

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

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ABSTRACT: The cost of construction materials is currently so high that only governments, corporate organizations and wealthy individuals can afford to do meaningful constructions. Unfortunately, production of cement involves emission of large amount of carbon-dioxide gas into the atmosphere, a major contributor for green house effect and global warming, hence it is inevitable either to search for another material or partly replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. With the passage of time to meet the demand, there was a continual search in human being for the development of high strength and durable concrete. High strength concrete (HSC) is used extensively throughout the world like in the gas, oil, nuclear and power industries are among the major uses. The application of such concrete is increasing day by day due to their greater structural performance, environmental friendliness and energy conserving implications. Apart from the usual risk of fire, these concretes are exposed to high temperatures and pressures for considerable period of time. The primary difference between high-strength concrete (HSC) and normal-strength concrete (NSC) relates to the compressive strength that shows the maximum resistance to concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute (ACI) defines high-strength concrete as concrete with a compressive strength greater than 60MPa. High-strength concrete is precise, where reduced weight is important or where architectural considerations for small support elements. By carrying loads very efficiently than normal-strength concrete, high-strength concrete also reduces the total amount of material placed and lower the overall expenditure and weight of the structure. High-strength concrete columns can hold more weight and therefore be made slimmer than regular strength concrete structures, which allows for more useable space, especially in the lower floors of buildings. High Strength Concrete is also used in other engineering structures like bridges, fly-over etc. From the general principles behind the design of high-strength concrete mixtures, it is clear that high strengths are made possible by reducing porosity, in homogeneity, and micro cracks in the hydrated cement paste and the transition zone. In the present study, the different admixtures were used to study their individual and combined effects on the resistance of concrete in addition to their effects on workability, durability and compressive strength by the replacement of admixtures by 10%, 15% of silica fume & 10%, 20% and 30% of fly ash by the weight of cement with a constant amount of 0.5% steel hook fibers are added by volume of concrete, throughout the study.

KEYWORDS: Carbon-dioxide, High Strength Concrete, Normal-Strength Concrete, Compressive Strength, concrete.

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I. INTRODUCTION

The use of high strength concrete (HSC) is continuously increasing due to its mechanical and durability advantages over normal strength concrete (NSC). In high-rise buildings, HSC can reduce the dimensions of the lower-story columns, which makes it a more cost-effective choice for builders than NSC, HSC is more brittle in comparison with NSC and that the confinement provided to HSC is less effective than in NSC. Therefore, greater confinement is required for the structures made from higher strength concrete to achieve similar strength and ductility enhancements. The addition of short discrete fibres (steel hook fibres) into the High Strength Concrete mixture can increase compressive strength and ductility, as already confirmed by several studies. These studies have also shown that the combination of discrete fibres can reduce the relatively large amount of confinement reinforcement required by design codes e.g., ACI 318-11 and CSA 23.3-04 Canadian Standard Association for HSC columns. Another advantage of adding discrete fibres to HSC mixtures in reinforced concrete structures is to prevent the premature separation of the concrete cover. Concern in using high strength fibre-reinforced concrete (HSFRC) for structural members has increased in recent decades both for scientists and producers, and especially in the field of precast members. Several experimental and theoretical investigations highlight the effectiveness of using HSFRC for members of framed structures. This study describes the development of high strength fibre reinforced concrete (HSFRC) with f_{ck} in the 60-100 N/mm² range. The objective of present study was mainly to increase the compressive strength, split tensile strength and flexural strength, with the aim of producing a concrete requiring less steel for use in the construction of prestressed concrete bridge superstructures. In addition to increasing compressive strength of the concrete and using fibre reinforcement to improve compressive strength, another development objective was to increase versatility by producing HSFRC that does not require special materials or special curing methods. The addition of high strength steel fibres to a reinforced concrete beam increased flexural strength and ductility of fibre-reinforced beams stems from the post-cracking tensile strength of high strength fibre-reinforced concrete. This residual strength also tends to reduce crack sizes and spacing's. The use of steel fibres is particularly attractive for high-strength concrete, which can be relatively brittle without fibres, or if conventional stirrups can be eliminated, which reduces reinforcement congestion. At present, the construction industry is turning towards pre-cast elements and requirement of post-tensioning has made the requirement of the high strength of concrete invariable. Today's construction is to attain savings in construction work. This can be achieved by using new and improved building materials, such as fibre-reinforced concrete. Compared to conventional concrete, fibre-reinforced concrete has higher static compressive, tensile, and shear strength, impact and fatigue strength, crack resistance and fracture toughness, heat resistance, and fire resistance.

II. RELATED WORK

P.S Song, S.Hwang examined on mechanical properties of high strength steel fiber reinforced concrete. The marked brittleness with low tensile strength and strain capacities of high-strength concrete (HSC) can be overcome by the addition of steel fibers. This paper investigated the mechanical properties of high-strength steel fiber-reinforced concrete. The properties included compressive and splitting tensile strengths, modulus of rupture, and toughness index. The steel fibers were added at the volume fractions of 0.5%, 1.0%, 1.5%, and 2.0%. The compressive strength of the fiber-reinforced concrete reached a maximum at 1.5% volume fraction, being a 15.3% improvement over the HSC. The splitting tensile strength and modulus of rupture of the fiber-reinforced concrete improved with increasing the volume fraction, achieving 98.3% and 126.6% improvements, respectively, at 2.0% volume fraction. The toughness index of the fiber-reinforced concrete improved with increasing the fraction. The indexes I_5 , I_{10} , and I_{30} registered values of 6.5, 11.8, and 20.6, respectively, at 2.0% fraction. Strength models were established to predict the compressive and splitting tensile strengths and modulus of rupture of the fiber-reinforced concrete. The models give predictions matching the measurements.

Vahid Afroughsabet, Togay Ozbakkaloglu examined on Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers. The effect of the addition of steel and polypropylene fibers on the mechanical and some durability properties of high-strength concrete (HSC). Hooked-end steel fibers with a 60-mm length were used at four different fiber volume fractions of 0.25%, 0.50%, 0.75%, and 1.0%. Polypropylene fibers with a 12-mm length were used at the content of 0.15%, 0.30%, and 0.45%. Some mixtures were produced with the combination of

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steel and polypropylene fibers at a total fiber volume fraction of 1.0% by volume of concrete, in order to study the effect of fiber hybridization. All the fiber-reinforced concretes contained 10% silica fume as a cement replacement. The compressive strength, splitting tensile strength, flexural strength, electrical resistivity, and water absorption of the concrete mixes were examined. Results of the experimental study indicate that addition of silica fume improves both mechanical and durability properties of plain concrete. The results also indicate that incorporation of steel and polypropylene fibers improved the mechanical properties of HSC at each volume fraction considered in this study. Furthermore, it was observed that the addition of 1% steel fiber significantly enhanced the splitting tensile strength and flexural strength of concrete. Among different combinations of steel and polypropylene fibers investigated, the best performance was attained by a mixture that contained 0.85% steel and 0.15% polypropylene fiber. Finally, the results show that introducing fibers to concrete resulted in a decrease in water absorption and, depending on the type of fibers, significant or slight reduction in the electrical resistivity of concrete compared to those of the companion plain concrete. A. Annadurai I, A. Ravichandran examined on development of mix design for high strength Concrete with Admixtures. The results of mix design developed for high strength concrete with silica fume and High range water reducing admixture (HRWR). It involves the process of determining experimentally the most suitable concrete mixes in order to achieve the targeted mean strength. In this research work 53 grade ordinary Portland cement, the locally available river sand, 10 mm graded coarse aggregate were selected based on ASTM C 127 standard for determining the relative quantities and proportions for the grade of concrete M60. For this design ACI 211.4R-93 guidelines were followed. Totally Five mixes were designed one mix was treated as basic mix with HRWR - 0.5% without silica fume, Four mixes were designed with Micro silica quantities varied from 5 to 9 percent weight of cementitious materials and HRWR varies between 0.6% to 0.9% with increment of 0.1% . Each mix 2 numbers of 150mm x 300 mm cylinders were cast then kept in curing tank after 24 hours of time period. After 28 days of curing the specimens were tested and the appropriate mix proportions were obtained.

III. MATERIALS

The materials used in present investigation include;

a) Cement-Ordinary Portland cement (OPC)

Ordinary Portland cement of 53 grades was selected for the experimental investigation. The compressive strength characteristics of cement were tested as per IS: 4031-1988 and IS: 12269-1987(9). The cement used in present study was Zuari cement. The experiments such as standard consistency, initial setting time, final setting time and specific gravity of cement are conducted on ordinary Portland cement.

b) Silica Fume

Silica fume is a waste by-product of the production of silicon and silicon alloys. It is available in different forms, of which the most commonly used is in a dandified form. Silica fume used was conforming to IS: 1331(PART-1) 1992 and also ASTM C (1240-2000). Silica fume was also referred as micro silica or condensed silica fume, is a byproduct material that is used as a pozzolanic. This by product is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy.

c) Fly-Ash

For this project Fly ash is taken from Rayalaseema thermal power plant (RTPP), Kadapa. RTPP has installed ESP for segregation and collection of fly ash into six different fields. As the field number increases the fineness of fly ash increases but the quantity decreases. Field-1 fly ash has coarse particles and is not suitable for concrete applications. Since maximum availability of fly ash is from field-2, some of them was used for our study. This fly ash conforms to the requirements of IS: 3812 part-I and also ASTM C-618 type-F.

d) Fine aggregates

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Sand is a naturally occurring material from Rock and Minerals by weathering and is composed of majorly SiO_2 , and Calcium carbonate. The sand used throughout the experimental work was obtained from the Muthireveluvanka near Chittoor, Chittoor district, Andhra Pradesh. This type of sand was used by many of researchers as an ingredient in concrete. According to IS 650:1966, the sand used in cement concrete should conform to the following specifications.

- Sand shall be of quartz, light gray or whitish variety.
- It shall be free from silt.
- The grains shall be angular. The shape of grains shall approximate to spherical form, enlarged and flattened grains being present only in negligible quantities.

e) Coarse aggregates

Gravels are popularly used as Coarse aggregates, which are free from organic impurities and silt. As per Indian standard specifications IS 383-1970 the coarse aggregates were tested and locally available gravels of size 20 mm passing 10 mm retained are taken and specific gravity of coarse aggregate is arrived as 2.68.

f) Steel hook fibres

Steel fibres make significant improvements in flexural, impact and fatigue strength of concrete. These fibres are used in concrete as crack arrester and would substantially improve its static and dynamic properties. Compressive strength of fibre reinforced concrete increased with increase in steel fibre content. The additions of steel fibres shear strength increases significantly. Steel hook fibers compliance to the requirements of ASTM A 820 (type-1 cold drawn wire).

g) Water

Water used for drinking can also be used for mixing concrete. Impurities in the water may affect concrete, its setting time, and its Compressive strength and Split tensile strength. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement. The characteristics of water, to which various chemical and biological substances were spiked, are presented in the table below and were analysed according to the standard methods for the examination of water (APHA 1994). Results compile to IS 3025 and IS 456-2000.

IV. TEST PROCEDURE

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting that the ingredients of good concrete and bad concrete are the same. If meticulous care is not exercised and good rules are not observed the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage it will result in good concrete. The various stages of manufacture of concrete are:

- a) Batching
- b) Mixing
- c) Placing
- d) Compaction
- e) Curing

a) Batching

Weight batching is the correct method of measuring materials. For important concrete invariably, weight batching system should be adopted. Use of weight system in batching, facilities accuracy, flexibility and simplicity. Different types of weight batches are available. The particular type to be used depends upon the nature of job.

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b) Mixing

Machine mixing is most effective method to mix the concrete. Concrete mixers commercially available are used by the concrete industry. Drum mixers are broadly used for mixing which are having blades attached to the inside of the rotatable drum. In commercial there are two other main types of mixers used like batch mixers and continuous mixers.

c) Placing

The concrete must be placed in systematic manner to yield optimum result.

d) Compaction

Compaction of concrete is this process adopted for expelling the entrapped air from the concrete In the process of mixing. Transporting and placing of concrete air is likely to get entrapped in the concrete. The lower the workability higher is the amount of air entrapped. In other words, stiff concrete mix has high % of entrapped air and therefore would need higher compacting efforts than high workable mixes. Compaction of concrete is this process adopted for expelling the entrapped air from the concrete In the process of mixing. Transporting and placing of concrete air is likely to get entrapped in the concrete. The lower the workability higher is the amount of air entrapped. In other words, stiff concrete mix has high % of entrapped air and therefore would need higher compacting efforts than high workable mixes. If this is not removed fully the concrete losses strength considerably. The relationship between loss of strength the air voids left due to lack of compaction. It can be seen that 5% voids reduce the strength of concrete by above 30% and 10% voids reduce the strength by over 50%. Therefore, it is imperative that 100% compaction of concrete one of the most important aim to kept in mind in good concrete-making practices.

e) Curing

Concrete while hydrating, releases high heat of hydration. The heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a through water curing.

V. TEST RESULTS

a) Compressive Strength Results

The cubes, cylinder and beams were taken tested 3, 7, 28, 56 and 90 days and results were obtained and the graphical views were shown in the below tabulations. By the results the calculations shows the increasing the compressive strength, split tensile strength, flexural strength. This result shows the maximum addition of steel fibres and fly ash at the peak point this makes the maximum utilization of steel fibres and fly ash should be added to the concrete at certain intervals to attain the maximum strength.

S. NO	SAMPLE	AVERAGE COMPRESSIVE STRENGTH				
		3 days	7 days	28 days	56 days	90 days
1	Controlled mix	27.62	44.23	68.07	75.18	78.74
2	10%SF+10%FA+0.5%SHF	36.96	49.40	75.33	79.77	81.11
3	10%SF+20%FA+0.5%SHF	40.18	50.07	81.92	82.67	83.40
4	10%SF+30%FA+0.5%SHF	39.33	49.63	76.60	81.06	82.00
5	15%SF+10%FA+0.5%SHF	39.18	49.48	74.88	80.51	81.55
6	15%SF+20%FA+0.5%SHF	36.96	48.67	74.67	79.11	80.66
7	15%SF+30%FA+0.5%SHF	36.41	47.33	71.55	73.55	78.00

Table 1 Compressive strength of concrete for different replacements of cement

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 fibres by volume of concrete were tested for 3,7,28,56 and 90 days

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using compressive test machine. The water to cement ratio was taken as 0.35. Three cubes were casted for each proportion and the average of three test samples was taken for the accuracy for results. At the room temperature, the concrete cubes were cured. The values of crushing loads obtained are taken and the compressive strength obtained are shown in table 1

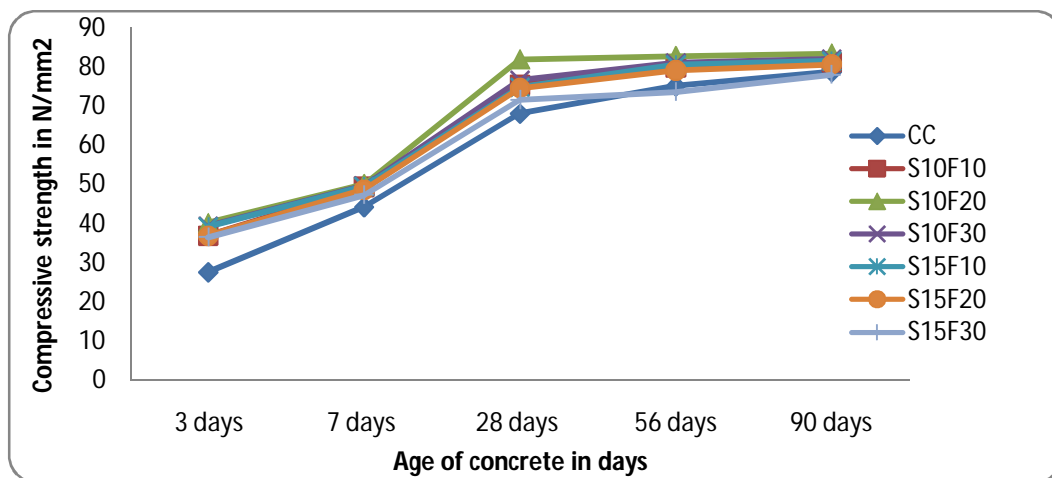


Fig 1 Compressive strength with increase in age of concrete

The Fig.1 shows the variation of compressive strength with increase in age of concrete. On comparing with controlled concrete, the compressive strength of concrete on replacing cement with 10% silica fume and 10% fly ash with 0.5% steel hook fibres as admixture shows higher results (green).The compressive strength of controlled concrete for 3, 7, 28, 56 and 90 days are 27.62, 44.23, 68.07, 75.18 and 78.74 N/mm².Compressive strength of concrete, increases with the addition of mineral admixtures. For this proportion (S10F10) the compressive strength variation for 3, 7, 28, 56 and 90 days are 36.96, 49.40, 75.33, 79.77 and 81.11 N/mm².At this proportion the compressive strength of concrete is increased by 10.7%.

b) Durability Test Results

S. No	Sample	Wet weight (kgs)	Dry weight (kgs)	Water absorption in %
1	CC	9.56	9.40	1.70
2	S10F10	9.52	9.42	1.06
3	S10F20	9.53	9.45	0.84
4	S10F30	9.44	9.39	0.53
5	S15F10	9.44	9.35	0.96
6	S15F20	9.46	9.40	0.63
7	S15F30	9.49	9.44	0.53

Table 2 Water absorption test for different proportions of concrete

From above table it is observed that, the percentage water absorption for different proportions of concrete varies with the silica fume and fly ash replacement. With increase in silica fume and fly ash replacement to cement shows decreased percentage of water absorption because of their fine particle size. At 10% and 15% replacement of silica fume with 30% fly ash gives low water absorption as 0.53%.

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VI. CONCLUSION

Based on the results obtained from the present investigation the following conclusions were made;

1. By the addition of steel hook fibres in concrete leads to increase in compressive strength and makes concrete into ductile.
2. In split tensile and flexural tests, we notices that crack width reduced due to the presence of steel fibres when compared with conventional specimen.
3. When the cement is replaced with 10% silica fume and 20% fly ash gives the optimum compressive strength, split tensile strength and flexural strength.
4. At 10% silica fume and 20% fly ash replacement to cement, compressive strength was increased up to 20.34% when compared with conventional concrete for 28 days.
5. At 10% silica fume and 20% fly ash replacement to cement, split tensile strength were increased up to 60.85% when compared with conventional concrete for 28 days.
6. At 10% silica fume and 20% fly ash replacement to cement, flexural strength were increased up to 38.74% when compared with conventional concrete for 28 days
7. The addition of silica fume and fly ash as replacement to cement, its normal consistency and initial setting time increases with increase in percentage and final setting time decreases with increase in percentage.
8. The use of mineral admixtures in concrete causes considerable reduction in the volume of large pores at all ages and thereby reduces the permeability of concrete mixes because of its high fineness and formation of C-S-H gel.

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