ESTEEM Academic Journal
Vol. 13, June 2017, 108-119

FLEXURAL CRACK PROPAGATION IN STEEL FIBRE CONCRETE BEAM

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ARTICLE HISTORY

Received
28 February 2017

Received in revised form
9 June 2017

Accepted
23 June 2017

ABSTRACT

The inclusion of steel fibres in the concrete matrix is the best alternative to control crack propagation along the failure plane. For decades, some of the studies carried out on steel fibre reinforced concrete beam (SFRC) had highlighted the effect of fibre dosage, fibre type and fibre size towards the mechanical behaviour of concrete, however, there are still uncertainties as to what extent does hooked end fibres with size of 35 mm and 60 mm at 40 kg/m^3 and 80 kg/m^3 respectively affected the flexural strength and crack produced in concrete. Thus, this study intends to investigate both effect of fibre dosage and fibre length of hooked end steel fibre towards flexural strength and crack propagation in 75 mm x 75 mm x 300 mm fibred concrete beam. In the study, hooked end steel fibres were incorporated into 12 beams having specified strength of 30 MPa. Meanwhile, the flexural strength of concrete was tested using Universal Testing Machine (UTM) under three point bending test. The incorporation of fibre at higher dosage with longer length has resulted in better results in terms of flexural strength and the crack produced as compared to the usage of short fibre at lower dosage

Keywords: hooked steel fibre; concrete; flexural crack; fibre reinforced beam

1. INTRODUCTION

Steel fibre reinforced beam (SFRC) has been defined by Nguyen (2001) as mixture of Portland cement, coarse aggregates, fine aggregates and water then it is incorporated with discrete discontinuous fibres. In general, steel fibre is preferred more than conventional steel bar due to its versatility and superior function in mechanical behaviour of concrete and this includes tensile strength, flexural strength, ductility and crack restraining ability. Most of the studies carried out were concerned about the excellence of steel fibre towards the mechanical behaviour of concrete while some other studies only focused on the effect of fibre dosage alone without relating it to the effect of fibre length on the flexural strength. Therefore, this studys to determine the effectiveness of both fibre length and fibre dosage specifically

p-ISSN 1675-7939; e-ISSN 2289-4934

towards the flexural strength of SFRC. The study also focuses on how different length of fibre at varied percentage would affect the crack restraining ability of SFRC beams.

2. ESTABLISHED RESEARCH

Faisal (1990) and Kawde and Warudkar (2017) had emphasised that SFRC had surpassed conventional reinforced concrete in terms of tensile strength, flexural strength, ductility and crack restraining ability hence making steel fibre to be the best substitute as reinforcement. Majority of the studies published were concerned about the superiority of metallic fibre in concrete in terms of its mechanical strength while some other studies were only focused on the effect of fibre dosage on mechanical behaviour of fibred concrete. In spite of that, studies dealing with the effect of steel fibre length are still limited hence, more research needs to be carried out to better understand how both fibre dosage and steel fibre length plays its role towards both mechanical behaviour of concrete and the capability to restrain crack.

Hameed et al. (2009) had justified that larger aspect ratio of metallic fibre resulted in effective increment of flexural strength and compressive strength despite that small number of fibre included in the mix. The findings from their study further verified that the crack control ability of fibre was also governed by the fibre's aspect ratio. In addition to that, steel fibres that were arranged randomly and spread throughout the concrete matrix have further increased the bonding strength of concrete matrix hence affected the post cracking behaviour of concrete significantly. Although research carried out by Ryabchikov et al. (2015) and McCormac and Brown (2014) had highlighted the significant improvements made by addition of steel fibre on the flexural strength, cracking resistance and durability. However, these studies are still inadequate since the length used by them were kept constant hence, indicating that consequences of using different fibre length on flexural behaviour of concrete are still unknown for sure. It is also uncertain as to what extent does the length of steel fibre affected the crack dimension produced when the beam containing hooked end steel fibres are subjected to flexure.

Flexural strength which is also known as the modulus of rupture is defined as the ability of material to restrain deformation under imposed load (Abbas, 2014). Improvement made on the flexural strength of concrete is greater in comparison to the increment made on its compressive strength whereby concrete containing 0.5% by concrete volume of steel fibre resulted in 138.96% of flexural strength as compared to the ordinary concrete and it was also found that the most optimum percentage of steel fibre by concrete volume is as much as 0.75% (Mahadik et al., 2014). In fact, in increase as high as 100% in the flexural strength has also been achieved (Nguyen, 2001). Experiment carried out by Ghosni et al (2014) on the flexural strength of hooked end steel fibre has recorded an increment between 20% and 59% in the steel fibre concrete as compared to the normal concrete and this percentage increased with an increased percentage of steel fibre added into the mix. In the experiment, it was found that concrete having 1.0% from concrete volume of hooked end steel fibre recorded the highest reading of flexural strength at 28 days which is equal to 8.5 MPa while concrete beam without the steel fibre resulted in flexural strength of only 5.6 MPa. Meanwhile, the compressive strength of the steel fibre reinforced concrete examined in the experiment is recorded to be higher than 33% than the normal concrete.

Crack pattern observed in conventionally reinforced concrete and steel fibre reinforced concrete is different as crack in conventional beam is more localized and concentrated in the

p-ISSN 1675-7939; e-ISSN 2289-4934

middle span where the beam is loaded while the steel fibre reinforced beam has a wider distribution of crack. It was observed that beam reinforced by both steel rod and steel fibre resulted in reduction of crack width as much as 40% while the crack load increased to 57% (Yuasrizam et al., 2012). Crack mouth opening displacement (CMOD) for short steel fibre has been recorded to be equal to 1 mm while longer steel fibre was approximately equal to 0.6 mm hence proving that longer steel fibre has the ability to stretch better than the short ones (Soetens & Matthys, 2014).

3. METHODOLOGY

The main aim of this study is focused on effect of fibres length and fibre dosage towards the flexural strength and crack propagation of SFRC. The specified strength for the concrete element was designed to be 30 N/mm^2 at 28 days. For three sets of mix, the specimens prepared were as in Figure 1. Prior to the execution of laboratory work, all of the materials were prepared beforehand. As overall, laboratory work involved for this particular study were slump test, casting and curing of concrete, cubes compressive test and finally, the three-point bending test. Throughout the flexural test, the resulting crack load, ultimate load, deflection and crack propagation were monitored so that comparison can then be made. The crack dimensions resulted under flexure were also measured accordingly.

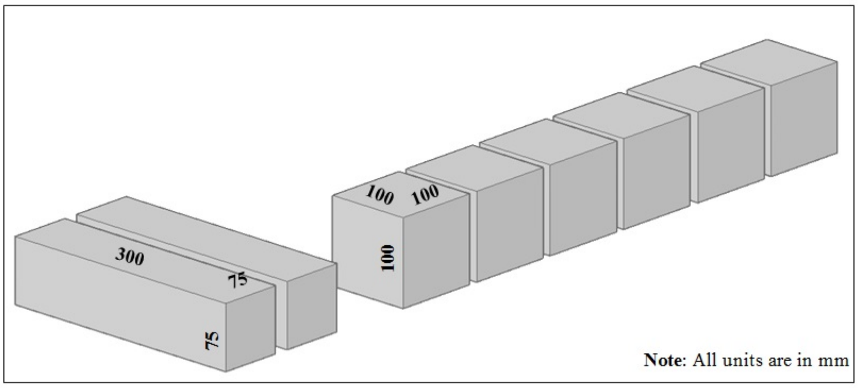

Figure 1: Specimens prepared for the experimental work

The standard that regulates the use of steel fibre for this study was EN 14889-1:2006 where it outlines the definitions, specifications, and testing for steel fibre that was added. The procedures of the experimental work were carried out based on BS EN 12390-2:2009 and EN 12350-2:2009 which provides guidelines in making of test cubes and testing for fresh concrete. Meanwhile, the standard that govern the testing procedure were BS EN 12504-1:2009 and EN 12390-5:2009 for compression test and flexural test respectively. Every equipment used was also ensured to comply with the standard accordingly.

3.1 Details of Steel Fibres

Steel fibre in the shape of hooked end possessed better physical properties than steel fibre with flat end shape due to the ability of hooked end steel fibre that is able to minimise the failure mode by changing the brittle shear failure to more ductile flexure failure (Faisal, 1990). The selection of fibre percentage was made to be from the concrete volume and it was

p-ISSN 1675-7939; e-ISSN 2289-4934

done due to the findings of experiment carried out by Faisal (1990) that found 1.0% addition of HESF made the most significant increment in flexural strength as compared to other fibre dosages at 0.5%, 1.5% and 2.0%. However this finding was against the finding made by Mohod (2012) which found that inclusion of 0.5% and 1.0% of steel fibres resulted in almost equal contribution towards the flexural strength of concrete. Hence, fibre dosage of 0.5% and 1.0% were selected in order to determine the most optimum fibre dosage.

The fibre dosage is kept maximum at 1.0% by the concrete volume as excessive dosage will cause balling effect and in return, making the steel fibre to clump and caused uneven mixing of concrete. Ghanem (2015) stated that steel fibre with 60 mm length is more prone to balling effect and form a clump of steel fibre during mixing. Thus, the manufacturer had supplied the longer steel fibre in collated form which are adhere together with weak glue which was only intended to prevent the fibres from getting entangled together without affecting the strength of the concrete.

Figure 2: Hooked End Steel Fibre

Table 1 summarised the physical properties of steel fibres used together with its respective dosage. Meanwhile, Table 2 tabulated the mechanical properties of hooked end steel fibres.

Table 1: Physical Properties of Steel Fibres

Type of Mix	Fibre Dosage by Concrete Volume (%)	Diameter of Fibre (mm)	Fibre Length (mm)	Aspect Ratio
PC	-	-	-	-
HE35A	0.5	0.75	35	47
HE60A	0.5	0.75	60	80
HE35B	1.0	0.75	35	47
HE60B	1.0	0.75	60	80

p-ISSN 1675-7939; e-ISSN 2289-4934

Table 2: Mechanical Properties of Steel Fibres

Mechanical Properties	Value
Tensile Strength	1200 N/mm^2
Modulus of Elasticity	205 000 N/mm^2
Poisson Ratio	0.29
Yield Strength	1275 N/mm^2

3.2 Mix Design of Concrete

Typically, the use of steel fibre is famous in high strength concrete (HSC) and ultra-high strength concrete (UHSC) and the ultimate concrete strength itself for both HSC and UHSC is already known to be high. However, this study is carried out in order to study the enhancement made by the incorporation of steel fibre in the normal strength concrete, thus, carrying capability of normal strength concrete can then be improved. Therefore, the characteristics strength of 30 MPa at 28 days is chosen for the concrete used.

Generally, water cement ratio used for normal concrete mix is between 0.45 and 0.60 and this is made in accordance to BS 882:1983. However, to comply with the negative workability impact induced by the addition of steel fibres, the water cement ratio for steel fibre mix is taken to be equivalent to 0.6 (Yuasrizam, 2012). The maximum aggregate size used is 20 mm. The design mix calculation for both plain concrete and steel fibre concrete in overall is tabulated as in Table 3.

Table 3: Material Composition of Concrete

Plain Concrete (PC)	Material	Steel Fibre Reinforced Concrete (SFRC)
0.5	Free Water/Cement	0.6
190	Water (kg/m^3)	190
380	Cement (kg/m^3)	315
770	Fine Aggregate (kg/m^3)	795
1060	Coarse Aggregate (kg/m^3)	1100
0	Steel Fibre (%)	0.5 – 1.0

p-ISSN 1675-7939; e-ISSN 2289-4934

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3.3 Testing Procedure

Compressive strength test was carried out using the automatic compression testing machine after 7 days and 28 days separately. Then, the average value of the compressive strength for each mix was recorded.

To achieve the main aim of this study, all of the beams casted would undergo flexural test at 28 days of ageing to check for its maximum flexural strength and the crack propagation under flexure. Flexural test was conducted using Universal Testing Machine (UTM) through the three-point bending test whereby the beam was supported on two rollers located at 20 mm away from each end then one roller is loaded at the upper mid span of beam. As the beam was loaded, the compressive stress would act on the upper side of the beam while the tensile stress acted at the lower side of the beam. The deflection rate exerted by the UTM was at 0.01 mm/s.

The dial gauge was placed under the mid span of beam to check for the maximum deflection occurred as the beam was subjected to flexure stress. The set up of three point bending test is as shown in Figure 3.

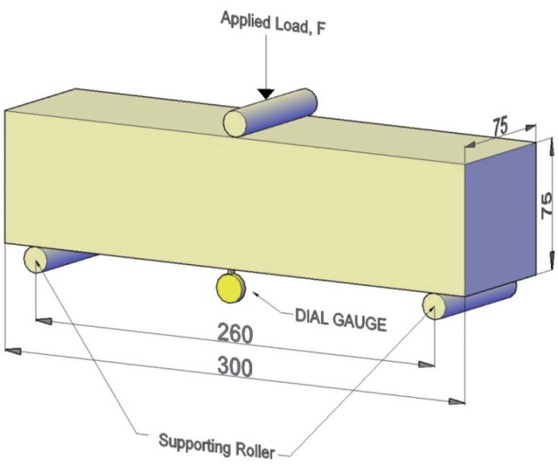

Figure 3: Set-Up of Three Point Bending Test

Note: All units are in mm

4. EXPERIMENTAL RESULTS

4.1 Compressive Strength Test

As the main intention of this study was to investigate the flexural behaviour of steel fibre concrete beam and its subsequent crack propagation, the use of small cubes having size of 100 mm x 100 mm x 100 mm were adequate although the results obtained was significantly higher than the specified strength. The reason was that there is better bonding in the smaller cube whereas larger cubes might have more voids, causing the compressive strength to be lower (Yakkali, 2015). The average values of the results obtained for each mix are tabulated as in Table 4.

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Table 4: Compressive Strength Result

Mix Type	7 days	28 days
PC (N/mm^2)	25.95	36.27
HE35A (N/mm^2)	28.43	40.86
HE60A (N/mm^2)	30.48	43.71
HE35B (N/mm^2)	33.25	42.84
HE60B (N/mm^2)	38.57	46.48

An experiment carried out by Faisal (1990) has found that 1.0% fibre dosage made an increment of 8% against the 0.5% fibre dosage. Meanwhile for this experiment, HE60B was found to be 6% greater than HE60A and HE35B to be 4% higher than HE35B. Thus, the findings from this experiment has also verified the investigation carried out by Sadoon et al. (2016) which in their experiment had found that compressive strength in long HESF was only slightly higher than short HESF. Nonetheless, the results obtained for SFRC cubes managed to achieve 25% of designated mean strength after 28 days as claimed by Nguyen (2001).

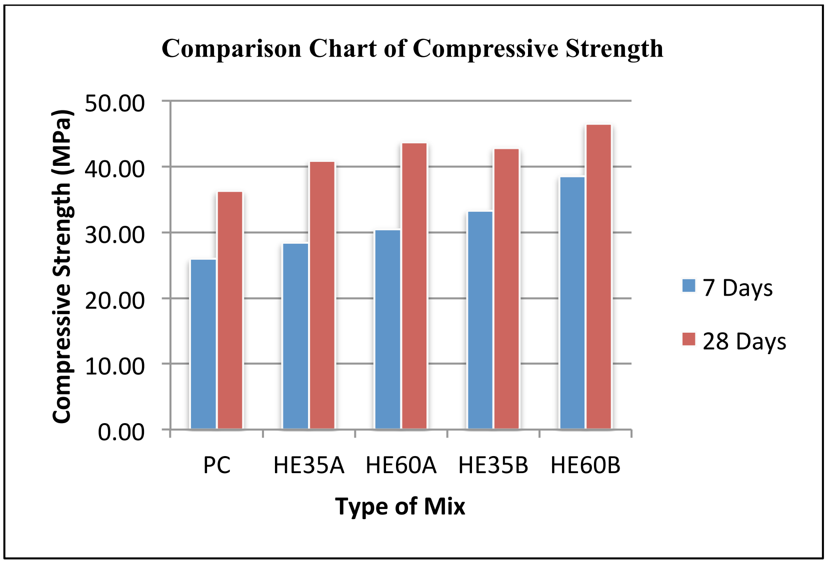

Figure 4: Comparison Chart of Compressive Strength

p-ISSN 1675-7939; e-ISSN 2289-4934

In reference to the comparison chart made on the compressive strength, mix having the long fibre and higher dosage of fibre, HE60B recorded the highest compressive strength for both 7 days and 28 days of ageing. Meanwhile, plain concrete remain the lowest even at the 28th days being 28% lower than HE60B. Thus, it is obtained that the compressive strength increases slightly with the increase in fibre dosage and fibre length.

4.2 Flexural Strength Test

The comparison graph on load and deflection relationship has found that the deflection for fibre reinforced beam continues to be yielded even beyond the maximum loading point instead of abruptly falling approaching zero value as seen in plain concrete beam.

Table 5: Flexural Strength Result

Mix Type	P_{crack} (kN)	Δ at P_{crack} (mm)	P_{ult} (kN)	Δ at P_{ult} (mm)	Flexural Stress, f_{cf} (N/mm^2)
PC	6.39	0.85	4.80	1.20	4.44
HE35A	6.23	0.50	9.05	1.85	8.37
HE60A	9.30	1.45	10.22	2.21	9.45
HE35B	7.35	0.80	10.99	1.75	10.16
HE60B	9.60	1.35	12.79	2.08	11.82

Through the experiment carried out, HE60B recorded the highest flexural stress of 11.82 N/mm^2 and this value is 60% higher than plain concrete beam and 14% higher than HE35B. Comparison made between two different lengths of HE35B and HE60B has found an increment as much as 14% and this value can be verified through finding made by Namdar et al. (2013) which found flexural strength for long steel fibre to be 10% greater than short steel fibre.

The beam with 40 kg/m^3 fibre dosage and short fibre recorded the lowest reading. Moreover, comparison made between long steel fibre and short steel fibre has found that longer steel fibre of 60 mm was able to sustain 16% more load than the shorter ones at dosage of 1.0% by the concrete volume. Meanwhile, at 0.5% fibre dosage, longer steel fibre was able to carry load more than 13% higher than shorter steel fibre. The finding obtained has further verified an experiment carried out by Pajak and Ponikiewski (2014) that found long steel fibres produces higher flexural strength than short fibres.

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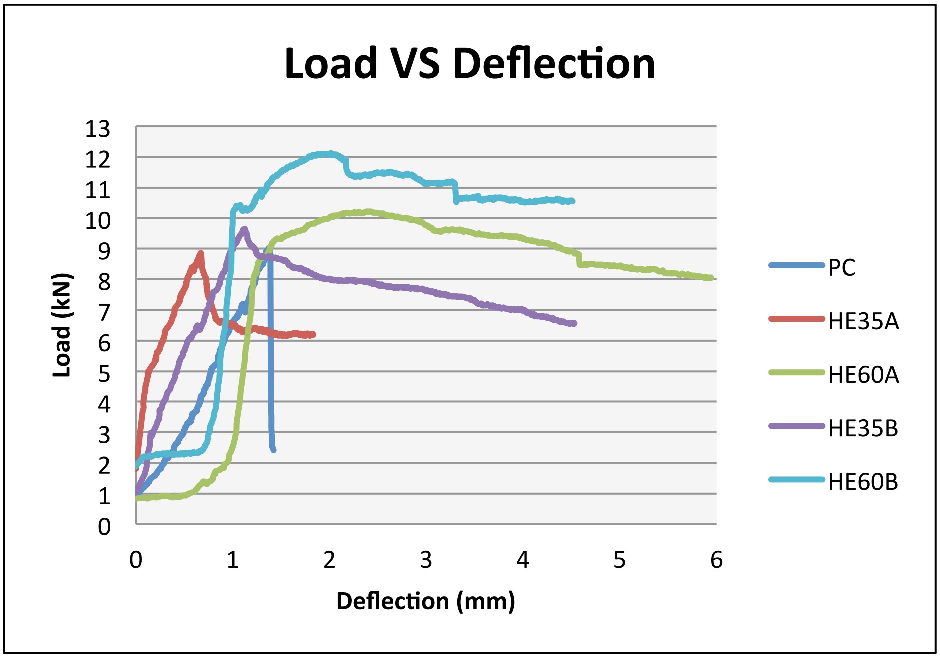

Figure 5: Relationship between load and deflection

4.3 Crack Propagation under Flexure

Although the crack opening for plain concrete beam under flexure is the lowest, however the crack observed for plain concrete was more localized and its mode of failure tended to be brittle as there was no residual strength yielded after the maximum load and this is as justified by Yuasrizam et al. (2016)

Table 6: Crack Measurement Result

Mix Type	Crack Length (mm)	Crack Mouth Opening (mm)	Type of Crack
PC	4.75	1.00	Localized
HE35A	5.50	6.90	Dispersed
HE60A	4.50	5.15	Dispersed
HE35B	7.00	4.75	Dispersed
HE60B	6.65	3.10	Dispersed

p-ISSN 1675-7939; e-ISSN 2289-4934

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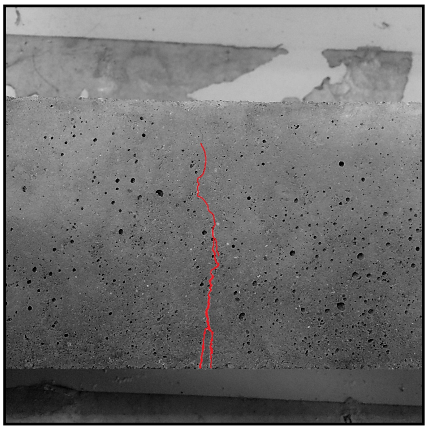

Figure 6: Crack Distribution of Plain Concrete Beam

Figure 7 illustrated the difference observed in the short steel fibre beam and long steel fibre beam. As it can be seen, longer steel fibre having crack opening of only 5.15 mm has better ability to arrest crack than the shorter steel fibre having the largest crack opening of 6.90 mm. The crack arresting ability of hooked end fibre played its critical role beyond the yield point because the pulling action of steel fibre within the concrete matrix had helped restrained further crack. Thus, beyond the ultimate strength, additional energy was required to stretch out the existing crack and to separate the fibre out of the concrete entirely.

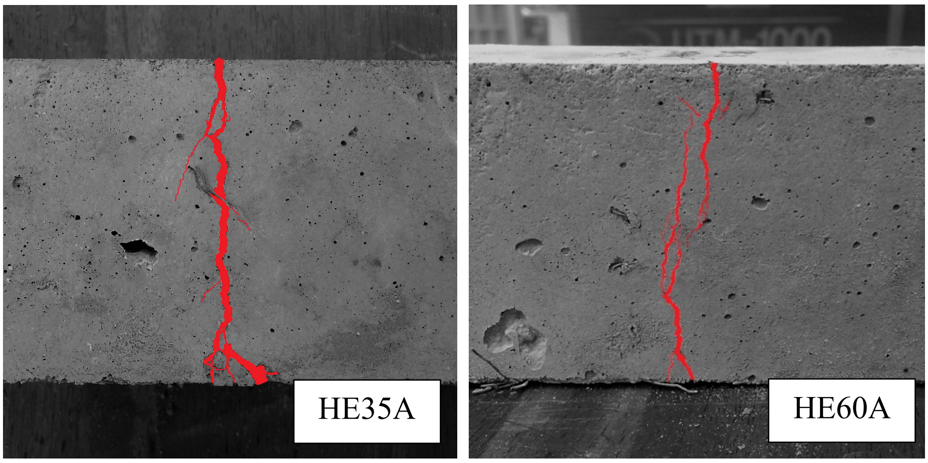

Figure 7: Comparison on the crack opening

5. CONCLUSION

Towards the end of this study, the conclusion that can be drawn is that the addition of 1.0% hooked end steel fibre with length of 60 mm recorded the most excellent improvement in terms of compressive strength and flexural strength with increment as much as 28% and 62% respectively in comparison to plain concrete. However, it is noted that the improvement made in the flexural strength of concrete was in particular sensitive to the fibre dosage and fibre length as compared to the increment made in compressive strength. Moreover, it was found that longer steel fibre arrest cracked more than 30% better than the shorter steel fibre due to its capability to stretch even more than the short steel fibre hence enabling the concrete to yield more residual strength beyond its failure mode. In conclusion, the use of longer hooked end steel fibre with 1.0% addition into the concrete mix significantly improved the

p-ISSN 1675-7939; e-ISSN 2289-4934

compressive strength, flexural strength and enhanced the crack propagation in concrete beams.

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