STRENGTH AND DURABILITY STUDIES ON ALCCOFINE CONCRETE WITH MICRO STEEL FIBRES

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The study of High Strength Concrete (HSC) has become interesting as concrete structures grow taller and larger. The usage of HSC in structures has been increased worldwide and has begun to make an impact in India. Ordinary cementitious materials are weak under tensile loads and fiber reinforced cementitious composites (FRCCs) have been developed to improve this weak point. Specimens such as cubes, cylinders were cast for High Strength concrete containing Alccofine as mineral admixture and reinforced with micro steel fibers to study the mechanical and durability properties at 28 days and 56 days of curing. The concrete were designed to have compressive strength of 60 MPa. Mixtures containing 0% and 10% replacement of cement by Alccofine and with 1%, 2% and 3% of micro steel fibers by weight of concrete were prepared. Durability properties such as Sorptivity, water absorption, resistance against Sulphuric acid, Sodium sulphate and Magnesium sulphate were studied for control, Alccofine and Alccofine with steel fibers for different days of curing. Mixtures incorporating Alccofine with fibers developed marginal increase in strength and durability properties at all ages when compared to control concrete.

Keywords: *HSC, Alccofine, Micro steel fibers, Fiber content, Compressive strength, Split tensile strength, Durability, Sorptivity, Acid and Sulphate resistance, Water absorption*

1. Introduction

The study of high strength concrete has become interesting as concrete structures grow taller and larger. The usage of high strength concrete in structures has been increasing worldwide and has begun to make an impact in India. The achievement of such high strength concrete has been made possible through the introduction of supplementary materials such as silica fume, slag, Alccofine, fly ash etc. The addition of micro steel fibers to concrete is expected to arrest cracks, and improve bond and corrosion resistance due to superior performance. Also, this would substantially increase the static and dynamic properties, thus changing an inherently brittle material with low tensile strength and impact resistance into a strong composite with superior crack resistance; improved ductility and distinct post-cracking behavior of concrete. [1] found out that by varying in the addition of micro steel fibers from 0 to 1.25% the concrete increases its compressive strength in the beginning and then reduces but the split tensile strength is gradually increased till final. [2] incorporating various types of steel fibers in to the concrete mixes achieved the mode of failure from brittle to more ductile [3] found that by addition of a supplementary cementatious material alccofine the compressive strength can be increased by varying the percentages from 0 to 18% the optimum was found to be 13% for M50 grade. [4] found that addition of steel fibre to light weight improved its strength characteristics improving the compressive strength to some extent and by increasing the split tensile and flexural strength largely. Thus they came to a conclusion that by varying the fiber content in light weight concrete by 1-1.5% is extremely effective in improving the strength and toughness of concrete.[5] found that for a high strength concrete by addition of 1.5% fibre showed maximum strength and above that percentage showed to decrease in strength but the split tensile strength showed increasing in strength by increasing in fibre volume fractions. [6, 7] found that by varying the percentages in the replacement of cement by metakaolin showed improved strength but the maximum strength was achieved when the cement was replaced by 10% of alccofine. [8] found that by addition of sulfuric acid the changes in weight and compressive strength was checked for 30, 60, 90,120 and 180 days. [9] performed their research

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on High strength concrete to understand the effect of steel fiber on strength and durability properties.[10] conducted research on experimental and statistical method to evaluate the effect of fly ash and fiber in various concrete properties.[11] made their research on concrete with locally available jute fiber in improving flexibility and ductility properties of concrete, found that addition of fly ash and fibers to concrete provide resistance to crack propagation and crack widening before being pulled out or stressed to rupture.[12] found the performance of concrete such as compressive strength, permeability and sorption under four curing conditions. Sorptivity coefficient was found using ASTM 1585 for two cement levels 350kg/m^{3}and 450kg/m^3. Results indicate sorptivity was decreased by 42.7% when cement was increased from 350kg/m^3 to 450kg/m^3. When replacement material silica fume was added to 10% sorptivity decreased from 64.5% to 68.3%.[13] made research on silica fume based steel fiber concrete with chemical admixture, found the optimum percentage of chemical admixture, fiber content and silica fume.[14] performed research on sorptivity with natural and RCA concretes with three methods of compaction based on sorptivity values and distribution along the height of the specimen.[15] done research on silica fume and nano-silica with forta-ferro and steel fibers to understand the mechanical properties, found that 8% silica fume and 2% nano-silica in the concrete reinforced with 1% content of steel fibers improves the performance of concrete.[16] made research on concrete with recycled fibers and aggregates on mechanical properties and inferred that, pavement thickness was reduced of about 8% and 16% for concrete with 0.5 and 1% respectively. Based on the literature review extensive research has been carried out on the use of steel fiber in concrete but much work has not been published in concrete with Alccofine and micro steel fibers. Hence in the present research work focussed on strength and durability properties of concrete with 10% Alccofine and micro steel fibers.

2. Experimental programme

2.1 Material Properties

2.1.1.Cement

The cement used was ordinary Portland cement of grade 43, having a specific gravity of 3.16 [18].

2.1.2.Alccofine

ALCCOFINE 1203 is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation, and it was procured from the local supplier. The specific gravity was noted as 2.9 and bulk density 600-700 kg/m^3. As per manufacturers manual the main element presented in the Alccofine are CaO and Silica (SiO_2) and Al_2O_3 constitute 31-33%, 33-35% and 23-25% respectively.

2.1.3.Aggregate

River sand passing through 4.75 mm and retained on 2.36 mm sieve was used as fine aggregate. The specific gravity and fineness modulus of the fine aggregate was 2.65 and 3 respectively. Aggregate passing through 20 mm sieve and retained on 12.5 mm sieve was used as coarse aggregate. The specific gravity and fineness modulus of the coarse aggregate was 2.7 and 6.5 respectively.

2.1.4.Micro steel fiber

Straight micro steel fibers was obtained from Go Green Technologies, Chennai with aspect ratio (l/d) of 43.33 was used in the present study is shown in Figure 1. Yield strength and elastic modulus were 2100 MPa and 2.1 x 10^5 MPa respectively.

Fig. 1- Micro steel fiber.

2.2 Specimen Details

The mix design was done as per ACI method and the guidelines given in ACI 211.1-91 [21] method for concrete with a characteristic compressive strength is 60 MPa. The mix proportion obtained is 1:0.56:1.89 (cement: fine aggregate: coarse aggregate) with a w/b ratio of 0.33. High range water reducer was used as workability agent and due to which w/b ratio reduced from 0.33 to 0.3. Slump test was used as measure of workability of concrete and was done as per the guidelines given in ASTM C143 [22]. All mixes fall under the medium workability range of 75 mm to 10 mm are shown in Table 2. The exact quantity of the materials is presented in Table 1 and 2. Specimens were cast as per IS and ASTM standards to study the strength and durability characteristics at 7 and 28 days of curing. Cubes were tested to evaluate compressive strength of concrete as per IS 516 [22], cylinders were tested as per ASTMC496 [22] to determine split tensile strength and prismatic specimens of size 100 mm x 100 mm x 500 mm as per IS 516 [22] after 28 days of curing, with the aid of 1000 kN capacity Universal Testing Machine (UTM) by subjecting the concrete specimens under four-point loading

Table 1

Mix proportions for 1 m^3 of concrete

Concrete Mix	M60
Cement (kg/m^3)	522.43
Alccofine (kg/m^3)	48
Fine aggregate (kg/m^3)	294.06
Coarse aggregate (kg/m^3)	982.8
Water (kg/m^3)	157
Superplasticizer	0.8 – 1.2%

Table 2

Mix Proportion percentages of Cement, Alccofine and steel fiber

Mix Designation	Cement (%)	Alccofine (%)	Micro steel fiber (%)	Slump (mm)
CC	100	0	0	88
AC10F0	90	10	0	86
AC10F1	90	10	1	87
AC10F2	90	10	2	91
AC10F3	90	10	3	95

for flexural strength. After 28 days of normal curing the specimens were also cured for acid and sulphate at 28 days. Acid curing was done with sulfuric acid of 0.1N and sulphate curing of sodium sulphate and magnesium sulphate was done for durability test such as acid resistance, sulphate resistance, water absorption and sorptivity.

3. Results and discussion

3.1 Effect of alccofine and micro steel fiber on compressive strength

The compressive strength of concrete cubes made with various weight fraction of steel fiber was plotted against different days of curing are shown in Figure 2. Three specimens were tested to assess the compressive strength for control and 10% alccofine with steel fiber content (0%, 1%, 2% and 3%) in weight fractions. Failure pattern obtained during testing were shown in Figure 9 and 10. From results it is clear that the maximum compressive strength is attained for mixes containing 10% alccofine along with 2% fibers at 7 and 28 days of curing and the strength has enhanced for all fiber specimens compared to control concrete.The percentage improvements in compressive strength compared to control concrete was found to be 7.35%, 23.93%, 32.51%, 25.13% and 7.62%, 24.48%, 33.56%, 28.29% at 7 and 28 days respectively.

3.2 Effect of alccofine and micro steel fiber on split tensile strength

Three cylinder specimens were tested to assess the split tensile strength with steel fiber content (0%, 1%, 2% and 3%) in weight fractions. From Figure 3 there is an increase in split strength of concrete with the increase in fiber content. The addition of steel fiber to HSC in weight fractions of 3% caused a maximum increase in strength compared to control concrete 7 and 28 days of curing. The percentage improvements in split tensile strength compared to control concrete was found to be 12.12%, 27.88%, 46.46%, 60.8% and 34.29%, 41.76%, 65.57%, 73% at 7 and 28 days of curing respectively.

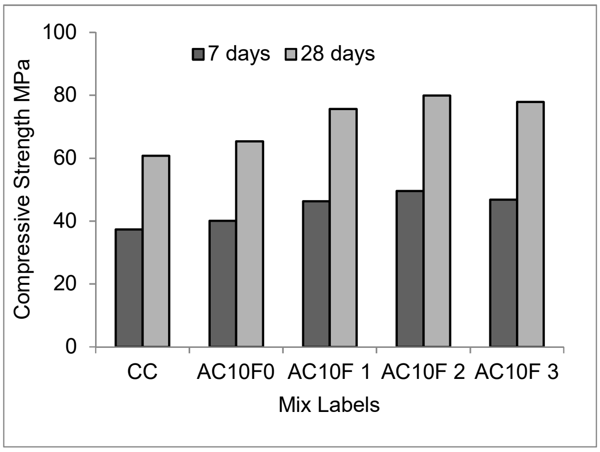

Fig. 2 - Compressive strength for 10% Alccofine and Micro steel fiber (%).

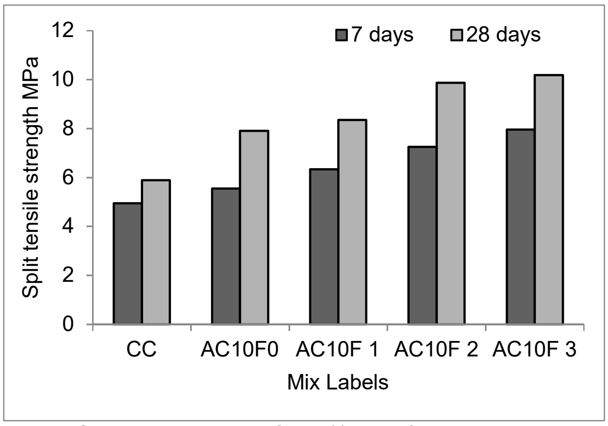

Fig. 3 - Split tensile strength for 10% Alccofine and Micro steel fiber(%) .

3.3 Effect of alccofine and micro steel fiber on flexural strength

The flexural strength test of the mixes was conducted on the prism specimens after 28 days of curing, and their results are presented in Figure 4. Three specimens were cast for control, 10% alccofine and Alccofine with steel fibers content (0%, 1%, 2% and 3%) in weight fractions. The results of control and 10% alccofine concrete were found to be 5.92 MPa and 6.59 MPa respectively. Mix with steel fibers were found to be in the range of 6.59 MPa to 9.37 MPa . There was a maximum increase in flexural strength for 3% steel fiber content. The percentage improvement in flexural strength compared to control concrete was 11.3%, 32%, 47.8% and 58.27% at 28 days.

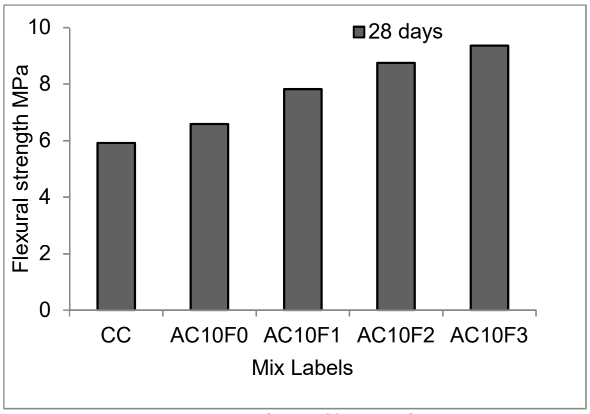

Fig. 4 - Flexural strength for 10% Alccofine and Micro steel fiber(%).

3.*4 Effect of alccofine and micro steel fiber on water absorption*

Saturated Water Absorption (SWA) tests on concrete mixes were executed using cube specimens of 100 mm x 100 mm x 100 mm size after 28 days curing in accordance with ASTM C642 [25]. The specimens were weighed before drying then the specimens were dried at 105^{o}C in a hot air oven. The samples were taken out at a standard duration. The variation of the weight of the saturated and the oven dried specimens were computed using

$$\text{Percentage water absorption} = \frac{W_s - W_d}{W_d} \times 100$$

where,

W_s = mass of the cube specimen at fully saturated state in g, and

W_d = mass of the oven dried specimen in g.

The specimen was cured for 56 days and the wet weight and dry weight of the specimens were calculated and the water absorption was calculated and the control concrete showed high water absorption. Permeability of concrete differs from absorption. Permeability relates to the size of the pores, their distribution and most importantly their continuity. As a result, permeability is not necessarily directly related to absorption. It has been related to water cement (w/c) ratio of concrete. Water cement ratio is the measure of the amount of water divided by the cement in a mix. Thus the concrete with low permeability has less water absorption thus the concrete mix withAC10F2 has low water absorption showing it has low permeability and control concrete has high permeability is shown in Figure 5.

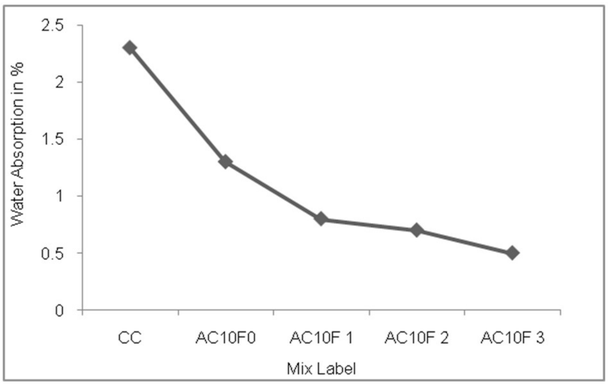

Fig. 5 - Water absorption

3.5 Effect of acid and sulphate curing on strength properties

Figure 6 shows that after normal curing of 28 days and acid curing of 28 days the results were noted. The specimens were treated to sulphuric acid of 0.1N and the corresponding results were achieved. There was a maximum reduction of strength of 2MPa for sulphuric acid. The specimens were also subjected to two kinds of sulphate solutions which are sodium sulphate solution and magnesium sulphate solution. These solutions were also taken for 0.1N and they were also subjected to strength test where in the specimen treated with sodium sulphate solution showed a variation of (0.64 to 1.73MPa) and the magnesium sulphate solution showed a strength variation of (0.22 to 1.2 MPa). Figure 11 shows the appearance of specimen after exposed to acid and sulphate curing at 28 days.

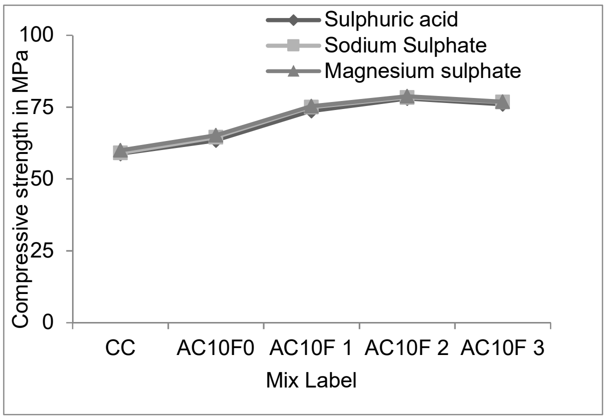

Fig. 6 - Graph for strength of acid and sulphate curing

3.6 Effect of acid and sulphate curing on weight reduction

After 28 days of normal curing the specimens were subjected to acid on sulphate solutions and their weight was checked. The results are shown in Figure 7. The specimens treated with sulphuric acid solution showed a large variation in their weight. It varied from (7.2 to 8.7%). Then the weight variation for the solution was a little lower than the acid solution. The sodium sulphate solution showed a weight variation of (3.7 to 5.9%) and the magnesium sulphate solution showed a weight variation of (1.7 to 4.5%). In all of the solution the mix with 10% alccofine and 2% fibre showed lower weight reduction.

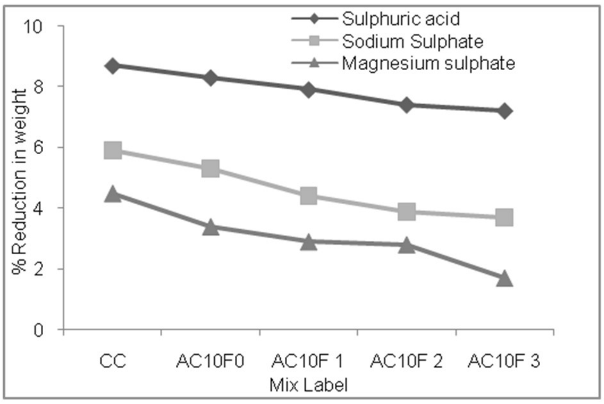

Fig. 7 - Weight reduction of specimen treated in acid and sulphate curing.

3.7 Effect of alccofine and micro steel fibre on sorptivity

The sorptivity curves attained for the mixes at the age of 28 days curing ASTMC1585 [26]. The graph is plotted for the square root of time versus the parameter Q/A is shown in Figure 8. It is found that the sorption coefficient is high for the control concrete which indicates that it has high water absorption and the sorption coefficient is less for the mix AC10F2 which indicates that it has low water absorption. Thus the mix with alccofine and fibre content give better results on the absorption. This is mainly due to superior matrix than control concrete.

4. Conclusions

From the results of the experimental investigation, the following conclusions were made on the addition of Alccofine and micro steel fibers.

1. The super-plasticizer for this high strength concrete was found to be 0.8 to 1.2 percent to maintain the adequate workability for Alccofine concrete and Alccofine with micro steel fiber concrete.
2. The maximum increase in compressive and split tensile strength for AC10F0 mix was

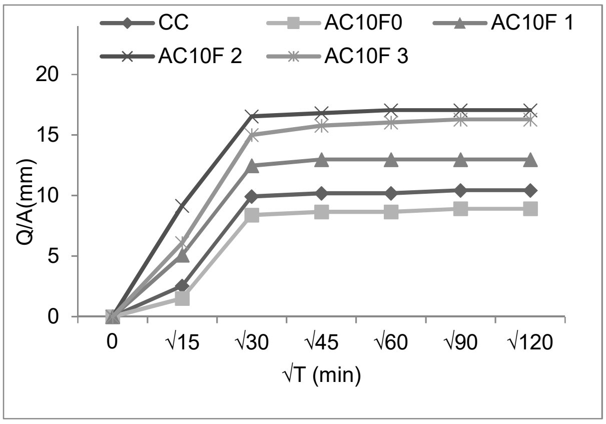

Fig. 8 - Sorption Coefficient.

Fig.9 - Failure pattern of CC specimen.

Fig. 10 - Failure pattern of AC10F2 specimen.

Fig. 11 - Specimens after exposed to acid and sulphate curing.

24.48% and 34.29% at 28 days compared with the control concrete.

3. The compressive, split tensile strength and flexural strength of concrete increases with the addition of micro steel fiber in Alccofine concrete. The strength improvement was calculated for 7 and 28 days, at all fiber content exhibit superior strength improvement for split tensile than flexural and compressive strength.
4. After acid curing the strength was reduced to a maximum of 2 MPa for all mix and the weight was reduced to a maximum of 8.7% when compared with normal curing.
5. After sodium sulphate curing showed a strength variation of maximum 1.73 MPa and 1.6 MPa and weight reduction of 5.9% and 3.9% for CC and AC10F2 respectively when compared to normal curing. Under magnesium sulphate curing showed a maximum reduction in strength of 1.2 MPa for AC10F2 and weight reduction of 4.5 % and 2.8 % for mix CC and AC10F2 when compared to normal curing.
6. The sorpitivity coefficient is high for the mix AC10F3 and least for the AC10F0 and control concrete. It was understood from the results that concrete with AC10F0 yielded better resistance against permeability than that of other mix
7. Compared to control concrete the Alccofine and Alccofine based fiber reinforced concrete shows enhanced strength and durability characteristics.

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