Flexural Toughness dependent on Fiber Distribution of Ultra-High Strength Cementitious Composites with Steel Fibers

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Abstract. The effect of fiber distribution on the flexural toughness of ultra-high strength cementitious composites reinforced with steel fibers was investigated. By comparing the flexural behaviors of beam specimens fabricated by different casting methods and the images for fiber distribution of the beam sections, a close dependency between them was found. The experimental results revealed that the flexural toughness was strongly dependent on the fiber distribution and its contribution was outstanding in a certain deflection range after first cracking occurred.

Keywords: Flexural toughness, fiber distribution, steel fiber, ultra-high strength, cementitious composites.

1 Introduction

Even though concrete is one of the most commonly used construction materials, it has some inherent drawbacks such as brittleness, low tensile strength, low strain capacity, etc. As a useful method to overcome these shortcomings, short-fiber reinforcement have been applied to concrete. It is well known that various mechanical properties of concrete are enhanced by incorporating fibers, which include tensile strength, compressive strength, toughness, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, and fire resistance [1-4]. Among them, the most noticeable benefit of incorporating fibers is to improve toughness [5,6].

Meanwhile, the mechanical properties of fiber reinforced concrete are considerably dependent on what kind of fiber it is, the geometry and volume fraction of fiber, fiber distribution characteristics, bond properties between fiber and matrix, and so on.

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[1] Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames. This determines the structure of the names in the running heads and the author index.

Especially, even if a type of fiber with a constant volume fraction is added to a concrete, the characteristics of fiber distribution has strong influence on the tensile properties[7,8].

Therefore, in this study, it was intended to investigate the effect of fiber distribution on the flexural toughness of ultra-high strength cementitious composites reinforced with steel fibers.

2 Experiments

The mix proportion of the material considered in this study is presented in Table 1. The steel fiber used has ultimate strength of 2,500 MPa, and its volume fraction was 2%. Two types of fibers with the same volume fraction were chosen for hybrid reinforcement; one is 0.2mm in diameter and 16.3mm in length, the other is 19.5mm in length with the same diameter.

Experimental test for evaluating flexural behavior and toughness was performed according to KS F 2566 [9]. Test specimens with dimensions of
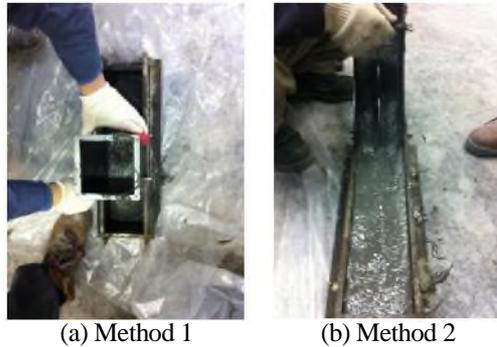

(a) Method 1   (b) Method 2
Fig. 1. Two different casting methods

100×100×400 mm were prepared and a four point bending test was conducted. The deflections at the loading points were measured by means of LVDTs.

To investigate the effect of fiber distribution on the flexural toughness, different fiber distributions in test specimens need to be obtained ahead. For the purpose, two different casting methods were adopted in fabricating bending test specimens as shown in Fig. 1.

Table 1. Mix proportion used for ultra-high strength cementitious composites

	Unit mass (kg/㎥)					
Cement	Silica fume	Sand	Filler	Water	Steel fiber	Anti-oamer
771	193	848	231	160	156	1.4

3 Results and analysis

Fig. 2 shows the flexural tensile behaviors obtained from the experiments, for both cases cast by method 1 and 2. The first cracking strength and the corresponding deflection, as well as the flexural tensile strength at the ultimate load and the corresponding deflection are tabulated in Table. 2. As can be seen in Fig. 2 and Table. 2, the flexural tensile behavior can be found to be strongly influenced by casting

method. The first cracking strength of specimens cast by method 1 was 42.5 MPa, but the case of method 2 had 51.6 MPa in average. The method 2 presented about 20% higher cracking stress than the method 1. The flexural tensile strength of the method 2 was much higher than the method 1. The method 1 produced 48.3 MPa but the method 2 gave 125.4 MPa. The method 2 provided approximately 2.5 times of the flexural tensile strength of the method 1.

This difference is thought to be closely related to the fiber distribution. Therefore, photos of the fiber distribution in a section as close as possible to the fractured section were obtained using digital camera.
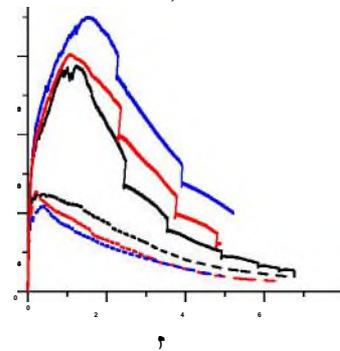

Fig. 2. Comparison of flexural behavior

Table 2. Flexural tensile test results

	At first cracking		At maximum load	
	Load (kN)	Defl. (mm)	Load (kN)	Defl. (mm)
1-1	45.0	0.050	50.9	0.212
1-2	39.9	0.048	43.6	0.372
1-3	42.7	0.050	50.5	0.286
Mean	42.5	0.049	48.3	0.290
2-1	47.6	0.053	140.1	1.492
2-2	51.9	0.061	115.1	1.233
2-3	55.3	0.062	121.1	1.083
Mean	51.6	0.059	125.4	1.269

The images taken for both cases were compared in Fig. 3. As can be seen, the density

of fibers distributed in the section is remarkably distinguished.

(a) Method 1   (b) Method 2
Fig. 3. Comparison of the fiber distribution in section

Flexural toughness was evaluated using some flexural toughness indices such as TI_5,

$_{TI}10,$ and $_{TI}30.$ The definition of the indices was not exactly equal to the ones in

KS F 2566. They are defined as the ratio of the area under the load-deflection curve up to first cracking load and the one between two consequent specified deflections. The specified deflections are $3\delta_{cr}$, $5.5\delta_{cr}$, and $15.5\delta_{cr}$. For example, the specified deflections in calculating TI_{10} index are $3\delta_{cr}$ and $5.5\delta_{cr}$. Additional indices of TI_{60}, TI_{100}, and TI_{200} were also used for more appreciable evaluation for ultra-high strength cementitious composites having high ductility and toughness.
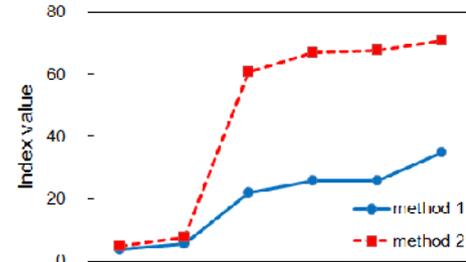

Fig. 4. Flexural toughness indices

The absorbed energy up to maximum load was calculated to be 12 N·m for method 1 and 126 N·m for method 2. The latter is about 10 times higher than the former. The total energy up to 5mm of deflection was also calculated, and it was 126 N·m for method 1 and 342 N·m for method 2. The method 2 gave 2.7 times higher energy than the method 1 and the ratio is roughly similar to the ratio in flexural tensile strength. Even though the same material, geometry, and amount of fibers are added, the energy absorption in bending can be said to be enormously dependent on the fiber distribution.

The flexural toughness indices for both methods were compared, and the result was shown in Fig. 4. Dramatic increase between TI_{10} and TI_{30} was found, and the increment in flexural toughness index in the case of method 2 was much higher than method 1. In any other zone, the incremental slope seems to be similar for both cases. It means that the effect of fiber distribution on the flexural toughness is biggest in this range.

4 Conclusions

The effect of fiber distribution on the flexural toughness of ultra-high strength cementitious composites reinforced with steel fibers was investigated. The experimental results revealed that the flexural toughness was strongly dependent on the fiber distribution and its contribution was outstanding in a certain deflection range. There was dramatic increase in the difference of toughness index according to fiber distribution in the range between the deflection of $5.5\delta_{cr}$, and $15.5\delta_{cr}$.

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