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Influence of Placing Method on Flexural Toughness of UHSCC with Steel Fiber

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Abstract

This study was aimed to investigate the effect of placing method on flexural toughness of Ultra-High Strength Cementitious Composites (UHSCC) reinforced with steel fibers. Experimental results on flexural behavior of UHSCC presented its strong dependency on placing method. A close relationship between them was proved by comparison between the flexural behaviors of beam specimens fabricated by different placing methods and the images for fiber distribution of the beam sections. Flexural toughness estimated by ASTM C 1018 as well as JCI-SF4 indicated that energy absorption capacity in bending could be different in several times of magnitude according to placing method.

Keywords: Flexural toughness, Placing method, Fiber distribution, Steel fiber, Cementitious composites

1 Introduction

Concrete is one of the most commonly used construction materials. However, it has some inherent drawbacks such as brittleness, low tensile strength, low strain capacity, etc. As a useful method to get over these shortcomings, discontinuous short-fiber reinforcement has been widely adopted. It is well known that incorporating fibers into cementitious materials can enhance various mechanical properties, including tensile strength, compressive strength, toughness, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, fire resistance, etc.[1][2][3]. Among them, the most noticeable benefit which can be obtained by incorporating fibers is to improve toughness [4][5]. Meanwhile, the mechanical properties of fiber reinforced concrete are considerably dependent on fiber properties such as geometry and volume fraction of fiber, fiber distribution characteristics, bond properties between fiber and matrix, and so on. Especially, even if the same type of fibers with the same volume fraction are added to a concrete, the characteristics of fiber distribution has strong influence on the tensile properties [6][7]. The fiber distribution is also significantly affected by placing method [8]. Therefore, in this study, it was intended to investigate the effect of placing method on the flexural toughness of ultra-high strength cementitious composites (UHSCC) reinforced with steel fibers. Flexural toughness was estimated according to ASTM C 1018 [9] as well as JCI-SF4 [10].

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 even 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 ASTM C 1018 [9]. Test specimens with dimensions of 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 (see Fig. 1). 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 placing methods were adopted in fabricating bending test specimens, as shown in Fig. 2. Method 1 is to place by putting fresh concrete above the center of the mold making it flow of itself toward both ends. On the other hand, method 2 is to place by putting at one end of the mold making it flow toward the other end.

Table 1. Mix proportion used for ultra-high strength cementitious composites Unit mass (kg/m^3)

Cement	Silica fume	Sand	Filler	Water	Steel fiber	Superplasticizer	Anti-foamer
771	193	848	231	160	156	46.3	1.4

Fig. 1. Four point bending test

(a) Method 1

(b) Method 2

Fig. 2. Two different placing methods3 Results and analysis

Fig. 3 shows the flexural tensile behaviors obtained from the experiments, for both cases placed by method 1 and 2. The first cracking load and the corresponding deflection, as well as the maximum load at load-deflection curve and the corresponding deflection are tabulated in Table. 2. As can be seen in Fig. 3 and Table. 2, the flexural tensile behavior can be found to be strongly influenced by placing method. The first cracking load of the specimens cast by method 1 is 42.5 kN, but the case of method 2 has 51.6 kN in average. The method 2 presents about 20% higher first cracking load than the method 1. The maximum load of the method 2 is much higher than the method 1. The method 1 produces 48.3 kN but the method 2 gives 125.4 kN. The method 2 provides approximately 2.6 times of the maximum load of the method 1. The modulus of rupture (MOR) calculated under the assumption the specimen is elastic until rupture takes place is 14.5 MPa and 37.6MPa for the method 1 and 2 respectively.

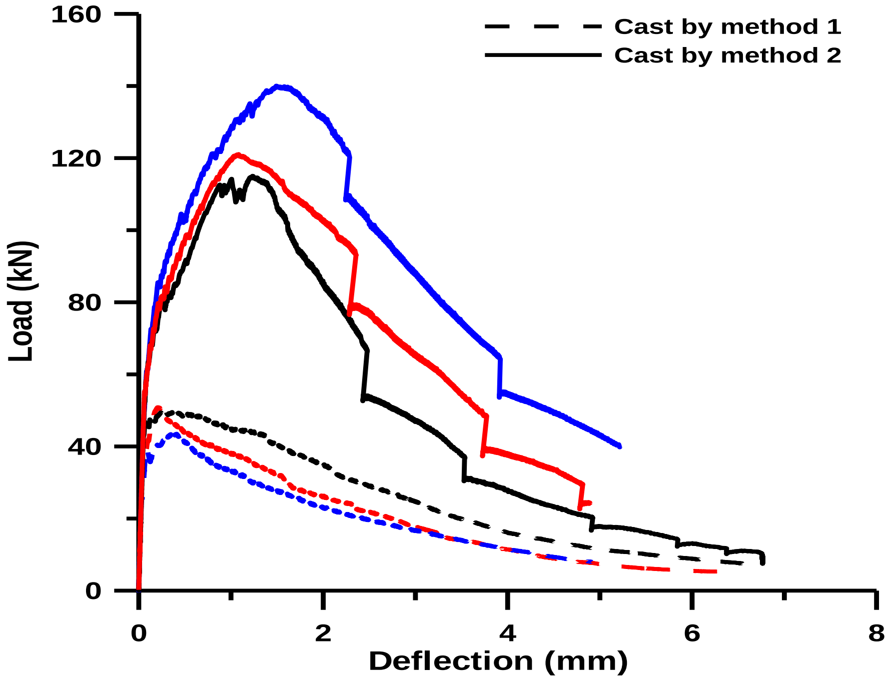
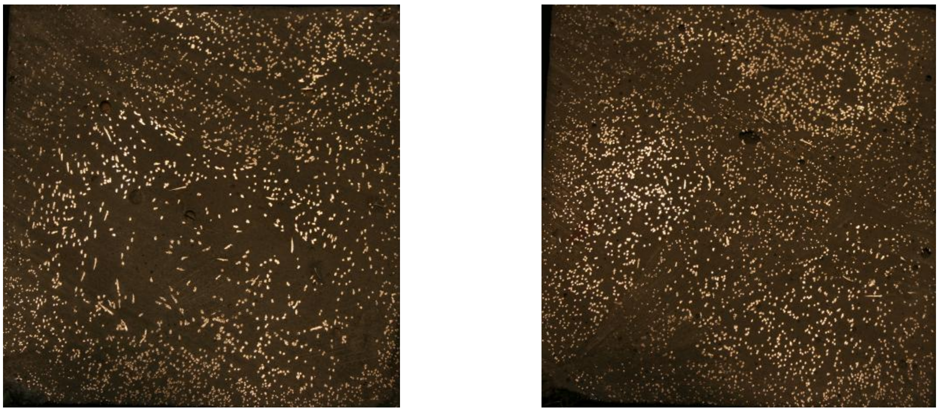


Fig. 3. Comparison of flexural behaviors

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

This difference was 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. The images taken for both cases were compared in Fig. 4. As can be seen, the density of fibers distributed in the section is remarkably distinguished. The number of fibers detected was 2,589 and 3,726 for method 1 and 2 respectively; the ratio of fibers' area to total area of the section in the image was 0.062 for method 1 and 0.073 for method 2. These quantitative values demonstrate the difference in fiber distribution.



(a) Method 1 (b) Method 2

Fig. 4. Comparison of the fiber distribution in section

Flexural toughness was evaluated according to ASTM C 1018 [9] as well as JCI-SF4 [10]. According to the ASTM C 1018 [9], Toughness indices I_5, I_{10} and I_{20} are calculated at specified deflections of $3\delta_{cr}$, $5.5\delta_{cr}$ and $10.5\delta_{cr}$, as shown in Fig. 5, in which δ_{cr} means the deflection at the moment of first cracking. In the same way, additional toughness indices of I_{30}, I_{60}, I_{100}, and I_{200} were also introduced for more comprehensive understanding of ductile behavior of the material. Fig. 6 shows the estimated flexural toughness indices for two different placing methods. It can be seen that the ratio of toughness indices between two different placing methods increases up to the deflection corresponding to I_{60} and thereafter the ratio does not show noticeable increase.

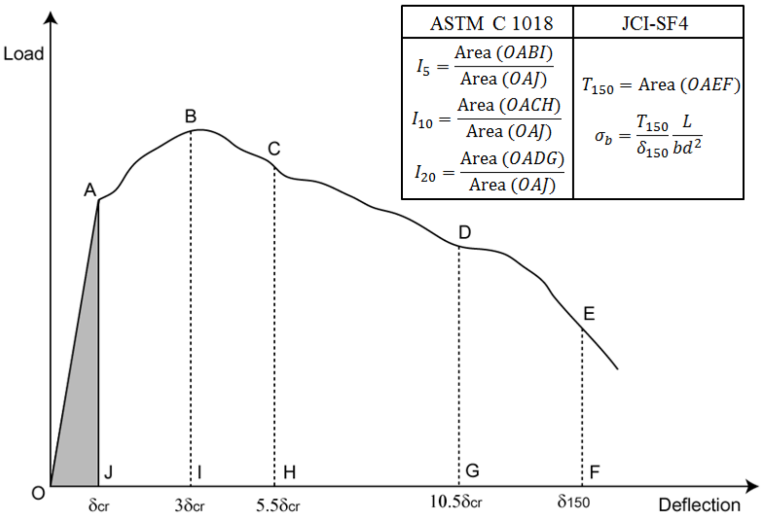
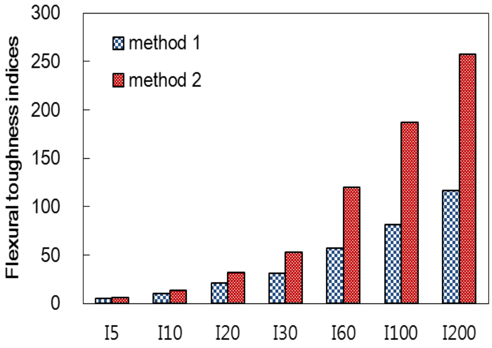
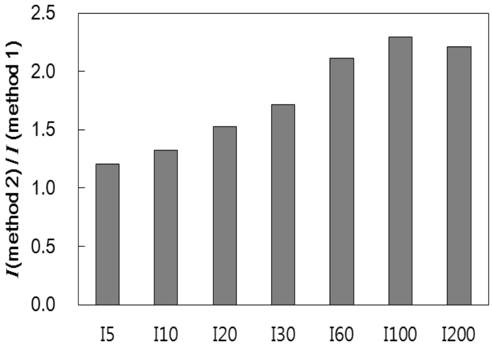


Fig. 5. Toughness definition in ASTM and JCI



(a) Flexural tough indices



(b) Index ratio between method 1 and 2

Fig. 6 Estimation of flexural toughness indices according to ASTM C 1018

The flexural toughness defined in JCI-SF4 [10] is the area under the load-deflection curve up to the deflection of $L/150$, where L indicates the span length of the tested specimen. It is expressed as T_{150}. JCI recommendations also defines the equivalent flexural strength (σ_b) which is expressed as $(T_{150}/\delta_{150})\times(L/bd^2)$, where b and d are the width and depth of the tested beam specimen. Fig. 7 compares the flexural toughness and the equivalent flexural strength for method 1 and 2. The calculated flexural toughness is 76 N·m for method 1 and 210 N·m for method 2. The method 2 gives 2.8 times higher flexural toughness than the method 1 and the ratio is roughly similar to the ratio in flexural tensile strength. The equivalent flexural strength is 11.3 MPa and 31.6 MPa for method 1 and 2 respectively. These results indicate that even though the same material, geometry, and amount of fibers are added, the energy absorption in bending can be enormously dependent on the placing method and the resultant fiber distribution.

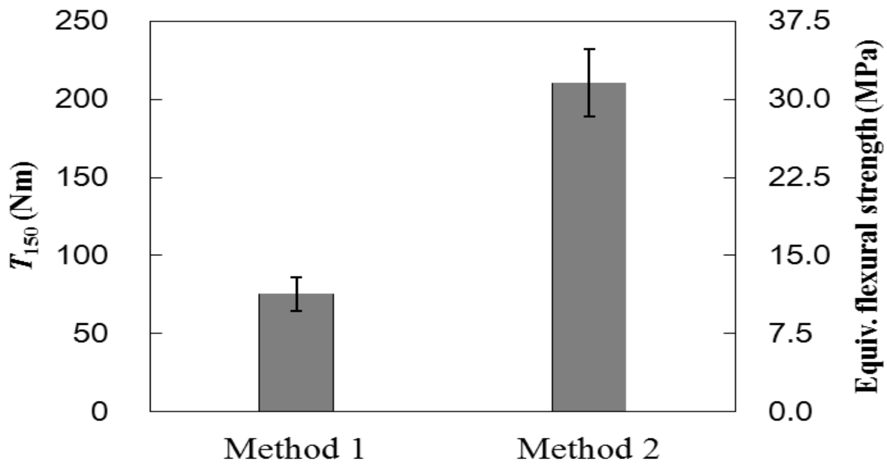


Fig. 7 Flexural toughness and equivalent flexural strength according to JCI-SF4

4 Conclusions

The effect of placing method on the flexural toughness of ultra-high strength cementitious composites reinforced with steel fibers was investigated. From this experimental study, the following conclusions were obtained: (1) flexural behavior of UHPCC had a strong dependency on placing method; (2) a close relationship between them was proved by comparison between the flexural behaviors of beam specimens fabricated by different placing methods and the images for fiber distribution of the beam sections.; (3) comparison of flexural toughness revealed that energy absorption capacity in bending could be different in several times of magnitude according to placing method.

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