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Method of Testing Flexural Toughness of Steel Fiber Reinforced Concrete

鋼繊維補強コンクリートの曲げタフネスの試験方法

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1. Introduction

Steel fiber reinforced concrete (SFRC) not only improves tensile and flexural strengths compared with ordinary concrete, but also has the characteristic of greatly increasing flexural toughness. However, a method of quantitatively evaluating flexural toughness has not yet been established, with there being only a method proposed by ACI Committee 544. This paper examines the method of ACI Committee 544, points out its fundamental defects, and shows the results of investigations on the influences of a number of factors on flexural toughness of SFRC.

2. Outline of Experiments

2.1 Materials Used

The steel fibers used were the kind manufactured by the steel sheet shearing method of dimensions of 0.5 x 0.5 x 30 mm. The coarse aggregate used was crushed stone of maximum size of 15 mm, while fine aggregate was river sand. The cement used was ordinary portland cement.

2.2 Specimens and Method of Testing Flexural Strength

The Specimens used were of dimensions of 10 x 10 x 40 cm, while flexure tests were performed by the four-point loading method with span as 30 cm. Loading was done up to maximum load at a rate the extreme fiber stress would be constant (9 kg/cm^2/min), following which loading was continued with the oil pumped at the time of maximum load maintained constant.

3. On The Method of Evaluating Flexural Toughness According to Proposal of ACI Committee 544

3.1 Outline

Fig. 1 shows typical flexural load-deflection curves of various fiber reinforced concretes. Of these curves, Type I is for the case of first crack load being maximum load, Type II is for the case of strength increased further after first crack to reach maximum, while Type III is for the case of deflection at maximum load being considerably larger than the deflection at first crack. Since flexural toughness is closely related to the shapes. of these load-deflection curves, in evaluating them it is necessary to use an index that will quantify the shapes. In the method of ACI Committee 544, the use of a toughness index is proposed as such an index. The toughness index, as shown in Fig. 2, is expressed as $(A_1+A_2)/A_1$ where the area surrounded by the curve up to first crack load and the abscissa is A_1, and the area surrounded by the curve up to the point where center point deflection reaches 1.9 mm and the abscissa is (A_1+A_2).

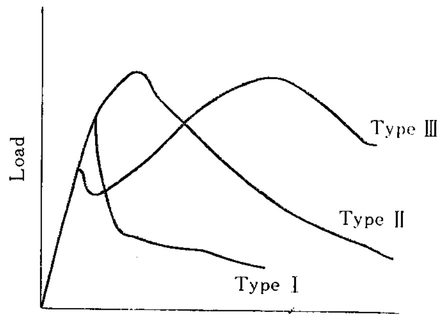

Fig. 1 Load-deformation curves of various fiber reinforced concrete

The results of examination of this method proposed by ACI Committee 544 will be described in this chapter.

3.2 Influences of Various Factors on Deflection Measurements

(1) Influence of Local Deformation of Concrete at Supports on Deflection Measurements

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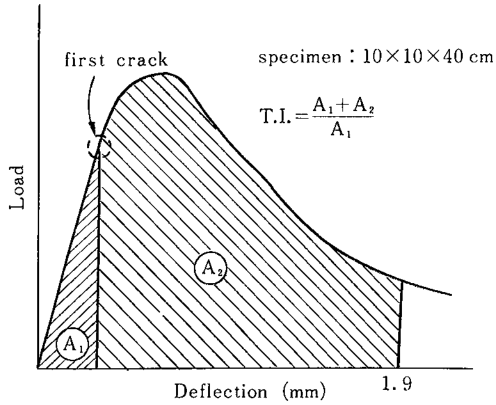

Fig. 2 Definition of the toughness index by ACI method

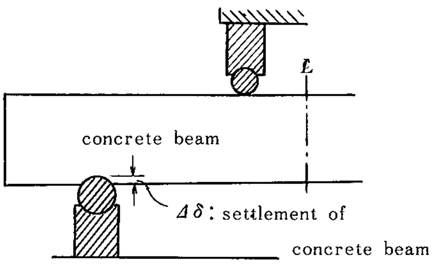

Fig. 3 Local deformation of concrete at the supports of bending apparatus

Cylindrical steel rollers of the kind shown in Fig. 3 are generally used as supports in flexural strength tests of concrete in a manner that they will be in linear contact with the concrete. Since the deflection of concrete until formation of first crack when concrete is subjected to flexural loading is very small, if the concrete at the parts in linear contact with the cylindrical rollers were to produce the slightest compressive elastoplastic deformation accompanying increase in load, the influence of this on deflection will be very great. Consequently, unless the influence of local deformation of the concrete at the supports are considered in measurement of deflection, the shape of the curve of SFRC will distinctly be different, while the value of toughness index will also be extremely different.

For example, Fig. 4 shows the flexural load-deflection curves of SFRC for the same specimen in the cases of considering and not considering the influence of local deformation of concrete at supports, and it may be seen that the shapes of the two are clearly different. Particularly, when attempting to evaluate flexural toughness by the toughness index proposed by ACI Committee 544, it is seen at a glance that the values of A_1 differ greatly between the two. Therefore, when the toughness index is determined for the two, there will be an extreme difference produced as shown in Table 1.

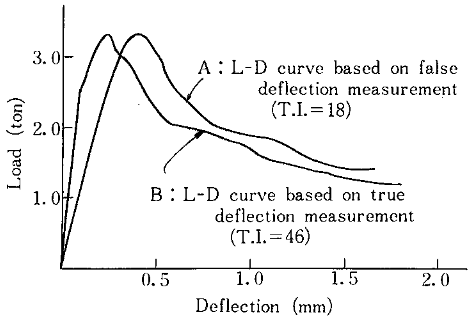

Fig. 4 Effects of local deformation of concrete on load-deformation curve

Table 1 Difference of T. I. determined for the two deflection measurement

Method of deflection measurement	A_1	A_1+A_2	T.I.
Author's	3.0	138.9	46
ACI's	8.3	146.7	18

Meanwhile, according to the proposal of ACI Committee 544, the value of deflection 1.9 mm is to correspond to approximately 15 times the deflection of 0.125 mm at the time of first crack. However, the deflection at the time of first crack measured by the authors applying flexural load by the identical method and using completely identical loads as the ACI proposal was about 0.05 mm (flexural stress of tensile fiber = 75 kg/cm^2), and it was confirmed that it was not more than one half of the value indicated in the ACI Committee 544 proposal. The above value also coincides approximately with calculated value of deflection as an elastic beam. This fact tells that ACI Committee 544 has not considered the effect of the minute settlement of the concrete beam at the supports.

(2) Influence of Measuring Location on Deflection Measurement

Fig. 5 shows the deformation characteristics of a specimen after reaching maximum load. It may be seen from this figure that crack width is increased with

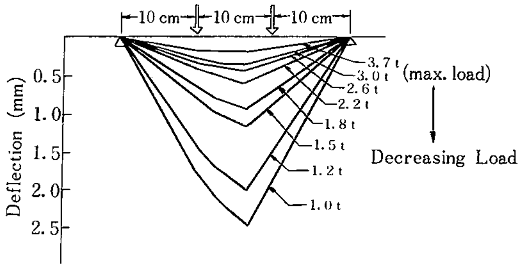

Fig. 5 Deformation characteristics of SFRC beam

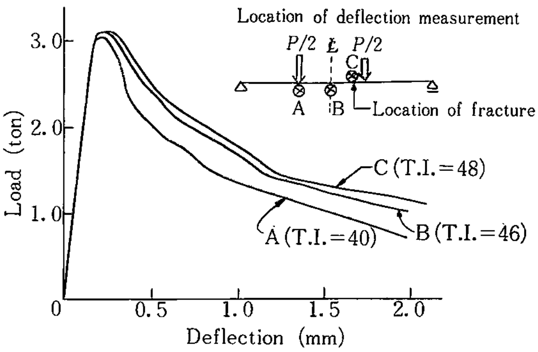

Fig. 6 Influence of location of fracture on toughness index

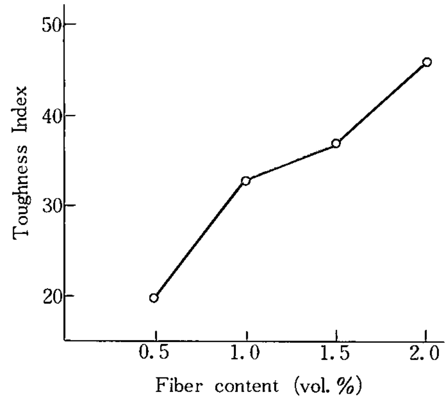

Fig. 7 Fiber content v. s. toughness index

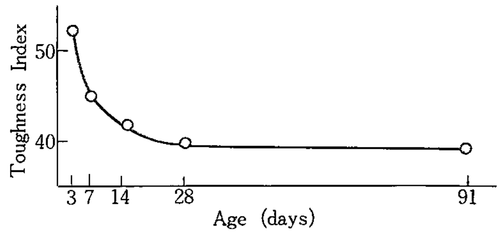

Fig. 8 Influence of age of concrete on toughness index

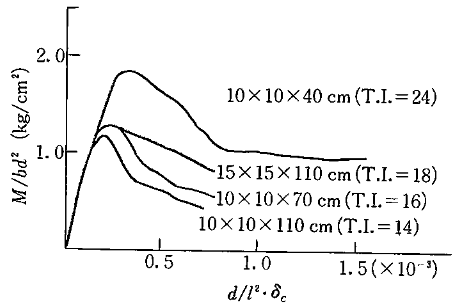

Fig. 9 Influence of size of specimens on toughness index

decrease in strength after maximum load, and moreover, that the cracked portion serves as a hinge through the bridging effect of steel fibers. Because of this, even though the location for measuring deflection may be constant, if the location at which a hinge is produced, in effect, the location at which fracture occurs is varied, the deflection value obtained will differ considerably. Fig. 6 shows this influence, and from this it may be seen that for the deflection of an SFRC beam measurements should be made at least at 3 locations within the section of equal moment, and that a toughness index sufficiently close to the true value would be obtained by the load deflection curve closest to the fracture location.

4. Influences of Various Factors on Flexural Toughness of SFRC

Since it was learned form the above that the value of toughness index could be correctly determined by the above procedure, a study was made by toughness index of the various factors influencing flexural toughness of SFRC.

Fig. 7 indicates the relation between toughness index and fiber content and it is seen that toughness index is prominently increased with higher fiber content.

Meanwhile, Fig. 8 indicates the relation between toughness index and age at testing of SFRC of identical mix proportions. It may be seen that toughness index is lowered with increasing age up to 28 days after which there is practically no change. Fig. 9 shows the influence of specimen size on toughness index. According to this, with specimens of constant cross section, toughness index is decreased the greater the length, while for specimens of identical lengths toughness index is higher with larger cross section.

5. Conclusions

Problems in evaluating flexural toughness of SFRC by the toughness index proposed by ACI Committee 544 have been explained, and the influences of various factors on flexural toughness of SFRC have been investigated applying this toughness index.

The authors are of the opinion that this toughness index is not necessarily suitable as an indicator for evaluating flexural toughness of SFRC. This will be elaborated on another occasion at which time the authors' hope to be able to propose a new method of evaluating flexural toughness.

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Reference

1) ACI Committee 544 Report, "Measurement of Properties of Fiber Reinforced Concrete, ACI Journal, July 1978.

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