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Experimental study of steel-fiber reinforced concrete beams with confinement

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Abstract

This paper presents an experimental study to the effectiveness of steel-fiber concrete in combination with the confinement in the compression zone of a flexural member. A range of stirrup configurations functioning as confining elements, were evaluated. The study was aimed to analyze the effect of these confining reinforcement variations to the load carrying capacity and cracking moment of a simply supported beam loaded in pure bending. Additionally, steel-fibers were added to the concrete mix to improve the mechanical properties of the material. Five steel-fiber beams were evaluated, having a variation in confining reinforcement configurations. The variations in confining reinforcements were especially, but not exclusively, concentrated in the compression zone of the beam. To monitor the influence of the steel-fibers, a controlling element without the use of steel-fiber (conventional concrete) was also produced, and tested in the laboratory. The beam test set up was designed to undergo a state of pure bending by the use of a two-point loading system. The testing methodology under increasing monotonic loading was deformation controlled. The results showed that the variation in configuration of the confining reinforcement in the compression zone played an important role to the ultimate moment capacity of the beam. The experiments also demonstrated that the type of confinement has major impact to the cracking moment of the element. The addition of steel-fibers influenced the cracking moment positively.

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Keywords: steel-fiber, confinement models, ductility, ultimate and cracking moment

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1. Introduction

A reinforced concrete member is a composite material that achieves its strength from the concrete in compression, and the reinforcing steel in tension. When this flexure element is under-reinforced, large deformations originated from the yielding of the steel bars in tension will occur prior to failure. While the interaction between the concrete in compression and the steel in tension determined the ultimate capacity of the beam, the deformation at failure defines as the ductility, is a contribution of the concrete and the steel behavior upon fracture, in the tension region of the element.

Since the addition of fibers to a concrete mix enhances the concrete ductility, and confinement increases the concrete compression strength, numerous studies to the both systems, researched individually, were conducted. However, the study and analysis to the contribution of these two mechanisms simultaneously applied to one flexure element, has not been explored. Also, the majority of studies on concrete confinement are limited to compression members. These members are either confined by wrapping or jacketing the entire member, or by the use of stirrups in the direction of the lateral strains.

The use of fiber concrete as a structural element has a very promising prospect, especially in high earthquake zones. The positive aspects of fiber concrete were underlined by the research work conducted by Hadi [1] and Paultre et al. [2], concluding that the addition of steel-fibers to the fresh concrete mix in a certain amount, improved the bond between the mortar matrix and the aggregates, and enhancing the energy absorption and toughness behavior. The steel-fibers thus contributed to the concrete ductility performance of the concrete, through the improvement of its stress-strain relationship behavior. Further, the study carried out by Antonius et al. [3], proved that the steel-fiber concrete maintained it is good ductility performance, even when exposed to substantially high temperatures. The steel-fibers imbedded in concrete are also less susceptible to corrosion when compared to the reinforcing concrete bars used in reinforced concrete elements [4]. Additionally, the continuing research work of Antonius [5] on steel-fiber concrete showed that the presence of these fibers take a major role in the deformation pattern of the resulting concrete, so that the fracture process of the concrete material can be controlled through the use of steel-fiber.

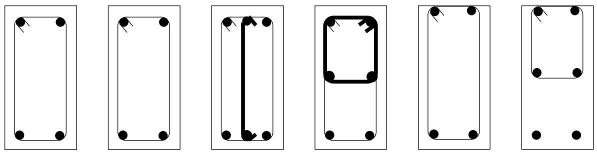
The information originated from research on the confinement of the concrete compression zone in flexural concrete elements is very limited; the majority of codes [6, 7], therefore do not include a provision to the application of stirrups as confining elements. The study conducted by Ziara et al. [8], is one of the researches on this topic. However, the experimentally based study was applied to conventional concrete elements, rather than steel-fiber beams. The use of stirrups to create a confinement in the compressions zone of a flexure element in the study, was aimed predominantly to divert the failure mode from crushing in the concrete compression area, to failure in the tension reinforcements. The research results underlined that the confining action increased the moment carrying capacity.

In this research work, an attempt has been made to confine the compression part of an element in flexure, by using a variation in stirrups configurations. The study also looked into the influence of steel-fibers in combination with the confinement action. A controlling element constructed of conventional concrete, was produced for comparison purposes. An identical element to this controlling beam was built using steel-fiber concrete material to study the behavior of the element, and to analyze the influence of the steel-fibers to the moment capacity, and the cracking moment of the beam. Further, four variations in stirrup confinements were designed. For each variation, one member was casted, cured and tested

2. Experimental program

To monitor the concrete compression strength, cylinders sized 150 x 300 mm were casted for the conventional as well as steel-fiber concrete, and tested simultaneously with the beams. The concrete had a cylindrical compression strength of 43 MPa for the conventional concrete, and a 50 MPa strength for the steel-fiber concrete. The reinforcing steel and stirrups had a yield stress of 420 MPa, and 455 MPa respectively. The member had a cross section dimension of 125 by 250 mm with a length of 2.20 meters, the reinforcing steel were deformed bars with a diameter of 10 mm, and the stirrups' bar diameter was 6 mm. Table 1 shows a detailed description of test elements. The notations BN stand for the conventional concrete member, while the code BF was used for distinguishing the steel-fiber elements. Both BN and BF had the regular stirrup configuration, covering the entire cross section of the beam. BF2 had an additional vertical stirrup leg. BF3 and BF5 were designed with a confinement in the compression zone of the flexure elements, except that for BF5 the stirrups were extended to the extreme fibers in compression, aimed to maximize the confinement area in compression. Also, the stirrups in the tension zone of this test specimen were omitted, since hypothetically tension confinement does not contribute to the increase in concrete tensile strength. A similar approach was conducted for BF4; the comparison study to the BF1 provided additional information into the extending of stirrups into the compression area.

Table 1. Specimen's specifications

Designation	BN	BF1	BF2	BF3	BF4	BF5
Cross-section Detail						

The steel-fibers used for the concrete had a length-to-diameter ratio of 50. This ratio was found most effective in terms of the benefit of the bridging mechanism between the mortar and the fibers [9, 10, 11]. Due to the bridging mechanism, the micro crack propagation will be delayed, and the tensile strength increased. The amount of straight steel-fibers in this study was set at 0.5% to the volume of the concrete. The concrete mix used a 0.6% of superplasticizer to the cement weight to enhance the workability of the mix, and to improve the homogeneous distribution of fibers. The concrete mix was ordered from a ready mix plant, and upon arrival at the casting scene, the fibers were added manually. A mixer was used at the site to promote the mixing process between the concrete and the fibers. The properties of basic material are shown in table 2.

Table 2. Material mix proportions

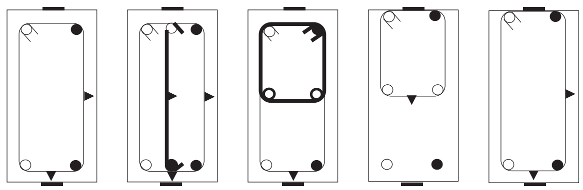
Material	By weight (kg/m^3)	Material	By volume ($liters/m^3$)
Cement	500	Water	140
Fly Ash	82.83	Viscocrete	0.6 %
Fine Aggregate	662.07	Fiber	0.5 %
Coarse Aggregate	1080.22	w/c	0.3

Prior to testing, the specimens were dried and painted, to ease the visual observation of crack propagation during the loading. The surface was further divided in grids to enable the detection of initial crack locations, as a function of the corresponding load. The test specimen was loaded with a two-point loading system to ensure a uniform bending moment between the two loading points. The beam was simply supported, and the supports were positioned at a distance of 50 mm from the beam's end. The loads were applied symmetrically, having a distance of 700 mm apart. Identical longitudinal reinforcement was placed in the tensile as well as the compression region of the beam. The confinement stirrups were positioned over a length of 700 mm at the center of the tests specimen, having a distance of 150 mm between each stirrup. The stirrups functioning as shear resistance elements were placed in the vicinity of the supports, having a distance of 100 mm apart to ensure that the beam failed in flexure.

Precision instruments were used to record the behavior of the beam under incremental monotonic loading. These precision instruments were a load cell to record the load, two linear vertical displacement transducers (LVDT) to measure the vertical deformation of the beam at mid-point, and one horizontally placed LVDT to monitor the vertical deformation of the beam. Care had to be taken during the positioning of loading points to avoid asymmetrical loading and lateral buckling. To record the responses of the concrete material and reinforcing steel, strain gauges were placed on the reinforcing steel bars, preceding the concrete casting. The strain gauges for measuring the concrete responses were placed after curing. To further enable the evaluation of the moment curvature of the beam, the concrete compression and tension strains were measured at midpoint using the PL 60-11 strain gauges, while for the compression and tensile longitudinal reinforcing steel the FLA 6-11 strain gauges were used. The stirrups placed in the vicinity of the beam's center point were predominantly functioning as confinement elements, their responses were recorded by positioning of strain gauges as can be seen in table 3.

Table 3. Details of strain measurements

BN, BF1	BF2	BF3	BF4	BF5



▬ : Concrete *strain gauges*

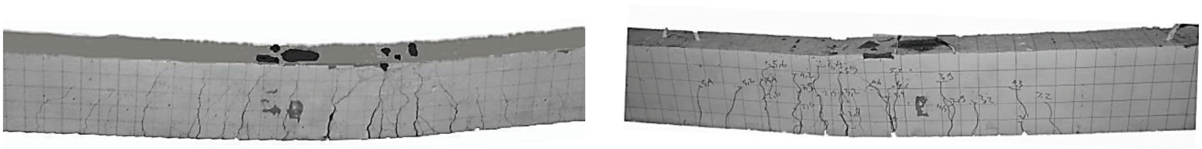
▲ : Stirrup *strain gauges*

● : Longitudinal steel *strain gauge*

3. Result and analysis

3.1. Ultimate moment capacity and cracking moment

All the six test specimens were completed at one day. It could be concluded that all beams fail in bending, and no lateral buckling was noticed during the loading process (fig. 1). The most important findings are the load-displacement responses of the members, and the determination of ultimate moment capacity and cracking moment of each beam. The ultimate moment capacity of the test specimens are shown in fig. 2. The graph also shows the moment at which initial cracking in the extreme fibers in tension was detected.



(a) (b)

Fig. 1. Prototype of test specimen after loading (a) non-fiber; (b) fiber.

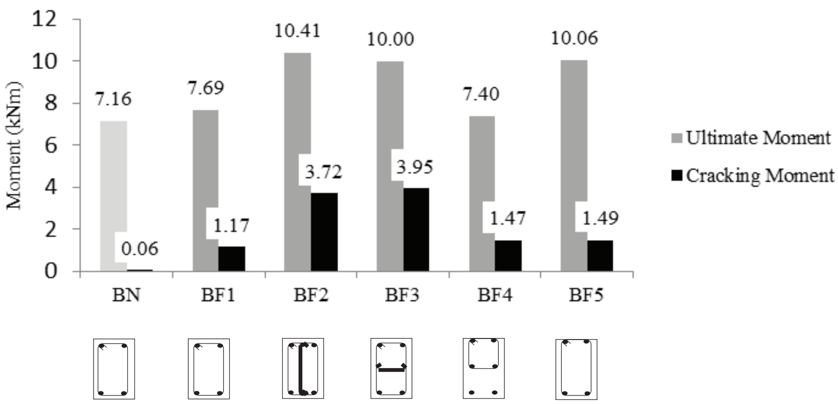


Fig. 2. Ultimate and cracking moment capacity

3.2. On the aspect of the steel-fiber addition

It can be concluded that the addition of steel-fibers to the concrete mix increased the cylinder compression strength by 16.3%, but enhanced the ultimate moment capacity of the test element BF1 by only 7.4 % compared to BN. The explanation to this sharp distinction lies in the fact that, by observing the strain response in the tension reinforcement, it was found that the failure of the beam was due to the yielding of the steel bars, rather than the crushing of concrete in the compression zone. The cracking moment of the steel-fiber beam BF1 however, increased substantially, underlining that the presence of fibers indeed amended a better tension behavior. An insignificant increase in ultimate moment capacity for the BF member suggested that the increase in compression strength due to the presence of steel-fibers could not be accessed optimally. The comparison to the confined elements BF3 and BF5 further showed that the use of confining stirrups, in combination with the steel-fibers could optimize the positive benefits of the steel-fiber material.

3.3. The analyses to the confinement of the compression zone

Studying the steel-fiber specimens BF1, BF2, BF3, BF4 and BF5, interesting facts were observed. It was found that BF2 resulted in an ultimate moment capacity close to BF3 and BF5, while theoretically, BF2 should exhibit a higher moment capacity since the area of longitudinal tensile reinforcement was 1.5 to that of BF3 and BF5. It was suggested that the reason for this undervalue was caused by the stress concentrations induced by the additional stirrup leg, resulting in the spalling of concrete cover. It was also alleged that the stirrups not optimally confined the concrete compression zone.

On the extension of confinement stirrups up to the extreme concrete fibers in compression, it was seen from the comparison between specimens BF1 and BF4 as well as BF3 and BF5, that this rather controversial configuration did not have a substantial effect on the ultimate moment capacity and the cracking moment. However, examining the specimens BF3 and BF5 having a stirrup configuration confining the concrete in compression, a significant enhancement in ultimate moment capacity was detected, when compared to BF1 and BF4.

Assessing the specimens BF1, BF4 to BF3, BF5, a 32.5% improvement in terms of flexure capacity was calculated, suggesting that a confinement of the compression zone is highly efficient. The fact that the confinement in the tension area is ineffective is shown by the evaluating the ultimate moment capacity of BF3 and BF5.

Test elements BF2 and BF3 exhibited a noticeable higher cracking moment when compared to all others steel-fiber specimens. These elements had a cracking moment of approximately 3 times the other test beams. This was due the stiffness factor of the stirrups and their higher reinforcement ratio, when compared to all other beams.

Analyzing the failure pattern of the beams visually, no substantial differences were monitored to the crack initiation and propagation of both the conventional and steel-fiber beams.

4. Conclusion

The use of steel-fibers in flexural elements is less significant in increasing the ultimate moment capacity when the element is designed as an under-reinforced beam. The use of these fibers however, increases the cracking moment substantially.

Concerning the confinement of the compression area by the stirrups in combination with the use of steel-fibers, it can be concluded that confining the compression zone of a member in flexure exclusively using stirrups will enhance the ultimate moment capacity of the member substantially; the extension of these stirrups up till the extreme fibers in compression is ineffective. The confinement of the tension area does not have impact on the moment behavior of the element. The stiffness and reinforcement ratio of the confining stirrups increases the level at which the first cracking in the element occur.

Acknowledgements

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