EXPERIMENTAL INVESTIGATIONS ON THE FLEXURAL STRENGTH OF HIGH STRENGTH FIBRE REINFORCED SELF COMPACTING CONCRETE

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ABSTRACT

High performing concretes are extremely popular and are important to deliver next generation concrete structures. High strength fibre reinforced self-compacting concrete provides the combined benefits of high strength, extremely improved placeability and enhanced ductility and crack resistance. The present study intends to experimentally investigate the performance of high strength self-compacting concrete reinforced with steel and sisal fibres in order quantify the improvement in the flexural behaviour due to fibre reinforcement.

Beam specimens are cast for high strength self-compacting concrete of grades M60 and M70 with varying amount of steel and sisal fibre reinforcement. The flexural strength and the deformation at failure of the specimen are monitored to assess the performance of concrete under flexure. The results of the experimental investigations demonstrate the improved performance of the concrete specimen due to incorporation of fibres both in terms of flexural strength and deformation capacity. Also, the type of fibre and volume fraction of fibre reinforcement had a significant impact on the flexural properties of the specimen.

Key Words: Fibre reinforced self-compacting concrete, High Strength, Flexural strength, Deformation capacity, Ductility.

INTRODUCTION

High performance concrete aims to enhance the overall performance of the concrete to deliver improved properties for specific intended purposes. Some of the key performance parameters that are aimed to be enhanced include strength, workability and ductility of concrete. High Strength Concretes (HSC) address the strength part of the performance delivering concretes with compressive strengths greater than 60 MPa. The high workability requirement to place concrete in narrow sections with dense reinforcement was addressed by the advent of Self-Compacting Concrete (SCC). Increased ductility or the deformation capacity of concrete is another key parameter which is essential to deliver satisfactory seismic performance. One of the popular methods to enhance the ductility and energy absorbing capacity of concrete is the incorporation of fibres into the concrete resulting in Fibre Reinforced Concrete (FRC).

A High Strength Fibre Reinforced Self-Compacting Concrete (HSFRSCC) is a special breed of concrete aimed to achieve all the above-mentioned performance attributes. High strength, increased placability and high ductility combine to make this concrete a truly special concrete. However, experimental investigations are necessary to assess and quantify the performance of concrete in each of the attributes and evaluate the influence of various parameters involved on the performance of concrete. In the present study an experimental investigation is carried out to assess the performance of high strength fibre reinforced self-compacting concrete under flexure.

Many previous researchers have carried out investigations to assess the performance of fibre reinforced self-compacting concrete. However, there is still scope for research in this area to accurately quantify the performance of this type of special concrete. Continued comprehensive experimental investigations on the performance of fibre reinforced self-compacting concrete can contribute a great deal to understand and assess the performance of fibre reinforced self-compacting concrete under various parameters. The present study intends to carry out an experimental study on the flexural performance of HSFRSCC and the influence of some of the parameters affecting the same.

MATERIALS AND METHODOLOGY

The major objective of the present study is to evaluate the performance of HSFRSCC under flexure and to understand the influence of type and volume fraction of fibres on the flexural strength and deformation capacity of concrete. The composition of the concrete used for the study are as explained below.

Cement: Ordinary Portland cement (OPC) of grade-53 conforming to all the required specification was used for the experimental study conforming to IS 12269:1987 [3] are shown in table 1.

Table 1. Properties of Cement

Parameter	**Value**
Specific Gravity	3.12
Fineness	5%
Standard consistency	32%
Soundness by Le-chatelier apparatus	4mm
Initial setting Time	58 mins
Final setting time	380 mins
Compressive Strength	58.2 MPa

Aggregates: Locally available crushed granite of size 12mm and downsize conforming to the local codal requirement were used as coarse aggregate. The manufacture sand obtained by crushers is used as fine aggregate. Table 2 and table 3 lists the properties of aggregates used as per IS 383:2016 [4].

Table 2. Properties of Fine Aggregates

Parameter	**Value**
Specific Gravity	2.61
Loose Density	1463 kg/cum
Water Absorption	0.9%
Gradation from sieve analysis	Zone 2

Table 3. Properties of Coarse Aggregates

Parameter	**Value**
Specific Gravity	2.64
Loose Density	1450 kg/cum
Water Absorption	0.5%

Water: Portable water was used for mixing and curing of concrete.

Chemical Admixtures: In order to achieve the required workability a commercially available super plasticizer 'Master Glenium-123' is used. A viscosity modifying admixture (VMA) is essential to maintain the viscosity of concrete during flow. For this purpose, 'Master Matrix-110' a commercially available VMA is used for the present mix.

Mineral Admixtures: Ground Granulated Blast Furnace Slag (GGBS) conforming to the required specifications was used a pozzolanic material. Use of pozzolanic material allows the increased cementitious material in the mix while keeping the heat of hydration under control. It also enables the increased 'fine material' content in the concrete required for a self-compacting concrete.

In order to achieve high concrete strength ultra fine supplementary cementitious material in the form of silica flume is used.

Fibres: For the present study one artificial fibre in the form of steel fibre and one natural fibre in the form of sisal fibre is considered. The properties of the fibres are as listed below.

Table 4. Properties of Fibres

Properties	**Steel Fibres**	**Sisal Fibres**
Length	35mm	35mm
Diameter	0.5mm	0.2 mm
Tensile strength	1150 MPa	335 MPa
Density	7.85 g/cc	1.58 g/cc
Modulus of Elasticity	210 GPa	15.83 GPa

Steel Fibres

Sisal Fibre

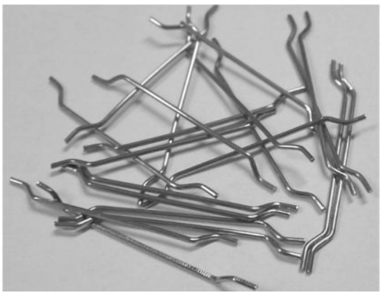 

Fig.1 Steel and Sisal Fibres used

Mix Proportioning: The initial mix proportioning is carried out for M60 and M70 grades of concrete considering the guidelines in IS 10262:2019 [2] and Nan Su et al [10]. Trial mixes are carried out in order to assess the fresh properties of self-compacting concrete and flow requirements are assessed using L-Box, J ring, U Box, T500 and flow table tests. Based on the findings of the flow test results suitable adjustments are made to the quantity of superplasticizer and VMA to meet the flow requirements as detailed in IS 10262:2019.

Flow tests are also carried out with fibre reinforcements. The desirable volume fraction of steel and sisal reinforcements to maintain the flow requirements for the present mix proportion are also established. It is found that the effective range of volume fraction to retain filling and passing ability requirements are 0.25% to 0.75% for both steel and sisal fibres[11].

Trial mixes are also cast to ensure the strength achievement of the mix. Minor adjustments are adopted for the quantity of cementitious materials and silica fume to meet the strength requirements. The following table lists the final mix proportion adopted for the high strength self-compacting concrete.

Table 5. Mix Proportions

Material	M60 Mix (kg/cum)	M70 Mix (kg/cum)
Cement	432	427
GGBS	131	192
Silica Fume	18	22.5
Water	167 (Litres)	157(Litres)
Fine Aggregate	934	940
Coarse Aggregate	698	704
Chemical Admixture	6.5(Litres)	7.25(Litres)

EXPERIMENTAL PROGRAM

The experimental investigations carried out on the fresh properties of concrete are not dealt with in detail here as the focus of study is to assess the flexural properties of concrete. The specimen cast include high strength self-compacting concrete with and without fibre reinforcement. Both sisal and steel fibres are used as fibre reinforcements in the study. Further, the volume fraction of the fibre reinforcement is varied to understand the influence of volume fraction of fibres on the flexural properties of concrete.

The following table lists the various specimens cast for the experimental program.

Table 6. Various Specimens with designations

Designation	Specimen
Grade M60	
S100	HSCC without fibre reinforcement
S101	HSFRSCC with 0.25% of steel fibre reinforcement
S102	HSFRSCC with 0.5% of steel fibre reinforcement
S103	HSFRSCC with 0.75% of steel fibre reinforcement
S104	HSFRSCC with 0.25% of sisal fibre reinforcement
S105	HSFRSCC with 0.5% of sisal fibre reinforcement
S106	HSFRSCC with 0.75% of sisal fibre reinforcement
Grade M70	
S200	HSCC without fibre reinforcement
S201	HSFRSCC with 0.25% of steel fibre reinforcement
S202	HSFRSCC with 0.5% of steel fibre reinforcement
S203	HSFRSCC with 0.75% of steel fibre reinforcement
S204	HSFRSCC with 0.25% of sisal fibre reinforcement
S205	HSFRSCC with 0.5% of sisal fibre reinforcement
S206	HSFRSCC with 0.75% of sisal fibre reinforcement

Beam specimens of dimension 100mm x 100mm x 500mm are cast for the above-mentioned cases and are subjected to two-point bending test using a universal testing machine. The test is carried out under load-controlled condition and the load vs deformation is noted at each interval until failure. The failure load and deformation are observed and compared to assess the behaviour under flexure.

Fig.2 Two point load flexural testing on beam specimen

RESULTS AND DISCUSSIONS

The tests on the fresh properties of HSFRSCC indicated that the effective range of fibre reinforcement for both steel and sisal fibre are between 0.25% and 0.75%. Fibre reinforcement beyond 0.75% have found to result in flow characteristics that do not meet the requirements of self-compacting concrete [11]. Hence, the maximum fibre reinforcement is restricted to 0.75% in the present study.

The table below shows the modulus of rupture and deflection at failure of high strength self-compacting concrete with different amounts of steel fibre reinforcement as obtained by the two-point bending test.

Table 7. Results of flexural test for M60 Grade concrete with steel fibre reinforcement

Specimen designation	Grade of concrete and type of fibre used	Volume fraction of fibre reinforcement (%)	Modulus of Rupture in MPa	Maximum Deflection in mm
S100	M60 – Steel fibre reinforcement	0	6.32	0.118
S101		0.25	7.45	0.122
S102		0.5	7.92	0.127
S103		0.75	8.01	0.129

Table 8. Results of flexural test for M70 Grade concrete with steel fibre reinforcement

Specimen designation	Grade of concrete and type of fibre used	Volume fraction of fibre reinforcement (%)	Modulus of Rupture in MPa	Maximum Deflection in mm
S200	M70 – Steel fibre reinforcement	0	6.91	0.121
S201		0.25	7.69	0.125
S202		0.5	7.99	0.129
S203		0.75	8.21	0.131

The variation of modulus of rupture and maximum deflection of M60 and M70 grade concrete specimen with the volume fraction of steel reinforcement is shown below.

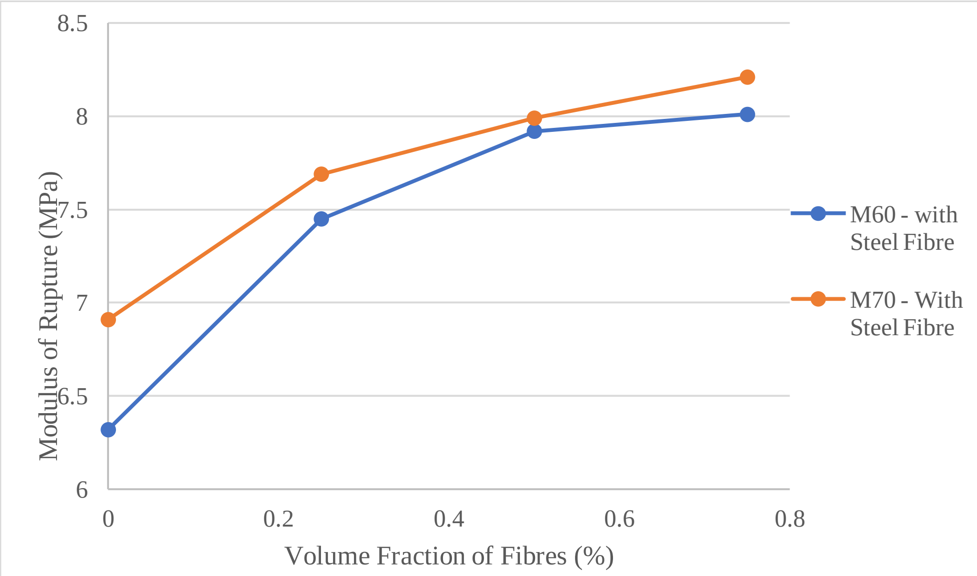

Fig.3 Variation of Modulus of Rupture of concrete with volume fraction of steel fibre reinforcement

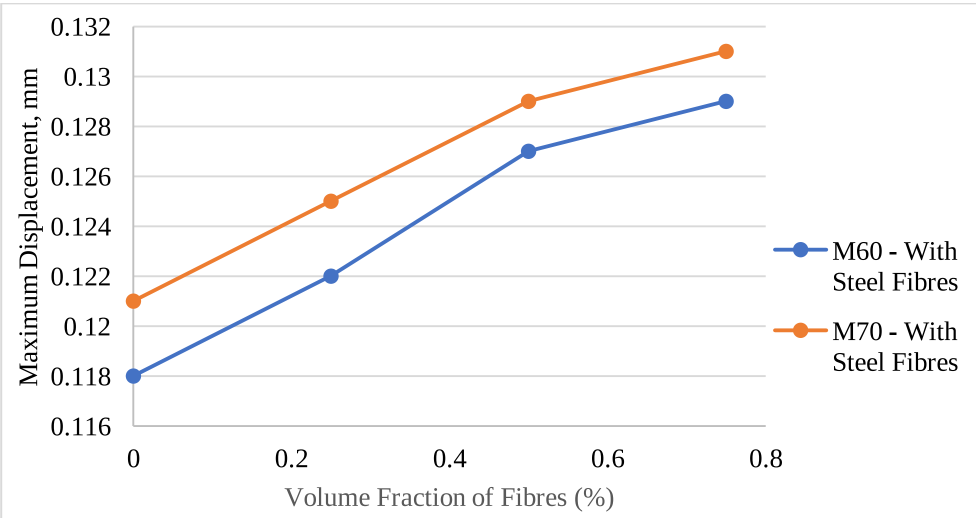

Fig.4 Variation of maximum displacement of concrete with volume fraction of steel fibre reinforcement

Incorporation of steel fibre has resulted in increased modulus of rupture indicating increased flexural strength and increased maximum deflection at failure indicating increased ductility. The maximum increase in the modulus of rupture and maximum deflection due to fibre reinforcement were 26.7% and 9.3% respectively.

The table below shows the modulus of rupture and deflection at failure of high strength self-compacting concrete with different amounts of sisal fibre reinforcement as obtained by the two-point bending test.

Table 9. Results of flexural test for M60 Grade concrete with sisal fibre reinforcement

Specimen designation	Grade of concrete and type of fibre used	Volume fraction of fibre reinforcement (%)	Modulus of Rupture in MPa	Maximum Deflection in mm
S100	M60 – Sisal fibre reinforcement	0	6.32	0.118
S104		0.25	6.99	0.12
S105		0.5	7.1	0.123
S106		0.75	7.25	0.126

Table 10. Results of flexural test for M70 Grade concrete with sisal fibre reinforcement

Specimen designation	Grade of concrete and type of fibre used	Volume fraction of fibre reinforcement (%)	Modulus of Rupture in MPa	Maximum Deflection in mm
S200	M70 – Sisal fibre reinforcement	0	6.91	0.121
S204		0.25	7.1	0.124
S205		0.5	7.35	0.126
S206		0.75	7.5	0.127

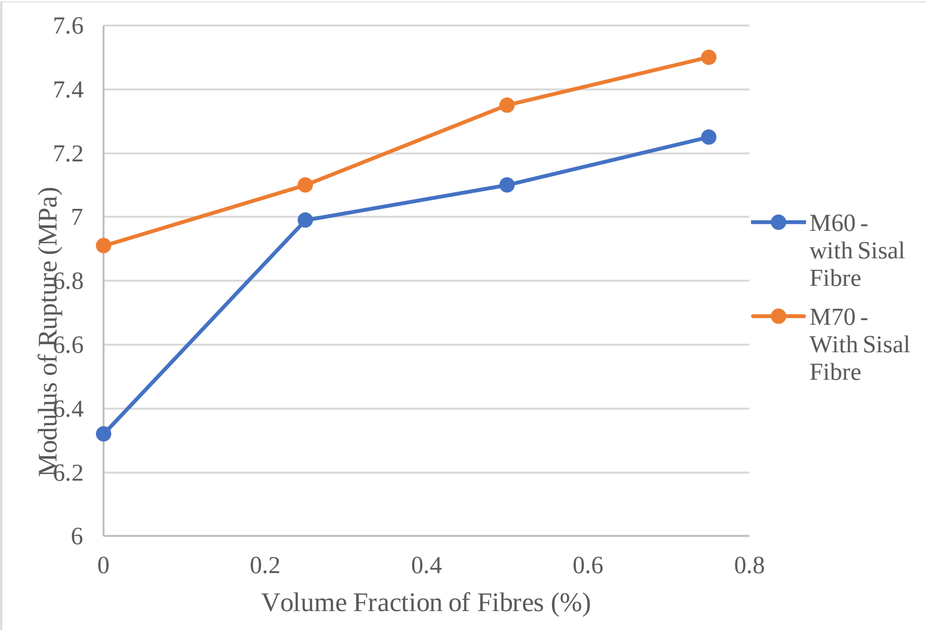

Fig.5 Variation of Modulus of Rupture of concrete with volume fraction of sisal fibre reinforcement

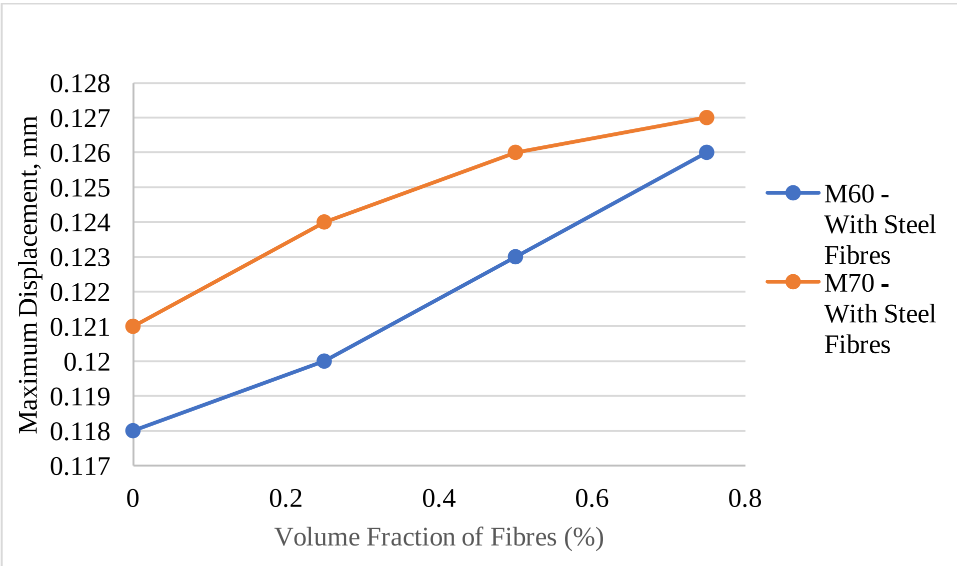

Fig.6 Variation of maximum displacement of concrete with volume fraction of sisal fibre reinforcement

Incorporation of sisal fibre has resulted in increased modulus of rupture indicating increased flexural strength and increased maximum deflection at failure indicating increased ductility. The maximum increase in the modulus of rupture and maximum deflection were 14.7% and 6.75% respectively.

CONCLUSIONS

The present study is carried out with an aim to investigate the flexural performance of high strength self-compacting concrete reinforcement with steel and sisal fibres. Following are the conclusions drawn from the study.

- Incorporation of steel and sisal fibres (in the effective range of up to 0.75% for HSSCC) resulted in the improvement of modulus of rupture and maximum deflection of the specimen.
- The incorporation of steel and sisal fibres have resulted in the increase in the modulus of rupture of concrete specimen up to 26.7% and 14.7% respectively.
- The HSFRSCC specimen showed higher deformation capacity at failure when reinforced with steel and sisal fibres. The maximum increase in deformation capacity was found to be 9.3% and 6.75% with steel and sisal fibres respectively.
- Incorporation of steel fibres have found to be more effective in improving the flexural capacity and ductility of the HSFRSCC specimen in comparison to that of sisal fibre.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.