Evaluation of Residual Strength Properties of Steel Fiber Reinforced Concrete

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Abstract
This study evaluated the residual strength properties of concrete reinforced with steel fibers. The objective was to determine its role in improving some of the mechanical properties of concrete. The purpose and significant of the study is to confirm the ability of steel fibers to prevent the onset of cracking as well as propagation of cracks in the concrete structures. This is evident by the higher residual strength properties of the specimen investigated. A total of 12 cubes (100m3), 12 cylinders (100mm diameter and 200mm height) and 21 prisms (100x100x400mm) were cast in the present investigation. After 28 days of curing, the cubes, cylinders, and prisms were subjected to compressive, tensile, and residual strength tests respectively. Residual strength test data was obtained from reloading of cracked beam specimens in a four point bending test. The compressive strength test results increased from 47MPa at 0% fibre volume to 48MPa at 0.5% fibre volume. This value however decreased to 45MPa at 0.75% fibre volume, indicating that the injection of straight steel fibres have little influence on the compressive strength. The split tensile test result increased steadily from 3.17MPa at 0% fibre volume to 5.66MPa at 1% fibre volume indicating that addition of steel fibres to concrete enhanced its tensile strength. The residual strength test result also showed an increment in the average residual strength from 1.81MPa at 0.5% to 3.37MPa at 1% fibre volume. This study has confirmed that addition of steel fibres to concrete enhanced its tensile and residual strength properties.

Keywords: Steel fibre, Residual strength, Fracture Resistance, Cyclic loading, split tensile strength.

INTRODUCTION
It is now well established that the addition of short, discontinuous fibers play an important role in the improvement of the mechanical properties of concrete. It increases elastic modulus, decreases brittleness, controls crack initiation, and its subsequent growth and propagation. Debonding and pull out of the fibers require more energy absorption, resulting in a substantial increase in the toughness and fracture resistance of the material to cyclic and dynamic loads.

In particular, the unique properties of steel fiber reinforced concrete (SFRC) suggest the use of such material for many structural applications, with and without traditional internal reinforcement. The use of SFRC is, thus, particularly suitable for structures when they are subjected to loads over the serviceability limit state in bending and shear, and when exposed to impact or dynamic forces, as they occur under seismic or cyclic action.

Generally, it has been observed that the addition of steel fibers can significantly improve the bending fatigue performance of concrete members. The extent of improvement on the fatigue capacity of FRC can be expected to depend upon the fiber volume content, fiber type and geometry. Various combinations of these parameters will give rise to different fatigue characteristics. However, at the moment, there does not seem to be a comprehensive appreciation of the advantages than can be attained with fiber addition, and there is limited information regarding the quantitative influence and relative importance of fiber parameters such as amount, aspect ratio and fiber type. In general, the addition of fibers has added a further dimension to the study of fatigue in concrete and has increased the complexity of analysis.

STATEMENT OF THE PROBLEM
Over the years, the use of concrete has being limited to conventional structures, therefore the need for concrete use under special conditions e.g in seismic areas has brought forth the need for concrete that possesses higher durability in terms of strength. In this regard, fibers have been studied and are believed to have the ability to enhance this property in concrete.

LIMITATION OF THE STUDY
The study was limited to loading and reloading tests on steel fibers reinforced concrete samples injected with steel fibers to determine their residual strength.
LITERATURE REVIEW
From the research and development work carried out by many researchers during the last three decades, it has been observed that among the various types of fibers used in the concrete matrix, steel fibers improve the toughness (energy absorption capacity) of the plain concrete by many fold and also enhances the flexural strength of concrete. Steel fiber reinforced concrete (SFRC) is a more appropriate material for construction and rehabilitation of bridge deck overlays, pavements and industrial floors when compared with conventional cement concrete.

The toughness characteristics of SFRC are beneficial in the shotcreting applications (such as tunnel lining) and in structural elements subjected to high rates of loading. One area of application where the beneficial effects of SFRC could be made use of is the construction of earthquake structures (Balasubramanian et al., 1997). Other discrete fibers have been developed for concrete reinforcement namely glass, synthetic and natural fibers. Steel fibers are the most used in concrete applications due to the following reasons: economy, manufacture facilities, reinforcing effects and resistance to the environment aggressiveness (Barros and Figueiras, 1998).

The energy absorption capacity of plain concrete is low. The ability of SFRC to absorb energy is one of the most important benefits of the incorporation of fibers into plain concrete. For content of fibers used in practice, the increase on compression, tensile shear and torsional strength is only marginal (Balaguru and Shah, 1992).

In structures with super abundant supports, like slabs on soil and tunneling lines, the increase on the material energy absorption capacity provided by fiber reinforced enhances the cracking behaviour and increases the load bearing capacity of these structures. Due to the relevance of the energy absorption capacity on fibrous concrete, several procedures have been proposed to evaluate this property (Barros and Figueiras, 1998), resulting in some entities that are intended to reproduce this property, namely, the toughness indexes, the equivalent flexural strength and the fracture energy. The other entities have reduced application on numerical simulation of SFRC structures.

The characteristics of concrete depend upon the kind of fibers utilized, volume proportion of the fibers and the aspect ratio of fibers. These conditions will improve the mechanical properties, including toughness, ductility tensile strength, shear resistance and loading limit of the fiber reinforced concrete. The materials that can be used for the fiber reinforcement include steel, glass, polyester, rayon, cotton and polythene. The most commonly used materials are steel and glass fibers that are acid resisting.

Natural fibers being vulnerable to alkali attack are not much popular. Similarly plastic fibers have recently been introduced in the field of reinforcement and are still in the development phase. It is considered that the contribution of plastic fibers to increase the static strength of concrete is limited; Nylons have the characteristics of a plastic material and presently have a limited application in the slab technology. It is generally believed that nylon fibers possess strength that is greater than the welded wire fabric in such slabs. However, there is still incomplete knowledge on the design/analysis of fiber reinforced concrete (FRC) structural members. The analysis of structural sections require as a basic pre-requisite, the definition of a suitable stress-strain relationship for each material to relate its behaviour to the structural response many stress-strain relationships in tension and in compression for FRC materials have been proposed.

The behaviour of a composite material is influenced by the characteristic of each component, their synergistic interaction and by their proportion in the mixture. In particular when fibers are added to a concrete mix fiber characteristics such as their type, shape, aspect ratio (L/f/Df) and volume content (Vf) play an important role in modifying the behaviour of the material. In addition, it will be emphasized that variations in specimen geometry, loading versus casting direction, loading rate and maximum aggregate size also modify the compression behaviour of fiber concrete (Bencardino, et al, 2008).

EXPERIMENTAL INVESTIGATION
Experimental investigations were conducted at the Structural Engineering Research Centre, Chennai using cubes, cylinders and the beams to evaluate compressive strength, split tensile strength and residual strength respectively. Plain concrete specimens for all studies were also cast. These plain concrete specimens served as the control experiment.

MATERIALS
The materials used in the study were cement, fine and coarse aggregate, water, chemical admixtures and steel fibers. They are described as follows:

i) Fibers
Straight steel fibers (Figure 1) from Stewol, India was used in the study. These fibers have 30mm length and 0.45mm diameter with a fiber aspect ratio l/d=30/0.45=66.7. The fibers consisted of independent units which could be put directly in bunches in the concrete mix and then allowed to scatter uniformly throughout the concrete mix by the mechanical action of the pan mixer blades.

ii) Cement
In the present investigation, ordinary Portland cement of 53 grade conforming to IS:269 1976 was used.
iii) Fine Aggregate
Locally available river sand in Chennai passing through IS sieve 2.36mm was used in the investigation.

iv) Coarse Aggregate
In the present investigation, locally available blue granite crushed stone aggregate of size 12.5mm was used.

v) Water
Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. The requirement of water should be reduced to that required for chemical reaction of hydrated cement, as any excess water would end up in formation of undesirable voids (and/or capillary pores) in the hardened cement paste of concrete. In the present investigation, portable water was used.

vi) Chemical Admixture
In the concrete, water-binder ratio is generally kept as low as possible so as to obtain the given degrees of workability. Structro 100" Super plasticizer which is a high range water reducing super plasticizer was used in this investigation to achieve this purpose.

Mix Design
The ACI Committee 211.1 method of mixture proportioning was adopted as a guide for arriving at the initial mixture proportions. However the final proportion was arrived at after a trial mix. A mix trial proportion of 1:1.9:2.55 by volume of cement, sand and coarse aggregates was used for all the specimens. A water cement ratio of 0.5 was adopted and the design strength of the concrete was grade 30 MPa. Fibres of 0.5%, 0.75% and 1% were added independently in each batch while a plain concrete mix (0%) batch was used as the control experiment. Table 1 shows the quantity of materials used per cubic meter of concrete.

Preparation of Test Specimens
A total of 12 cubes (100mm), 12 cylinders (100mm diameter and 200mm height) and 21 prisms (100x100x400mm) were cast in the present investigation. The specimens were cast in two series. The first series consisted of 3 cubes and 3 cylinders and 3 prisms with no fibers present in the mix. The second series consisted of the 9 cubes, 9 cylinders and 18 prisms with percentage of fibers present being 0.5%, 0.75% and 1%. Concrete was mixed in a pan type mixer machine with the fibers being added mid way into the mixing process.

The concrete/fiber mix was then poured into the various specimen moulds. The specimens were compacted on a vibrating table in order to assure a dense mix and a uniform distribution of the fibers. The specimens were demoulded after 24 hours and cured in water for 28 days.

**TESTING OF SPECIMENS**

**Cube Compression Test**
All the cubes were tested in surface dried condition. For each mix combination, three cubes were tested at the age of 28 days using compression testing machine of 100 tonne capacity. The tests were carried out at a uniform stress rate, after the specimen was centered in the testing machine. The loading was continued until the specimen reached its ultimate load. The ultimate load divided by the cross sectional area of the specimen is equal to the ultimate compressive strength.

**Split Tensile Test**
The cylinders were tested in saturated surface dried condition. For each mix combination, three cylinders were tested at the age of 28 days using compression testing machine of 100 tonne capacity. The tests were carried out at a uniform stress rate, after the specimen was centered in the testing machine. The loading was continued until the specimen reached its ultimate load. The split tensile strength is calculated by using the formula given in IS 5816:1999, splitting tensile strength of concrete- method of tests.

**Residual strength Test (Four point bending)**
The Residual strength of fiber reinforced concrete was determined as per ASTM C 1399 – 07a procedure. A steel plate of 12mm thickness was kept below the specimen. The steel plate was used to help control the rate of deflection when the beam cracks. After the beam cracked in a specified manner, the steel plate was removed and the cracked beam was reloaded to obtain data to plot a reloading load–deflection curve. If cracking had not occurred after reaching a deflection of 0.20 mm the test was discarded. The average residual strength (ARS) for each beam was calculated using the loads determined at reloading curve deflections of 0.50, 0.75, 1.00, and 1.25 mm.

\[
ARS= \left(\frac{(PA+PB+PC+PD)}{4}\right) \times k
\]

Where:
\[k=\frac{L}{bd^2}\]

PA+PB+PC+PD = Sum of recorded loads at specified deflections
L= Span length
b= Average width of the beam
d= Depth of the beam

**RESULTS AND DISCUSSION**
The results of the various tests carried out to determine the mechanical properties of steel fiber reinforced concrete are presented here.

**Cube Compressive Strength**
The results of the compressive strength of 100mm cubes at 28 days are shown in Table 2. It can be seen from the results that there is a slight increase of about 2% in the compressive strength when the fiber volume was increased to 0.75%. There was reduction in the compressive strength and this
again increased slightly when the fiber volume was increased to 1%. The insignificant increment and reduction indicate that the injection of straight steel fibers have little influence on the compressive strength which it seems is due to the strength of the concrete alone.

Split Tensile Test
The results of the split tensile tests carried out on the cylinders are shown in Table 2. It can be seen from the results that there is a good amount of enhancement in the tensile strength property of the concrete upon the addition of the steel fibers. The value increased about 79% at the fiber volume of 1%. One of the major objectives of adding the steel fibers in concrete is to enhance its tensile strength. The fibers used in this study have achieved the objective.

Average Residual Strength
From the results the peak load was observed at 26.9kN, 38.4kN and 43.2kN respectively for 0.5%, 0.75% and 1% fiber replacements at initial loading. Figures 2 to 4 shows the typical load-deflection curves (initial loading and reloading) for 0.5%, 0.75% and 1% SFRC. It was observed that average residual strength increases as fiber volume increases.

CONCLUSION
From the investigations carried out, the following conclusions are derived;

- The injection of straight steel fibers have little influence on the compressive strength as insignificant increment and reduction were observed for various volumes of fiber in concrete.
- There is a good amount of enhancement in the split tensile strength of concrete upon the addition of the steel fibers. The value increased by about 79% at the fiber volume of 1%.
- It was observed that average residual strength increased with increase in fiber volume.

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APPENDIX
Table 1: Quantity of Materials per Cubic Meter of Concrete

<table>
<thead>
<tr>
<th>Materials</th>
<th>Kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>400</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>760</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1020</td>
</tr>
<tr>
<td>Water</td>
<td>200</td>
</tr>
<tr>
<td>Super plasticizer</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 2: Material Properties of Specimens Tested By Olutoge (2010)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Compressive Strength (MPa)</th>
<th>Split Tensile Strength (MPa)</th>
<th>Residual Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>47</td>
<td>3.17</td>
<td>-</td>
</tr>
<tr>
<td>0.5%SFRC</td>
<td>48</td>
<td>4.33</td>
<td>1.81</td>
</tr>
<tr>
<td>0.75%SFRC</td>
<td>45</td>
<td>4.65</td>
<td>3.30</td>
</tr>
<tr>
<td>1%SFRC</td>
<td>48</td>
<td>5.66</td>
<td>3.37</td>
</tr>
</tbody>
</table>

Figure 1: Steel Fibers
Figure 2: Typical Load Deflection Plots (0.5% FRC)

Figure 3: Typical Load Deflection Plots (0.75% FRC)

Figure 4: Typical Load Deflection Plots (1% FRC)