INVESTIGATION ON THE STRENGTH PROPERTIES OF HYBRID FIBRE REINFORCED SELF COMPACTING CONCRETE

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ABSTRACT. Self-Compacting Concrete (SCC) is a high performance concrete which flows under its own weight through restricted sections without segregation, bleeding and does not require any external vibration for compaction. Incorporation of fibres enhances hardened properties of SCC. Therefore the main objective of this paper is to study the fresh properties of hybrid fibre reinforced self-compacting concrete (HFR–SCC) such as T_{50cm} (sec), flow spread (mm), L-box (H_2/H_1), V- funnel time (sec) reinforced with different hybrid fibres and the hardened properties of HFR- SCC such as compressive strength, flexural strength and split tensile strength at ages of 7 & 28 days. Seven number of mix of different proportions of steel and basalt fibres are used. Percentages of steel and basalt fibres used in respective mix are 0%, 0.25% and 0.5% by volume of concrete fractions. The merging of different fibres in the mix has been found to strengthen the properties of hardened HFR-SCC in terms of its compressive strength, tensile strength and flexural strength. The properties of fresh HFR-SCC (T_{50cm} flow, slump flow, L-box, V- funnel) decreases with an increase of amount of fibres content. Addition of basalt fibres improves compressive strength and reduces cracks in the concrete mix. Addition of steel fibres improves split tensile strength as well as flexural strength.

Keywords: Self Compacting Concrete, Hybrid Fibre Reinforced Self Compacting Concrete, Steel Fibres, Basalt Fibres

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INTRODUCTION

Self-compacting concrete is a high performance concrete which flows under its own weight through restricted sections without bleeding and segregation [1]. Self-compacting concrete does not require any external vibration for consolidation [15]. Self-compacting concrete completely fills the formwork and achieves full compaction even in the presence of heavily congested reinforcement mesh. The production process of SCC is same as that of normal conventional concrete, but its production requires suitable selection of aggregates and finely ground cementitious materials along with proper water powder (w/p) ratio to maintain its workability without bleeding and segregation. Proper selection of finely ground aggregates increases the packing density of solid particles and enables the reduction of water content. For producing SCC incorporation of highly finely ground powder (fly ash and silica fume) is necessary to enhance the slump value and cohesiveness. Further water reducing admixtures or super plasticizer (SP) and viscosity modifying agents (VMA) are also used in producing SCC.

Fibre reinforced self-compacting concrete (FRSCC) is produced from cement, various size of aggregates which incorporate with fibres. FRSCC as concrete containing dispersed randomly oriented fibres [26]. As any other cement-based materials, the SCC has a brittle nature. To improve its mechanical properties as well as the behavior under the impact, different kinds of fibres can be applied. Fibres are spread uniformly in the mix, which prevents or delays initiation and propagation of mix cracking. This supplement changes large single cracks into a system of multiple smaller cracks, which is desired from safety and durability point of view [23]. According to the material and geometrical parameters like: diameter, length, aspect ratio, longitudinal profile and cross-sectional shape, the fibres enhances the mechanical parameters of the mix under tension and flexure. Among the fibres available in the market the best performance can be observed for steel fibres [17]; [22].

Hybrid fibre reinforced self-compacting concrete (HFR-SCC), it is a new kind of composite material produced adding different type, shape and dimensions of fibres in a SCC [14]. Adding two or more fibres to the concrete mix enhances the strength of the concrete and it is known as HFR-SCC. The fracture properties of concrete get increased upon the addition of fibres. Addition of steel fibres improves the flexural strength as well as the deflection capacity. The formation of micro cracks can be reduced when fibres are used. Inclusion of hybrid fibres reduces the generation of first crack and increases the failure load [18].

EXPERIMENTAL INVESTIGATION

The objective is to study the properties of fresh HFR–SCC such as T_{50cm} (sec), flow spread (mm), L-box (H_2/H_1), V- funnel time (sec), properties of hardened HFR-SCC such as compressive strength, flexural strength and split tensile strength at ages of 7 and 28 days. Seven number of mix of different proportions of steel and basalt fibres has been used in present experimental programme. Percentage of steel and basalt fibres used in respective mix has been tabulated in Table 1. In each mix, six cubes of (150 mm x 150 mm x150 mm), six beams of (100 mm × 100 mm × 500 mm) and six cylinders of (150 mm × 300 mm) specimens has been casted in order to determine the compressive strength, flexural strength and split tensile strength of HFR-SCC. Details of mix proportions are shown in Table 2.

Table 1 Experimental programme of HFR-SCC

SR. NO.	MIX	FIBRE PROPORTION (%)	
		STEEL FIBRES	BASALT FIBRES
1	M-S0-B0	0	0
2	M-S0.25-B0	0.25	0
3	M-S0.25-B0.25	0.25	0.25
4	M-S0.25-B0.5	0.25	0.5
5	M-S0.5-B0	0.5	0
6	M-S0.5-B0.25	0.5	0.25
7	M-S0.5-B0.5	0.5	0.5

Table 2 Mix proportions of SCC

CEMENT (kg/m^3)	FLY ASH (kg/m^3)	FINE AGGREGATES (kg/m^3)	COARSE AGGREGATES (kg/m^3)	WATER (liters)	SUPER PLASTICIZER (liters)
410	205	846	602	246	7.2

Materials Used

Ordinary Portland Cement - 43 grade was used to carry out the research work. Physical properties of cement are presented in Table 3. Tape water was used for all mixtures. Natural river sand of zone II was used as fine aggregates. The maximum size of aggregates was limited to 12.5 mm. Physical properties of coarse aggregates are presented in Table 4. Master Genelium SKY 8765 was used as high range water reducing admixture. Technical data of super plasticizer are presented in Table 8. In the present paper, the hybrid mixes were prepared with the use of steel and basalt fibres. Composition and technical data of basalt fibres are shown in Table 5 & 6. Technical data of steel fibres are shown in Table 7.

Table 3 Physical properties of OPC (Grade -43)

SR. NO.	PROPERTY	UNITS	RESULT OBTAINED	PERMISSIBLE RANGE SPECIFIED (IS: 8112-1989)
1	Specific gravity	-	3.15	3.10-3.15
2	Normal consistency	%	32	30-35
3	Initial setting time	minutes	65	30 (minimum)
4	Final setting time	minutes	410	600 (maximum)
5	Soundness (expansion by Le – Chatelier test)	mm	3	10 (maximum)
6	Fineness (specific surface)	cm^2/gm	2340	2250 (minimum)
7	Compressive strength			
	7 days	MPa	35.50	33.00 (minimum)
	28 days		45.10	43.00 (minimum)

Table 4 Physical properties of coarse aggregates

SR. NO.	PROPERTY	RANGE OF VALUES
1	Crushing strength	22.8%
2	Fineness modulus	6.925
3	Water absorption	0.77 %
4	Specific gravity	2.72

Figure 1 Chopped basalt fibres

Figure 2 Round crimped steel fibres

Table 5 Composition of basalt fibres

SR. NO.	CHEMICAL NAME	PERCENTAGE
1	SiO_2	51.6 % - 59.3%
2	Al_2O_3	14.6% - 18.3%
3	CaO	5.9% - 9.4%
4	MgO	3.0% - 5.3%
5	$Na_2O + K_2O$	3.6% - 5.2%
6	TiO_2	0.8% - 2.25%
7	$Fe_2O_3 + FeO$	9.0% - 14.0%
8	Others	0.09%- 0.13%

Table 6 Technical data of basalt fibres

SR. NO.	PARAMETERS	CORRESPONDING VALUES
1	Appearance	Golden brown fibres
2	Odour	Odourless
3	pH	Not applicable
4	Density	2.6g/cm^3
5	Diameter	6 micron
6	Length	12 mm
7	Melting point	Higher than 1450^{0}C

Table 7 Technical data of steel fibres

SR. NO.	PARAMETERS	CORRESPONDING VALUES
1	Length	30 mm
2	Diameter	0.5 mm
3	Aspect ratio	60
4	Ultimate strength	1100 MPa

Table 8 Technical data of super plasticizer- Master Glenium SKY 8765

SR. NO.	PARAMETERS	CORRESPONDING VALUES
1	Aspect	Light brown free flowing liquid
2	Relative density	1.07 ± 0.01 at 25^{0}C
3	pH	>6 at 25^{0}C
4	Chloride ion content	<0.2%

RESULTS OF PROPERTIES OF FRESH HFR-SCC

Table 9 Results of properties of fresh HFR-SCC

SR. NO.	MIX	% FIBRES	T_{50}CM (SEC)	FLOW SPREAD (MM)	L-BOX (H_2/H_1)	V-FUNNEL TIME (SEC)
1	M-S0-B0	0	3.2	760	0.97	6.7
2	M-S0.25-B0	0.25	3.5	750	0.94	7.4
3	M-S0.25-B0.25	0.5	3.7	740	0.93	7.7
4	M-S0.25-B0.5	0.75	3.8	735	0.87	8.4
5	M-S0.5-B0	0.5	3.7	724	0.89	7.6
6	M-S0.5-B0.25	0.75	3.8	705	0.86	7.8
7	M-S0.5-B0.5	1	4.1	700	0.85	8.6

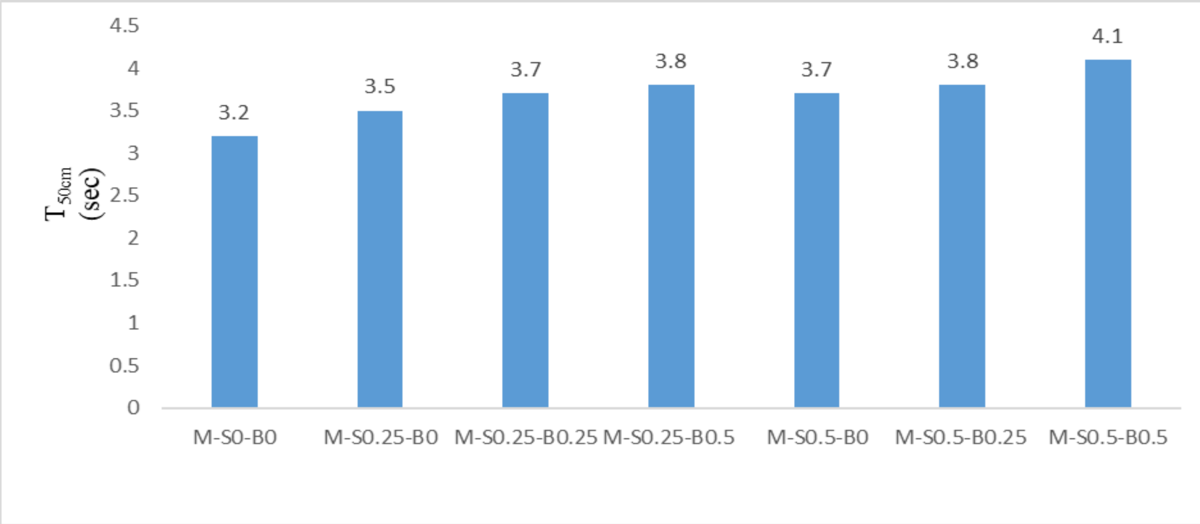

Figure 3 Variation of T_{50cm} for HFR-SCC mixes

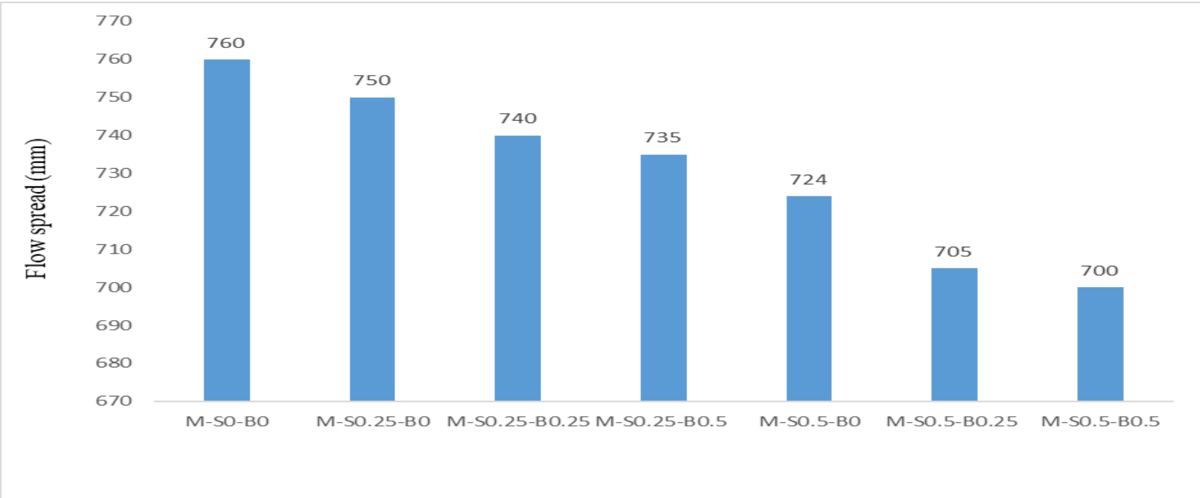

Figure 4 Variation of flow spread for HFR-SCC mixes

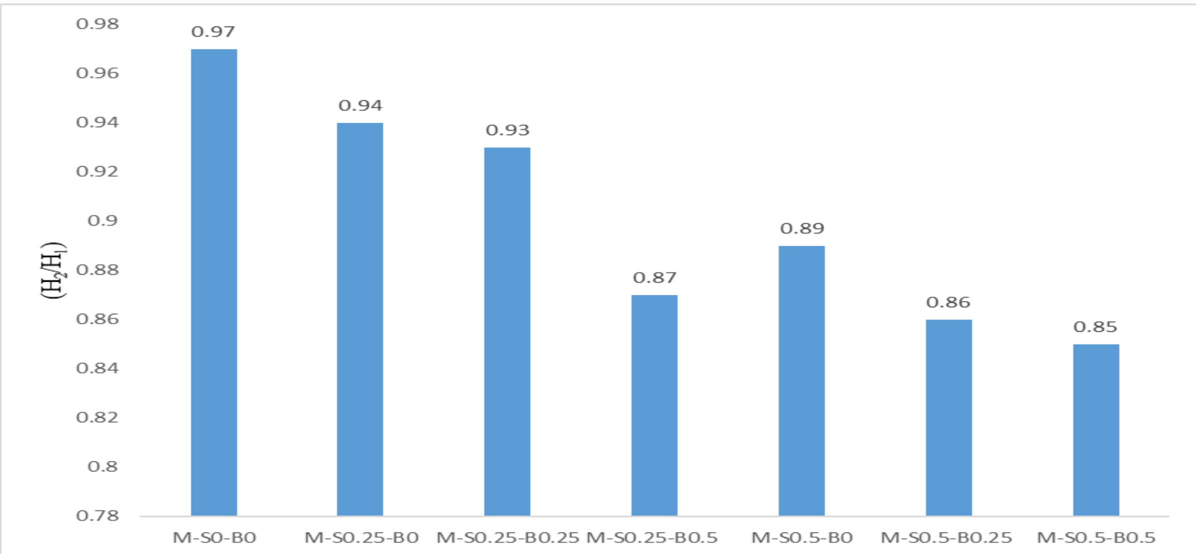

Figure 5 Variation of L-box (H_2/H_1) for HFR-SCC mixes

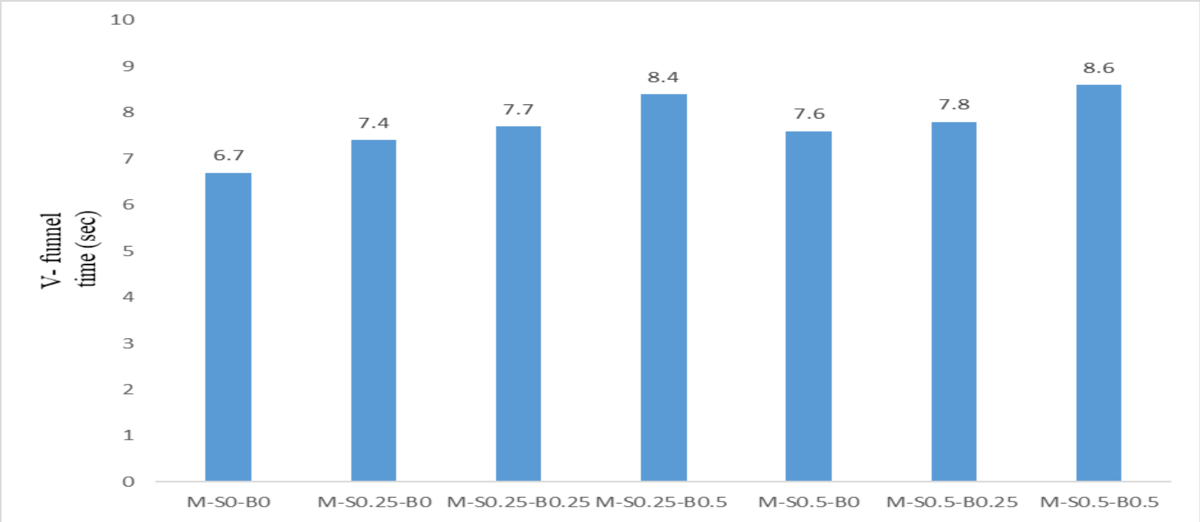

Figure 6 Variation of V-funnel time (sec) for HFR-SCC mixes

Table 9 and figure 3-6, indicate reduction of flow value owing to inclusion of fibres. The reason for this phenomenon is that a network structure may form due to the distributed fibres in the concrete, which restrains mixture from segregation and flow.

Slump Flow

The slump flow decreases with increase in fibres percentage. The decrease in flow value was observed maximum 7.9 % for M-S0.5-B0.5 i.e. SCC reinforced with 0.5% steel and 0.5% basalt fibres with respect to the control mix (M-S0-B0). This is because the fibres percentage is maximum in this mix as compare to other mixes.

T_{50} Flow

The T_{50} flow, which is measured in terms of time (seconds) increases as the slump flow value decreases. The maximum time taken to flow was observed for M-S0.5-B0.5 i.e. SCC reinforced with 0.5% steel and 0.5% basalt fibres. T_{50} flow time 3.7 sec was same for both M-S0.25-B0.25 and M-S0.5-B0 but slump flow value was different. Similar, T_{50} flow time 3.8 sec was same for both M-S0.25-B0.5 and M-S0.5-B0.25.

L-Box

The L-box value increases as the slump flow value increases. The increase in slump value is due to the increase in the percentage of fibres as well as the L-box value also increases. The maximum value obtained in the M-S0-B0 i.e. SCC reinforced with 0% steel and 0% basalt fibres.

V-Funnel

The V-funnel test, which is measured in terms of time (seconds). V-funnel value increases as the slump flow value decreases. The decrease in slump value was due to the increase in the percentage of fibres. It was observed that mix M-S0.5-B0.5 had the maximum V-funnel value whereas M-S0-B0 had the minimum value.

RESULTS OF PROPERTIES OF HARDENED HFR-SCC

To compare the properties of hardened HFR-SCC mixes the standard specimens were tested after 7 days and 28 days of curing. The results are summarized in Table 10-12.

Results of Compressive Strength of HFR-SCC

Table 10 Results of compressive strength of HFR-SCC

SR. NO.	MIX	AVERAGE COMPRESSIVE STRENGTH AT 7 DAYS (N/mm^2)	AVERAGE COMPRESSIVE STRENGTH AT 28 DAYS (N/mm^2)
1	M-S0-B0	30.01	39.40
2	M-S0.25-B0	30.45	39.85
3	M-S0.25-B0.25	32.67	41.92
4	M-S0.25-B0.5	37.85	49.82
5	M-S0.5-B0	35.11	47.40
6	M-S0.5-B0.25	37.11	48.85
7	M-S0.5-B0.5	32.74	42.81

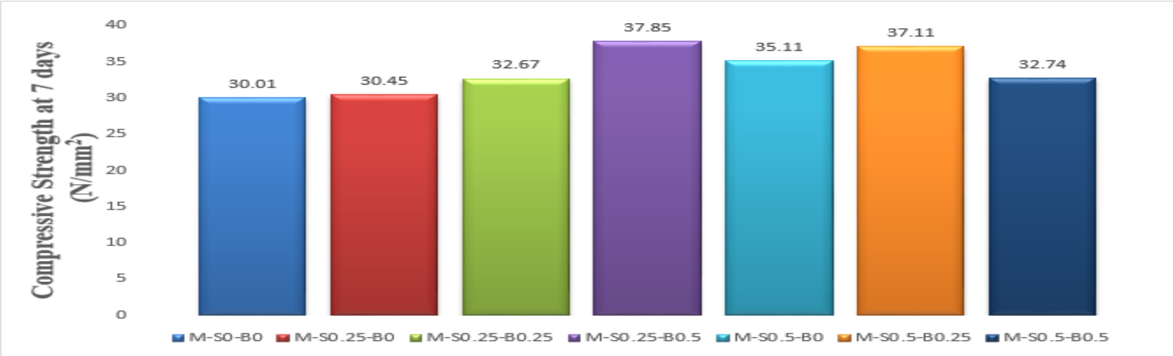

Figure 7 Variation of compressive strength for HFR-SCC mixes at 7days

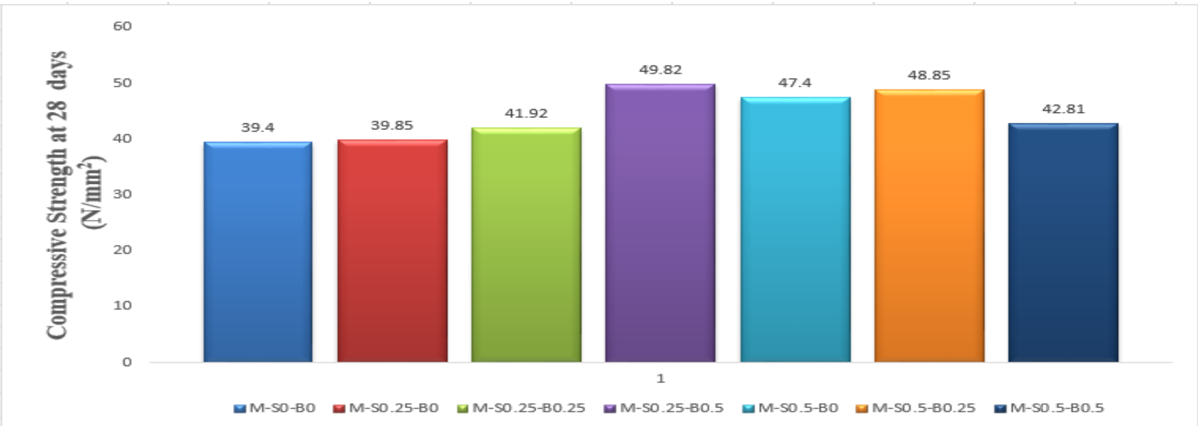

Figure 8 Variation of compressive strength for HFR-SCC mixes at 28 days

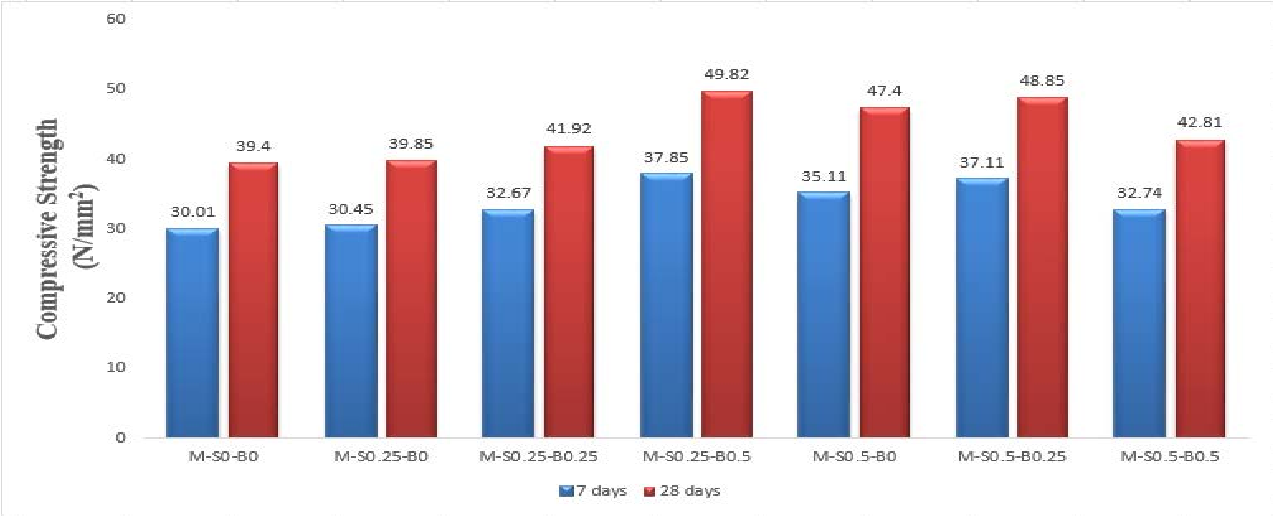

Figure 9 Variation of compressive strength HFR-SCC mixes at 7 and 28 days

Compared to the plain SCC (M-S0–B0), the compressive strength at 28 days of SCC reinforced with steel fibres 0.25% and 0.5% increased by 1.14% and 20.30% respectively. Compared with the plain SCC (M-S0–B0), the compressive strength of SCC reinforced with 0.25% steel and 0.5% basalt fibres (M-S0.25–B0.5) increased by 26.45%. Compared with SCC reinforced with 0.25% steel and 0.25% basalt fibres (M-S0.25–B0.25), compressive strength of SCC reinforced with 0.25% steel and 0.5% basalt fibres (M-S0.25–B0.5) increase by 18.85%. Fig.8 shows that maximum compressive strength at 28 days was 49.82 MPa for M-S0.25-B0.5.

Results of Split Tensile Strength of HFR-SCC

Table 11 Results of split tensile strength of HFR-SCC

SR. NO.	MIX	AVERAGE SPLIT TENSILE STRENGTH AT 7 DAYS (N/mm^2)	AVERAGE SPLIT TENSILE STRENGTH AT 28 DAYS (N/mm^2)
1	M-S0-B0	2.43	3.31
2	M-S0.25-B0	2.48	3.45
3	M-S0.25-B0.25	2.50	3.48
4	M-S0.25-B0.5	2.60	3.53
5	M-S0.5-B0	3.14	4.07
6	M-S0.5-B0.25	3.12	4.02
7	M-S0.5-B0.5	3.02	3.98

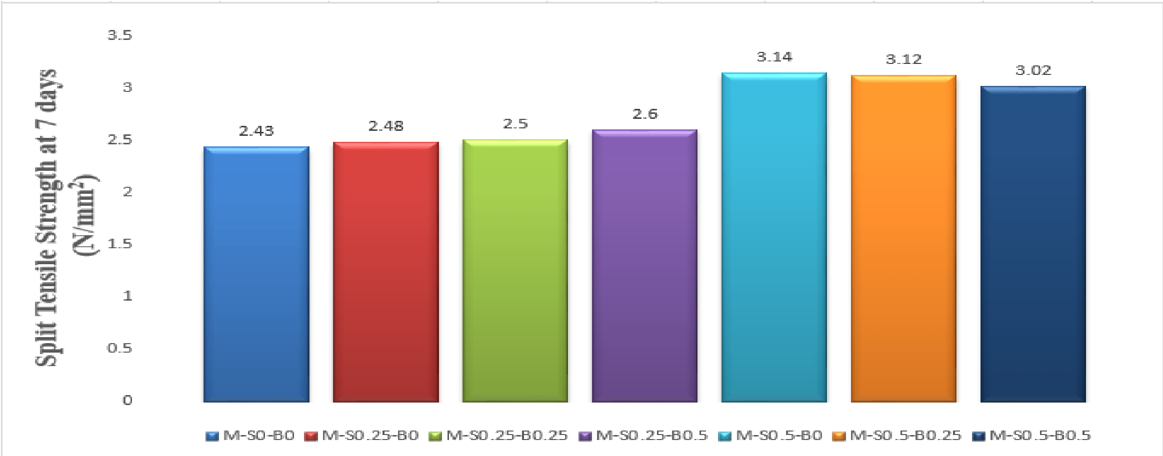

Figure 10 Variation of split tensile strength for HFR-SCC mixes at 7 days

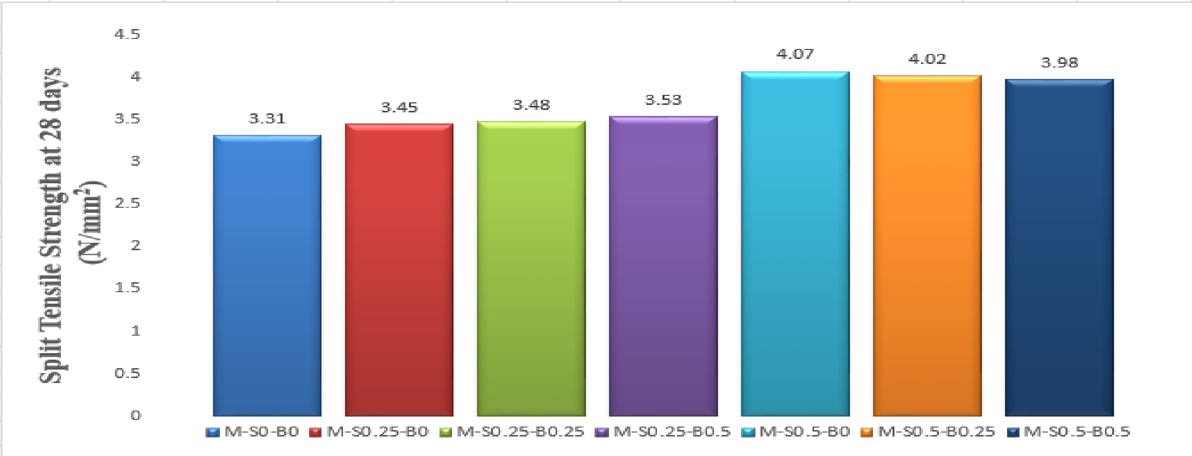

Figure 11 Variation of split tensile strength for HFR-SCC mixes at 28 days

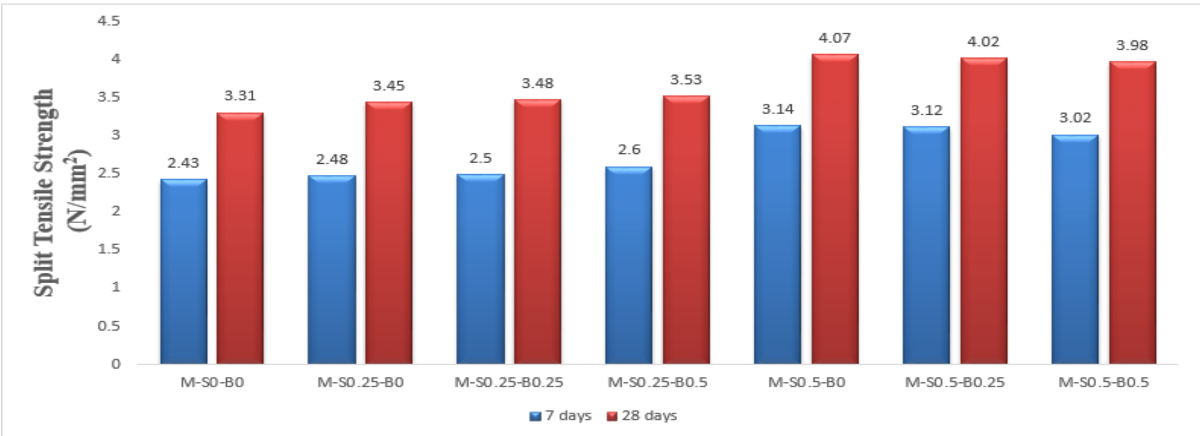

Figure 12 Variation of split tensile strength for HFR-SCC mixes at 7 and 28 days

The percentage enhancement of split tensile strength at 7 days for steel fibres over plain SCC (M-S0–B0) was 2.05% & 29.21 % when added 0.25% & 0.5% respectively. Compared with SCC reinforced with 0.25% steel and 0.25% basalt fibres (M-S0.25–B0.25), 7 days split tensile strength of SCC reinforced with 0.5% steel and 0.25% basalt fibres (M-S0.5–B0.25) increased by 24.8%. Split tensile strength of SCC reinforced with 0.25% steel and 0.25% basalt fibres (M-S0.25–B0.25) at 7 days show no obvious improvement as compared to plain SCC (M-S0–B0). The percentage enhancement of split tensile strength at 28 days for steel fibres over plain SCC (M-S0–B0) was 4.22% & 22.96 % when added 0.25% & 0.5%

respectively. Maximum split tensile strength at 28 days was 4.07 MPa for M-S0.5-B0. Compared with SCC reinforced with 0.5% steel and 0 % basalt fibres (M-S0.5–B0), 28 days split tensile strength of SCC reinforced with 0.5% steel and 0.25% basalt fibres (M-S0.5–B0.25) decreased by 1.24%.

Results of Flexural Strength of HFR-SCC

Table 12 Results of flexural strength of HFR-SCC

SR. NO.	MIX	AVERAGE FLEXURAL STRENGTH AT 7 DAYS (N/mm^2)	AVERAGE FLEXURAL STRENGTH AT 28 DAYS (N/mm^2)
1	M-S0-B0	5.69	7.77
2	M-S0.25-B0	5.95	7.82
3	M-S0.25-B0.25	5.96	7,9
4	M-S0.25-B0.5	6.34	8.31
5	M-S0.5-B0	7.53	9.61
6	M-S0.5-B0.25	6.69	8.34
7	M-S0.5-B0.5	6.1	8.13

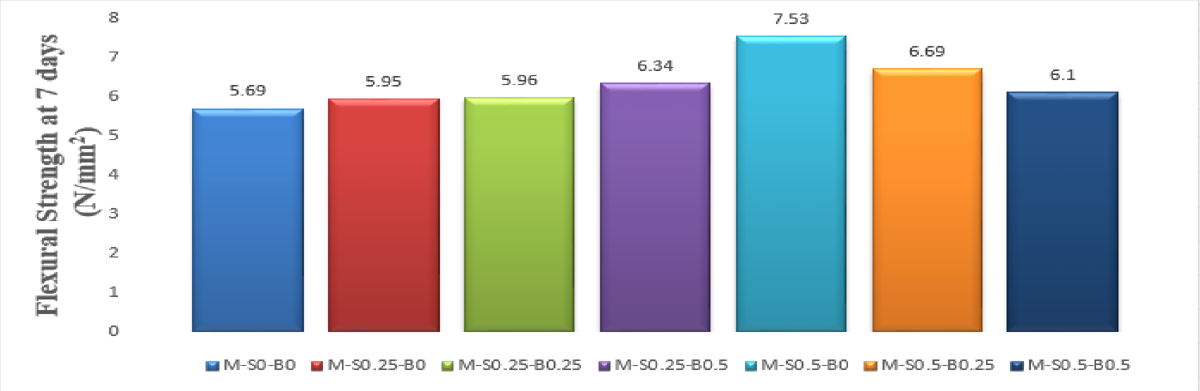

Figure 13 Variation of flexural strength for HFR-SCC mixes at 7 days

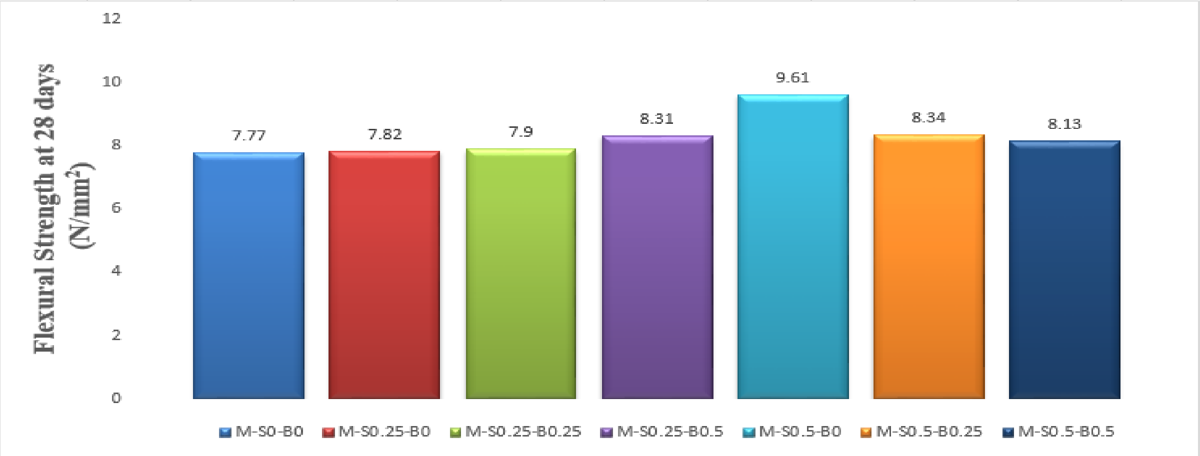

Figure 14 Variation of flexural strength for HFR-SCC mixes at 28 days

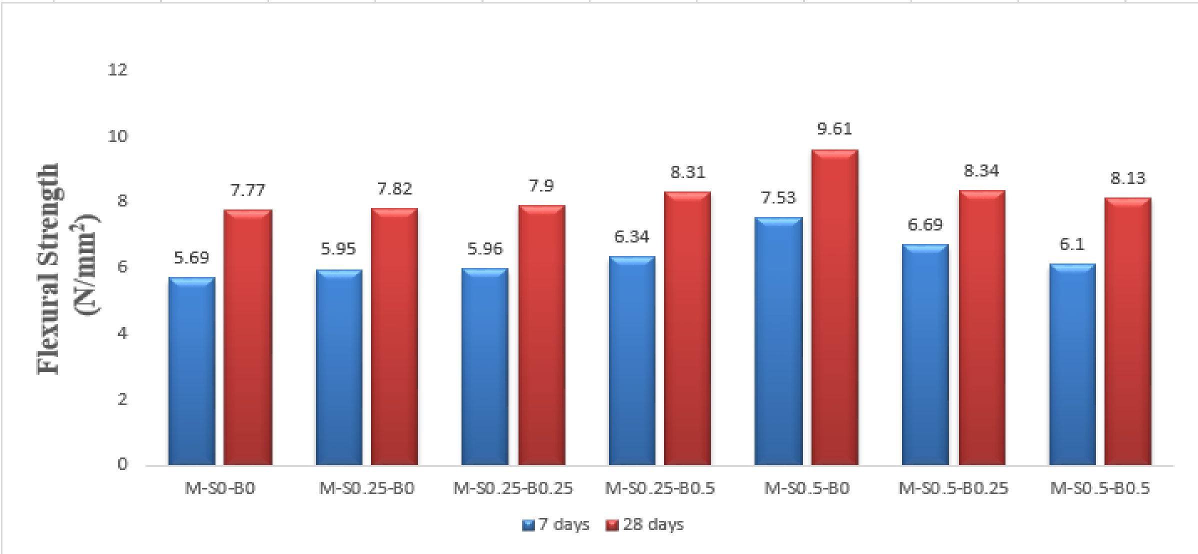

Figure 15 Variation of flexural strength for HFR-SCC mixes at 7 and 28 days

Compared with the plain SCC (M-S0–B0), the enhanced percentage of the flexural strength of SCC reinforced with 0.5% steel fibres (M-S0.5-B0) at 7 days was 32.33%.Compared with SCC reinforced with 0.25% steel and 0.25% basalt fibres (M-S0.25–B0.25), 7 days flexural strength of SCC reinforced with 0.5% steel and 0.25% basalt fibres (M-S0.5–B0.25) increased by 12.24%.The percentage enhancement of flexural strength at 28 days for steel fibres over plain SCC (M-S0–B0) was 23.68 % when added 0.5% . Compared with SCC reinforced with 0.25% steel and 0% basalt fibres (M-S0.25-B0), 28 days flexural strength of SCC reinforced with 0.25% steel and 0.5% basalt fibres (M-S0.25-B0.5) increased by 6.26 %. Maximum flexural strength 9.61MPa was observed for M-S0.5-B0.

CONCLUSIONS

- Addition of fibres to self-compacting concrete causes loss of basic characteristics of SCC measured in terms of slump flow.
- Reduction in slump flow was observed maximum 7.9 % for M-S0.5-B0.5 i.e. SCC reinforced with 0.5% steel and 0.5% basalt fibres with respect to the control mix (M-S0-B0).
- Addition of fibres to self-compacting concrete improve mechanical properties like compressive strength, split tensile strength and flexural strength of the mix.
- Addition of basalt fibres improves compressive strength and reduce cracks in the concrete mix.
- Compared to the plain SCC (M-S0–B0), 28 days compressive strength of SCC reinforced with steel fibres 0.25% and 0.5% increased by 1.14% and 20.30% respectively.
- Compared with the plain SCC (M-S0–B0), 28 days compressive strength of SCC reinforced with 0.25% steel and 0.5% basalt fibres (M-S0.25–B0.5) increased by 26.45%.
- Compared with the SCC reinforced with 0.25% steel fibres (M-S0.25–B0), 28 days compressive strength of SCC reinforced with 0.25% steel and 0.5% basalt fibres (M-S0.25–B0.5) increased by 25.03%.

- 0.5% addition of steel fibres to SCC at 7-days was observed to increase the compressive strength by 17%, split tensile strength by 29.21 % and flexural strength by 32.33% with respect to the plain SCC.
- Addition of steel fibres improves split tensile strength as well as flexural strength.
- Compared with SCC reinforced with 0.25% steel and 0.25% basalt fibres (M-S0.25–B0.25), 7 days split tensile strength of SCC reinforced with 0.5% steel and 0.25% basalt fibres (M-S0.5–B0.25) increased by 24.8%.
- Compared with the plain SCC, the enhanced percentage of the flexural strength of SCC reinforced with 0.5% steel fibres (M-S0.5-B0) at 7 days was 32.33%.

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