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Replacing stirrups with steel fibers in high-strength concrete beams

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ABSTRACT

This study examines the feasibility of eliminating the minimum stirrups in reinforced high-strength concrete (HSC) beams by incorporating 0.75% (by volume) of hooked steel fibers. In addition, the shear capacity of steel-fiber-reinforced HSC (SFR-HSC) beams without stirrups was compared with plain HSC beams with various amounts of stirrups. For this, ten large reinforced HSC beams, with and without stirrups and steel fibers, were fabricated and tested. Test results indicate that the SFR-HSC beams exhibited higher flexural strength but lower ultimate deflection capacity and ductility than the plain HSC beams. The failure mode of lightly-reinforced HSC beams was transformed from concrete crushing at the compressive zone to longitudinal steel bar rupture by including the steel fibers. However, both the reinforced HSC and SFR-HSC beams exhibited flexural failure modes, and as a result, it was concluded that the minimum shear reinforcement for reinforced HSC beams can be efficiently eliminated by including 0.75 vol% of steel fibers. Furthermore, a portion of shear stirrups was able to be eliminated by using 0.75 vol% steel fibers, and the amount of stirrups eliminated were quantitatively evaluated.

1. INTRODUCTION

In recent years, the development of low carbon high strength concrete containing high volume mineral admixtures. Replacing Portland cement with mineral admixtures such as fly ash, silica fume and blast furnace slag has been a widely adopted strategy due to their pozzolanic reactivity and latent hydraulic activity. Thus, for the low-carbon high strength concrete (HSC) incorporating high volume of mineral admixtures exhibit fast and enhancement of early age strength need to be steam-cured with heat. For the improve strain capacity and ductility of HSC added steel fibers. its inhibition of crack

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propagation and widening through fiber bridging mechanisms, and it is improved shear strength of concrete beams (Aoud H et al. 2012).

In addition to using steel fibers can reduce minimum shear stirrups when the factored shear force is smaller than or equal to the share resistance of plain concrete beams (Parra-Montesinos GJ 2006). Base on this, the ACI Subcommittee， 319-F recommended the use of a minimum fiber volume fraction of 0.75% for replacing minimum shear reinforcement through the use of steel fibers.

This study, the evaluation of shear characteristics of HSC with and without steel fibers and stirrups. A series of ten large high strength reinforced concrete(HSC) and high strength steel fiber reinforced concrete(SFR-HSC) beams were tested to evaluate the effects of steel fibers in shear capacity. Five of the beams were designed to have a minimum shear reinforcement, and another five beams were designed to have strong flexure capacity due to shear failure. In order to evaluate the flexural behavior and shear capacity of HSC beams with and without steel fibers and stirrups. And evaluation of the shear contribution of steel fiber reinforced high strength concrete beams.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Specimens Preparation

The mix proportions of binders are summarized in Table 1. The water-to-binder ratio was 0.275, Type Ⅰ Portland cement and Type Ⅲ blast furnace slag were used as cementitious materials. And the hooked steel fibers with a diameter of 0.55 mm and s length of 35 mm were included at 0.75% by volume. In order to accelerate the strength development of material and structure specimens, steam curing with heat 60℃ was applied.

Table 1 Mixture proportions

Case	W/B	BS/B	Water	Cement	BS	Sand	Aggregate	Vf (%)
HSC	0.275	0.6	1	1.45	2.18	4.12	5.62	0.00
SFR-HSC	0.275	0.6	1	1.45	2.18	4.12	5.62	0.75

For the material specimens were evaluated to compressive and flexure bending test and fabricated three specimens for each type. Three cylindrical specimens of each type with a diameter of 100 mm and height 200 mm were tested according to KS F 2405. The flexural bending test specimens with a cross section of 100 x 100 mm and a length of 400 mm of prismatic beams were tested according to KS F 2408. In the structure specimens, a series of ten large HSC and SFR-HSC beams with a length of 2 m, 3.2 m and 4.4 m were fabricated and tested to evaluate the effects of steel fibers in shear capacity. Five of the beams were designed to have a minimum shear reinforcement and add 0.75 vol.% of hooked steel fiber without stirrups due to flexure failure, and marks as 2.0m-0.00%, 2.0m-0.75%, 3.2m-0.75%, 4.4m-0.00%, 4.4m-0.75%, respectively. Another five beams were designed to have strong flexure capacity and change stirrups spacing（0.00d, 0.25d, 0.375d, 0.50d）due to shear failure, and marks as 0.00d-0.00%, 0.25d-0.00%, 0.375d-0.00%, 0.50d-0.00%, 0.00d-0.75%, respectively.

2.2 Test Setup and Procedure

A series of five full-scale reinforced concrete beams were tested under four-point flexure and loading was using a UTM with a maximum capacity of 2000 kN through displacement control. The load, longitudinal steel and shear stirrup strains, and mid-span deflection were all recorded using a data logger. The load was measured from a load cell affixed to an actuator. And the steel strain gauges were attached to the center of the longitudinal steel and stirrups in order to evaluate the yielding point and failure mode of beams. To measure the mid-span deflection were using LVDTs, and the support settlement was subtracted from the mid-span deflection measurement. Recording the load after the first crack, then crack patterns and widths were investigated at each loading step during testing, and the crack width was specially measured using a crack width comparator.

Fig. 1 Structural test setup

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 Mechanical Properties

The slump flow was tested according to KS F 2402. All of the mixture without steel fiber get over 350 mm and 550 mm with steel fiber.

Table 2 Compressive and flexure strength

Case	Slump flow (mm)	Compressive strength (MPa)	Flexure strength (MPa)
HSC	350	72.0	10.2
SFR-HSC	550	67.0	7.0

The SFR-HSC exhibited higher compressive strength, flexure strength were found to 72 MPa, 10 MPa respectively. That are approximately 7.5% and 45.7% higher than those HSC. It is steel fibers helped inhibit crack propagation and widening in the cement matrix (bridge effect) lead to exhibit higher compressive strength and strain capacity. The fiber bridge effect is that fibers bridge the facing crack surfaces to limit crack propagation and post-crack opening through frictional force at the fiber-matrix interface. The especially flexural test show that load-carrying capacity of HSC specimens suddenly dropped to almost zero immediately after first cracking. However, the SFR-HSC specimens exhibited deflection-hardening behavior and a higher load-carrying capacity after first cracking according to the fiber bridging capacity sustained in the matrix. It is concluded that the addition volume of 0.75% hooked steel fibers to high strength concrete is effective in improving the strength and strain capacity under both compression and flexure.

3.2 Load-Deflection Curves

Fig. 2,3 shows the load-defection behavior of HSC beams with and without steel fibers and stirrups. All of five full-scale beams exhibit similar behavior. The load increased very rapidly with a slightly increase in the deflection. Then initial cracks occurred on the bottom surface of the beams, the stiffness decreased due to the reduced effective cross section area, which resists compressive and tensile stresses of an external load (Yoo DY 2015). And after the steel yielded, a significant decrease in the stiffness was observed in beams. Among them, the HSRFC beams exhibit that a decrease in the stiffness was much smaller than HSC beams and a gradual decrease in the load carrying capacity after reaching the peak load. This was caused by the incorporated steel fibers bridge the cracks and inhibited post crack widening.

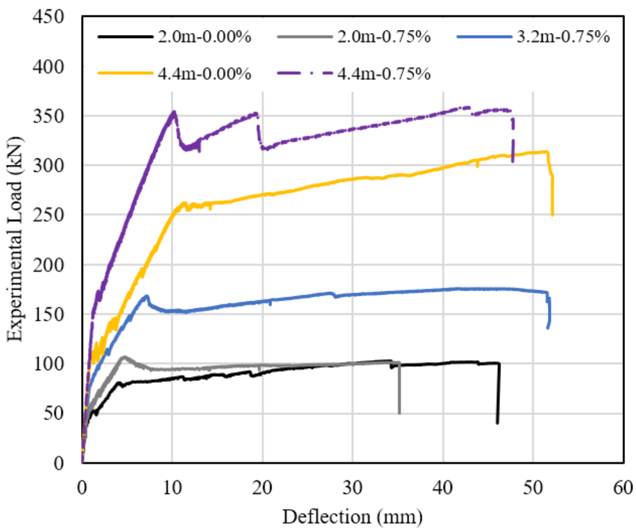

Fig. 2 Flexure load-deflection curves

Through test result of the five beams which were designed to a minimum shear reinforcement and added 0.75 vol% of hooked steel fiber without stirrups due to flexure failure (Fig. 1). The SFR-HSC beam without stirrups occurred a higher load capacity compare with HSC beams with stirrups. This is caused by the deflection-hardening behavior of HSC according to excellent fiber bridge effect. And the initial cracking strength increased by added steel fibers too. The ultimate deflection values of SFR-HSC beam smaller than HSC beams. The load capacity of beams suddenly decreased incorporating steel fibers, regardless of the beam size. Because the high bond strength between longitudinal steel bars and high strength fiber reinforced concrete and the crack localization phenomenon, the deformation of the longitudinal bar was localized at specific cracks where the crack width was significantly increased. And steel fiber inhibits the post crack widening, due to increasing in the steel strains at localized cracks (Deluce JR 2013, Walraven JC 2009). Through the testing observation, the vertical flexural cracks were formed from the bottom surface of the beams until failure.

All of five beams exhibited a flexural failure mode which beams were designed to have a minimum shear reinforcement. The longitudinal steel bars exhibited much larger strains than the stirrups, regardless of the beam size. Hence, it can be concluded that the high strength concrete with 0.75 vol% of hooked steel fibers (length 35mm, diameter 0.55 mm) can be used as an alternative to the minimum number of stirrups.

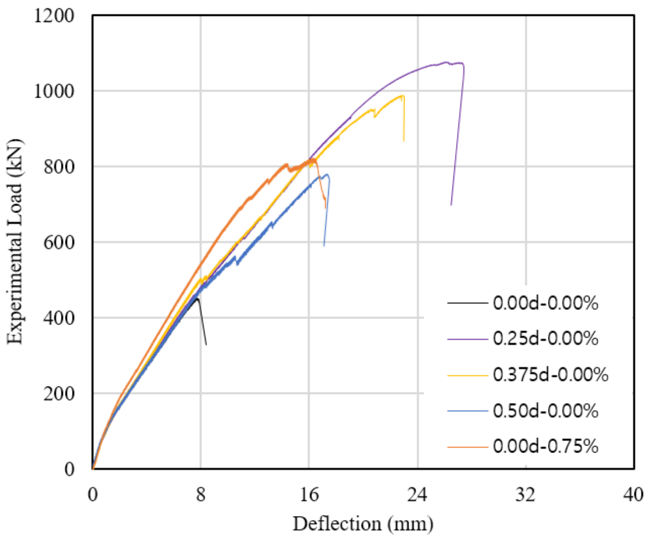

Fig. 3 Shear load-deflection curves

Through test result of the five beams which were designed to strong flexure capacity and change stirrups spacing due to shear failure (Fig. 3). The HSC without steel fibers and stirrups failure at 442 kN by the shear load. The SFR-HSC beams with steel fibers and without stirrups occurred a higher load capacity compare on HSC beams with minimum stirrups (0.50d) and without steel fibers. This is caused by the deflection-hardening behavior of HSC according to excellent fiber bridge effect. In general, the addition of steel fibers led to reductions in post crack widths and resulted in a more diffused cracking than without steel fibers. Hence, the SFR-HSC beams exhibit a more diffused cracking pattern and many secondary cracks growing out of the primary cracks between the shear region. And the initial cracking strength increased by added steel fibers compare with 0.50d beams, yet. All of five beams exhibited a shear failure mode which beams were designed to have a strong flexure capacity. The ultimate shear load of HSC beams with increase stirrups were 226 kN, 389 kN, 493 kN, 537 kN, respectively. And the ultimate shear load of SFR-HSC occurred 411 kN, which is approximately 5.6 % higher than minimum stirrups of HSC beams (0.50d). According to this values, the influence of the steel fibers on the shear strength of SFRC-HSC beams is 185 kN, which is approximately 13.3 % higher than minimum stirrups.

Hence, it can be concluded that HSC with 0.75 vol.% of hooked steel fibers showed same shear capacity notified in ACI Subcommittee 319-F recommended, which can be replacing minimum shear reinforcement through the use of steel fibers.

3. CONCLUSIONS

In this study, for the evaluating properties of high strength concrete beams with and without steel fibers and stirrups were fabricated and tested. The Following conclusions were drawn:

1. The high strength concrete incorporating hooked steel fiber 0.75 vol.% is effective in improving the strength and strain capacity under both compression and flexure.
2. Five of the beams exhibited a flexural failure mode which beams were designed to have a minimum shear reinforcement. The SFR-HSC beams without stirrups exhibited higher flexure strength but smaller ultimate deflection and ductility compare with HSC beams.
3. Five of the beams exhibited a shear failure mode which beams were designed to have a strong flexure capacity. The influence of the fibers on the shear strength of SFRC-HSC beam is 185 kN, which is approximately 13.3 % higher than minimum stirrups.
4. The high strength concrete with 0.75 vol% of hooked steel fibers (length 35mm, diameter 0.55 mm) can be used as an alternative to the minimum number of stirrups.

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