that ensures accurate determination of the net deflection at the mid-span exclusive of any effects due to seating or twisting of the specimen on its supports. Two alternative arrangements for measuring net mid-span deflection have evolved. In the first arrangement three electronic transducers or similar digital devices mounted on a supporting frame are positioned along the centerline of the top surface of the test specimen, one at the mid-span and one at each support (Fig. 1). The average of the support deflections is electrically subtracted from the mid-span deflection. The second arrangement employs a rectangular jig which surrounds the specimen and is clamped to it at the supports (Fig. 2). Two transducers or similar digital devices mounted on the jig at mid-span, one on each side, measure deflection through contact with appropriate brackets attached to the specimen. The average of the measurements represents net mid-span deflection.

6.3 *Data Compilation System*—An X-Y plotter coupled directly to electronic outputs of load and deflection is the simplest acceptable means of expediently and accurately obtaining the relationship between load and net mid-span deflection, subsequently termed the load-deflection curve. A data acquisition system capable of digitally recording load and deflection at least every second and plotting it is also suitable.

NOTE 8—Accurate determination of the areas under the load-deflection curve subsequently needed for computation of toughness indices is only possible when the scales initially chosen for load and deflection are reasonably large. A load scale on which 1 in. (25 mm) corresponds to a flexural stress of the order of 150 psi (1 MPa), or no more than 20 % of the estimated first-crack strength, is recommended. For the preferred 14 by 4 by 4 in. (350 by 100 by 100 mm) specimen size, where first-crack deflection is of the order of 0.002 in. (0.05 mm), a deflection scale on which 1 in. (25 mm) corresponds to about 10 % of the estimated end-point deflection for I-20 is recommended. When testing is continued to a higher end-point deflection, the scale may have to be reduced to avoid excessively large load-deflection plots. With some plotting equipment it is possible to use a relatively large scale up to the $I_{10}$ criterion and switch to a smaller scale at higher deflections without interrupting the test. This keeps the size of the plot reasonable without adversely affecting the ability to accurately determine the area up to first crack and the areas up to the $I_5$ and $I_{10}$ deflection criteria. For test specimens that exhibit a very rapid decrease in load and increase in deflection immediately after first crack, the shape of the portion of the load-deflection curve immediately following first crack may be affected by the response rate of the data recording and plotting system.

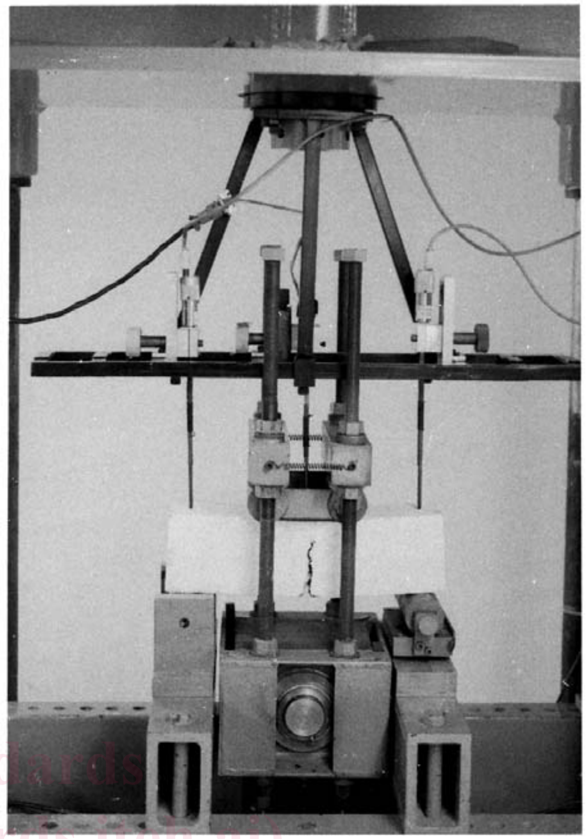

FIG. 1 Arrangement Using 3 Transducers



## 7. Sampling, Test Specimens, and Test Units

7.1 *General Requirements*—The nominal maximum size of aggregate and cross-sectional dimensions of test specimens shall be in accordance with Practice C 31 or Practice C 192 when using molded specimens, or in accordance with Test Method C 42 when using sawn specimens, except when the following specific requirements are contravened:

7.1.1 The length of test specimens shall be at least 2 in. (50 mm) greater than three times the depth, and in any case not less than 14 in. (350 mm).

7.1.2 The width of test specimens shall be at least three times the maximum fiber length. The three times maximum fiber length requirement for width and depth may be waived at the option of the purchaser to permit specimen width or depth of 6 in. (150 mm) when using fibers of length 2 to 3 in. (50 to 75 mm).

7.1.3 The depth and size of test specimens shall conform to either of the following two sets of requirements:

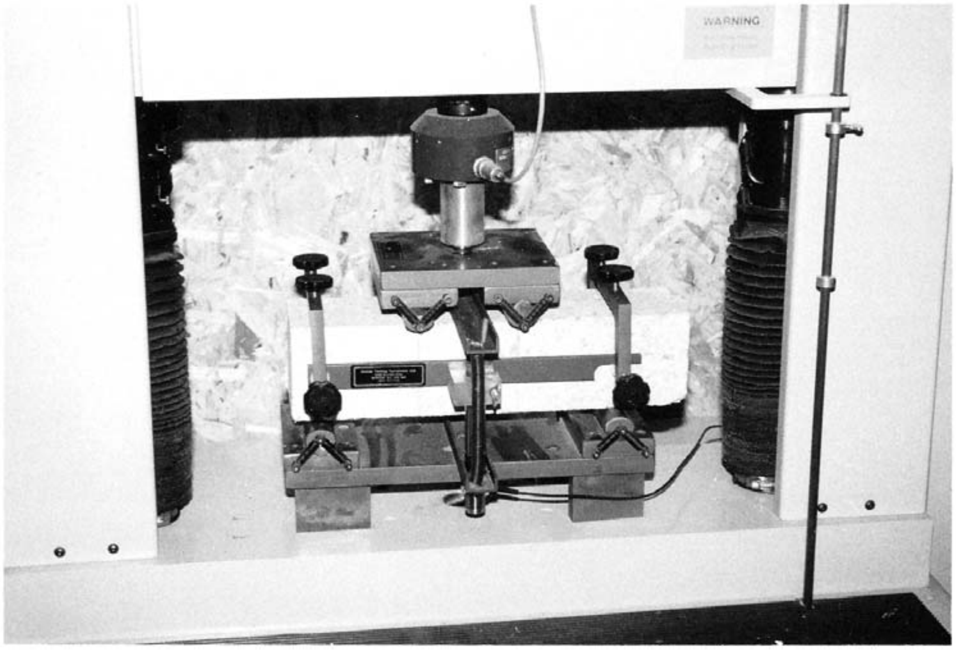

FIG. 2 Arrangement Using Rectangular Jig

7.1.3.1 *Thick Sections*—The depth of test specimens shall be at least three times the maximum fiber length. Subject to meeting this requirement and the requirements of 7.1, 7.1.1, and 7.1.2, the preferred specimen size is 14 by 4 by 4 in. (350 by 100 by 100 mm). When the preferred size is not large enough to meet all of these requirements, specimens of square cross-section large enough to meet the requirements shall be tested. The three times maximum fiber length requirement for width and depth may be waived at the option of the purchaser to permit specimen width or depth of 6 in. (150 mm) when using fibers of length 2 to 3 in. (50 to 75 mm).

7.1.3.2 *Thin Sections*—When the requirements of 7.1 and 7.1.3.1 are not met in the application in which the concrete is to be used, as for example in overlays or shotcrete linings, specimens of depth equal to the section thickness actually used shall be tested.

NOTE 9—When testing freshly mixed fiber-reinforced concrete, it may be desirable to prepare additional specimens of the preferred standard size in order to make proper comparisons of their performance with results obtained on other jobs or reported in the literature. The results of tests of beams with steel fibers longer than one-third the width or depth of the beam may not be comparable to test results of similar-sized beams with fibers shorter than one-third the width or depth because of possible preferential fiber alignment, and different size beams may not be comparable because of size effects.

7.2 *Freshly Mixed Concrete*—Samples of freshly mixed fiber-reinforced concrete for the preparation of test specimens shall be obtained in accordance with Practice C 172.

7.2.1 Specimens shall be molded in accordance with Practice C 31 or Practice C 192, except that compaction shall be by external vibration, as internal vibration or rodding may produce nonuniform fiber distribution. Make sure that the time of vibration is sufficient to ensure adequate consolidation, as fiber-reinforced concrete requires a longer vibration time than concrete not containing fibers, especially when the fiber concentration is relatively high. Take care to avoid placing the concrete in a manner which produces lack of fiber continuity between successive placements by using a wide shovel or scoop and placing each lift of concrete uniformly along the length of the mold. Use a single layer for specimens of depth 3 in. (75 mm) or less and two layers for specimens of depth greater than 3 in. (75 mm).

7.2.2 In placing the final layer, attempt to add an amount of concrete that will exactly fill the mold after compaction. When trowelling the top surface, continue vibration in order to ensure that fibers do not protrude from the finished surface.

7.2.3 Curing shall be in accordance with Practice C 31 or Practice C 192.

7.3 *Hardened Concrete*—Samples of hardened fiber-reinforced concrete from structures shall be selected in accordance with Practice C 823.

7.3.1 Sawn specimens shall be prepared and cured in accordance with Test Method C 42.

7.4 *Test Unit*—At least three specimens from each sample of fresh or hardened concrete shall be prepared for testing.

## 8. Conditioning

8.1 When the time between removal of test specimens from their curing environment and the start of testing is likely to exceed 15 min, drying shall be minimized by applying a curing compound or by other appropriate techniques.

## 9. Procedure

9.1 Molded or sawn specimens representing thick sections, as defined in 7.1.3.1, shall be turned on their side with respect to the position as cast before placing on the support system. Molded or sawn specimens representing thin sections, as defined in 7.1.3.2, shall be tested as cast without turning. Specimens representing shotcrete panels of any thickness shall be tested as placed without turning.