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Development Strength of Headed Reinforcing Bars for Steel Fiber Reinforced Concrete by Pullout Test

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Abstract In order to compare the development performance of headed reinforcing bar and straight reinforcing bar in tension for steel fiber reinforced concrete (SFRC), pullout test of specimens with reinforcing bar which was anchored on simple beam perpendicularly was conducted. The experimental variables were steel fiber volume ratio (V_{Rsf}), concrete compressive strength, and existence of head. As the result of test, splitting failure of concrete in the development direction of reinforcing bar in most specimens was observed. For development detail of headed reinforcing deformation bar, specimens with 1% V_{Rsf} showed approximately 63%~119% increase in pullout strength compare to specimens with 0% V_{Rsf}. Test result shows that SFRC is more effective in increasing pullout strength for headed reinforcing bars than increasing pullout strength of straight bars.

Keywords: Headed Reinforcing Bars, Pullout Test, Development Strength, Steel Fiber Reinforced Concrete

1. INTRODUCTION

The Steel Fiber Reinforced Concrete(SFRC) is a composite material made by mixing steel fiber which has short length and small cross-section with mixture of hydraulic cement, and aggregate in order to improve the drawbacks of concrete.

SFRC may affection on anchorage performance of headed reinforcing bar since it is highly effective for increasing compressive strength and tensile strength.

The tensile force of headed reinforcing bars is transferred to the concrete through a combination of a bearing force at the head and bond forces along the bar. In contrast, the straight reinforcing bars in tension is transferred through bond force to the concrete alone.

The researches which are written by 2 researchers including Seung-Hwa Lee(2017), and 2 researchers including Hye-Jung Sim(2016) reports the fact that steel fiber is affecting on improvement of anchorage performance of headed reinforcing bar.

The purpose of this study is to evaluate the development of headed reinforcing bars in tensile force applied vertically to steel fiber reinforced concrete (SFRC). In order to compare the development performance of headed reinforcing bar and straight reinforcing bar in tension for SFRC, pullout test of specimens with reinforcing bar which was anchored on simple beam perpendicularly was conducted. The experimental variables were steel fiber volume ratio (VRsf), concrete compressive strength, and existence of head. Ultimate pullout strengths, load-strain curves, and fracture modes were evaluated through this test.

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2. EXPERIMENT

2.1 Plan of specimens

The total of 16 specimens are made in variation of the ratio of steel fiber volume fraction (steel fiber content rate 0%: NC series, 1%: SC series), the compressive concrete strength (24MPa, 40MPa), edge distance (4x of steel diameter: 4D series, 6x: 6D series), The developmental detail of steel bar (Bond and development of straight reinforcing bars: H series, mechanical development by headed reinforcing bar : NH series) (Table. 1)

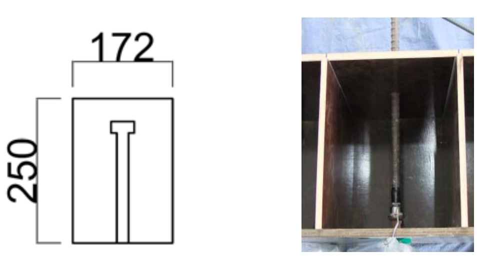
In order to meet the ACI318-14 and KCI2012 codes, avoiding side-face blowout, this experiment planned to keep the minimum edge distance for 2x and 3x as standard. All of

Table 1. Detail of Specimens

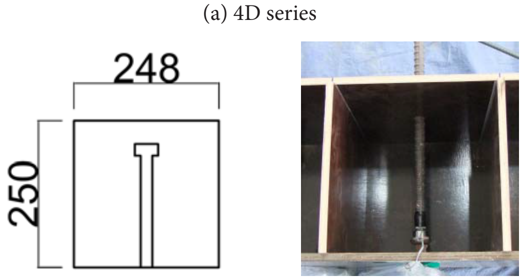
No	Specimen	V_{Rsf} (%)	f_{ck} (MPa)	Edge distance (mm)	Reinforcing bar
1	NC24-4D-H	0	24	76	Headed
2	NC24-4D-NH	0	24	76	Non-headed
3	NC24-6D-H	0	24	115	Headed
4	NC24-6D-NH	0	24	115	Non-headed
5	NC40-4D-H	0	40	76	Headed
6	NC40-4D-NH	0	40	76	Non-headed
7	NC40-6D-H	0	40	115	Headed
8	NC40-6D-NH	0	40	115	Non-headed
9	SC24-4D-H	1	24	76	Headed
10	SC24-4D-NH	1	24	76	Non-headed
11	SC24-6D-H	1	24	115	Headed
12	SC24-6D-NH	1	24	115	Non-headed
13	SC40-4D-H	1	40	76	Headed
14	SC40-4D-NH	1	40	76	Non-headed
15	SC40-6D-H	1	40	115	Headed
16	SC40-6D-NH	1	40	115	Non-headed

the specimens have unified the anchorage distance (220mm) after calculating the basic anchorage distance of ACI318-14 and KCI2012. To account for the effect of the edge distance on only one axis, the vertical axis which is perpendicular to the minimum edge distance should have a sufficient edge distance. Consequently, the size of the specimen designed to have 250mm x 172mm x 350mm for 4D Series and 250 mm x 248mm x 350mm.

Specimens' position of placements is showed in the Figure1.



(a) 4D series



(b) 6D series

Figure 1. Specimen shape and positioning

2.2 The Compressive strength of Concrete and Flexural Tensile Strength

The compressive strength of the concrete used in the test specimens was 24 and 40 MPa. For the compressive strength test, cylindrical specimens with a diameter of 10 cm and a height of 20cm were prepared according to KSF 2404.

The flexural tensile strength of the concrete ($f_{r,test}$) was 500 x 100 x 100(mm) rectangular parallelepiped specimen prepared as a three-point load test specimen according to KS F 2408 and tested as shown in Figure.

The flexural tensile strength means the strength against tensile stress generated in a member subjected to a bending moment. The theoretical flexural tensile strength acting on flexural members by KCI2012 is about 11% larger than splitting tensile strength and is calculated by Eq.(1).

$$f_{r,\ theor} = 0.63\ \lambda\ f_{ck}^{1/2} \quad (1)$$

Where, $f_{r,\ theor}$ = flexural tensile strength (MPa=N/mm^2)

λ = lightweight concrete coefficient

f_{ck} = the compressive strength of concrete

Table 2. The compressive strength of concrete and Flexural tensile strength

Specimen	f_{ck} (MPa)	$f_{r,test}$ (MPa)	$f_{r,theor}$ (MPa)	$f_{r,test}$ / $f_{r,theor}$
NC24 series (fck=24MPa)	28.76	5.25	3.38	1.55
NC40 series (fck=24MPa)	46.98	7.67	4.32	1.78
SC24 series (fck=40MPa)	31.79	7.17	3.55	2.02
SC40 series (fck=40MPa)	40.95	7.65	4.03	1.90

(a) Test set-up

(b) NC series

(c) SC series

Figure 2. Flexural tensile force and fracture shape

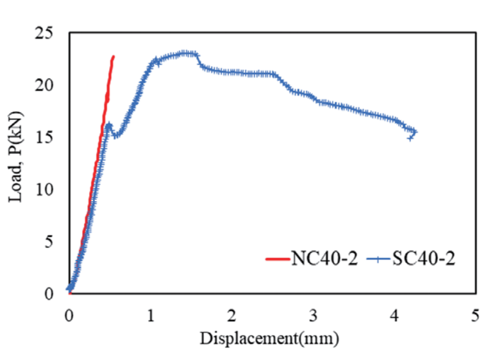


Figure 3. Load-displacement curve by bending tensile strength test

Figure 3 shows the load-displacement curves obtained by bending tensile strength test for typical specimens of NC series and SC series according to presence or absence of steel fiber. As shown in Figure 2 and 3, the NC specimens with no steel fibers were fractured when concreted cracks appeared. On the other hand, SC test specimens with steel fiber were found to be resistant to tensile stress, so that the steel fiber resisted flexural deformation even after cracking.

According to the Table 2, the Flexural tensile strength increased with the increasing compressive strength of concrete. In the case of NC series, $f_{r,test}$ was 5.25 ~ 7.67 and for SC series, $f_{r,test}$ was 7.17 ~ 7.65. The flexural tensile strength of the test specimens with steel fiber was evaluated.

The experimental bending tensile strength of every specimens was evaluated to be higher than the theoretical bending tensile strength. In the case of NC series, $f_{r,test}$ / $f_{r,theor}$ was 1.55 ~ 1.78, and for SC series, $f_{r,test}$ / $f_{r,theor}$ was 1.90 ~2.02. Which meant the experimental and theoretical variance of the specimen containing steel fiber was evaluated to be larger. From this, it can be seen that the incorporation of the steel fiber greatly affects the increase of the flexural tensile strength compared to the increase of the compressive strength.

2.3 Reinforcing Bar Tensile Strength

In order to determine the material properties of reinforcing bars used in pull-off test specimens, three tensile test specimens of reinforcing bars were prepared in accordance with the provisions of KS B 0801(metal material tensile test specimen). The results of the material test of reinforcing bars are shown in Table 3.

Table 3. Reinforcing Bar Tensile Strength

Bar type	Yield strength (MPa)	Tensile strength (MPa)
D19 (Headed reinforcing bar)	497	617
D19 (Reinforcing bar)	461	607

2.4 Pull-out Test

As shown in Figure 4, the pull-off test specimens were pulled at both ends with 2000mm UTM and pulled out at the center of the beam

Figure 4. Pull-out test

The main data to be obtained from the experiment are the relative displacement of the concrete surface and the headed reinforcing bar at the lower end of the specimen when the pullout load acts on the specimen, the compressive stress of enlarged head, and the bond stress of the reinforcing bar. The progress of the experiment proceeded until the pullout failure or splitting failure occurred due to the pullout load. The relative displacements of concrete and reinforcing bars were measured by pulling a 50mm displacement gauge (LVDT) at the 650mm point of the concrete surface. To measure the compressive stress of the enlarged head, a reinforcing bar strain gage (WSG) was attached to the end of the reinforcing bar to which the enlarged head was fastened. To measure the total stress of the reinforcing bar by pulling, WSG was attached to the reinforcing bar outside the lower part of the specimen.

3. EXPERIMENT RESULT

3.1 Fracture Positioning and Strength

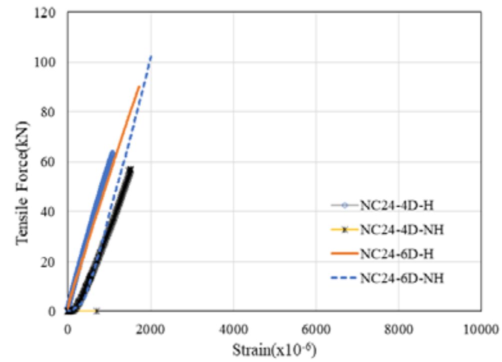
Table 4 shows the failure conditions at the time of final fraction of each representative specimen. SC40-4D-NH specimens were excluded from the analysis of the final failure condition and results due to the specimen loading failure. In table 4, all of the NC series specimens were split into two pieces because of the splitting failure and the final fracture occurred. It was found that the nodal shape of the rebar was not distorted on the section of the specimen and the slip of the contact surface of reinforcing bar and concrete since the adhesive stress loss did not occur.

SC series specimens with enlarged headed reinforcing bars showed splitting failure except SC4D-6D-H specimens. However, due to the resistance of the steel fiber to the tensile strain, the specimen did not separate into two pieces, but the fracture width was large at the portion to be pulled out and the final fracture occurred. Although the SC40-6D-H specimen has small cracks due to splitting it has the piercing distance of 6 times the diameter of the reinforcing bar and the largest concrete compressive strength among the specimens. Therefore, the anchorage performance such as pressure stress and adhesive stress is high, it broke and was destroyed. SC24-4D-NH specimens with edge distances of four times the reinforcement diameters showed splitting failure while SC24-6D-NH specimens with pylon distances of six times the reinforcement diameter and SC40-6D-NH specimens, in the test specimen, the pullout failure occurred in which the reinforcing bar was pulled out and cone shaped by the end of the concrete

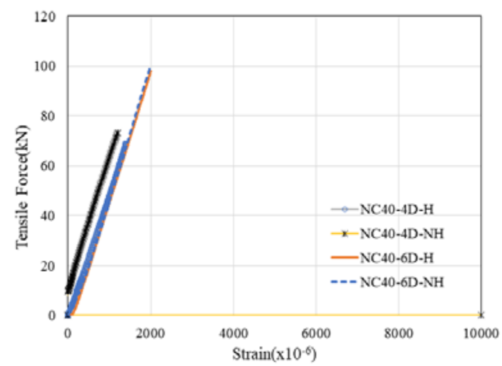
3.2 Experimental History and Load-strain Curves.

In Table 5, the maximum tensile force and tensile stress by pullout test are compared. Figure 5 compares the relationship between the tensile strength and the strain of the pullout reinforcement

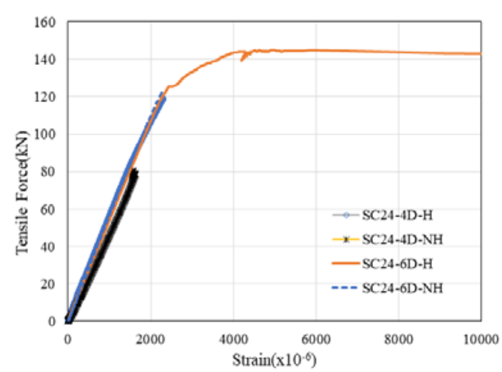
Table 5 and Figure 5 show the maximum pullout strengths with and without headed reinforcement. As as result, the strength ratio according to the presence or absence of headed reinforcement (T_{max-H} / T_{max-NH}) was 0.88 to 1.11 in NC series specimens, it was evaluated as having no effect. In this experimental situation, 1) tensile stress acts on the concrete due to the bending moment generated in the member of splitting, and the tensile stress is larger than the flexural tensile strength of the concrete,



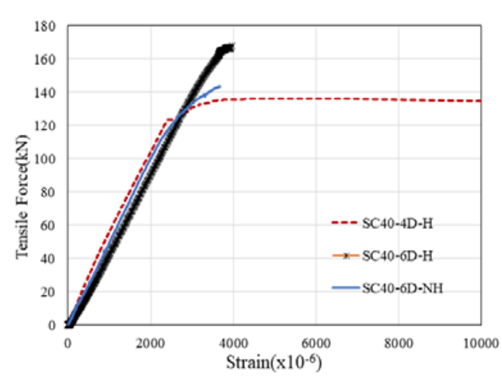
(a) NC24 series



(b) NC40 series



(c) SC24 series



(d) SC40 series

Figure 5 Drawing Load-Rebar Strain Curve

Table 4. Failure Shape

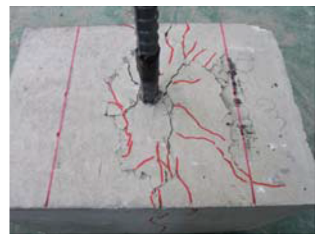
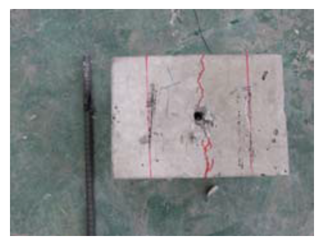
Specimen	Failure shape		Failure mode
NC24-4D-H			Concrete splitting failure
SC24-6D-NH			Concrete pullout and cone failure
SC40-6D-H			Steel tensile failure

Table 5. Test Results

No	Series	Specimen	Maximum tensile force T_{max} (kN)	Maximum tensile stress (MPa)	Yield of reinforcing bar	T_{max-H} / T_{max-NH}
1	NC24-4D Series	NC24-4D-H	63.6	221.8	Not yield	1.11
2		NC24-4D-NH	57.2	199.5	Not yield	-
3	NC24-6D Series	NC24-6D-H	90.2	314.5	Not yield	0.88
4		NC24-6D-NH	102.0	355.9	Not yield	-
5	NC40-4D Series	NC40-4D-H	68.9	240.2	Not yield	0.94
6		NC40-4D-NH	73.2	255.2	Not yield	-
7	NC40-6D Series	NC40-6D-H	98.0	341.8	Not yield	0.98
8		NC40-6D-NH	100.1	349.0	Not yield	-
9	SC24-4D Series	SC24-4D-H	118.8	414.2	Not yield	1.48
10		SC24-4D-NH	80.3	280.0	Not yield	-
11	SC24-6D Series	SC24-6D-H	147.0	512.7	Yield	1.19
12		SC24-6D-NH	123.1	429.5	Not yield	-
13	SC40-4D Series	SC40-4D-H	150.7	525.6	Yield	-
14	SC40-6D Series	SC40-6D-H	167.7	584.9	Yield	1.17
15		SC40-6D-NH	143.4	500.1	Yield	-

Table 6. Comparison of $f_{r,teat}$ and $f_{r,pullout}$

No	Series	Specimen	$f_{r,test}$ (MPa)	$f_{r,pullout}$ (MPa)	$f_{r,pullout}$ / $f_{r,test}$
1	NC24-4D Series	NC24-4D-H	5.25	1.77	0.34
2		NC24-4D-NH	5.25	1.60	0.30
3	NC24-6D Series	NC24-6D-H	5.25	2.52	0.48
4		NC24-6D-NH	5.25	2.85	0.54
5	NC40-4D Series	NC40-4D-H	7.67	1.33	0.17
6		NC40-4D-NH	7.67	1.42	0.18
7	NC40-6D Series	NC40-6D-H	7.67	1.90	0.25
8		NC40-6D-NH	7.67	1.94	0.25
9	SC24-4D Series	SC24-4D-H	7.17	3.31	0.46
10		SC24-4D-NH	7.17	2.24	0.31
11	SC24-6D Series	SC24-6D-H	7.17	4.10	0.57
12		SC24-6D-NH	7.17	3.44	0.48
13	SC40-4D Series	SC40-4D-H	7.65	2.92	0.38
14		SC40-4D-NH	7.65	-	-
15	SC40-6D Series	SC40-6D-H	7.65	3.25	0.42
16		SC40-6D-NH	7.65	2.77	0.36

2) Split failure occurs due to two factors, such as splitting of reinforcing bar under tension by pushing concrete, cracking to the side with smaller edge distance. In the case of NC series specimens, it is considered that the bending stress due to the force in the unreinforced concrete which is weak against the tensile stress has great influence on the spit fracture of the member, and the split head is broken before it exhibits the bearing resistance performance of the headed reinforcing bar. The compressive strength of NC24 series and NC40 series were 28.76 MPa and 46.98 MPa, respectively, but the maximum yield strength ratio of the specimens with the same edge distance was 0.98 ~ 1.28. However, the maximum pullout ratio with increasing distance was 1.37 ~ 1.78.

In the case of the SC series specimens, the maximum pulling force ratio according to the presents or absence of the headed reinforcement was 1.17 to 1.48.

The specimens with a steel fiber content of 1% increased about 21% ~ 43% compared with specimens with a steel fiber content of 0%.

Details of mechanical anchorage by headed reinforcing bar the specimens with 1% steel fiber content increased about 63% ~119% compared to those with 0% steel fiber content. It was confirmed that the increase of the anchorage strength of the straight reinforced bar and the headed reinforced bar reinforced by the steel fiber affected the increase of the tensile strength of the concrete. Also, it was found that the steel fiber mixing ratio is more effective in increasing the mechanical anchorage performance of the expanded head type reinforcing bars than the anchorage performance of the straight type reinforcing bars due to adhesion

3.3 Comparison of Flexural Tensile Strength and Maximum Anchorage Strength

In case of this specimen, maximum strength is affected by bending tension by installing test specimen in simple beam form. Table 6 compares the flexural tensile strength ($f_{r,test}$) obtained from the concrete material test and the maximum flexural tensile stress ($f_{r,pullout}$) due to the flexural strength calculated using the tensile strength of the pullout test.

For the NC series specimens, the ratio of the maximum flexural tensile stress to the flexural tensile strength by the pullout test, $f_{r,pullout}$ / $f_{r,test}$, was 0.17~0.54. SC series specimen $f_{r,pullout}$ / $f_{r,test}$ was 0.31 ~ 0.57, and the bending stress due to the drawing showed a large effect on the anchorage performance.

4. CONCLUSION.

The purpose of this study is to evaluate the anchorage performance of a headed reinforced concrete to apply a headed reinforced concrete used in mechanical anchorage to steel fiber reinforced concrete. The results of this study are summarized as follows.

(1) The experimental flexural tensile strength and theoretical flexural tensile strength were 1.55~1.78 and 1.90~2.02, for unreinforced concrete and 1% reinforced concrete. Compared to the increase in compressive strength, it can be seen that it greatly influences.

(2) All of the NC series drawn specimens were finally fractured by splitting failure. Most of SC series drawn specimens were split cracked, but specimens with headed reinforcing bars and edge distances equal to 6 times the diameter of the steel reinforcement were broken. Among the SC series specimens without headed reinforcement, the pylons with 6 times the diameter of the reinforcing bars showed pullout failure in which the reinforcing bars were pulled out of the concrete by cone drawing.

(3) The pullout ratio of NC series drawn specimens was 0.88 ~ 1.11 with no headed reinforcement and showed not tendency to show any significant effect on the increase of anchorage performance. On the order hand, in the case of the SC series specimens, the maximum pullout ratio according to the present of the headed reinforcement was 1.17 to 1.48.

(4) Detailed of settlement of headed reinforcing bar without enlarged head and details of settlement of headed reinforcing specimens increased 21% ~ 43% and 63% ~ 119%, respectively, compared to NC series drawn specimens. I was confirmed that the increase of the anchorage strength of the straight reinforced bare and the headed reinforcing bar reinforced by the steel fiber affected the increase of the tensile strength of the concrete. Also, it was found that the steel fiber mixing ratio is more effective in increasing the mechanical anchoring performance of the headed type reinforcing bars than the anchoring performance of the straight type reinforcing bars due to adhesion.

(5) It is considered that the splitting failure is affected by the pavement distance of the reinforced bar and the flexural tensile strength of the concrete. Therefore, it is considered that reinforcement in the direction perpendicular to the expanded bar steel is necessary in the concrete member to improve the anchorage performance of the enlarged bar.

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