FLEXURAL AND PUNCHING SHEAR CHARACTERIZATION FOR SELF COMPACTING CONCRETE REINFORCED WITH STEEL FIBRES

Abibasheer Basheerudeen
School of Mechanical and Building Sciences (SMBS),
VIT, Vellore, Tamilnadu, India.

S.K. Sekar
School of Mechanical and Building Sciences (SMBS),
VIT, Vellore, Tamilnadu, India.

ABSTRACT
Steel fibre reinforced self compacting concrete (SFRSCC) possess the advantages of both Self compacting and fibre reinforced concrete. This paper deals with the behaviour and capability of SFRSCC in flexure and punching shear by conducting experimental investigation on prism and slab-column specimen. Six concrete mixes were considered for the study, three with fibres and three without fibres. Third-point loading and punching shear test was used to characterize the concrete reinforced with steel fibre volume fraction of 0.5&0.75%. Flexural studies demonstrated that, higher amount of steel fibres provide higher toughness which enables the material to take up large deflections. In the case of punching shear capacity, addition of fibres reported a substantial increase in capacity and also with increase in fibre dosage. It was also observed, at constant volume fraction of fibres, specimen with higher grade of concrete exhibited superior performance in flexure and punching shear.

Key words: Self compacting concrete; Steel fibres; Modulus of rupture; Toughness; Punching shear.

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1. INTRODUCTION
Self compacting concrete is (SCC) is a concrete which is able to flow under its own weight, completely filling the formwork, even in the presence of congested reinforcement, without any mechanical vibration. The additions of fibres substantially improve the toughness and stress distribution of concrete, increase in post crack strength, fatigue, abrasion and can enhance the bar spacing and decrease the labour costs. Application of fibre reinforced concrete include seismic resistant structures, repair and rehabilitation of structures, road pavement, bridges, tunnel segment linings and industrial floors (Khaloo et al.2005; Khaloo et al.2014).Enhanced properties of fibre reinforced concrete are dependent on the volume fraction, type, geometric characteristics, distribution and orientation of the used fibres (Bentur et al.2007; Ding et
al.2012). Even though plastic, glass, carbon fibres are available in the market, the most commonly used fibre is steel. Out of the various forms of steel fibres, hooked end steel fibres are widely used due to its higher strengthening effect on the cement matrix as compared with other types of steel fibres (Ameeri 2013). The most common method to assess the flexural performance of fibre reinforced concrete is by conducting bending test. Experimental test methods and characterization of toughness is available in various standards ASTM C-1018, ACI-544 guidelines, JCI specifications, RILEM draft recommendations, EFNARC specification. The type of loading arrangement in all the standards was third point loading, but vary in the dimension of the specimen, rate of loading and toughness measurement (Sivakumar et al. 2013). Flat slab system in widely used now a day, as it offers many advantages. The slab –column junction fails abruptly due to punching shear because high shear stresses are developed around the supporting columns. Various investigators Alexander and Simmonds, Jiang and Shen, Yankelesky and Leibowitz and Braestrup have not considered the post fracture properties in their theoretical analysis of punching shear strength of concrete slabs (Kumar et al. 2012). The various methods to increase the punching shear capacity of flat slab are shear reinforcing using stirrups [inapplicable to shallow depth], method using headed-studs [time consuming] have inherent disadvantages. The technique of using steel fibres have effectively controlled the cracking of slab-column connections and improvement in punching shear (Cheng et al. 2010; Naaman et al. 2007). The focus of the present study is to investigate experimentally the influence of steel fibres on flexural properties and punching shear capacity in self compacting concrete, giving more emphasis to post crack performance. Six different mixes with two volume fraction (0.5&0.75%) were considered for the study.

2. EXPERIMENTAL INVESTIGATION

Flexure and Punching shear studies were conducted on six different mixtures, three with fibres and three without fibres. All the mixtures had the same type of hooked end Steel fibres. Concrete mix compositions were varied as per the following factors: (1) w/p ratio (0.7, 0.9&1.1 by volume), (2) Volume fraction of fibres (0.5&0.75%). The mix design methodology, mix proportions, mixing sequence, fresh properties and hardened properties (compression, tension, modulus of elasticity) of SFRSCC mixtures used for this study is explained in the work carried out by the author (Basheerudeen et al. 2015). The concrete mix composition is given in Table 1.

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<td>0.00%</td>
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<td>90</td>
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<td>90</td>
<td>156</td>
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<td>0.7</td>
<td>120</td>
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<tr>
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<td>1.1</td>
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2.1. Materials
The materials used for the present investigation are Cement, Ground granulated blast furnace slag (GGBS), Coarse aggregate, Manufactured sand (M-sand), Super plasticizer, Steel fibres&water. Ordinary Portland cement (OPC) of 53 grade was used for all the mixes, confirming to IS specifications. The fineness of the cement was 320 m2/kg with a specific gravity of 3.15. GGBS used for the current study is having a fineness of 450 m2/kg and a specific gravity of 2.9. Two different types of coarse aggregates were used for the present investigation with maximum sizes of 12.5 and 20mm. The properties of the selected aggregates were confirming to IS specifications. The specific gravities of 12.5 and 20mm aggregates are 2.8 and 2.78 respectively. Locally available M-sand was used for the study, well graded sand falling under Zone-II category as per Indian specifications. The specific gravity and bulk density were found to be 2.6 and 14.95 kN/m3. A polycarboxylic ether based high range water reducer with a solid content of 40% was used. The specific gravity is between 1.09 - 1.11. Glued steel fibres conforming to ASTM – 820 & EN-14889 standards were used. The aspect ratio of the fibres is 65 and the tensile strength is 1100 MPa. Potable water free from chlorides and sulphates was used for mixing as well as for curing the concrete.

2.3. Specimens
Flexural performance was conducted on specimen of size 100x100x500mm with a Japanese Yoke set up. The yoke is positioned along the length of the prism and restraints are provided at the ends to eliminate extraneous deflection. Due to the restrained effect, pure bending will take place at the mid span and the experimental values obtained from this set up will offer an accurate load-deflection plot (Sivakumar et al.2013; Jayakumar et al.2014). For punching shear, specimens were prepared like junction of column and slab. Column height of 100mm X 100mm dia and slab thickness of 50mm X 300mm dia was used. The specimens were prepared in a laboratory mixer with overall mixing duration of 7 min. For each mixture, nine samples and 3 samples for flexural and punching shear tests respectively were produced and tested. A total of 54 specimens and 18 specimens for flexural test and punching shear tests respectively were used. The casting surface was levelled and finished using a trowel, after filling the mould. The specimens were demoulded after 24hrs and are immersed in water for curing under controlled environment until tested.

2.4. Investigated Parameters
The flexural performance of toughness parameters were obtained by testing a simply supported beam under third point loading according to the ASTM C 1609 standard. The test was conducted on a flexural testing machine having flexural capacity of 100kN and a displacement rate of 0.5 mm/min. True mid span deflections were recorded with a dial gauge. From the load-deflection curve; Modulus of rupture, Absolute toughness, Post crack toughness, Residual toughness & Flexural toughness were calculated. The test setup is shown in Figure1.

Punching shear specimen was tested on compression testing machine of capacity 2000kN. The slab column specimen was kept at the center of compression testing machine and the specimen was fitted with two dial gauges; at the center and at the periphery to record the deflection until failure. A smooth continuous steel plate bent into a circular shape was prepared to provide a perimeter support for the specimen. For punching shear failure to happen, support diameter was kept 0.5 times the diameter of the slab (Kumar et al. 2012). A photograph of the test set up is shown in Figure 2.
3. EXPERIMENTAL RESULTS & DISCUSSION

3.1. Flexural Properties

Table 2 present the results obtained from compressive strength test and flexural toughness test at 3, 7&28days. Figure 3 present the values obtained from flexural studies of fibre reinforced concrete.

Figure 1. Test set up for Flexural studies

Figure 2. Test set up for Punching shear
Table 2 Mechanical results of cube compressive strength test and Third point loading test.

<table>
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<tr>
<th>Mix ID</th>
<th>Steel fibre (%)</th>
<th>Age of the specimen (days)</th>
<th>Compressive strength (MPa)</th>
<th>Flexural strength (MPa)</th>
<th>Absolute toughness (Nm)</th>
<th>Post crack toughness (Nm)</th>
<th>Residual toughness (Nm)</th>
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Figure 3 Influence of fibre reinforcement on bending behavior at various ages of concrete
3.1.1. Flexural Strength

Flexural strength is defined as the maximum stress in the outermost fibre and is calculated at the surface of the specimen on the tension side. The flexural strength of the specimen shall be expressed as the modulus of rupture, calculated as $Pl/bd^2$.

- $P$ = maximum load applied to the specimen.
- $l$ = length of the span on which the specimen was supported.
- $b$ = measured width of the specimen.
- $d$ = measured depth of the specimen at the point of failure.

Figure 4 represents the Modulus of rupture (MOR) or flexural strength of all concrete mixtures at 3, 7 & 28 days. The MOR increases with increasing age and the 28th day MOR lies between 8.55-10.35 MPa without fibres, whereas with fibres it lies between 9.45-11.25 MPa. The rate of increase of flexural strength with fibres for M1 is 9%, for M2 is 31% and for M3 is 11%. For the same volume fraction of fibres (0.75%) but with different concrete grades (M2 & M3), enhancement of 20% flexural strength was observed for higher grade of concrete. The randomly distributed steel fibre offers a bridging force across the micro-crack preventing from expanding to macro-crack. As a result of this effect, increasing the volume fraction of fibres enhance the maximum bending load of the specimen. From the present study, it is confirmed that the influence of steel fibres in the flexural strength of concrete is superior to tensile and compressive strengths. In general addition of fibres enhanced the flexural capacity of the specimens, but the rate of increase depends on the dosage of fibre and the grade of concrete.

![Figure 4 Influence of fibres on the Flexural strength at different ages of concrete](image)

3.1.2. Absolute Toughness

Absolute toughness represents the area under the load-deflection curve up to failure load. The area below the load-deflection plot (Figure 5), which is the gauge of energy absorption capacity, was increasing on fibre addition. The improvement of toughness due to the addition of fibres is clearly exhibited in Figure 6. The rate of increase is about 14 times for M1+0.5%, 19 for M2+0.75% and 20 for M3+0.75% compared with plain concrete respectively. The highest absolute toughness (102.37 Nm) at 28th day was reported for M2+0.75%. The highest absolute toughness is 23% higher than M1+0.5% and 7% higher than M3+0.75%. At a constant volume fraction of fibres, the specimen with higher grade concrete had maximum energy absorption capacity than a specimen with lower concrete grade. This is in agreement with the studies conducted by Khaloo et al. (2014).
3.1.3. Post crack Toughness

Post crack toughness is defined as the area under the load-deflection curve from the ultimate load to the load at failure. Figure 7 gives a comparative study of post crack toughness for different concrete mixes at 3, 7 & 28 days. As it can be observed from Figure 7, post crack toughness increases with increasing age of concrete. Figure 8-10 display the energy absorbed by the specimen (Hatched portion) from the point of ultimate load to the failure load, the behavior is inelastic. The post crack toughness of M1+0.5%, M2+0.75% & M3+0.75% are 70.55, 95.70 & 85.36 Nm respectively. The post peak energy of mix M2+0.75% & M3+0.75 are more pronounced in comparison with M1+0.5%. This is due to the presence of larger amount of steel fibres which provides higher toughness to the material for large deflections.

![Figure 5 Load-Deflection curve at 28th day with fibres](image)

![Figure 6 Influence of fibres on the Absolute toughness at different ages of concrete](image)
Flexural and Punching Shear Characterization for Self Compacting Concrete Reinforced with Steel Fibres

Figure 7: Comparison of post crack toughness at various ages of concrete.

Figure 8: 28th day Post crack toughness for M1+0.5%.

Figure 9: 28th day Post crack toughness for M2+0.75%.
3.1.4. Residual Toughness

It is measured from the area between the first drop in load after ultimate load till 3mm deflection of the load-deflection curve. Figure 11 gives the Residual toughness values for the various fibre concrete mixes at 3, 7 & 28 days. The 28th day toughness value ranges from 26.08 - 31.76Nm. The hatched portions in Figure 12-14 shows the region of residual toughness for the fibre concrete mix at the 28th day, also indicates the capacity of the specimen after failure. It is observed that, for lesser volume fraction of fibres, the curve drops quicker compared to higher volume fractions. This enabled M2+0.75% & M3+0.75% to absorb more energy over the entire deflection region.

![Ultimate Load Graph](image)

**Figure 10** 28th day Post crack toughness for M3+0.75%

**Figure 11** Comparison of Residual toughness at various ages of concrete
Figure 12 Residual toughness for M1+0.5%

Figure 13 Residual toughness for M2+0.75%

Figure 14 Residual toughness for M2+0.75%
3.1.5. Flexural Toughness

Area under the load deflection curve of concrete in flexure until a deflection of $1/150$ times the span. Flexural toughness is an important factor when dealing with fibrous concrete. Higher strength of concrete results in higher brittleness and lower ductility. Addition of fibres improves the ductility. As seen from Figure 15, addition of steel fibres increased the flexural toughness of the specimen. The specimen with 0.75% fibre volume fraction (M2&M3) exhibit higher flexural toughness compared to M1+0.5%. Flexural toughness of M1+0.5% & M3+0.75% is almost 87% & 93% of M2+0.75%. When the volume fraction of fibres was kept constant, the specimen with higher grade of concrete had shown higher flexural toughness. The use of lower w/p ratio and the better bonding between the cement matrix and higher amount of steel fibres might have contributed to the toughness enhancement.

![Graph of Flexural Toughness at various ages of concrete.](image1)

**Figure 15** Comparison of Flexural toughness at various ages of concrete.

![Typical failure patterns for concrete prisms after flexural loading.](image2)

**Figure 16** Typical failure patterns for concrete prisms after flexural loading.

3.2. Punching Shear

To understand the punching shear failure, load-displacement plot were drawn and presented in Figure 17-18. It is observed that, punching shear failure had occurred abruptly for the entire non fibrous specimen. The crack which was originated from the tension side of the slab transmitted across the slab. Due to the formation and propagation of the cracks the stiffness of the slab is reduced. Once the ultimate load is reached, a sudden fall in the load carrying capacity is observed and finally the specimen fails in punching shear. The results from Figure 18 indicate a substantial increase of punching shear capacity with the
introduction of steel fibres and increased fibre dosage. Addition of fibres increased the punching shear capacity by 10% for M1+0.5%, 26% for M2+0.75 & 18% for M3+0.75%. For the constant volume fraction of fibres, higher grade of concrete showed higher punching shear capacity. The mode of failure observed is ductile. Even at the failure load, the crack bridging effect of steel fibre did not allow the specimen to split completely. Presence of steel fibres appreciably improved the concrete ductility and integrity in the area of slab column connections. The reason behind the increase of punching shear is due to the bridging effect of the steel fibres across the cracks in the concrete, which led to the transfer of tensile stresses until the steel fibres are totally pulled out or broken.

Figure 17 Punching shear strength – deflection response of non fibrous concrete

Figure 18 Punching shear strength – deflection response of fibrous concrete
4. CONCLUSION

The present study was aimed to investigate the benefits of incorporating steel fibres in self compacting concrete by conducting experiments. Flexural and punching shear test were performed and the result obtained can be summarized as follows:

- The performance of flexural and punching shear properties is significantly increased with the addition of steel fibres, and the increase was more prominent with 0.75% volume fraction of steel fibres.
- The influence of steel fibres in the flexural strength of concrete is superior than tensile and compressive strengths.
- Absolute toughness was enhanced by 20% with the addition of 0.75% volume fraction of steel fibres as compared to control mix.
- Behaviour of specimens in the post crack region is inelastic. Presence of higher amount of steel fibres provides higher toughness enabling the specimen to take up large deflections.
- M1+0.5% absorbed less energy over the entire deflection region as compared to M2+0.75% & M3+0.75%. This is because for lesser volume fraction of fibres, the load-deflection curve drops quicker compared to higher volume fractions.
- The use of lower w/p ratio and the better bonding between the cement matrix and higher volume fraction of fibres have contributed to the enhancement of flexural toughness.
• Punching shear capacity was increased by 26% with the addition of 0.75% volume fraction of fibres, in comparison with control concrete.
• The mode of failure changed from brittle to ductile with the addition of steel fibres, and the performance depends on the dosage of steel fibre and the grade of concrete.
• Specimen with higher grade concrete had higher energy absorption capacity and punching shear strength than a specimen with lower concrete grade, for constant volume fraction of fibres.
• Overall, the incorporation of steel fibres enhanced the flexural and punching shear properties and the extent of increase depend on amount of steel fibre and the grade of concrete.

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REFERENCE


