INVESTIGATION ON MECHANICAL BEHAVIOUR OF SELF COMPACTING CONCRETE REINFORCED WITH STEEL FIBRES

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ABSTRACT

Fibre reinforced self compacting concrete (SFRSCC) mingles the advantage of both Self compacting and fibre reinforced concrete. In the at hand investigation, the behavior and capability of SFRSCC in flexure and punching shear were tested by conducting experiments on prism and slab - column specimen to characterize the concrete reinforced with steel fibre volume fraction of 0.5 & 0.75%. Out of six concrete mixes considered for the study, three mixes were added with fibres and three without fibres. Flexural studies on prism resulted that incorporation of higher amount of steel fibres yielded higher toughness which enables the material to resist large deflections. Study on punching shear capacity reported that addition of fibres produced a substantial increase in capacity and is found to increase with addition of fibre dosage. Results indicated that at a constant volume fraction of fibres, improved performance in flexure and punching shear is observed in concrete mixes.

Keywords

Self compacting concrete, Steel fibres, Modulus of rupture, Toughness, Punching shear

Academic Discipline And Sub-Disciplines

Engineering

SUBJECT CLASSIFICATION

Civil (concrete technology)

TYPE (METHOD/APPROACH)

Experimental investigation

INTRODUCTION

Self compacting concrete (SCC) is a concrete which flows under its own weight thereby completely filling the formwork even in the presence of congested reinforcement without any means of mechanical vibration. Additions of fibres substantially improved the toughness and stress distribution of concrete thereby increase resistance in post crack strength, fatigue, abrasion and decrease the labour costs. Fibre reinforced concrete has numerous practical applications such as seismic resistant structures, repair and rehabilitation of structures, road pavement, bridges, tunnel segment linings and industrial floors [1-2].Improved properties of fibre reinforced concrete are reliant on the volume fraction, type, geometric characteristics, distribution and orientation of the used fibres [3-4].

Even though plastic, glass, carbon fibres are available in the market, widely used fibre is steel. Hooked end steel fibres are widely used because of its higher strengthening effect on the cement matrix as compared with other types of steel fibers [5].

Experimental test methods and characterization of toughness were performed as per standards ASTM C-1018, ACI-544guidelines, JCI specifications, RILEM draft recommendations, EFNARC specification. As per standards three point loading arrangement was employed to determine the flexural strength, but it may vary in dimension of the specimen, rate of loading and toughness measurement [6]. Flat slab system is widely used now days because of its additional advantages. Failure in slab –column junction is due to punching shear because high shear stresses are developed around the supporting columns. Various investigators such as Alexander and Simmonds, Jiang and Shen, Yankelesky and Leibowitz and Braestrup failed to consider the post fracture properties in their theoretical analysis of punching shear strength of concrete slabs [7].

There are several methods available to increase the punching shear capacity of flat slab. Shear reinforcing using stirrups (inapplicable to shallow depth) and headed-studs (time consuming) methods have inherent disadvantages. The technique of using steel fibres have effectively controlled the cracking of slab-column connections and improvement in punching shear [8-9].The main objective 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.

EXPERIMENTAL INVESTIGATIONS

Study on Flexural performance and punching shear were conducted on six different mixtures, three with fibres and three without fibres. Same type of hooked end Steel fibres is added to all the six mixtures. Concrete mix proportions 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 and hardened properties(compression, tension, modulus of elasticity) for different SFRSCC mixtures used in this study is explained in the work carried out by the author[10]. The composition of different concrete mixtures is given in Table 1

Table 1 Composition of concrete mixtures

Mix ID	(v_f)	Vol: of cement	Vol: of GGBS	Vol: of water	Vol: of paste	w/p	Vol: of CA (12.5mm)	Vol: of CA (20mm)	Vol: of M-sand
M1+0%	0.00%	134	90	156	380	0.7	120	180	300
M1+0.5%	0.50%	134	90	156	380	0.7	120	180	300
M2+0%	0.75%	120	80	180	380	0.9	120	180	300
M2+0.75%	0.75%	120	80	180	380	0.9	120	180	300
M3+0%	0.75%	109	72	199	380	1.1	120	180	300
M3+0.75%	0.75%	109	72	199	380	1.1	120	180	300

METHODOLOGY

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 found to be 320 m^2/kg with a specific gravity of 3.15. GGBS used for the investigation had a fineness of 450 m^2/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 found to be 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/m^3. A polycarboxylic ether based high range water reducer with a solid content of 40% was used. Specific gravity of super plasticizer was ranging between 1.09 - 1.11. Glued steel fibres conforming to ASTM – 820 & EN-14889 standards were used for the investigation. The aspect ratio of the fibres is 65 and the tensile strength was 1100 MPa.Potable water free from chlorides and sulphates was used for mixing as well as for curing the concrete.

Specimens

Flexural performance of SCC mixes was conducted on specimen of size 100x100x500mm with a Japanese Yoke set up. The yoke is positioned along the length of the prism and restrains are provided at the ends to eliminate extraneous deflection. Due to the controlled effect, pure bending will take place at the mid span and the experimental values obtained from this set up will offer an precise load-deflection plot [6,11]. For punching shear, specimens were prepared like junction of column and slab. Column height of 100mm X 100mm diameter and slab thickness of 50mm X 300mm diameter was used. 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.

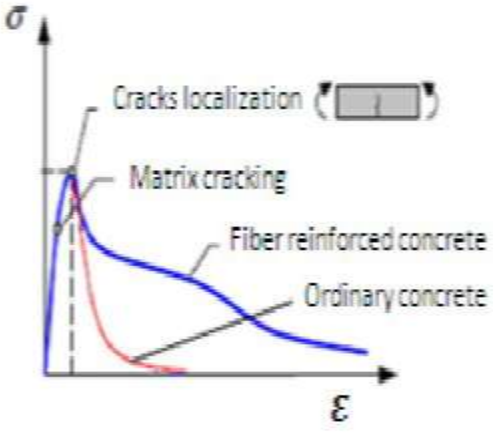
RESULTS AND DISCUSSION

Flexural properties

The results obtained from compressive strength test and flexural toughness test at 3,7 &28days respectively is shown in Table 2 . The schematic representation of concrete in flexure is displayed in Fig 1 and the values obtained from flexural studies of fibre reinforced concrete are shown in Fig 2.

Table2: Mechanical results of cube compressive strength test and Third point loading test.

Mix ID	Steel fibre (%)	Age of the specimen (days)	Compressive strength	Flexural strength	Absolute toughness	Post crack toughness	Residual toughness	Flexural toughness
M1	0	3	46.50	7.75	4.85			
		7	63.30	8.65	6.16			
		28	71.80	11.35	8.03			
M1	0.5	3	51.30	8.20	48.52	45.19	19.52	30.06
		7	68.70	9.10	72.51	58.49	22.96	38.86
		28	74.90	13.25	85.03	72.55	28.08	42.12
M2	0	3	43.20	7.40	5.20			
		7	49.80	9.20	6.36			
		28	58.00	8.55	7.30			
M2	0.75	3	48.40	10.90	59.80	48.89	23.64	41.96
		7	54.50	11.35	80.28	70.27	26.04	40.45
		28	63.60	12.25	104.37	97.70	33.76	47.23
M3	0	3	32.48	6.85	4.52			
		7	45.70	8.75	5.76			
		28	48.90	9.55	6.73			
M3	0.75	3	37.50	8.10	53.58	46.40	16.47	35.75
		7	48.00	9.55	65.37	58.55	24.85	37.06
		28	51.20	10.45	97.59	87.36	30.55	44.28



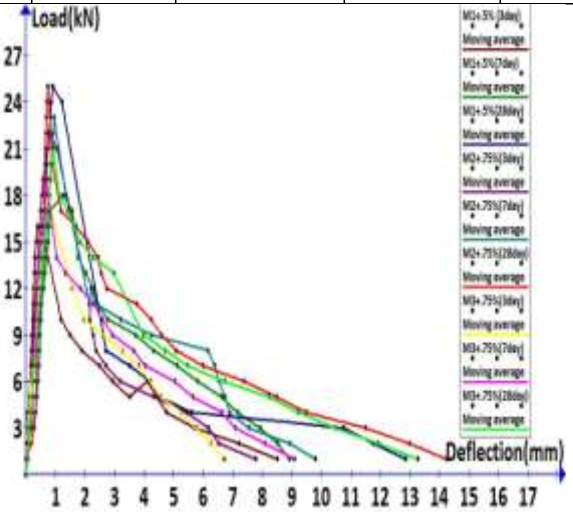


Fig 1: Schematic representation of Concrete behavior in flexure [16] .

Fig 2: Influence of fibre reinforcement on Bending behavior at various ages of concrete.

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 by using the formula Pl/bd2.

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.

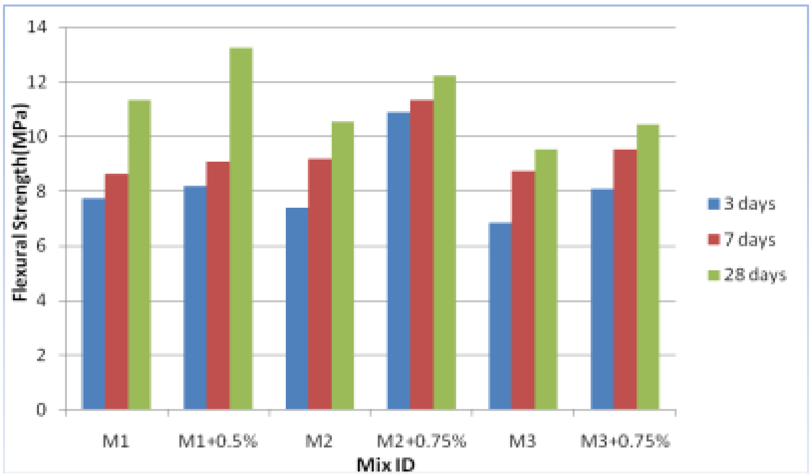


Fig 3 Influence of fibres on the Flexural strength at different ages of concrete

Fig 3 represents the Modulus of rupture (MOR) or flexural strength of all concrete mixtures at 3, 7 & 28days respectively. The MOR increases with increase in age and the 28th day MOR lies between 8.55-10.35MPa without fibres, whereas in concrete incorporated with fibres it lies between 9.45-11.25MPa.The rate of increase of flexural strength with fibres for M1, M2 and M3 mix is 9% , 31% and 11% respectively. 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 steel fibres which were distributed randomly 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 results obtained, it can be concluded that the influence of steel fibres in the flexural strength of concrete is superior to tensile and compressive strength. 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.

Absolute toughness

Absolute toughness represents the area under the load-deflection curve up to failure load. The area below the load-deflection plot (Fig 4), which is the gauge of energy absorption capacity, was increasing on addition of fibres. The improvement of toughness due to the addition of fibres is clearly exhibited in Fig 5.The rate of increase is about 14 times for M1+0.5%, 19 times for M2+0.75% and 20 times for M3+0.75% compared with plain concrete respectively. The highest absolute toughness (102.37Nm) 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 Alireza Khaloo et al[2].

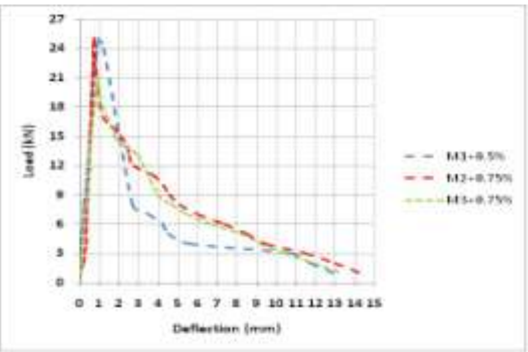


Fig 4 Load-Deflection curve at 28th day with fibres

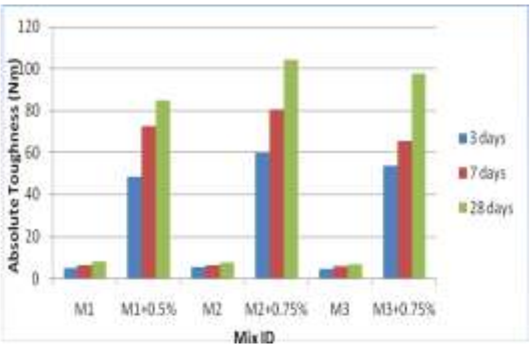
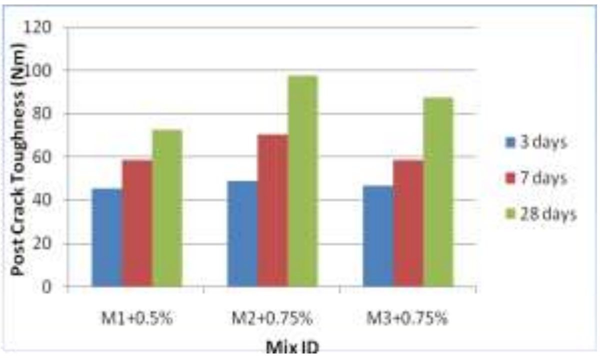


Fig 5 Influence of fibres on the Absolute toughness at different ages of concrete

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. Fig 6 gives a comparative study of post crack toughness for different concrete mixes at 3,7&28days. It can be observed from Fig 8 that the post crack toughness increases with increasing age of concrete. Fig 7-9 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 & 85.36Nm 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.



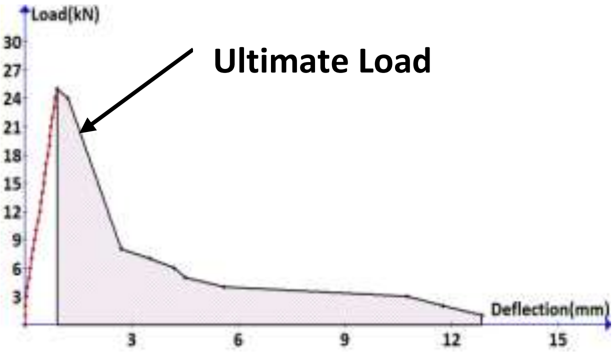


Fig 6 Comparison of post crack toughness at various ages of concrete.

Fig 7 28th day Post crack toughness for M1+0.5%

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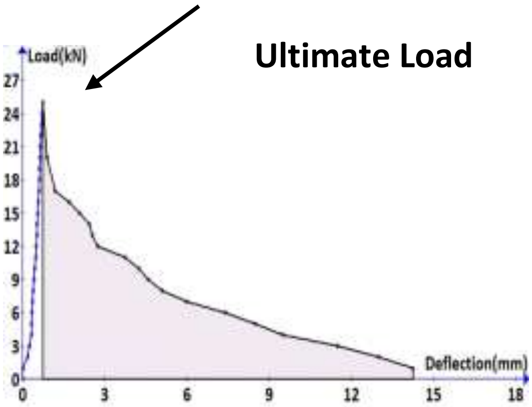


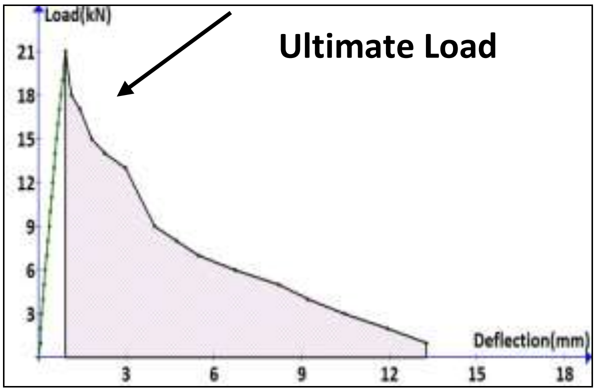
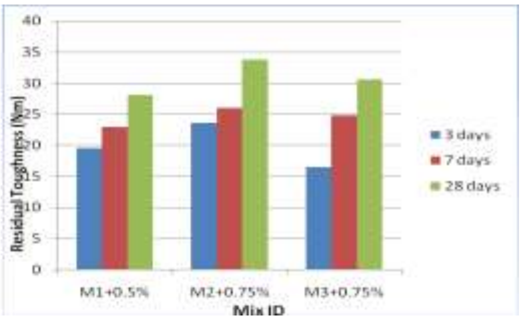


Fig 8 28th day Post crack toughness for

Fig 9 28th day Post crack toughness for M2+0.75%.
M3+0.75%

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. Fig 10 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 Fig11-13 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.



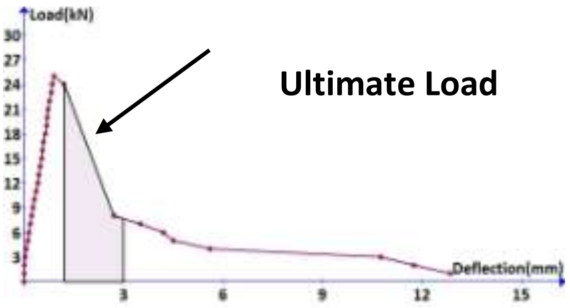
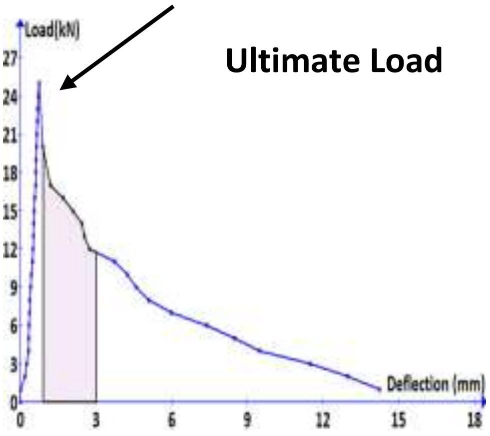

Ultimate Load

Fig 10 Comparison of Residual toughness

at various ages of concrete

Fig 11 Residual toughness for M1+0.5%


Ultimate Load

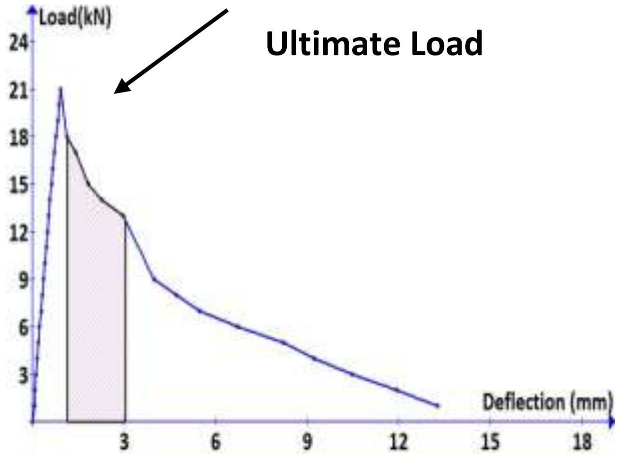

Ultimate Load

Fig 12 Residual toughness for M2+0.75%

Fig 13 Residual toughness for M2+0.75%

Flexural toughness

It is measured from the area under the load deflection curve of concrete in flexure until a deflection of 1/150times 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. From Fig 14, it is observed that 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.

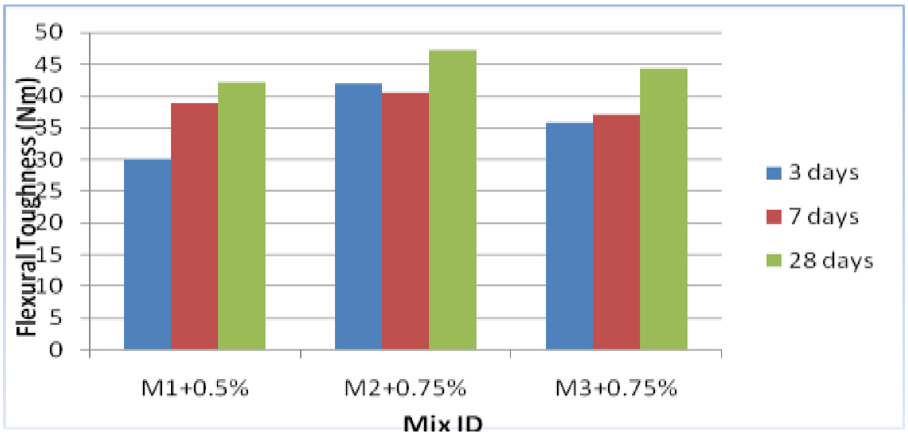


Fig 14 Comparison of Flexural toughness at various ages of concrete.

Punching shear

To understand the punching shear failure, load-displacement plot were drawn and presented in Fig15-16.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 specimens fails in punching shear.The results from Fig 16, 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. Failure mode observed in the specimen 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.

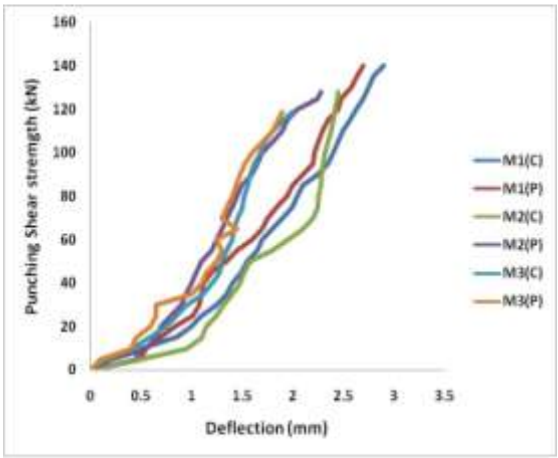


Fig 15 Punching shear strength –deflection response of non fibrous concrete.

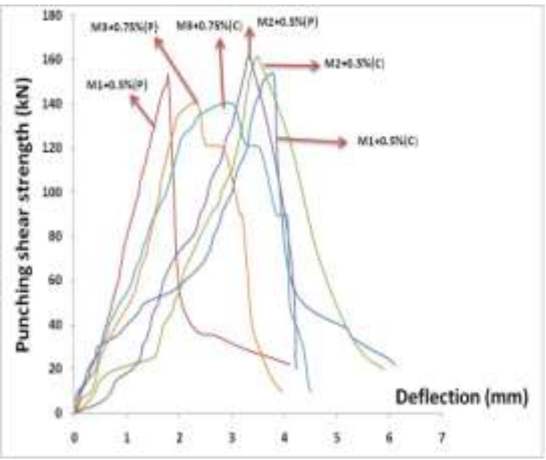


Fig 16 Punching shear strength –deflection response of fibrous concrete.

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

I. 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.

II. The influence of steel fibres in the flexural strength of concrete is superior to tensile and compressive strengths.

III. Absolute toughness was improved by 20% with the addition of 0.75% volume fraction of steel fibres as compared to control mix.

IV. Behavior 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.

V. 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.

VI. 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.

VII. Punching shear capacity was increased by 26% with the addition of 0.75% volume fraction of fibres, in comparison with control concrete.

VIII. 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.

IX. Specimen with higher grade concrete had higher energy absorption capacity and punching shear strength than a specimen with lower grade concrete, for constant volume fraction of fibres.

X. On the whole, 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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