An Experimental Investigation on Mechanical and Durable Properties of High Strength Fiber Reinforced Concrete by Partial Replacement of Cement with Silica Fumes and Fly Ash

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Abstract - *In this study, the various types of admixtures were used to study individual and as well as combined effects on the concrete strength in addition to the effects on durability, workability and compressive strength by replacement of admixtures by 10 %, 15 % of silica fume and 10 %, 20 % and 30 % of fly ash by weight of cement with a fixed amount of 0.5 % steel hook fibers that are added by volume of concrete throughout the study.*

Key Words: High strength concrete, silica fume, fly ash, Steel fibres, Concrete strength

1. INTRODUCTION

The main difference between normal strength concrete NSC and high strength concrete HSC is that the compressive strength that shows highest resistance to concrete sample for the applied pressure. Even though there is no specific point of division between normal strength concrete and high strength concrete the American Concrete Institute (ACI) explains that high strength concrete as concrete with compressive strength greater than 60N/mm^2.

The usage of fine Pozzolanic materials in high strength concrete like fly ash, silica fume lead to reduction in crystalline compounds mostly calcium hydroxide. Also there will be reduction in thickness of interfacial transition zone of high-strength concrete. Usage of mineral admixtures like silica fume SF, fly ash FA in concrete is effective to increase in the strength and make durable for high strength concrete in future. Addition of admixtures to concrete mixture will increase the strength of concrete by pozzolanic action and fills the voids that are created between cement particles.

1.1 Economic Benefit

Cement represents the most expensive component of a concrete mixture. As it is a highly energy intensive material, the increasing energy costs reflect on higher Cement costs. Most of the pozzolanic and cementitious materials in use today are industrial by-products, which require no expenditure of energy for use as mineral admixtures. When used as partial Cement replacement, up to 70% Cement by mass, mineral admixtures can result in substantial energy and cost savings

2. MATERIALS

Silica Fume

Silica fume is a by-product in the production of silicon and silicon alloys. Silica fume is available in various forms of which the most usually used is in dandified form. As per IS: 1331(PART-1) 1992 and ASTM C (1240-2000) Silica fume is being used. It is also referred as micro silica or as condensed silica fume which is a by-product material that is being used as pozzolanic. This by-product is a result of reduction of high purity quartz with coal as an electric arc furnace in manufacturing of silicon or ferro-silicon alloy.

Fly Ash-As per ASTM C 618

A) Class F fly ash

This type of fly ash is produced in the process of burning harder and older anthracite and bituminous coal. Class F is usually low-calcium fly ash which has carbon content less than 5% but occasionally it's carbon content is as high as 10%. This type of fly ash is pozzolanic in nature and lime CaO content is less than 20%. Having pozzolanic properties alumina, glassy silica of Class F fly ash require a cementing agent like Portland cement, hydrated lime, quicklime with water in to react and form cementations compounds. Class F ashes will only react with the by products produced when cement reacts with water. Instead of this, when chemical activator like sodium (water glass) is added to Class F fly ash that leads to the formation of High strength concrete.

B) Class C fly ash

Class-C fly ash is produced by burning of sub bituminous coal or younger lignite. In addition to pozzolanic properties, Class C ashes will also possess self-cementing properties. In the presence of water Class C ashes will react and harden same as cement and also gains strength over time. Class C fly ash usually contains carbon content less than 2% with more than 20% lime (CaO). Self-cementing Class C fly ash does not require an activator in contrast to Class F. In Class C fly ashes sulphate (SO4) and Alkali contents are generally higher.

Steel Fibres

Steel fibres make significant improvement in impact, flexural and fatigue strength of concrete. These fibres used as crack arrester for concrete and also significantly improves static and dynamic properties of concrete. With increase in steel fibres content in concrete the Compressive strength of fibre reinforced concrete increased significantly.

A) Uses of steel fibers in concrete

In concrete Steel Fibers are usually used for the following reasons:

- To control plastic shrinkage and drying shrinkage cracks.
- To reduce permeability of concrete in which it further reduces bleeding of water can be reduced.

B) Steel Fiber Reinforced Concrete (SFRC)

Concrete is most extensively used structural material around the globe with production of more than seven billion tons per year. For various reasons in concrete cracks are usually observed. The main cause for concrete to develop cracks is may be due to structural, economic, or environmental factors but mostly the cracks are formed due to the weakness of material to resist tensile forces.

2. EFFECT ON INITIAL AND FINAL SETTING TIME

Table 1 gives the results of initial and final setting time for different replacement percentages of Cement with Fly ash. Initial setting time test results shows very slight increase in initial setting time of Cement for different dosages 0%, 10%, 20% and 30% of Fly ash in Ordinary Portland Cement. Final setting time test results shows very slight decrease in final setting time of Cement for different dosages 0%, 10%, 20% and 30% of Fly ash in Ordinary Portland Cement.

TABLE 1- Initial and final setting time for different percentages of cement with fly ash

S.NO	Mix Proportion	Initial Setting Time (minutes)	Final Setting Time (minutes)
1	100% OPC and 0% FA	40	350
2	90% OPC and 10% FA	60	320
3	80% OPC and 20% FA	70	280
4	70% OPC and 30% FA	80	250

Table 2 gives the result of initial and final setting time for different replacement percentages of Cement with Silica fume. Initial setting time test results shows very slight increase in initial setting time of Cement for different dosages 0%, 10% and 15% of Silica fume in Ordinary Portland Cement. Final setting time test results shows very slight decrease in final setting time of Cement for different dosages 0%, 10% and 15% of Silica fume in Ordinary Portland Cement.

TABLE 2- Initial and final setting time for different percentages of cement with silica fume

S.NO	Mix Proportion	Initial Setting Time (minutes)	Final Setting Time (minutes)
1	100% OPC and 0% SF	40	350
2	90% OPC and 10% SF	45	340
3	85% OPC and 15% SF	50	330

3. TESTS ON CONCRETE

3.1 Tests for hardened concrete

Compressive Strength Testing Machine is used for the determination of compressive strength for cubes and cylinders. The specimens after subjected to curing drying for 1 day are loaded in compressive strength testing machine.

Based on usual compatibility and equilibrium conditions used for normal reinforced concrete except the contribution of the fibers in the tension is recognized and the ultimate flexural strength analysis is being presented in this paper.

Following assumptions are considered in the analysis

1. Plane sections remain plane after bending
2. The compressive force is equal to the tensile force.
3. The internal moment is equal to the applied bending moment.

Split tensile test as per IS specifications IS 5816:1999 is to be conducted. The size of cylinder is 150 mm diameter and length of 300 mm length is considered. "The cylinders are placed horizontally between the loading plate surfaces of compression testing machine. Align the sample such that the lines are marked on the ends is vertical and centered over the bottom plate of the apparatus. Put other plywood strip over the specimen and bring down upper plate to touch the plywood strip. Apply the load uniformly until we reach the breaking load (P)". [1]

3.2 Tests carried out on fresh concrete

Slump cone test

Slump cone test apparatus was made according to IS: 7320-1974 and used for calculating normal consistency of concrete Fresh concrete was filled in slump cone by tamping each layer for 25 times with a tamping rod. Later on metal cone is raised slowly in the vertical direction. As soon as the settlement of concrete slump of the concrete measured by scale.

Compaction factor test

"Place the concrete sample in the upper hopper to its edge by using the hand scoop and level it. Cover the cylinder and open the trap door at bottom of the upper hopper so that concrete falls into the lower hopper. Push the concrete sticking on its sides gently with the road. Open the trap door of lower hopper and allow the concrete so that it will fall into the cylinder below". [2]

Remove excess concrete above the top level of cylinder with the help of trowel and level it. Clean the outside of the cylinder. Weight the cylinder with concrete rounding off to the nearest 10 gm. This weight is known as weight of partially compacted concrete (P1). Empty the cylinder and then fill it again with same concrete mixture into three layers approximately 5 cm deep and each layer has to be heavily rammed to obtain full compaction. Level the top surface and weigh the cylinder with fully compacted concrete. The weight we get is known as the weight of fully compacted concrete (P2). To find the weight of empty cylinder (P)

Compaction Factor= (P1-P2 / P2-P)

3.3 Strength of concrete for different types of tests

Compressive strength of concrete

The compressive strength of concrete for different replacements of cement with 10 % and 20 % of silica fume and 10 %, 20 % and 30 % of fly ash with 0.5 % steel hook fibers by volume of concrete is tested for 3,7,28,56 and 90 days by using compressive test machine (CTM). The water to cement ratio in concrete mix was taken as 0.35. Three cubes were casted for each proportion and the average of three test samples was taken for the accuracy of results. At the room temperature and immersing the cubes in water tank or sump the concrete cubes were cured.

Compressive strength of concrete increases with the usage of mineral admixtures. Considering the proportion (S15F20) the compressive strengths for 3, 7, 28, 56 and 90 days are 36.41, 47.33, 71.55, 73.55 and 78 N/mm^2. By using this proportion the compressive strength of concrete has been increased by 5.11%.

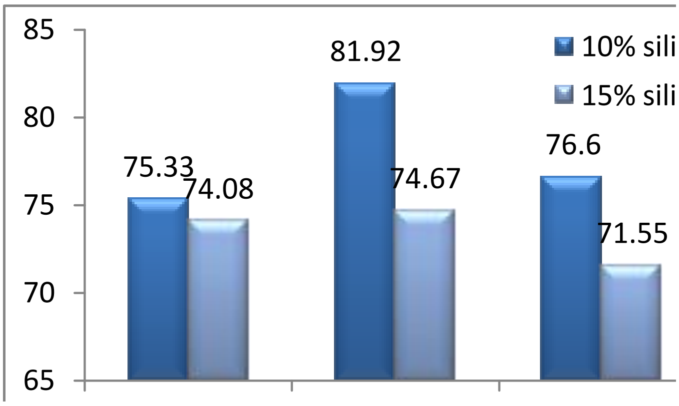

Chart -1: 28 days compressive strength variation for 10% and 15% silica fume for every 10%, 20% and 30% of fly ash replacement.

From the above graph it is observed that for every 10 %, 20% and 30% of fly ash replacement the difference in compressive strength reaches to a maximum at 10% of silica fume. With the increasing silica fume replacement to 15% it shows decreasing compressive strength values of concrete. Hence it is concluded that at 10% silica fume and 20% fly ash replacement the mix gives maximum 28 days compressive strength as 81.92 N/mm^2. Therefore this replacement percentage (S10F20) can be considered as optimum mix.

Split tensile strength of concrete

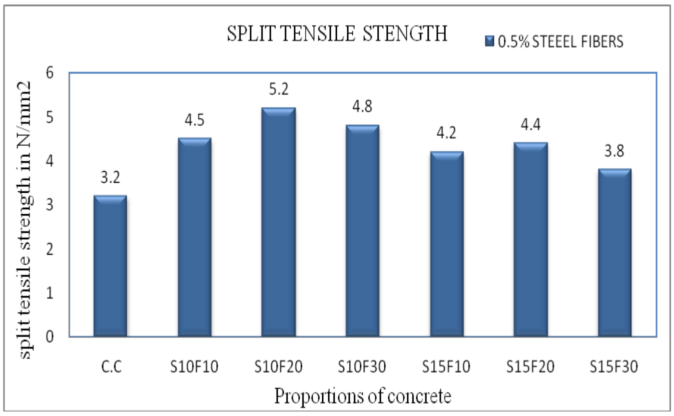

Chart -2: Tensile strength at 28 days for various percentages of Silica Fume and Fly Ash

From the above chart-2 it can be seen that the comparison of split tensile strength results of concrete for different replacements of silica fume and fly ash with 0.5 % of steel hook fibers as admixture. At 10 % of silica fume and 20% of fly ash the mix gives the maximum 28 days split tensile strength as 5.2N/mm^2.

Flexural strength of concrete

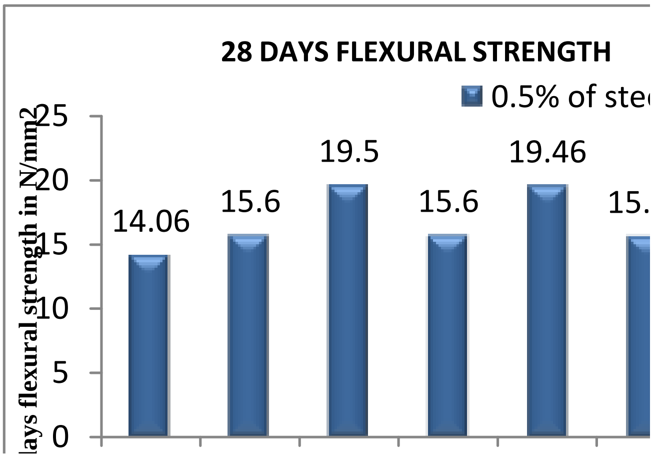

Chart-3: Flexural strength at 28 days for various percentages of Silica Fume and Fly Ash

Comparison of tests on concrete

TABLE 3: 28 Days strength comparison in percentage

Type of Test	S10 F10	**S10 F20**	S10 F30	S15 F10	S15 F20	S15 F30
Compressive strength	10.7%	**20.34 %**	12.51 %	10%	9.8%	5.11%
Split Tensile Test	37.61 %	**60.85 %**	47.70 %	29.66 %	37%	18.04 %
Flexural Test	10.99 %	**38.74 %**	10.99 %	38.42 %	10.45 %	8.85
Compressive strength on cylinder	9.21%	**19.37 %**	9.15%	6.18%	13.35 %	5.86%

S is % of silica fume; F is % of fly ash

From the above table it is observed that the percentage variation of compressive strength, split tensile strength and flexural strength is maximum at 10% of silica fume and 20% of fly ash replacement with 0.5% of steel hook fibers as admixture.

4. CONCLUSIONS

Based on the results obtained from the experimental investigation the following conclusions were made

1. Addition of steel hook fibers in concrete will result in increase of compressive strength and makes concrete more ductile.
2. In split tensile and flexural tests, it is noticed that crack width has been reduced due to the presence of steel fibers when compared to conventional specimen.
3. When the cement is replaced with 10 % of silica fume and 20 % of fly ash it gives optimum compressive strength, split tensile strength and flexural strength.
4. At 10% of silica fume and 20% of fly ash replacement to cement the compressive strength is increased up to 20.34% when compared to conventional concrete for 28 days.
5. At 10% of silica fume and 20% of fly ash replacement to cement the split tensile strength is increased up to 60.85% when compared to conventional concrete for 28 days.
6. At 10% of silica fume and 20% of fly ash replacement to cement the flexural strength is increased up to 38.74% when compared to conventional concrete for 28 days.
7. Addition of silica fume and fly ash as replacement to cement in concrete its normal consistency and initial setting time increases with the increase in percentage and final setting time decreases with increase in percentage.
8. Use of mineral admixtures in concrete causes significant reduction in the volume of voids and hence reduces the permeability of concrete mix because of its high fineness and formation of C-S-H gel.

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