The Effect of Polypropylene and Carbon Fibres on High Performance Concrete

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***Abstract*—The objective of this study is to design fibre reinforced high performance concrete mix of grade M65. The mineral admixture used is silica fume. Silica fume is replaced at 2.5%, 5.0%, 7.5%, 10.0%, 12.5% and 15.0% by weight of cement. Then polypropylene fibres are added at 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% by volume fraction. To the optimum polypropylene content carbon fibres are replaced at 25%, 50% and 75%. The results showed that silica content of 12.5% has the maximum compressive strength. When fibres are added there is tremendous increase in the flexure strength and impact strength with increase in fibre volume fraction. The compressive strength, split tensile strength and modulus of elasticity shows moderate increase. Thus ductility is improved in case of Hybrid Fibre Reinforced High Performance Concrete.**

Keywords*— High performance concrete;silica fume; polypropylene fibre; carbon fibre;hybrid fribre reinforced high performance concrete

1. INTRODUCTION

Concrete is a composite material composed of water, coarse granular material (the fine and coarse aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. There are many types of concrete available, created by varying the proportions of the main ingredients below. In this way or by substitution for the cementations and aggregate phases, the finished product can be tailored to its application with varying strength, density, chemical and thermal resistance properties. Concrete has relatively high compressive strength, but much lower tensile strength. For this reason it is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. High-performance concrete (HPC) is a relatively new term for concrete that conforms to a set of standards above those of the most common applications, but not limited to strength. Applications of silica fume (SF), fly ash (FA) and ground slag in concrete are effective ways to prepare high-performance concrete (HPC). Reduction of water-cement ratio (up to 0.3) is possible only with the use of super plasticizer. High performance concrete (HPC) is considered as a high strength and relatively brittle material, this inverse relation between strength and ductility is a serious drawback in the use of HPC. A compromise between strength and ductility can be obtained by using discontinuous fibres. Addition of fibres to concrete makes it an isotropic material and converts its brittle behavior to ductile behavior. Commonly used fibres are steel, Polypropylene, nylon, asbestos, glass and carbon. These fibres will act as crack arresters and will improve static and dynamic properties. Polypropylene fibres are found to be suitable to increase impact strength. They possess very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to flexural strength. Carbon fibres are inert, medically safe and stronger than steel fibres and more chemically stable than glass fibres in an alkaline environment. Moreover, Carbon fibres are low in density, especially compared to steel fibres; their strength-to-density ratio is one of the highest among all fibre types. Carbon fibres have much higher specific strength and stiffness than metallic fibres.

In this experimental study, high performance concrete containing silica fume has polypropylene and carbon fibres added to investigate the effect on various mechanical properties.

II. EXPERIMENTAL STUDY

A. *Materials*

Ordinary Portland cement by Dalmia and silica fume supplied by Corniche was used in this study. The cement and silica fume properties are given in Table I and Table II respectively. The coarse aggregate used are of nominal size 20mm and fine aggregate used was M-sand of 2.75 fineness modulus. The specific gravity and water absorption of coarse and fine aggregates were 2.76 and 0.52% and 2.58 and 2.04% respectively. The super plasticizer used is CERAPLAST-300 to attain a required compacting factor of 0.89. The properties of polypropylene and carbon fibres are shown in Table III.

B. *Experimental procedure*

The control mix was designed as M65 grade. The mix proportion of the control mix was 1: 2.32:2.77 with water cement ratio of 0.37. The workability of the mix was fixed at compacting factor of 0.89. Then silica fume was added to the control mix at 2.5%, 5.0%, 7.5%, 10.0%, 12.5%, and 15% to replace cement by weight. The polypropylene fibre was added from 0.1%, 0.2%, 0.3%, 0.4% and 0.5% volume fraction to the HPC mix with 12.5% silica fume. Finally to the optimum polypropylene dosage, carbon fibres were replaced at 25%, 50% and 75% volume fraction. Workability test were carried out for each mix and the super plasticizer dosage was altered to attain a compacting factor of 0.89. The concrete was mixed in tilting drum type mixer.

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TABLE I. PHYSICAL PROPERTIES OF CEMENT

Grade	OPC 53
Specific Gravity	3.14
Fineness, %	6
Standard consistency, %	30
Initial setting time (min)	100
Final setting time (min)	243

TABLE II. PROPERTIES OF SILICA FUME

Item	**Analysis Results**
Specific Gravity	2.2
SiO_2	92.3%
LOI	2.7%
Moisture	0.2%
Pozzolanic Activity Index	137%
Specific Surface Area	$22m^2/g$
Bulk density	$603kg/m^3$
+45 microns	0.2

TABLE III. PROPERTIES OF FIBRES

Properties	**Polypropylene**	***Carbon***
Density	0.91g/cc	1.65g/cc
Length	12mm	10mm
Diameter	18 microns	7 microns
Aspect ratio	666.67	1428.57

C. Specimen Preparation

Each type of freshly prepared concrete mix was cast into cubes, cylinders, prisms and cylindrical cuttings to test the mechanical properties like compressive strength, split tensile strength, modulus of elasticity, flexural strength and impact strength. The cubes were of 150 x 150 x 150 mm dimension and cylinders were of 150 x 300 mm. Prismatic specimen of dimension 100 x 100 x 500 mm were used for flexural strength and cylindrical cuttings of 150 x 50 mm were used for testing impact strength. After demoulding curing of specimen were done by completely immersing them in water storage tank. Compressive strength was taken for 3, 7 and 28 days while rest of the specimen was cured for 28days.

III. RESULTS AND DISCUSSION

The compressive strength and split tensile strength were conducted in Compression Testing Machine of 3000kN capacity. Flexural strength was obtained by loading the prismatic specimen under 3-point loading setup. The impact strength was tested using drop weight test. The results of mechanical tests are consolidated below in Table IV.

A. Compressive Strength

The compressive strength of cube specimens were tested at 3, 7 and 28 days. The control mix had a compressive strength of 65.2 N/mm^2. The silica fume replaced cement by weight at 2.5%, 5.0%, 7.5%, 10%, 12.5% and 15% to make HPC mix. The replacement of cement by silica fume showed increase in compressive strength till 12.5% and then it decreased for 15% replacement of cement. So the optimum replacement of silica fume is 12.5% with an increased compressive strength of 2.6% when compared to the control mix. The addition of polypropylene fibre into the HPC mix at 0.1%, 0.2%, 0.3%, 0.4% and 0.5% will slightly increase the compressive strength. The maximum fibre volume fraction of 0.5% yields 1.12% increase. This 0.5% volume fraction of polypropylene fibre is replaced at 25%, 50% and 75% with carbon fibre. The 50% replacement with carbon fibre reduces the compressive strength by 7.93% with reference to single fibre reinforced HPC mix..

B. Split Tensile Strength

The split tensile strength of normal control mix for 28 days was 4.10 N/mm^2. Replacement of cement with 12.5% silica fume caused an increase of 10.73%. With addition of polypropylene fibre, split tensile strength increases with increase in fibre volume fraction and a maximum increase of 36.6% was obtained for 0.5% addition. Further for the hybrid combination of 50% polypropylene and 50% carbon, the split tensile strength decreased to 5.35%. Thus the tensile strength decreases with addition of hybrid fibres.

C. Modulus of Elasticity

The modulus of elasticity of fibre reinforced HPC increases as the fibre volume fraction increases. This is because of the enhanced fibre-matrix bond. The increase in modulus of elasticity for polypropylene fibre volume fraction of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% are 6.07%, 8.99%, 10.93%, 16.49% and 24.51% respectively. Relatively when comparing the hybrid fibre combination, modulus of elasticity increases up to 50% replacement and the decreases for 75% replacement. While in case of hybrid fibre combination, the modulus of elasticity decreases by 6% for 50% replacement with reference to single fibre reinforced HPC mix.

TABLE IV. MECHANICAL PROPERTIES OF SPECIMENS

Type of Concrete	Fibre Volume Fraction (%)	Compressive Strength (N/mm^2) (28 Days)	Split Tensile Strength (N/mm^2) (28 Days)	Modulus of Elasticity (GPa) (28 Days)	Flexural Strength (N/mm^2) (28 Days)	Impact Strength (No. of blows) (28 Days) First crack	Ultimate Failure
Control Mix	------	65.20	3.54	52.68	5.80	30	37
High Performance Concrete	------	66.89	3.67	54.36	6.05	15	18
Single Fibre Reinforced HPC	0.1	67.20	3.85	55.88	6.19	32	40
	0.2	67.34	4.12	57.42	6.23	39	47
	0.3	67.55	4.28	58.44	6.48	55	68
	0.4	67.11	4.56	61.37	6.76	78	90
	0.5	68.59	4.92	65.59	6.91	111	117
Hybrid Fibre Reinforced HPC	PP - 75% CF - 25%	62.13	4.10	60.88	6.13	20	27
	PP - 50% CF - 50%	63.55	4.67	61.65	6.30	50	64
	PP - 25% CF - 75%	50.48	4.02	58.61	5.92	14	18

D. Flexural Strength

The flexural strength of polypropylene fibre reinforced concrete is much higher when compared to normal mix as well as HPC mix. As the fibre volume fraction increases the flexural strength also increases. Hence maximum flexural strength is obtained for 0.5% fibre volume fraction. The increase in strength for 0.1%, 0.2%, 0.3%, 0.4% and 0.5% are 2.31%, 2.97%, 7.1%, 11.73% and 14.21% respectively with reference to HPC mix. While incorporating hybrid fibres, the strength increases upto 50% replacement and the decreases for 75% replacement. Thus for hybrid fibre combination, the flexural strength decreases with reference to single fibre reinforced HPC mix. For 50% replacement with carbon fibre a decrease of 14.59% is observed.

E. Impact strength

Normal mix is highly brittle. Replacement of cement by weight using 12.5% silica fume showed an increase in brittleness of 100%. But on addition of polypropylene fibre the brittleness of concrete was decreased tremendously. With increase in fibre volume fraction the number of blows for first

Crack was increased by 6.67%, 30%, 83.33%, 160% and 270%. While the number of blows for failure was also increased with increase in fibre volume fraction as follows: 8.11%, 27.03%, 83.78%, 143.24% and 216.25%. When considering the hybrid combination, the impact strength increases up to 50% replacement and decreases for 75% replacement. In case of hybrid fibre combination, the decrease in the number of blows for first crack and ultimate failure for 50% replacement with carbon fibre are 122% and 82.81%

respectively. Thus for hybrid fibre combination, impact strength is tremendously reduced when compared to single fibre reinforced HPC mix.

IV. CONCLUSIONS

Based on the experimental study conducted on the mechanical properties of Hybrid Fibre Reinforced High Performance Concrete (HFRHPC) the following conclusions can be warranted:

- The replacement of cement using silica fume increased the compressive strength as well as reduced the heat of hydration. The silica fume was replaced from 2.5% to 15% and optimum dosage of silica fume obtained was 12.5% replacement by weight of cement. The compressive strength was increased by 2.6% when compared to the normal control mix. This increase in compressive strength was due to the Pozzolanic activity of silica fume.
- Workability of the mix was drastically affected on addition of silica fume and hybrid fibres. As the fibre dosage increases workability decreases. The superplasticiser dosage was adjusted to maintain a constant compacting factor of 0.89.
- The compressive strength of polypropylene fibre reinforced HPC mix increased with increase in fibre volume fraction. The increase in polypropylene fibre dosage from 0.1% to 0.5% showed an increase in compressive strength from 3.07% to 5.2% with reference to the normal mix. But in case of hybrid fibre combination, 50% replacement with carbon showed a decrease of 7.93% with reference to single fibre reinforced HPC mix.
- The split tensile strength of silica fume replaced mix showed only a slight increase of 10.73% when compared to the control mix. Addition of

polypropylene from 0.1% to 0.5% caused an increase from 24.63% to 36.6% with reference to the control mix. On further replacing 0.5% polypropylene with carbon fibres, the 50% replacement showed a decrease of 5.35% in split tensile strength. Thus addition of fibres the split tensile strength of HFRHPC decreased.

- The modulus of elasticity increased on replacement with 12.5% silica fume by 3.2% when compared to the control mix. When polypropylene fibres were added from0.1% to 0.5%, the modulus of elasticity increased with increase in fibre volume fraction. The increase was observed from 6.07% for 0.1% addition to 24.5% for 0.5% addition. Later when carbon fibres replaced polypropylene fibres, the decreases in tensile strength was even more prominent. For 50% replacement with carbon fibre a decrease of 6% is found out.
- The flexural strength of HPC mix with 12.5% silica replacement did not show much increase. But when fibres were added the flexural strength was improved. As the polypropylene fibre volume fraction increased from 0.1% to 0.5% the increase in flexural strength was from 6.03% to 21.18%. Hybrid fibre combination reduced the flexural strength considerably up to 14.59%.
- Impact strength is the measure of ductility of concrete. When silica fume is used to replace cement by weight, the brittleness of concrete increases. The number of blows for first crack and failure are 15 and 18 respectively when compared to that of control mix whose number of blows for first crack and failure are 30 and 37 respectively. On addition of polypropylene fibres, impact strength is improved with increase in fibre volume fraction. The number of blows for first crack increased from 6.67% to 270% and that for failure increased from 8.11% to 216.25% with reference to the control mix. But on replacing 50% with carbon, impact strength was also decreased to a great extent.
- Addition of silica fume increased the compressive strength but was weak in tension and impact.
- The fibrous concrete had better tensile, flexure and impact strength when compared to the control mix and HPC mix.
- Addition of carbon fibers had a negative effect on mechanical properties of HPC mix. The compressive strength, split tensile strength, flexural strength, modulus of elasticity and impact strength decreased to a great extent.
- Hence addition of polypropylene fibre is highly recommendable to improve the mechanical properties of HPC mix.

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