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Review

Toughness characterization of steel fibre reinforced concrete – A review on various international standards

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Toughness measurements are considered to be an important scale for evaluating the post crack performance of a fibre reinforced concrete. There are various international standards that lay down different testing procedures and the corresponding deflection measurements. This paper presents a complete review on the various flexural testing methods for fibre reinforced concrete (FRC) prescribed by different standards and the methods for characterizing the toughness of FRC. Also reviewed are the significant advantages of these methods, the ways in which the deflections are measured and the practical problems associated with the measurement of deflection. This paper also discusses the various factors such as size of the specimen, stiffness of the testing machine, the rate of loading and type of loading, which influence the test results.

Key words: Toughness, fibre reinforced concrete, flexural loading, size effect, stiffness.

INTRODUCTION

Toughness characterization of fibre reinforced concrete (FRC) becomes more complicated due to erroneous misrepresentation of post peak behavior as a result of the extraneous deflections arising out at testing. The source of error lies either from the machine in which the deflection is recorded or at the point of measurement of deflection. In general the deflection can be measured either from the flexural specimen or outside the specimen. In the former case, the deflection is measured by means of providing notches in the flexural specimen, and the crack mouth opening displacement is measured, and in the latter case, the net deflection is calculated either by measuring the cross head displacement, or by setting up a Japanese yoke at the neutral axis to calculate the net deflection (Gopalaratnam and Gettu, 1995; Barr et al., 1996). Since the deflection of flexural specimens essentially reflects the post cracking behavior of FRC, it becomes vital to calculate it ideally and accurately. Erroneous deflection measurements could lead to overestimation of the resultant toughness of FRC, and cause misconceptions about the composite material property. In the present study, a brief review of various testing methods for FRC and deflection measurement techniques adopted by different standards is presented. There is a need to develop a new set of guidelines which can enhance the experimental techniques in FRC. These guidelines would draw from the experience of the current standards.

Proposed guidelines by different standards for flexural testing

In general, the guidelines proposed by various standards call for similar testing methodology (third point loading) and to some extent differ in the size of specimen adopted. The real adequacy of any tests method lies entirely in preventing the extraneous deflections which can occur either due to the support settlement, lack of stiffness of the testing machine or rigidity of the deflection measuring device (LVDT). Over decades, toughness measurements have been evaluated using an un-notched concrete beam in flexure either by using a four-point loading (or third point loading) or midpoint loading arrangement. Due to the problems associated with support settlement, lifting of beams at supports and sudden drop in load after peak load (lack of stiffness of testing machine) leads to extraneous deflections and

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Table 1. Experimental test methods and toughness characterization by various standards.[1]

Name of the standard	Dimensions of the specimen (L*b*h) mm	Rate of loading (mm/min)	Type of loading arrangement	Maximum deflection measured	Toughness measurement
ASTM C-1018[5] (1992)	300*100*100	0.05 to 0.10	Third point loading	Up to the point where there is no resistance on further loading	Determination of toughness indices and residual strength factors
ACI-544 guidelines[6] (1988)	350*100*100	0.05 to 0.10	Third point/Mid-point loading	Up to 1.9 mm	Ratio of energy absorbed by a FRC to that of plain concrete.
JCI specifications[7] (1984)	300*100*100	L/1500 to L/l300	Third point loading	Up to L/150	Energy absorbed up to a deflection of L/150 mm
RILEM draft recommendations[8] (1985)	B>50, d<25, L	0.25	Third point loading	Up to 3 mm	Energy absorbed up to a deflection of 3 mm
EFNARC specification[9] (1993)	450*125*75	0.25 ± 0.05	Third point loading	Up to 25 mm	Residual strength factors up to deflection of 1 and 3 mm

ASTM – American Society for Testing and Materials, ACI – American Concrete Institute, JCI – Japanese Concrete Institute, EFNARC – European Federation of National Association of Specialist Contractors and Material suppliers to construction industry, RILEM - International Union of Testing and Research Laboratories for Materials and Structures.

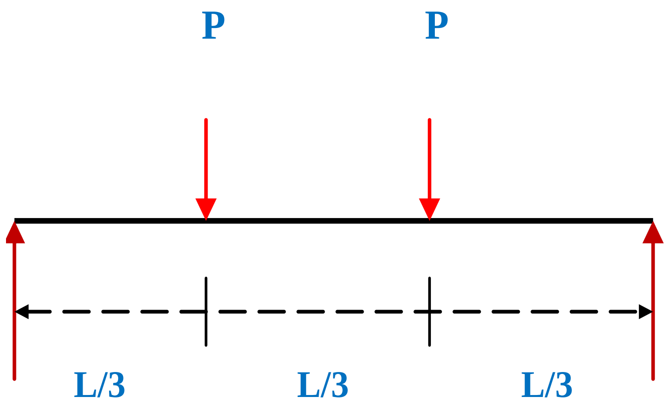

Figure 1. Third point loading test arrangement.

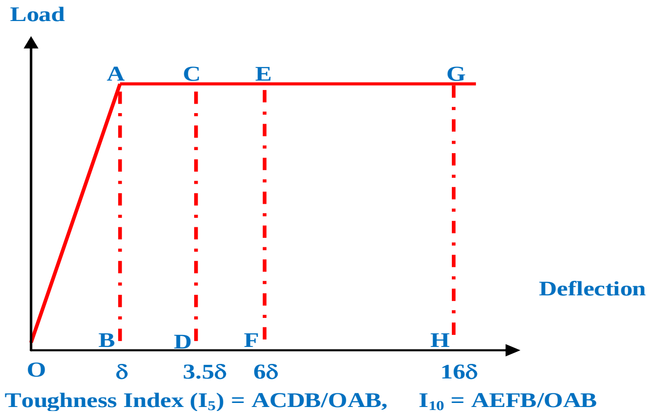

Figure 2. A typical load–deflection plot of FRC.

hence ends up in exaggerated toughness values (Taylor et al., 1997). Recently, it was found suitable to characterize the post peak behavior of the FRC using a centre notched beam wherein, deflections were calculated from the beam specimen and not outside the specimen and gives good characterization of FRC materials. A summary of the various specifications is given in Table 1, and these specifications are discussed in the following part of this work.

ASTM C -1018 Specification (1992)

The ASTM test procedure has been used widely due to its simplicity in testing FRC. A third point loading arrangement as shown in Figure 1 is used for testing the beam specimens. The deflection measurement is done using the cross head displacement and toughness (amount of energy required to deflect and crack an FRC beam) is calculated and reported in terms of indices ((I_5, I_{10}, & I_{20}) and residual strength factors (R_{10} & R_{20}). A typical load-deflection plot and the calculation of toughness indices are shown in Figure 2. The third point loading which is adopted in this method has an

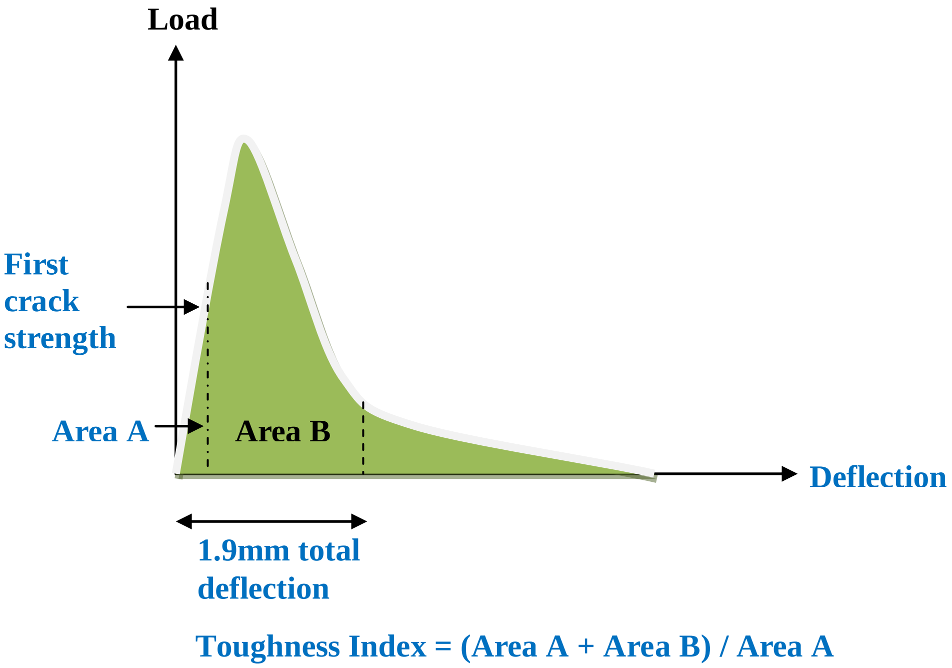

Figure 3. Load deflection curve for fibre reinforced concrete.

advantage, wherein the maximum bending area is increased and subsequently utilizes the efficient fibre action against the bending stresses. On the other hand, the disadvantage with this loading arrangement is due to the failure of beam by shear exactly near one of the loading points. The practical disadvantage with this method lies in the measurement of net deflection (deducting end displacements with central deflection) and first crack deflection which is difficult to locate on the load deflection plot, since the non-linear part of the load deflection curve of FRC is not distinctive. The entire calculation of toughness indices lies in evaluating the exact first crack deflection which is practically impossible to measure. In addition to this, the net deflection is measured against the cross head displacement without taking into account either the support displacement or support settlement which could lead to the calculation of erroneous net deflection. In this standard, toughness indices are evaluated based on multiples of the first-crack deflection which makes it more important to accurately identify the deflection at first crack.

The limitations of this standard are corrected by adding a frame (or 'yoke') around flexural beam specimens that allows direct measurement of the net central deflection of the beam. The use of a yoke eliminate extraneous deflections and results in load deflection curves that are significantly different from those observed by using the traditional cross-head displacement of so-called stiff testing machines. Hence, the practice of measuring displacement directly off the test specimen rather than via the testing machine is preferred by most researchers (Gopalaratnam and Gettu, 1995; Barr et al., 1996).

ACI 544 Specification (1988)

The real application of toughness indices originated with the introduction of the ACI Toughness Index. ACI Committee 544 defines the toughness index as the ratio of the amount of energy required to deflect a fibre concrete beam by a prescribed amount to the energy required to bring the fibre beam to the point of first crack. A sample load –deflection plot and the toughness index calculation is shown in Figure 3. A third point or a four point bend tests are used to characterize toughness. The limitations of this specification include the wide range of parameters that have been used to interpret test results, more variation in the calculated deflections in third-point bend tests compared with three-point bend tests, the difficulty of determining accurately the occurrence of first crack, the extraneous deflections recorded via the testing machine relative to the actual net central deflection of the test specimens and the influence of size effects of specimens on the test results (Gopalaratnam, V.S., and Gettu, R., 1995; Barr, B., *et al.,* 1996). Similar to the ASTM method, these limitations can be overcome by recording the crack mouth opening displacement (CMOD) via notched or the net central deflection via a 'yoke' arrangement subjected to three-point loading.

JCI SF-4 Specification (1984)

The Japanese Concrete Institute (JCI) defines toughness as the area under the load deflection curve up to a limiting deflection of L/150. Identifying the exact occurrence of first crack deflection which is difficult in the ASTM method is not a great concern with this standard. Unlike the ASTM method, the instability in the load-deflection plot right after the first crack is not of major concern in the JCI method, since the end point deflection of span/150 is too far out in the curve to be affected by the instability in the initial portion. However, a limitation of the JCI toughness definition is that the limiting end point deflection is much greater than the acceptable deflection/serviceability limits. The Belgian, Dutch and German specifications have partially overcome this limitation by requiring energy absorption computations also at smaller deflection limits.

EFNARC Specification (1993)

Unlike the other standard methods for the characterization of FRC, this standard recommends the use of a plate test in place of beam test to characterize toughness of FRC. A 600 × 600 mm plate (100 mm thick) is simply supported along all four edges with a 500 × 500 mm span. Load is applied through a 100 × 100 mm punch at a rate of 1.5 mm/min. A plot of the load versus central deflection is used to compute the energy absorbed, until a deflection of 25 mm. The performance of the slab is classified in toughness class a, b or c, for energy absorption capacities of 500, 700 and 1000 J (Nm), respectively. The EFNARC recommendation uses toughness classification identical to that proposed by the Norwegian Concrete Association. However, this approach to characterize toughness was found to be irrelevant for general purpose use.

RILEM Draft Recommendation - 50 FMC (1985)

RILEM recommendation primarily suggests the determination of fracture properties of plain concrete and FRC. This recommendation covers the determination of the critical stress intensity factor and the critical crack tip opening displacement of concrete, using three point bend tests on notched beams. Also there is an advantage of avoiding possible errors due to bending effect by means of reducing the gauge length of LVDT as small as possible and CMOD measured exactly at the centre of beam to avoid eccentricity. This type of testing is unique in that all the material properties can be determined from a single test performed on a notched beam specimen.

FACTORS AFFECTING THE TOUGHNESS RESULTS

Size effects

The size of beam specimens has more direct impact on the test results than the other factors discussed below. It is observed from table 1 that, size of the specimens does not differ greatly for all standards. None of the toughness measurements derived by any standard is size independent. However, for a given size of specimen, the toughness was found to be more sensitive to type of fibre and constituent materials. In reality, even if the energy based indices at small displacements do not exhibit size dependent behavior, the strength and ductility of brittle cementitious composites are inherently size dependent (Gopalaratnam and Gettu, 1995). As a result, none of the toughness measures discussed here and available to date can realistically claim to be truly size-independent.

Type of loading arrangement

It is a general practice of adopting a four point loading test to characterize FRC, since it is easier to conduct and no sophisticated techniques are involved in it. But the real disadvantage with this method is to measure the true deflection at the neutral axis, since bending area is increased. Also, the failure of the beam could occur as a result of shear stress (under the load) rather than bending stress. A mid-point loading configuration is probably more appropriate compared to the four points loading, specifically for notched beam specimens. This setup has numerous advantages in which the stability throughout the test is maintained for both un-reinforced and high strength concretes with low fibre content.

Stiffness of the testing machine

Previously, toughness tests were generally carried out in stiff testing machines that allowed deflection control only. Recently, many research laboratories have carried out tests on closed-loop servo controlled testing machines and achieved stable fracture tests in concrete specimens. The real advantage of such testing machines is in avoiding the sudden drop in load after reaching the peak load. Moreover, one could even control the test by means of the displacement recorded by the opening of the notch. In addition to this, the closed loop testing arrangement allows the crack mouth opening displacement (CMOD) to be used directly to monitor the response of FRC specimen.

Notched versus un-notched beam tests

Compared to an un-notched specimen, deflections in the notched mid-point loaded specimen are always localized at the crack mouth (notch) and the rest of the beam does not undergo any inelastic deformations. This can minimize the energy dissipated over the entire volume of the specimen and, hence, all the energy absorbed can be directed towards the fracture along the notch plane (Gopalaratnam and Gettu, 1995; Barr et al., 1996).

Subsequently, the energy dissipated in these tests can be directly correlated to material response. Also, static tests carried out on centrally notched beam specimen's exhibit the actual deflection of the beam rather than the apparent deflection recorded through the testing machine. Hence, the real advantage of the notched beam test is the possibility of toughness characterization of FRC in terms of CMOD measurements, which are not subjected to any possible errors of the kind observed for traditional deflection measurements.

Deflection measuring techniques

In general none of the standards specifies the type of deflection recording techniques, either recording a traditional cross head displacement, CMOD or setting up an LVDT with yoke arrangement placed at the neutral axis. It is necessary to prevent extraneous deflections from the specimen arising at support settlement or due to lifting of beam at the ends. In recent practice, the use of clip gauge to record CMOD is a good method of quantifying the deflection, as it is measured from the specimen and free from errors. Among all standards, the tests carried out in JCI standard claim to be independent of the type of deflection measuring technique.

CONCLUSIONS FROM THE REVIEW

It can be summarized from the review that, factors like stiffness of the testing machine, accuracy of deflection measurement, and the rate of loading determine the efficacy of the toughness measurement. In general, the various standards have similar test procedures but differ significantly in toughness measurements. The accuracy of any toughness measurement depends upon the true deflection obtained from either un-notched flexural specimen or notched specimens. Also the limit state of serviceability criteria has to be considered for the maximum deflection measured and this maximum limit depends upon the type of application the structure is subjected for use.

REFERENCES

ACI Committee 544 (1988). "Measurement of properties of fiber reinforced concrete". ACI Mater. J. 85:583-593.

ASTM (1992). Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (using Beam with Third-Point Loading), ASTM C 1018-92, ASTM Annual Book of Standards, Vol. 04.22, ASTM Philadelphia, USA, pp. 510-516.

Barr B, Gettu R, Al-Oraimi SKA, Bryana LS (1996). "Toughness Measurement - The Need to Think Again". Cem. Concrete Compos. 18:281-297.

EFNARC (1993). Specification for Sprayed Concrete, Final Draft Published by the European Federation of National Associations of Specialist Contractors and Material Suppliers to the Construction Industry (EFNARC), Hampshire, UK, p. 35.

Gopalaratnam VS, Gettu R (1995). "On the Characterization of Flexural Toughness in Fiber Reinforced Concretes". Cem. Concrete Compos. 17:239-254.

JCI (1984). Method of Tests for Flexural Strength and Flexural Toughness of Fiber Reinforced Concrete. JCI Standard SF-4, Japan Concrete Institute Standards for Test methods of Fiber Reinforced Concrete, Tokyo, Japan, pp. 45-51.

RILEM Draft Recommendation (1985). 50FMC, "Determination of fracture energy of mortars and concrete by means of three-point bend tests on notched beams". Mater. Struct. 18:285-290.

Taylor M, Lydon FD, Barr BIG (1997). "Toughness Measurements on Steel Fibre-reinforced High Strength Concrete". Cem. Concrete Compos. 19:329-340.