MATEC Web of Conferences **138**, 03001 (2017) DOI: 10.1051/matecconf/201713803001
EACEF 2017

Effect on the Load Transferring Properties Fiber Reinforced Steel in Concrete based on Different Mix Ratio

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Abstract. This paper analyses the correlation between the load transfer section and the overall toughness of steel fiber reinforced concrete. The specimens were created with different mixing ratios and different types of steel fiber, and the flexural behaviour properties according to the respective types of steel fiber were analysed. The results showed three types of load – displacement curves, and it was confirmed that the different fiber types affected the load transfer section on the overall toughness.

1 Introduction

The main purpose of steel fiber mixing in steel fiber reinforced concrete is to provide a bridging in the concrete matrix to reduce cracking in the concrete during loading, but they cannot increase the overall strength of the concrete. Following the impact point, the deformation and residual load occur due to the bridging reaction between of the fiber and concrete matrix, and the residual load has an effect on the derivation of toughness of steel fiber reinforced concrete. With the aim of investigating the influence of bridging reaction in the load transfer zone on total toughness, this study conducted an evaluation of the effect of flexural behaviour on steel fiber reinforced concrete, mixed with hooked steel fiber, crimped steel fiber, crimped stainless steel fiber, each having different tensile strength.

2 Materials and Test Procedure

2.1 Test Materials

The material used in this study was grade 1 regular Portland cement mixed with fine and course aggregate produced in Company K. The hooked steel fiber sample was also taken from Company K and the crimped steel fiber and crimped stainless steel fiber were taken from Company S, all respectively used to make the concrete specimens for this study. The aspect ratio of the steel fiber was 70. The fiber types were determined by considering the need to prevent uneven distribution of fiber due to the wall effect, thus the value would

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have to be smaller than the section of the specimen used in the toughness assessment method divided by 2.5[1]. Table 1 shows the properties and detailed images of the different types of fibers that were used in this study, and the mix design is shown in Table 2.

Table 1. Properties and Details of Steel Fiber

Category	**Hooked Type**	**Crimped Steel Type**	**Crimped Type**
Code	H-SF	C-SF	C-SLF
Material	Steel	Steel	Stainless Steel
Section	Circular	Circular	Circular
Tensile Strength (N/mm^2)	1,300	2,896	1,941
Length(mm)	35	35	35
Diameter	0.5	0.5	0.5
Aspect Ratio	70	70	70
Image			

Table 2 Mix design of the Concrete Specimens

<table>
<tr><th rowspan="2">Type</th><th rowspan="2">Fiber Content (%)</th><th rowspan="2">W/C (%)</th><th rowspan="2">S/a (%)</th><th colspan="4">Unit Weight(kg/m³)</th><th rowspan="2">S.P. (Cx%)</th><th rowspan="2">AE (Cx%)</th></tr>
<tr><th>W</th><th>C</th><th>S</th><th>G</th></tr>
<tr><td>Plain</td><td>0</td><td rowspan="7">45</td><td rowspan="7">51</td><td rowspan="7">200</td><td rowspan="7">440</td><td>778</td><td rowspan="7">748</td><td rowspan="7">1.0</td><td rowspan="7">0.02</td></tr>
<tr><td>H-SF0.5</td><td>0.5</td><td rowspan="6">766</td></tr>
<tr><td>H-SF1.0</td><td>1.0</td></tr>
<tr><td>C-SF0.5</td><td>0.5</td></tr>
<tr><td>C-SF1.0</td><td>1.0</td></tr>
<tr><td>C-SLF0.5</td><td>0.5</td></tr>
<tr><td>C-SLF1.0</td><td>1.0</td></tr>
</table>

2.2 Test Procedure

Three concrete specimens of 100x100x400mm were made to undergo flexural behaviour property testing and toughness assessment. The test was conducted in 4 point bending test based on the instructions outlined in KS F 2566:2014, *Flexural Test Method of Fiber Reinforced Concrete*. The tensile stress load rate was set to 0.06±0.04 MPa (N/mm^2) per second. After the bending test, the toughness of the specimen was derived by calculating the area below the load displacement graph for up to 2.0 mm, which corresponded to 1/150 of the span.

3 Experimental Results

3.1 Flexural Behaviour Properties

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The flexural property testing of the OPC specimen showed that its load decreased drastically after reaching the maximum load. However, specimens reinforced with steel fiber showed that its load was being transferred to steel fiber after the crack was formed in the concrete matrix, resulting in a delayed effect of crack diffusion and the residual load maintaining in the matrix due to the fiber bridging effect. The fracture was delayed gradually, showing a decrease in the load after the maximum load or slight increase in the load after maximum load for each of the specimens based on the difference of the shape, quality of material, and content of the fiber.

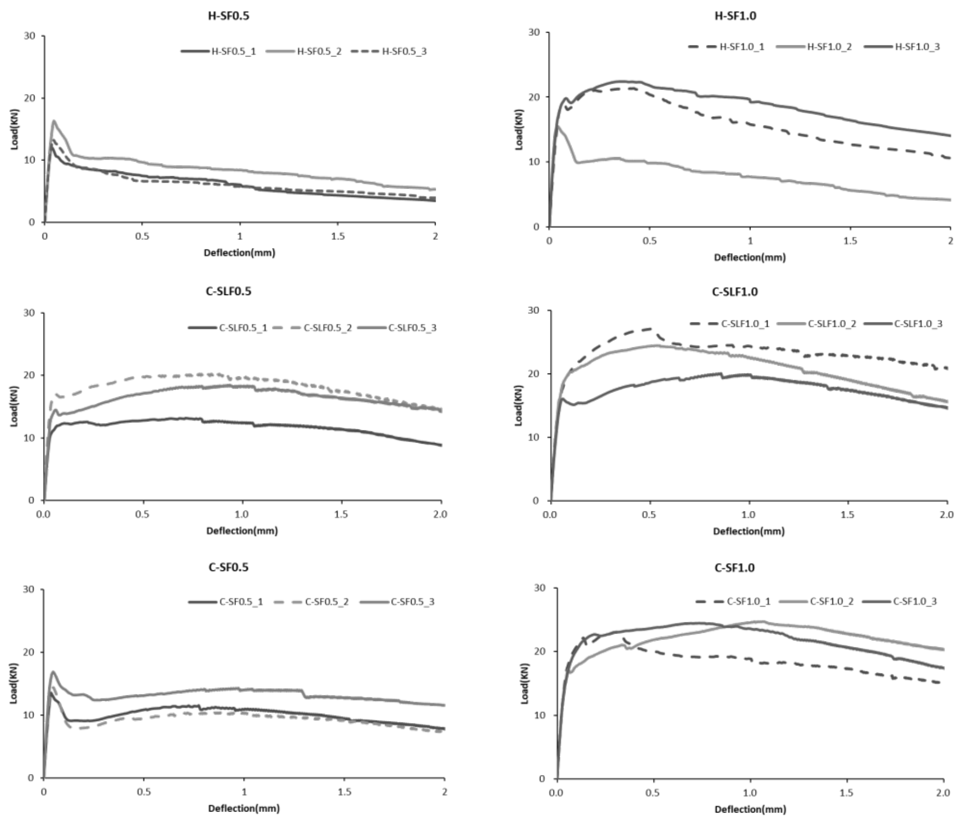

Fig. 1. Flexural Load Displacement Curve of the Specimens Mixed with Different Steel Fibers

3.2 Load Transfer Types by Fiber Mixing Ratio and Material Properties

The load – displacement curve of the SFRC was divided into three cases (Type A, Type B, and Type C). Type A showed that the load was decreased after the peak load and was followed by a more gradual decrease without an increase in the load. Type B showed that the load was decreased slightly after the peak load and was followed by an increase and a subsequent gradual decrease after the second peak load. Lastly, with Type C, the load increased after the peak load without any decrease and then the load gradually decreased and the residual load maintained.

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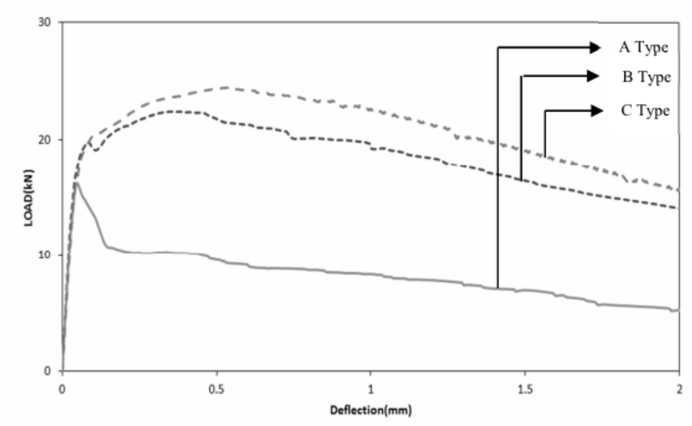

Fig. 2. Load Transfer Properties by different Steel Fiber Type and Mixing Ratio

4 Analysis

4.1 Analysis of the Flexural Behaviour Properties

The area below the load displacement curve is divided into five zones based on the load transfer type for the detailed anlysis of the flexural behavior properties. Table 3 shows a detailed description of the range of each section. Figure 3 shows the diagram of the slope and area by section.

Table 3. Range Variance by Section

Category			Range (d : displacement, mm)	Energy absorption mechanism
Section	**Toughness by section**	**Slope by section**		
1	S1a	G1a	0 ≺d≼ initial crack point	Linear elastic behaviour
	S1b	G1b	initial crack point ≺d≼ first peak load	Progress of fine cracks inside the matrix
2	S2	G2	first peak load ≺d≼ lowest load point	Concrete-fiber load transfer section
3	S3	G3	lowest load point ≺d≼ second peak load	Fiber bridging and pull-out action
4	S4	G4	second peak load ≺d≼ 2.0	

4.2 Toughness Analysis Based on Area

Figure 3 shows the graph representing the toughness of each section. In the case of the first section, the different results were derived despite the same size due to the behavior of the concrete matrix.

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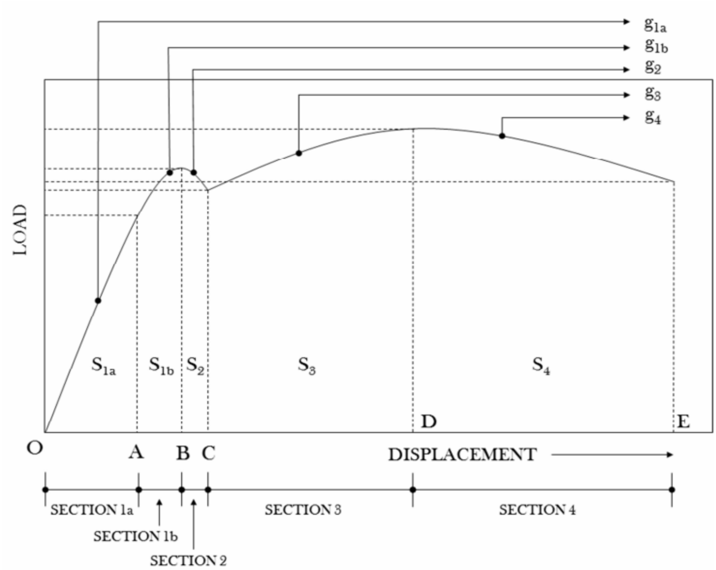

Fig. 3 Area (Toughness) and Slope of the Load Displacement Curve by Section

The second section in Figure 4 shows that the area decreases with the increase of the steel fiber content. It is surmised that the thorough placement of the fiber in the matrix enhances the crack inhibition performance and makes the load transfer rate more efficient.

The third section shows that the energy increases following the increase of the fiber content. This is due to the increased amount of the fiber absorbing the energy and can handle increased amount of strain.

The 4th section shows that the amount of energy absorbed by the fibers was increased as the amount of fiber mixture increased. This is considered to be a natural extension of the fourth section resulting from the decrease of load in the second section and increase in the load of the third section.

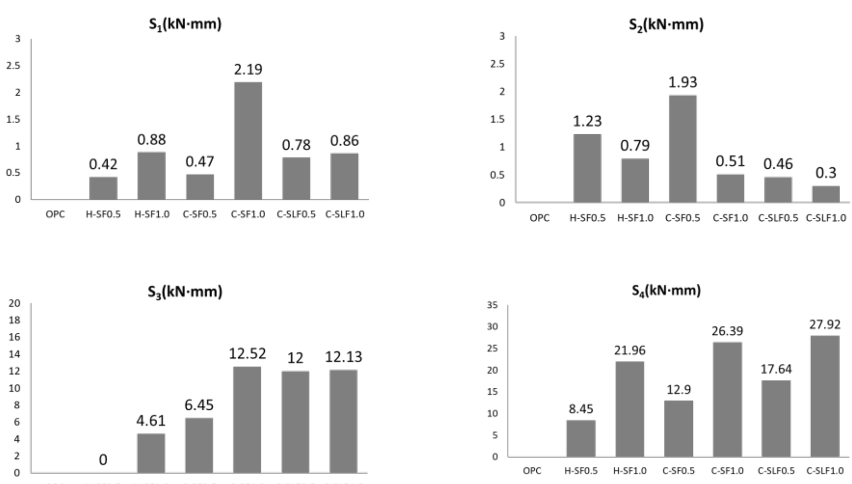

Fig. 4 Toughness by Different Sections

4.3 Equation between the Load Transfer Section and the Toughness

The analysis of the above area shows the area of the load trasfer sesction (S_2) and the area of the load re-increase section(S_3) affect the toughness. In consideration of this factor, the load transfer facter equation was established. And the result of L.T.F. and toughness is shown in the following Table. 4 .

$$L.T.F. = (S_3/S_2)^{1/2} \tag{1}$$

The regression equation of the overall toughness based on the distribution of the LTF was verified by equation (2).

$$T_b = 17.64((S_3/S_2)^{1/2})^{0.45} \tag{2}$$

Table 4. LTF and Toughness

Specimen	Load Transfer Factor (LTF)	Toughness
H-SF 0.5	0	13.86
H-SF 1.0	5.84	28.23
C-SF 0.5	3.34	21.91
C-SF 1.0	24.06	41.61
C-SLF 0.5	26.09	30.88
C-SLF 1.0	40.57	41.22

The analysis results on the degrees of freedom, F-statistic, significance probability, and coefficient of determinant has been calculated accordingly and have been displayed in Table 5. Based on these results, the coefficient of the determinant (R^2) was figured out to be 0.798. The figures derived from the testing indicates that the proposed correlation model can offer a considerable level of accuracy and reliability in determining the appropriate connection between the toughness of the concrete and the load transfer factor.

Table 5. LTF and Coefficient of Determinant (R^2)

Degree of freedom(df)	F-statistic	Significance probability(sigf)	Coefficient of determinant(R^2)	Regression Model
3	11.84	0.041	0.798	$Y=17.64x^{0.45}$

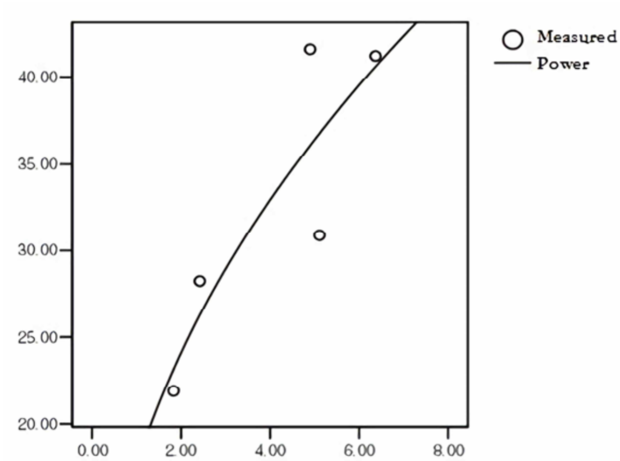

Fig. 5 Regression Model Based on the Load Transfer Factor (LTF) and Toughness

5 Conclusions

In this study, three types of steel fiber were used to investigate the effect of the load transfer performance between concrete matrix and steel fiber of steel fiber reinforced concrete. As a result of section analysis, the area of the load transfer section (second section) and the area after the load transfer section (third section) was shown to affect the overall toughness. Lastly, to determine the correlation between the energy transfer capacity of steel fiber and the overall toughness of the load transfer section, the study developed a regression model (T_b) using the LTF.

This research was supported by a grant (NRF-2016RIC IB2009489) from National Research Foundation of Korea

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