The Effects of Aggregate Sizes and Fiber Volume Fraction on Bending Toughness and Direct Tension of Steel Fiber Reinforced Concrete

Hyun-Woo Cho, Jae-Heum Moon, and Jang-Hwa Lee

Abstract**—**In order to supplement the brittle property of concrete, fibers are added into concrete mixtures. Compared to general concrete, various characteristics such as tensile strength, bending strength, bending toughness, and resistance to crack are superior, and even when cracks occur, improvements on toughness as well as resistance to shock are excellent due to the growth of fracture energy. Increased function of steel fiber reinforced concrete can be differentiated depending on the fiber dispersion, and sand percentage can be an important influence on the fiber dispersion. Therefore, in this research, experiments were planned on sand percentage in order to apprehend the influence of sand percentage on the bending properties and direct tension of SFRC and basic experiments were conducted on bending and direct tension in order to recognize the properties of bending properties and direct tension following the size of the aggregates and sand percentage.

Keywords**—**Steel Fiber Reinforced Concrete, Bending Toughness, Direct tension.

I. Introduction

STEEL Fiber Reinforced Concrete (SFRC) includes steel fiber into concrete in order to make up for the brittle properties. Compared to general concrete, various characteristics such as tensile strength, bending strength, bending toughness, and resistance to crack is superior and even when cracks occur, improvements on toughness as well as resistance to shock is excellent due to the growth of fracture energy.

SFRC, which is gained by mixing steel fiber into the short length within the concrete in random directions, can control the micro crack extension and local crack growth within the section as the concrete is under tensile stress. This can be done through its role as a bridge. By doing so, ductility within the area increases after the occurrence of the crack along with the tensile strength [1] – [3]

Through the mixture of steel fiber, the increase of tensile strength within the concrete as well as improved ductility can bring improvements in behavior for concrete structures that have the tendencies of destruction.

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The increase in bridging function for the steel fiber becomes is influenced on the fiber dispersion, and fiber dispersion plays an important role in fiber dispersion.

Therefore, in order to apprehend the influence that sand percentage leaves on the bending properties of SFRC, experiments regarding aggregates were planned, and basic experiments were conducted on bending properties and direct tension in order to understand their properties.

II. Experiment Plan and Method

A. Experimental Design

In this experiment, experiment was preceded as sand percentage was transformed with 44.4, 51.5, and 61.5% on the concrete combination that exerted the design strength of 42MPa.

In addition, the experiment was conducted in the form as twisted steel, which is known for its outstanding bond strength and toughness was fixed and the volume fraction showed changes between 1.0, 1.25, and 1.5%. The biological properties of twisted steel fiber are the same as that of Table I[4]. In the test content, slump and amount of air within the Fresh concrete was measured, and in the hardened concrete, compressive strength, bending toughness, and direct tensile experiments were conducted.

In terms of mixing conditions, combination of 20% of substituted fly ash was applied. Moreover, in order to satisfy the objective slump and (120±25 mm) and amount of air (4.5±1.5%), water reducer and AE was controlled as the combination was settled as shown in Table II.

B. Experimental Method

In this research, twin shaft mixer was used in form of method to create the concrete combination.

TABLE I
PROPERTIES OF TWISTED STEEL FIBER

Type of Fiber	Diameter (mm)	Length (mm)	Aspect Ratio (*l/d*)	Tensile Strength (MPa)
Twisted	0.375	30	80	2,300

As the experiment was based on the properties of Fresh concrete, the measurements were attributed on KS F 2402 for slumps and KS F 2421 for the amount of air.

TABLE II
MIX PROPORTIONS OF CONCRETE

Specimens	S/a (%)	G_{max} (mm)	W/B (%)	V_f (%)	Unit weight (kg/m^3)						
					W	C	FA	G	S	WRA	AEA
S44F1.0				1.0							
S44F1.25	44.4	13	40	1.25	162	260	64.8	938	822	2.08	0.20
S44F1.5				1.5							
S51F1.0				1.0							
S51F1.25	51.5	13	40	1.25	181	363	91	786	836	2.92	0.33
S51F1.5				1.5							
S61F1.0				1.0							
S61F1.25	61.5	13	40	1.25	204	411	102	592	944	3.30	0.37
S61F1.5				1.5							

*W : Water, C : Cement, FA : Fly Ash, G : Coarse agg., S : Fine agg.
WRA : Water Reducing Agent, AEA : AE Agent

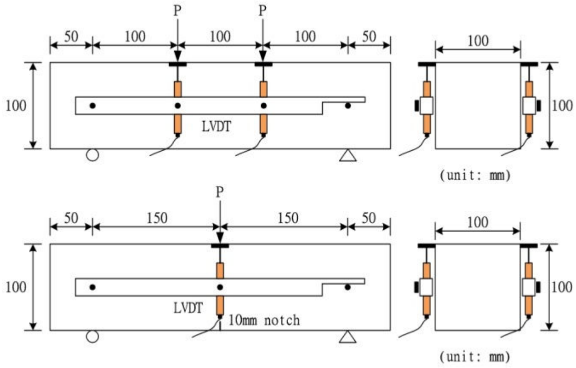

Fig. 1 Experimental method of bending Toughness

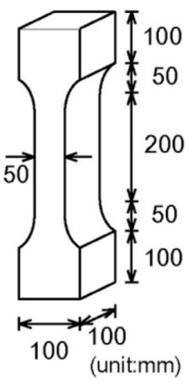

Fig. 2 Shape of Specimen

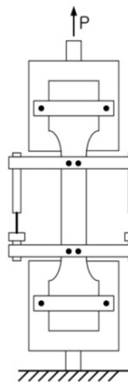

Fig. 3 Experimental Method

As for the experiment based on the properties of hardened concrete, the compressive strength was created by basing ∅100×200 mm cylindrical specimens on KS F 2403 and measured based on KS F 2405.

In case of experiment on bending toughness, by taking the combination in Table II as the base, rectangular specimen of 100×100×400mm are created, and based on KSF 2408 and Rilem TC 50[5],4 point loaded bending experiment and 3 point loaded bending experiments were conducted in the same way as that of Fig. 1.

Direct tensile experiment was designed the dog-bone specimen in the same way as what is shown in Fig. 2, and the experiment that measures the strain by using LVDT were conducted as shown in Fig. 3[6, 7]. Through these experiments, relations between tensile stress-crack opening displacement of SFRC following the fiber shape and fiber volume content are aimed to be understood.

III. RESULT AND DISCUSSION

A. Properties of Fresh Concrete

As a result of measurement in the operation of fresh concrete, operation function becomes better as the amount of sand percentage increases, and as the amount of fiber volume fraction increases, fiber ball phenomena occurs.

In case of combination with 44.4% of sand percentage, fiber ball phenomenon formed as the fiber volume fraction exceeded over 1.25%. Also, in the combination with 51.5% of sand percentage, it has been displayed that the operation function drastically decreased when the fiber input is 1.5%.

However, in case of the combination with 61.5% of sand percentage, the fiber volume fraction increased up to 1.5% and fiber ball phenomenon did not take place. Thus, it did not satisfy its targeted slump of 120±25mm.

Out of the 9 combinations, separation in material took place in 3 combinations due to fiber ball phenomenon, making it impossible to measure the formation and slumps. In case of combinations that satisfied the targeted slump of 120±25mm, 1% of fiber was added into 61.5% of sand percentage.

TABLE III
PROPERTIES OF FRESH CONCRETE

S/a	Slump (mm)		
	V_f = 1.0%	V_f = 1.25%	V_f = 1.5%
44.4%	30	N.A	N.A
51.5%	70	20	N.A
61.5%	105	60	20

Fig. 4 Fiber ball Phenomenon (S44F1.25, S44V1.5, S51V1.5)

B. Compressive Strength

Specimen were cured in a tub with the maintenance in temperature of 20℃ for 28 days. Then, the compressive strength was measured. All combinations satisfied the designed compressive strength of 42MPa, and increasing effects of compressive strength was minute depending on the increase of sand percentage. Also, it has been displayed that there was no change in the compressive strength following the fiber volume fraction.

TABLE IV
EXPERIMENTAL RESULTS ON COMPRESSIVE STRENGTH

S/a	Compressive Strength (MPa)		
	V_f = 1.0%	V_f = 1.25%	V_f = 1.5%
44.4%	55.58	N.A	N.A
51.5%	56.94	55.63	N.A
61.5%	65.20	60.26	63.15

TABLE V
RESULT OF BENDING TESTS

Specimens	First Crack Strength		Flexural Strength	
	kN	MPa	kN	MPa
S44F1.0	28.50	8.55	32.32	9.69
S51F1.0	28.16	8.44	34.88	10.46
S51F1.25	30.80	9.24	36.91	11.07
S61F1.0	25.88	7.76	38.26	11.48
S61F1.25	31.79	9.53	38.86	11.65
S61F1.5	28.89	8.66	41.08	12.32

C. Experimental Result on Bending Toughness

Table V and Fig. 5, 6 display the results of 4 point bending tests that are currently used as the standardized test method for the evaluations of flexural strength of concretes. For each mixture, 3 specimens were tested and the average values were obtained for the first crack strength and the flexural strength. As is it displayed in Table V, as the amount of sand percentage and fiber volume fraction increases, the bending strength also increases as well. This is determined as through the increase in fiber dispersion as the amount of sand percentage increases[8].

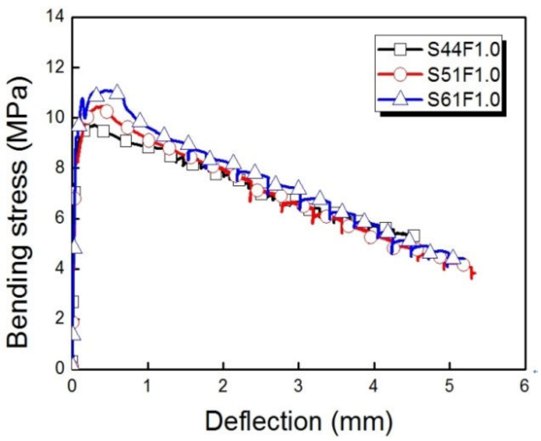

Fig. 5 Post peak behavior of Steel Fiber Reinforced Concrete (4 point bending,S/a=44.4,51.5,61.5%, V_f=1.0%)

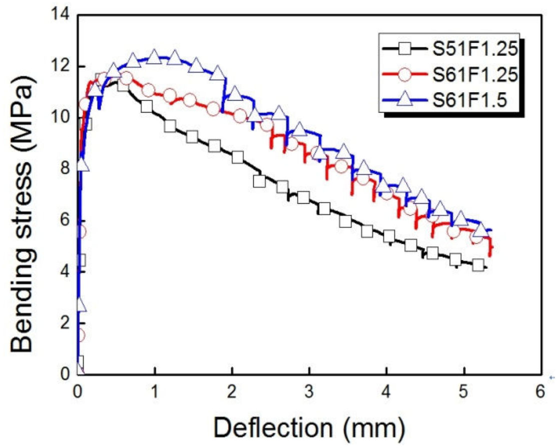

Fig. 6 Post peak behavior of Steel Fiber Reinforced Concrete (4 point bending,S/a=51.5,61.5%, V_f=1.25, 1.5%)

To obtain the fracture energy of a fiber reinforced concrete, 3 point bending tests were performed based on Rilem TC 50. Table VI shows the obtained fracture energy of each fiber reinforced concrete mixture and the test results showed that the fracture energy increases with higher fiber volume. Moreover, as the amount of sand percentage becomes enhanced and the amount of input fiber increases, the destruction energy increases as well. This is also caused by the increase in the fiber dispersion.

TABLE VI
FRACTURE ENERGY OF STEEL FIBER REINFORCED CONCRETE

S/a	Fracture Energy (N·m/m^2)		
	V_f = 1.0%	V_f = 1.25%	V_f = 1.5%
44.4%	6,392	N.A	N.A
51.5%	11,890	17,981	N.A
61.5%	21,299	23,532	20,626

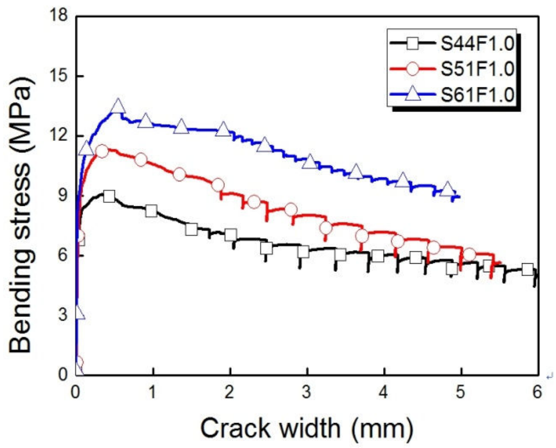

Fig. 7 Post peak behavior of Steel Fiber Reinforced Concrete (3 point bending,S/a=44.4,51.5,61.5%, V_f=1.0%)

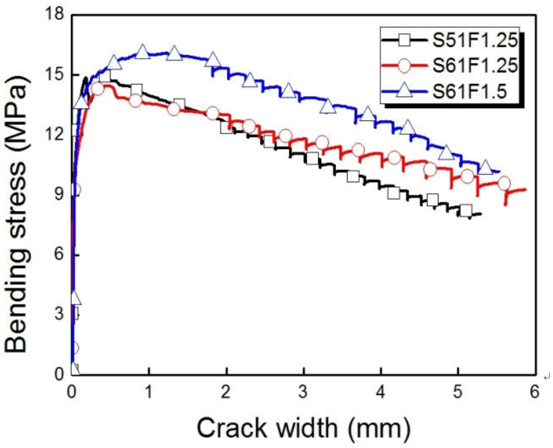

Fig. 8 Post peak behavior of Steel Fiber Reinforced Concrete (3 point bending,S/a=51.5,61.5%, V_f=1.25, 1.5%)

D. Experimental Result on Direct Tension

Experimental results on direct tension following by sand percentage and fiber volume fraction was diagramed in Tables 7 as well as Fig. 9 and 10. As the amount of fiber volume fraction increases and maximized tensile strength, tensile stress-crack opening displacement curve becomes gentle without drastic stress reduction [9]. Following the increase in sand percentage and fiber volume fraction, the toughness of steel fiber reinforced concrete becomes increased as well. However, it does not cause a big difference on the tensile stress.

TABLE VII
TENSILE STRENGTH OF STEEL FIBER REINFORCED CONCRETE

S/a	Tensile Strength (MPa)		
	V_f = 1.0%	V_f = 1.25%	V_f = 1.5%
44.4%	3.20	N.A	N.A
51.5%	2.52	3.68	N.A
61.5%	2.82	3.17	3.12

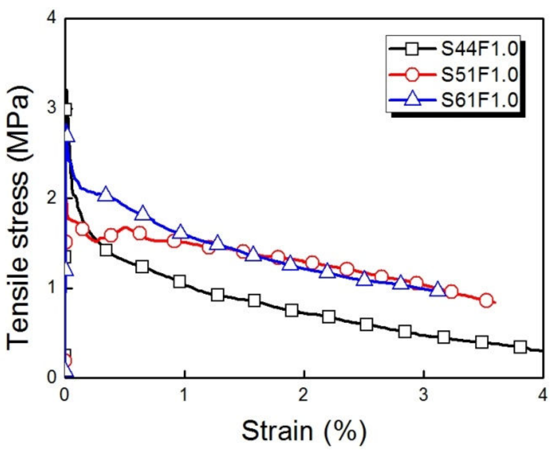

Fig. 9 Post peak behavior of Steel Fiber Reinforced Concrete (Direct tension,S/a=44.4,51.5,61.5%, V_f=1.0%)

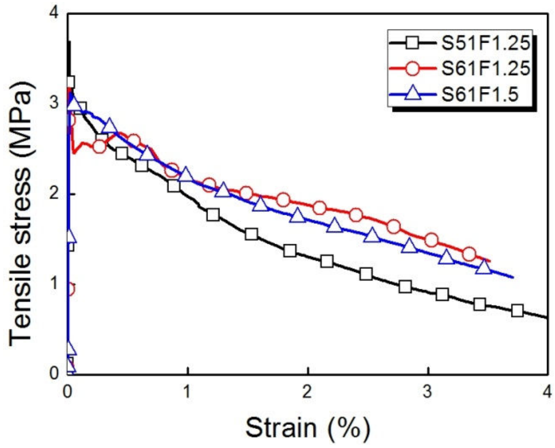

Fig. 10 Post peak behavior of Steel Fiber Reinforced Concrete (Direct tension,S/a=51.5,61.5%, V_f=1.25, 1.5%)

IV. CONCLUSION

In this research, an experimental was conducted in order to apprehend the changes in properties in the bending toughness and direct tension following the sand percentage and fiber volume fraction of steel fiber reinforced concrete, and the conclusion was extracted as shown in the following.

(1) The amount of fiber volume fraction becomes augmented as the amount of sand percentage increases. Then, this leads to an enhancement in the operation of steel fiber reinforced concrete.
(2) The experiment on bending toughness and direct tension was conducted under the permitted conditions of the operation as fiber volume content was amplified. As a result, the amount of sand percentage becomes raised, and as the amount of fiber volume fraction increase, bending stress and fracture energy becomes augmented as well as an increase in the toughness.
(3) As the amount of sand percentage became greater, fiber dispersion became enhanced, causing the bending toughness and direct tension functions of steel fiber reinforced concrete to become increased as well.

In case of steel fiber reinforced concrete, as the amount of fiber volume fraction increases, there is a weakness as to the significant reduction in its operation. It has been confirmed in this research that as the amount of fiber volume fraction increases, bending toughness and direct tension become amplified as well. Therefore, in order to allow operation in the bending toughness and direct tension of steel fiber reinforced concrete even without the increase in fiber volume fraction and fiber ball phenomenon, additional researches are in the progress of being planned for conduction.

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