Enhancing Flexural Capacity of Steel Fibre Reinforced High Strength Concrete Beams

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Abstract – The steel fibres are generally used as a resistance of cracking and strengthen of concrete, in this study hooked end steel fibres of length 35mm with thickness of 0.5 mm diameter is used. In this program consist of tests on steel fibre reinforced high strength concrete (SFRHSC) beams were conducted under flexural loading. Steel fibre reinforced high strength concrete (SFRHSC) beams include two different volume fraction i.e. 1% and 2% the cross sectional dimensions and span of beams were fixed same for all types of beams. The specimens were conducted ultimate load, load deflection, ductility, crack load and characteristics of beams with and without steel fibres have been carried out and quantitative comparison was made on significant stages of loading. It was observed that one control beam is casted with HSC and two beams are casted with SFRHSC. These two beams are compared with control beam. It was concluded that SFRHSC beams showed enhanced properties compared to that of HSC beams. A modified procedure has been suggested to calculated the ultimate load, load deflection, ductility, crack load obtained in the experimental investigation was also compared with the all types of beams.

Keywords – Flexural Strength, Steel Fiber Reinforced High Strength Concrete, Mechanical Properties, Steel Fibres.

I. INTRODUCTION

Fibre reinforced concrete (FRC) is Portland cement concrete reinforced with more or less randomly distributed fibres. In FRC, thousands of small fibres are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties in all directions.

It has been successfully used in construction with its excellent flexural-tensile strength, resistance to spitting, impact resistance and excellent permeability and frost resistance. It is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. Fibre is a small piece of reinforcing material possessing certain characteristics properties. The principle reason for incorporating fibres into a cement matrix is to increase the toughness and tensile strength and improve the cracking deformation characteristics of the resultant composite. Plain concrete possesses a very low tensile strength limited ductility and little resistance to cracking internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks eventually leading to brittle fracture of concrete. In the past, attempts have been made to impart improvement in tensile properties of concrete members by way of using conventional reinforced steel bars and also by applying restraining techniques. Although both these methods provide tensile strength of concrete members, they however, do not increase the inherent tensile strength of concrete itself.

When loaded on plain concrete the micro cracks propagated and open up, and owing to the effect of the stress concentration, additional cracks form in the places of minor defects. The structural cracks precede slowly or by tiny jumps because they are retarders by various obstacles. The development of such micro cracks is the main cause of in elastic deformations in concrete. It has been recognized that the additional of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties this type of concrete is known as fibre reinforced concrete.

Lot of researches have been carried out on the properties of steel fiber reinforced high strength concrete beams, the results, volume dosage of steel fiber and the beam height on ultimate flexural behavior of steel fiber reinforced high-strength concrete beams are not completely appropriate for practical purposes. Therefore, the present study investigate the ultimate load, ultimate deflection, crack load, volume dosage of steel fiber and the beam strength on flexural behavior of steel fibre reinforced high-strength concrete beams, which has great instruction in the design and applications of steel fibre reinforced high-strength concrete beams.

When steel fibers are added to high strength concrete, the increase in fiber volumetric ratio results in an increase in the compressive strength of the concrete and a considerable amount of increase in the tensile strength of the fiber reinforced specimens is observed in split cylinder tests (Mukesh Shukla (2011) Okay and Engin, (2012). However, when this addition exceeds a certain volumetric level, the increase in the strength becomes less (Song and Hwang, 2004; Mohammadi et al., 2008). Volumetric ratio of fiber also increases energy absorbing capacity in bending (Gao et al., 1997). Wang and Lee (2007) experimentally demonstrated that steel fiber reinforced concrete. As the volume content of the fiber increases, ductility under constant load increases in the diagrams. In other words, no difference is observed up to crack, but...
duction of steel fibers (Rao and Seshu, 2005, Amitrana). In a research study, the effect of steel fibers on cracks in reinforced concrete beams was investigated and it was concluded that a steel fiber dosage of 30-40 kg/m^3 was appropriate to have an appreciable improvement on cracks (Altunet al., 2007). Dupont and Vandewalle (2002) and Paine et al. (2002) studied the contribution of steel fibers of reinforced concrete beams and determined that a steel fiber dosage of 1-2% by absolute volume was ideal from that aspect after having performed experiments.

II. PRODUCTION OF HIGH STRENGTH CONCRETE

The manufacture of high strength concrete is to more compressive strength lesser cracks but the water absorption will be more to reduce the water absorption will add some materials will grow to find its due to place in concrete construction for all the obvious benefits in the modern batching plants high strength concrete is produced in a mechanical manner of course one has been taken care about mix proportioning shape of aggregates, use of supplementary cementations materials, silica fume we are adding these materials the voids between the aggregates will be reduce but one of the defect is water absorption will be more to reduce the water absorption will be adding HRWR (high range water reduces). With the modern equipment’s understanding the role of the constituent materials, production of high strength concrete has become a routine matter.

III. FIBRE REINFORCED CONCRETE

Fibers are generally used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact abrasion, and shatter resistance in concrete. Generally fibers do not increase the flexural strength of concrete, and so cannot replace moment resisting or structural steel reinforcement. The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed “volume fraction” (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fiber's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to “ball” in the mix and create workability problems.

Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that ductility increases when concrete is reinforced with fibers. The results also indicated that the use of micro fibers offers better impact resistance to that of longer fibers.

1. Steel Fibre Reinforced Concrete

1.1 Introduction

The use of Steel Fiber Reinforced Concrete (SFRC) has received much attention in concrete industry as more research is being performed and more is being understood about its material properties and behavior. When steel fibers are added to high strength concrete, the increase in fiber volumetric ratio results in an increase in the compressive strength of the concrete and a considerable amount of increase in the tensile strength of the fiber reinforced specimens is observed in split cylinder tests.

1.2 Properties of Concrete Improved by Steel Fibres

i. Flexural Strength: Flexural bending strength can be increased of up to 3 times more compared to conventional concrete.
ii. Fatigue Resistance: Almost 1 1/2 times increase in fatigue strength.
iii. Impact Resistance: Greater resistance to damage in case of a heavy impact.
iv. Permeability: The material is less porous
vi. Shrinkage: Shrinkage cracks can be eliminated.

1.3. Advantages of steel fibres

i. More ductile concrete with a high load bearing capacity-resulting in thinner slabs with equal or better performance than their mesh counter parts
ii. Efficiency crack control -3,200 fibres on average per Kg
iii. Durability –steel fibres slabs reinforce the structure through of the concrete
iv. Quick and Easy application – steel fibres can be added at the concrete plants or at the job site directly.
v. Efficiency & Cost effective –on average a draw mix slab will cost between 10-15% less than an equivalent mesh slabs.

1.4 Objectives

i. Increase the ultimate flexural strength of RC beam by using High Strength concrete (M60) grade and adding with the addition of steel fibres.
ii. Improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions, by utilizing the inherent material properties of fiber reinforced concrete.
iii. Steel fibers in different volumes have been added and the performances has been Compared.
iv. To study the effect of different proportions of steel fiber mixes.
IV. PROPERTIES OF FIBRES ARE USED

<table>
<thead>
<tr>
<th>Fibre Properties</th>
<th>Steel Fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>35 mm</td>
</tr>
<tr>
<td>Shape</td>
<td>Hooked End</td>
</tr>
<tr>
<td>Size / Diameter (mm)</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>60</td>
</tr>
<tr>
<td>Density (kg / m³)</td>
<td>7850</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>210</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>532</td>
</tr>
</tbody>
</table>

V. TESTS CONDUCTED AND RESULTS

An experimental program was carried out to study the performance of HFRC beams with and without fibres, by Two-point loading. The beams of 150 mm x 250 mm in cross section and overall length of 3000mm provided with 3 nos. 1 beam was control beam without another 2 beams are steel fibre reinforced high strength concrete beams 1% and 2% of steel fibres in total volume of concrete in that beam 2 bars of 8mm φ on tension zone and 2 bars 12mm φ in compression zone and as the 6mm stripes were used.

![Fig.1. specimen details](image)

![Table 2: Specification of beam](image)

<table>
<thead>
<tr>
<th>Specification of beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of beam</td>
</tr>
<tr>
<td>Depth of beam</td>
</tr>
<tr>
<td>Width of beam</td>
</tr>
<tr>
<td>Steel bars</td>
</tr>
<tr>
<td>Stirrups</td>
</tr>
<tr>
<td>Clear cover</td>
</tr>
</tbody>
</table>

2. Testing Procedure

All the beams were tested, under two-point loading as per ASTM C 78, in a loading frame of 500 KN capacity and 100mm bearing was given on both ends, resulting in an effective test span of 2800mm as shown in (fig.2). The deflections were measured at mid span and load points using mechanical dial gauges of 0.01mm accuracy. Three dial gauges were setup on the tension side of the specimen under load points and center of the beam to measure slope at the ends. The strains at extreme fibres were measured using demountable mechanical strain gauge. The crack widths were measured using a demo gauge with a least count of 0.02mm, the pallets are placed at constant distance.

For the applying of loading proving ring is used with a capacity of 500KN and to measure displacement dial gauges are used with an accurate of 0.2mm, the diagram of proving ring and dial gauges was shown below. The strain and crack width can be measured by using the demo gauge the first crack and end crack can be measured. The deflections can be measured at different load levels, the crack development and propagation was measured during the process of testing.

A total of 3 beams were casted and tested in this investigation to study the strength and load deflection behavior of the hybrid fiber reinforced concrete beams. The test results of the ultimate load, yield load, deflection and crack width as shown in figure below. Concrete mix for all beams are taken from the mix design as per the ACI codal provision, respectively.
Table: 3 Ultimate Load Yield Load Data of the Beam

<table>
<thead>
<tr>
<th>Beam Designation</th>
<th>Control beam</th>
<th>1% steel fibres</th>
<th>2% steel fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate load (KN)</td>
<td>56.19</td>
<td>68.16</td>
<td>76.430</td>
</tr>
<tr>
<td>Yield load (KN)</td>
<td>37</td>
<td>39</td>
<td>43.000</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td>27</td>
<td>21.075</td>
<td>23.000</td>
</tr>
<tr>
<td>Crack width (mm)</td>
<td>1.18</td>
<td>1.047</td>
<td>1.185</td>
</tr>
</tbody>
</table>

Fig.4. Ultimate load, yield load, deflection & max crack width

APPENDIX

MIX DESIGN

Step 1
Select slump and required strength

\[ Fc_r = \frac{(8702.34+1400)}{0.9} = 11224.8 \text{psi} \]

Step 2
Max size of aggregate = 1/2 in
Bulk specific gravity of aggregate = 2.806
Water absorption = 0.39%
Dry Bulk density = 95.50 lb/ft³

Step 3
Vol of Coarse aggregate = 0.68 (As per code provision)
Dry wt/yd³ of concrete = (0.68X95.50X27) = 1753.38 lb

Step 4
Slump = 1 to 2
C:A size = 1/2 in
For this condition water content = 295 lb/yd³ (As per code provision)
Entrapped air = 2%
Voids of sand = \((1) - (106.8/(2.75X6.24)) \times 100 = 37.76\%

The mixing water adjustment = (37.76-35) \times 8 = +22.08 lb/yd³
Water content = 295+22.08 = 317.08

Step 5 1/2 in
11000 = >0.29
11224 = > X
12000 = > 0.26
X = 0.283
For field convenient 
(0.9X11224) = 10101.6 psi

Step 6
Wt of cementations material = (317.08/0.283) = 1120.42 lb

Step 7
Cement content/yd³ of concrete = 1120.42 lb
Volumes/yd³ of all materials expect sand
Cement = ([1120]/(3.15X62.4)) = 5.69 ft³
Coarse Aggregate = [1753.38/ (2.806X62.4)] = 10.01 ft³
Water = [317.08/62.4] = 5.08 ft³
Air = [0.02X27] = 0.54 ft³
Total = 21.32 ft³

Required sand Vol/yd³ = [27-21.32] = 5.68 ft³
= [5.68X62.4X2.75] = 974.68 lb

Material content:
Cement = 1120.42 lb
Coarse Aggregate = 1753.38 lb
Sand = 974.68 lb
Water = 317.08 lb

VI. CONCLUSION

The hybrid fibre volume fraction of 0.5% with 70% - 30% steel polyolefin combine significantly improves the overall performance of high-strength reinforced concrete beams.

The increase in ultimate load was found to be 15.24% when compared to reference beam. The increase in ultimate deflection was found to be 22.03% when compared to reference beam.
Adjustments:

Cement = 1120.42 lb
Coarse Aggregate = \((1753.38)\times[(1) + (0.39/100)]\)
= 1760.22 lb
Fine Aggregate = \((974.68)\times[(1) + (1.21/100)]\)
= 986.47 lb
Water = \((317.08) - (974.68 \times (0.0638 - 0.0121)) - (1753.38 \times (0.0033 - 0.0039))\)
= 264.77 lb

As Per Indian Units:

Cement = 661.04 Kg/Cum
Coarse Aggregate = 1038.52 Kg/Cum
Fine Aggregate = 582.01 Kg/Cum
Water = 184 Kg/Cum

Mix for silica fume:

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>Silica Fume</th>
</tr>
</thead>
<tbody>
<tr>
<td>8%</td>
<td>608.15</td>
<td>52.88</td>
</tr>
<tr>
<td>9%</td>
<td>601.55</td>
<td>59.49</td>
</tr>
</tbody>
</table>

Mix for HRWR:

<table>
<thead>
<tr>
<th>Mix</th>
<th>Water</th>
<th>HRWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25%</td>
<td>175.74</td>
<td>8.26</td>
</tr>
<tr>
<td>1.5%</td>
<td>174.08</td>
<td>9.92</td>
</tr>
</tbody>
</table>

Compaction Mix:

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>F.A</th>
<th>C.A</th>
<th>Water</th>
<th>S.F</th>
<th>HRWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>608.1</td>
<td>582.0</td>
<td>1038.5</td>
<td>175.7</td>
<td>52.8</td>
<td>826</td>
</tr>
<tr>
<td>#2</td>
<td>601.5</td>
<td>582.0</td>
<td>1038.5</td>
<td>174.0</td>
<td>59.4</td>
<td>9.92</td>
</tr>
</tbody>
</table>

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