Compresive Strength of Steel Fibre Reinforced Concrete and its Application in Deep Underground Engineering

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Abstract— The Steel Fiber Reinforced Concrete (SFRC) is mainly being used to improve the structural strength and reduce the steel reinforcement that is required. Steel fibers of length 60mm and 35mm were used for the test. The specimens were prepared with steel fibers in ratio of 4% to volume of mortar to study the supporting effect of SFRC in a soft rock tunnel. The experiment was done to find the compressive strength of the specimens. The experimental results showed that SFRC can be used instead of plain concrete in a soft rock tunnel because SFRC can withstand large deformations as compared to plain concrete. In the concrete, Blast furnace slag (GGBS), HRWR plasticizer are being used to increase the strength, durability and produce high performance concrete. The specimens casted were subjected to 3 different curing methods namely: Normal Curing, Hot Air Oven Curing and Steam Curing. The results showed that M13 mix showed having 60% steel fiber of 60mm and 40% steel fiber of 35mm gave the best results.

Key words: SFRC, Steel Fiber Reinforced Concrete, Ground Granulated Blast Furnace Slag, High Range Water Reducers, Compressive strength, steel fibres, super plasticizer

I. INTRODUCTION

In deep mines excavation, soft rock plays a major role in mining engineering. Due to these soft rocks large deformations occurs which cannot be resisted by plain concrete, bolting, wire mesh because of elastic brittleness of plain concrete. To improve the mechanics performance and tensile strength of the concrete, steel fibers are being added to it. The steel fibers helps in bridging the cracks that develop in the concrete. Steel fibers also improves the toughness of the concrete beneath any kind of loading. The fiber reinforcements can be treated as aggregate inclusions of same magnitude and thus can be used as a replacement of longitudinal reinforcements in reinforced structural members. The presence of fibers in the concrete enhances the resistance of conventionally reinforced structural members to cracking, deflections and other conditions. The experimental results showed that adding steel fibers to concrete increases the tensile strength of the concrete by 40-50%.

In this project a series of concrete mix were tested with different dosage of steel fibers. GGBS is added to the concrete mix as it helps in attaining higher ultimate strength than concrete made with Portland cement. Also use of HRWR plasticizers done so as to reduce the water content and increase the workability of the concrete.

II. BACKGROUND ON CONCRETE

Concrete is one of the most widely used and useful building material. It can be casted to any particular structural shape like rectangular beam, slabs and columns in a building or a cylindrical water storage tank. Concrete is very easily available and also transported easily to sites. Concrete has a high compressive strength and less tensile strength. To overcome this drawback reinforcement is being done. Most commonly used concrete reinforcement is a steel bar. The concrete has following advantages like high compressive strength, good fire resistance and water resistance and very long service life. It also has following disadvantage like poor tensile strength, low strength per unit weight.

One of the most important property of Steel fiber reinforced concrete (SRFC) is higher resistance to cracking and crack propagation and because of this it has enhanced extensibility, arrest crack by bridging action and has the ability to hold the matrix along even when the cracking of concrete occurs extensively. Thus, it used in soft rock tunnel in deep underground engineering.

III. EXPERIMENT IN MECHANICAL PROPERTIES

The details of materials used in the investigation are as follows:

A. Raw Materials:

- Ordinary Portland cement of grade 53 having 28 days strength of 48 MPa was used having specific gravity of 3.11.
- River sand obtained passing through 4.75 mm IS sieve with fineness modulus 2.5 and specific gravity 2.67 was used as fine aggregate.
- Machine crushed well graded blue granite stone with maximum size of 13mm having fineness modulus 6.9 and specific gravity 2.73 was used as coarse aggregate.
- Hooked end type steel fibers of length 60mm and 35mm having aspect ratio (l/d) 120 and 70 were used. Their specific gravity was 7.9.

Property of fiber	Steel	
Appearance	Hooked	
Length (L)	60mm	35mm
Aspect ratio (l/d)	120	70

Table 1: Dimensions of steel fibers used

- A polycarboxylate ether based super-plasticizer having specific gravity 1.16 was used as chemical admixture (HRWR).
- Ground granulated blast furnace slag was used along with cement to act as a binder.

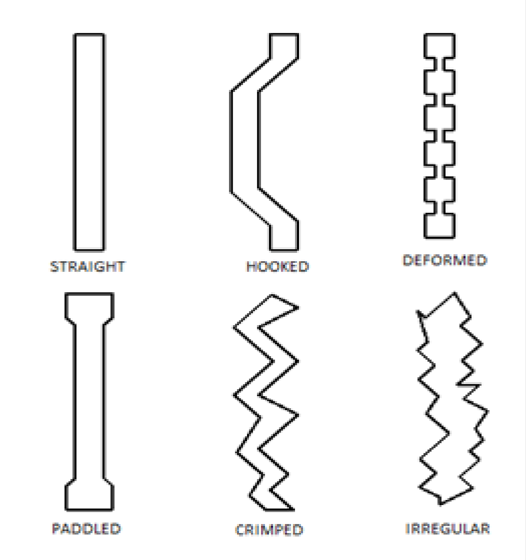

Fig. 1: Shapes of Steel Fibers available in market

B. *Mix ratio:*

- Geometry size = 100x100x100 mm
- Three different combinations of coarse aggregate to mortar were taken.
- Coarse aggregate: mortar = (60%: 40%),
- (50%: 50%), (40%: 60%)
- Mortar = 1:2.68 (binder : fine aggregate)
- Binder (cement + GGBS) = 1:1
- Water content = 0.3% volume of binder
- Steel fiber dosage = 4% volume of mortar
- HRWR dosage = 1% volume of binder.

C. *Specimen Preparation:*

Total 54 cubes were prepared for the test out of which 9 cubes were plain concrete without any reinforcements and 45 cubes were steel fiber reinforced concrete (SFRC). The steel fiber dosage in concrete is being mentioned in Table 2.

These cubic specimens (100x100x100 mm) were used to measure their compressive strength. The cubes were subjected to three different type of curing methods namely normal curing, steam curing and hot air oven curing. The curing was done for 28 days and then the test for compressive strength was done. The results give the 28 day strength for concrete.

MIX NO.	CA: Mortar	SF. Ratio (60mm : 40mm)
M1	60:40	Only 60mm
M2	50:50	Only 60mm
M3	40:60	Only 60mm
M4	60:40	Only 35mm
M5	50:50	Only 35mm
M6	40:60	Only 35mm
M7	60:40	60:40
M8	60:40	50:50
M9	60:40	40:60
M10	50:50	60:40
M11	50:50	50:50
M12	50:50	40:60
M13	40:60	60:40
M14	40:60	50:50
M15	40:60	40:60

Table 2: Mix Proportions (Steel fiber dosage)

For plain concrete cubes were casted having
CA: Mortar ratio (60: 40), (50: 50), (40: 60).
The specification of materials used are shown in Table 3.

D. *Curing Condition:*

In this study, three different type of curing were adopted for the specimens. After remoulding of the concrete, they were

S.no	**Ratio(CA/M)**	**CA**	**FA**	**Binder**		**SF(4% of Vm)**		**Plasticizer**	**Water**
	%	kg	kg	Cement(kg)	GGBS(kg)	kg		ml	ml
	For SF 60 mm								
M1	60-40	4.32	2.1	0.39	0.39	0.114		7.8	234
M2	50-50	3.6	2.61	0.48	0.48	0.141		9.6	288
M3	40-60	2.88	3.18	0.57	0.57	0.171		11.4	342
	For SF 35 mm								
M4	60-40	4.32	2.1	0.39	0.39	0.114		7.8	234
M5	50-50	3.6	2.61	0.48	0.48	0.141		9.6	288
M6	40-60	2.88	3.18	0.57	0.57	0.171		11.4	342
	For SF 60(60mm)-40(35mm)					**60mm**	**35mm**		
M7	60-40	4.32	2.1	0.39	0.39	0.066	0.045	7.8	234
M8		4.32	2.1	0.39	0.39	0.057	0.057	7.8	234
M9		4.32	2.1	0.39	0.39	0.045	0.066	7.8	234
	For SF 50(60mm)-50(35mm)					60mm	35mm		
M10	50-50	3.6	2.61	0.48	0.48	0.084	0.057	9.6	288
M11		3.6	2.61	0.48	0.48	0.069	0.069	9.6	288

M12		3.6	2.61	0.48	0.48	0.057	0.084	9.6	288
	For SF 40(60mm)-60(35mm)					**60mm**	**35mm**		
M13	40-60	2.88	3.18	0.57	0.57	0.105	0.069	11.4	342
M14		2.88	3.18	0.57	0.57	0.084	0.084	11.4	342
M15		2.88	3.18	0.57	0.57	0.069	0.105	11.4	342

Table 3. Specification of Materials used

subjected to normal curing, steam curing and hot air oven curing for a period of 28 days. In normal curing, the specimen was cured in the water bath for 28 days. In hot air oven curing, the specimen were kept in a hot water bath for 3-4 hours and then kept in water bath for normal curing. In steam curing, the specimen were placed in steam chamber for 3-4 hours and then then kept in water bath for normal curing method. These curing methods were adopted so as to accelerate the hardening of the concrete and achieve high early strength. This accelerated hardening helps in removal of formwork thereby reducing cycle time leading to cost savings.

Steam curing is advantageous where early strength of concrete is required or when further heat is needed to accomplish the work. Two types of steam curing used are steam at atmospheric pressure (for enormous precast concrete units) and aggressive steam in autoclaves (for small factory-made units).

E. Test for Compressive Strength:

The testing for compressive strength of specimens casted were done in compressive testing machine having load capacity of 2000kN. The specimens were tested after 28 days and results were noted carefully.

F. Bridging Action By Steel Fibres:

The resistance to pullout of steel fibers is important for the efficiency of concrete. This pullout strength of steel fibers improves the post cracking tensile strength of concrete. In SFRC, the steel fibers provided bridge the cracks which helps in increasing the ultimate strength and greater toughness of the concrete. The fibers play an important role in confining the materials. The resistance to pullout of steel fibers is important for the efficiency of concrete. This pullout strength of steel fibers improves the post cracking tensile strength of concrete. In SFRC, the steel fibers provided bridge the cracks which helps in increasing the ultimate strength and greater toughness of the concrete. The fibers play an important role in confining the materials.

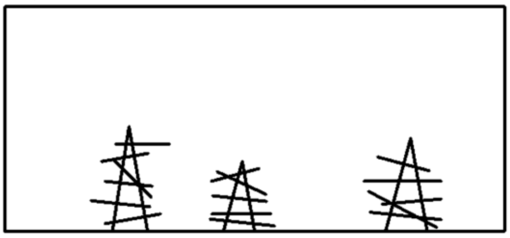

Fig. 2: Bridging action behavior

G. Workability of Concrete:

The steel fibers in concrete, their fiber aspect ratio and volume fraction affects the workability of concrete. As the fiber content increases in the concrete, the workability decreases. Mostly the steel fiber dosage is limited up to 2% of volume of concrete and l/d ratio to 100 to provide a workable mix. To solve the workability problems, modifications are done in concrete by the use of additives.

IV. EXPERIMENT ANALYSIS AND RESULTS

Experiment for compressive strength on specimens were made with the help of compression testing machine. The experimental results show that addition of steel fibers in concrete results in increasing the compressive strength of concrete by 30-40% as compared to plain concrete. Also it was found that steam curing was the better curing method that must adopted so as to increase the compressive strength of the concrete as steam curing accelerates the initial hardening of the concrete. For the results we saw that mix M13 gave the best results for compressive strength. This is because of the good bonding between the hooked shaped steel fibers and the concrete. After the testing few fragments came out of the specimen but the specimen retain their integrity. On the other hand in plain concrete specimens get broken down into many fragments and lose their integrity. Thus this experiment show that SFRC is tougher than plain concrete.

Mix No.	**Normal curing (N/mm^2)**	**Hot oven curing (N/mm2)**	**Steam Curing (N/mm2)**
P1	15.6	17.5	19.8
P2	14.2	15.8	17.3
P3	15.1	19.7	21.1

Table 4: Compressive Strength of plain Concrete

The given two tables compare the compressive strength of plain concrete and SFRC. We have seen from the result that addition of steel fibers to the concrete leads to increase in compressive strength of the concrete by 30-40% respectively. As per previous research by College of Resources and Safety Engineering, Central South University, Changsha, China by WANG Qi-sheng we found that design compressive strengths for SFRC for soft rock tunneling was around 33-35 N/mm^2 which was lesser than the results that we obtained from mix M13. Thus this mix can be used as an application in soft rock tunneling in deep underground engineering. Also additon of GGBS and HRWR admixture was done which lead to increase in ultimate strength of the concrete as well as reducing the water content and increasing the workability of the concrete.

Mix No.	**Normal curing (N/mm^2)**	**Hot oven curing (N/mm2)**	**Steam Curing (N/mm2)**
M1	27.9	30.6	31.7
M2	24.9	28.6	32
M3	21.5	31.4	32.8
M4	20.7	27.9	33.9

M5	34.7	30.7	32.5
M6	33.7	32.9	35.4
M7	27.3	29.2	32.3
M8	25.2	30.1	35.9
M9	29.5	32.5	34.7
M10	25.2	28.7	31.5
M11	18.6	23.3	26.2
M12	21.7	26.4	29.4
M13	32.2	36.8	37.9
M14	26.5	35.6	38.9
M15	24.3	33.9	35

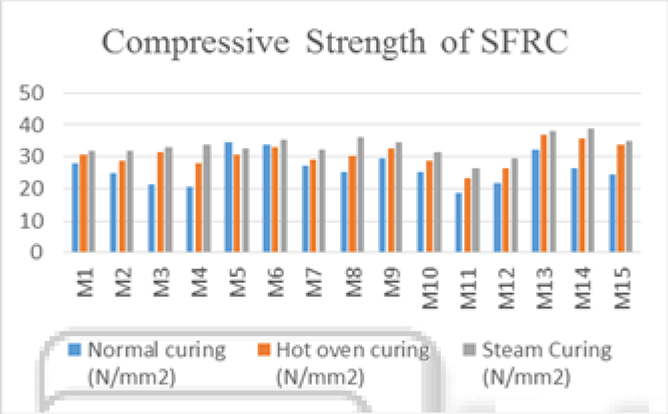

Fig. 3: Bar graph comparing the compressive strength of SFRC

V. RESEARCH SIGNIFICANCE

The present study shows variation of compressive strength of different dosages of steel fibers, its comparison with plain concrete and the application of SFRC in soft rock tunneling in deep underground engineering. The improvements in the concrete can be done by adding GGBS and HRWR admixture to the concrete.

VI. CONCLUSIONS

In this experiment the study of addition of steel fibers in different concrete mixes was done. The study was done to study the compressive strength of SFRC in soft rock tunnel in deep underground engineering. Also comparison of compressive strength was done between plain concrete and SFRC and superiority of SFRC over plain concrete was studied. Replacing 50% cement by GGBS led to increase in compressive strength of the concrete according to different curing methods. Initial hardening and high early strength of the concrete can be obtained by steam and hot air oven curing than normal curing. Correspondingly varying the fiber with different aspect ratio and the combination of steel fiber with different lengths shows a significant variation in the compressive strength.

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