EFFECT OF FLY ASH AND METAKAOLIN ON THE STRENGTH AND STABILITY CHARACTERISTICS OF SELF COMPACTING CONCRETE

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This research examined the workability, mechanical properties and durability properties of self-compacting concrete (SCC) with fly ash and glass fibers. Glass fiber was added to the concrete at a rate of 0.25% by the weight of binder, fly ash and metakaolin was replaced at the rate of 5%, 10%, 15%, 20%, 25% and 30% respectively to the cement. The workability of fresh concrete samples was assessed using slump flow, slump flow T50and J-ring. The overall strength of hardened concrete was investigated by using compressive, tensile strength and flexural strength tests for a fixed water/binder ratio of 0.35with grade of M30 at 28, 56 and 180 days. The mechanical properties of SCC show an enhanced performance compared to the control mix and satisfy the fresh concrete properties such as filling ability and passing ability. SCC shows better resistance to the external environment. Thus, it shows a successful use of waste products in the SCC leads to the sustainable nature.

Keywords: *Self-compacting concrete, fly ash, metakaolin, glass fibers*

1. Introduction

The properties of self compacting concrete (SCC) render good materials for use in structures with complicated and narrow sections and reduce the labor for casting concrete. Fibers with very small diameters have a high surface area, which increases their distribution in the concrete matrix and negatively affects the workability of SCC they influence the properties of fresh and hardened SCC [1]. SCC can be placed under its own weight without any mechanical compaction and improve high workability, passing ability and high deformability [2-4]. With the increasing pressure on the construction industry to reduce and optimize energy and cement consumption, the use of supplementary cementitious materials (SCMs) is a possible solution to reduce the global CO_2 emissions due to cement production [5]. SCC has the advantages of workability improvement, reduction in water demand, less segregation, reduced heat of hydration, increased long term strength, significant reduction of permeability and chloride resistance, reduced expansion due to alkali-silica reaction and increased sulfate resistance [6]. Fibers have the property of substituting a single large crack with a dense network of micro-cracks, and subsequently bridging the micro-cracks within the cement matrix and would transfer the induced tensile stresses from the cement matrix to the fibers, rendering ductile post-cracking behavior [7]. Resistance to segregation during casting is another reason for using SCC. This property makes concrete homogeneous during transport and pouring [8].

Filling ability is described as the concrete's ability to completely fill the desired space under its own weight. Passing ability is the concrete's ability to flow freely in small spaces around steel, reinforcement bars without clogging up or segregating, and segregation resistance is its capability to remain in a consistent state during transportation as well as before and after placement [9-11]. The main purpose of using SCC is to reduce the period of construction, to assure compaction in confined zones of structure where it was difficult to vibrate and to avoid noise caused during vibration [12]. The use of SCC has become popular during recent years due to the noise reduction during the construction phase and avoiding vibration [13, 14]. It is necessary to consider benefits such as waste incorporation to concrete, gains in durability provided by the high volume of mineral additions utilized, and in particular, the use of Portland cement in smaller proportions than those currently used [15].The use of mineral additives such as slag, fly ash and silica fumes has been the subject of numerous investigations in all areas of self-incorporating concrete [16]. SCC has been portrayed as the most dynamic improvement in strong advancement for a drawn-out period of time [17]. SCC can be put and alter at any place by its self-weight. SCC is a staggeringly fluid mix it has incredible detachment, high deformability and has the low yield weight [18-23]. The use of waste materials in concrete has a benefit from the environmental point of view as the CO_2 emissions are reduced [24].This helps to find one of the most environmentally and technically appropriate solutions for the disposal and recycling of industrial waste.

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Table 1

Particle size distribution of cement, fly ash, metakaolin and fine aggregate

Percentiles	Cement	Fly Ash	Metakaolin	Fine Aggregate
	Size (μm)	Size (μm)	Size (μm)	Size (μm)
95.00	0.736	0.665	0.444	0.452
90.00	0.692	0.623	0.403	0.416
80.00	0.643	0.568	0.35	0.368
60.00	0.576	0.49	0.2856	0.304
50.00	0.546	0.452	0.2626	0.2774
40.00	0.516	0.41	0.2416	0.2517
30.00	0.484	0.355	0.2211	0.2254
20.00	0.443	0.275	0.1987	0.1964
10.00	0.380	0.1782	0.1688	0.1598
5.00	0.320	0.133	0.1444	0.1344
Peaks				
Diameter (μm)	0.546	0.452	0.2626	0.2774
Vol %	100	100	100	100
Width	0.240	0.35	0.18	0.2

2. Experimental approach

2.1. Materials for self-compacting concrete mixture

2.1.1. Cement

In this study, cement which is of the Ordinary Portland cement of 43 grade confirming to IS 8112 was used as additive in mixes. The chemical compositions of used cement are silica 18.1%, iron oxide 4.42%, aluminium oxide 6.10%, calcium oxide 65.1%, magnesium oxide 4.03%, sulphur trioxide 1.20%. The physical properties are specific gravity 3.12, normal consistency is 32% and fineness is 90%. Mineralogical composition of cement are C_2S of 21.5%, C_3S of 55.11%, C_3A of 8.5% and C_4AF of 6%. Particle size distribution of cement is shown in Table 1.

2.1.2. Fly ash

In this study, local available low calcium class-F fly ash with specific gravity 2.82 is procured from Tuticorin thermal power plant in Tamilnadu. The chemical composition of fly ash with minimum requirements as per IS 3812: 2003 are bulk density is 0.994 g/cm^3 and the Chemical composition of class F fly ash are silica 59.79%, iron oxide 8.04%, aluminium oxide 21.18%, calcium oxide 3.97%, magnesium oxide 1.88%, titanium oxide 1.13%, phosphorous 0.36%, sulphate 0.94%, alkali oxide 3.79% and LOI of 5.01%. Particle size distribution of fly ash is shown in Table 1.

2.1.3. Metakaolin

Metakaolin is an industrial by-product material purchased from the market, it has important potential in the improvement of concrete composites and it is an extremely reactive pozzolanic admixture. Physical properties of metakaolin are specific gravity of 2.60. Chemical composition of metakaolin are silica 59.79%, iron oxide 0.68%, aluminium oxide 45.25%, calcium oxide 0.06%, magnesium oxide 0.03%, titanium oxide 0.10%. Particle size distribution of metakaolin is shown in Table 1.

2.1.4. Aggregate

For the preparation of all the test specimens, good quality and well-graded aggregates in dry condition was utilized. An M-sand was purchased from local retailer and coarse aggregates with maximum size of 20mm are used. Physical properties of the fine aggregates are specific gravity of 2.63, fineness modulus of 3.6, and water absorption of 2.24%. Physical properties of the coarse aggregates are specific gravity of 2.71, fineness modulus of 4.08, and water absorption of 0.38%. Both coarse and fine aggregates conform to IS 383-1970. Particle size distribution of aggregate is shown in Table 1.

2.1.5. Glass fibers

Glass fiber is a material comprise of fine filaments of glass. It is a material utilized as warm structure protection. Glass fiber has mechanical properties and it is a less expensive and altogether less weak when utilized in composites. Glass fiber of length 15mm is being used in SCC specimens. The chemical composition are silicon dioxide of 53%, calcium oxide of 20%, aluminium oxide of 14%, boron oxide of 7%, magnesium oxide of 4%, iron oxide of 0.2%, titanium oxide of 2% and fluorides of 0.5%.

2.1.6. Superplasticizer

Super plasticizers are called as high-water reducers. For the blending of SCC admixtures are expected to build the strength of SCC. A new-generation copolymer-based superplasticizer (SP)

Table 2

Quantities of materials used in this study

Mix	Binder (Kg/m^3)			Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)
	Cement	Fly ash	Metakaolin		
M1	450	0	0	806	838
M2	405	22.5	22.5	806	838
M3	360	45	45	806	838
M4	315	67.5	67.5	806	838
M5	270	90	90	806	838
M6	225	112.5	112.5	806	838
M7	180	135	135	806	838

designed for the production of high-performance concrete Sicka 1050 was used in this work. Their physical and chemical characteristics are pH of 8.2 and the form is liquid. This increases the workability of concrete with reduced water.

2.2. Manufacture of self-compacting concrete

One control (SCC) and three SCC mixes at M30 grade were prepared. The water–cement ratio, SP dosage, and aggregate and fiber volumes were kept constant in all mixtures. The SP content was 2% by the weight of binders, the water/binder ratio was 0.35, and the glass fiber content was 0.25% by the weight of binders for all the mixes. Fly ash and metakaolin was replaced to cement at 5%, 10%, 15%, 20%, 25% and 30% respectively. Quantity of Materials required per cubic meter for self-compacting Concrete according to mix design was given in Table 2.

2.3. Preparation, casting and curing of SCC specimens

Weighed quantity of coarse aggregate and fine aggregate was first put and mixed for 1min, followed by the cement, fly ash, and metakaolin and were dry mixed for 2 min. Then SP was mixed with water, 70% of mixing water was added in the mixture, the remaining water was added 2 min after wet mixing was begun and the process was continued. Mixing was continued for another 5 min after addition of all of the mixing water. The glass fibers were directly added to the mixtures after addition of all of the water and then the mixture was casted in the mould and was left for the curing periods. After the curing period it was tested for fresh and hardened properties of three samples and the average is kept in the results.

3. Results and discussion

3.1. Properties of fresh concrete

The fresh properties of SCC are assessed for the filling ability, viscosity, passing ability and resistance to segregation. The slump flow diameter and the time to reach 500 mm (T500) were measured. In the J-ring test, the diameter and the J-ring height difference is measured. A mix that is prone to segregation will produce a non-circular pool of concrete as cement paste separates from the aggregates. The passing ability of fresh concrete was checked to ensure that the concrete can pass through congested reinforcement and small openings without any vibration and the J-ring flow test was used to assess the passing ability of fresh concrete. If the mix is prone to bleeding, a ring of clear water may form after a few minutes. The workability of concrete decreased when the binders in the mix was increased due to the lesser specific gravity than that of OPC [5]. Fresh properties of SCC are shown in Table 3.

Table 3

Fresh properties of SCC

Mix	Filling ability		Passing ability
	Slump (mm)	T 50cm	J-ring speed (mm)
M1	720	3.8	700
M2	700	4.0	700
M3	690	4.5	690
M4	680	4.8	670
M5	680	5.0	660
M6	670	5,2	650
M7	670	5.3	650

3.2. Compressive strength

The GPC samples of size 150X150X150 mm are tested for compressive strength in compressive testing machine of capacity 1000 KN. The testing is done on a set of three identical samples for each case at the age of 7 and 28 days. The mean values obtained for the compressive strength are represented in Fig. 1. Microcavities increased at addition of 10% of fly ash and metakaolin, releasing the internal pressure resulting from chemical water, due to this the compressive strength was increased at longer

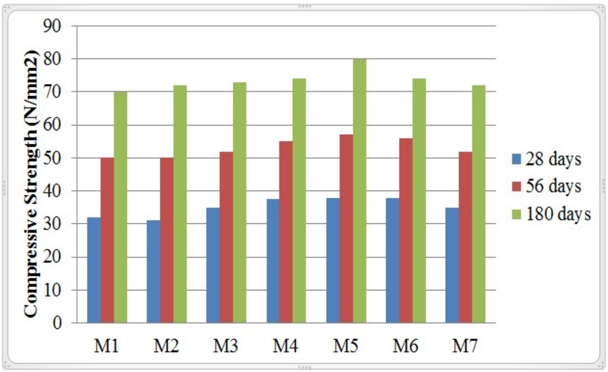

Fig.1 - 28, 56 and 180 Days compressive strength.

age curing [3]. When adding fly ash and metakaolin above 20% leads to decrease in compressive strength at all the ages of curing, due to the considerable increase in the amount of internal pores. Fly ash due to its spherical structure occupy empty spaces in the cement past, thus, would result in more compact microstructure with better mechanical properties [7], but it gains more strength at later ages due to this property it cannot gain more strength at 20% in 180 days curing by 14.8% compared to the conventional concrete. The compressive strength was increased upto 20% addition of metakaolin and fly ash by 0.2%, 4%, 6.2% and 14.28% compared to the conventional concrete at 180 days. Compressive strength results are shown in Fig.1.

3.3 Split tensile strength test

Split tensile strength test was carried out in the cylinder specimen of height 300 mm and dia of 150mm and are tested the specimens conforming to ASTM C39. Glass fibers would influence the tensile strength of the concrete by bridging micro-cracks within cement paste, rendering ductile post-cracking behavior. Along with binders, glass fibers also has the property of filling the voids which increases the tensile strength at addition of fly ash and metakaolin at 20 and 30% which is originated with the bending behavior of flexible fibers [7]. The tensile strength decreased for most of the mixes at 28 days curing due to the formation of porous ITZ between aggregates and cement paste which deteriorate the concrete strength comparing to normal concrete. At addition of 25% of metakaolin and fly ash the strength was increased by 12.5% at 180 days and 20% at 56 days strength compared to the conventional concrete. At all ages strength was increased compared to the conventional concrete. At 28 days strength there was only slight change in the strength compared to the conventional concrete. However, at later age curing the strength has enhanced due to addition of flexible glass fibers that will increase ductility by bridging the split parts and transferring tensile stress from the cement matrix to the fibers by 2.5%, 4.5%, 8.2%, 10% and 12.5% respectively till

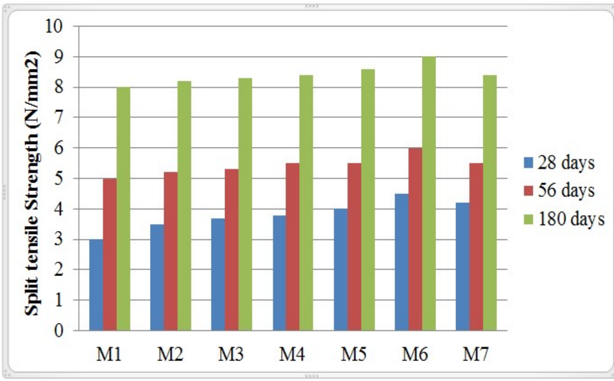

Fig.2 - 28, 56 and 180 Days Split tensile strength.

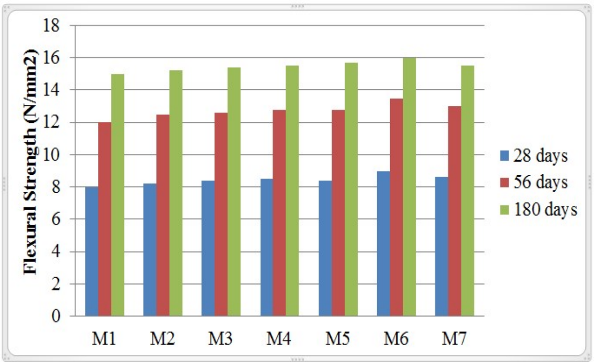

Fig.3 - 28, 56 and 180 Days flexural strength.

25% addition at 180 days compared to the conventional concrete. Split tensile strength results are shown in Fig.2.

3.4. Flexural strength

Flexural strength was carried out in specimen of size 150mm x 150mm x 700mm and is tested in compressive testing machine with flexural testing device. Flexible glass fibers tend to fill the generated empty space within the cement matrix due to their bending behavior. The glass fibers are capable of bridging the cracks at the tension zone and inhibit crack propagation by stretching. More void occupied by glass fibers would lead to an improvement in the concrete ductility, and hence, more promotion in the flexural strength at mix 3 and 4 [7]. The reason behind the enhanced strength during later age curing is due to the tendency of fibers to fill the generated empty space within the cement matrix due to their bending behavior, more void occupation by fibers would lead to an improvement in the concrete ductility, and hence, more promotion in the flexural strength. Lower strength at 28 days curing is due to the property of fly ash which shows enhanced performance only at later age curing and also due to the formation of pores. Addition of 25% of metakaolin and fly ash shows the optimum content with increase in strength of 13.4% at 180 days and 12.5% at 56 days compared to the conventional concrete. At all ages the flexural strength of SCC was increased compared to the conventional concrete in 180 days by 3.5%, 5%,7.5%,10% and

13.4% respectively for each percentage replacements up to 25%. Flexural strength test results are shown in Fig.3.

3.5 Water absorption

The water absorption is directly affected by the concrete's porosity. The higher water absorption can be accredited to the slow pozzolanic reaction results in low amount of hydration products. Therefore, voids within the concrete containing 30% fly ash and metakaolin was found. By prolonging the curing time to 180 days, the pore structure and the interfacial zone produced at early ages is densified by more hydration products, leading to the reduction of the absorption of SCCs compared with 28 days. This improvement is due to the pozzolanic effect of fly ash at the later ages [5]. Specimens with higher contents of fly ash revealed higher water absorption, which was attributed to the formation of gel in the binder. The low calcium level affected the re-organization of silicate, thereby reduced the C-A-S-H gel products, increased the pores at 28 days curing and showed less homogenize structure [9]. 28 days water absorption was more compared to the 56 and 180 days water absorption. When addition of metakaolin and fly ash at greater percentages, water absorption was increased at 28 days by 16% compared to the conventional concrete. But at 180 days the water absorption was decreased by 50% compared to conventional concrete at replacement by 20% and 25% respectively. Water absorption values are shown in Fig.4.

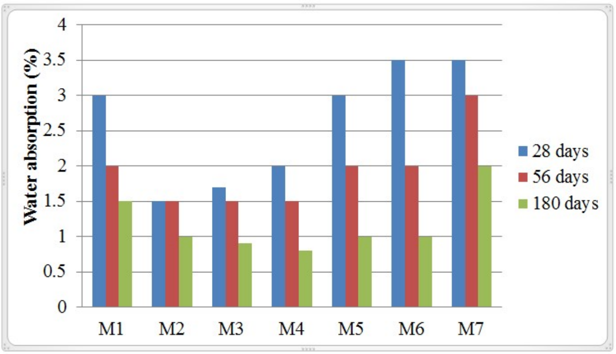

Fig.4 - 28, 56 and 180 Days water absorption.

3.6 Acid attack test

The specimen 150x150x150 mm cube is immersed in 5% of hydrochloric acid (HCl) mixed water for 180 days.

During the chemical curing, the acid solution is refreshed to maintain the PH. After this, the cube is taken out from the solution and weight loss is noted which is compared with the weight of normal curing and are tested using compression testing machine to find the strength of the cube which is compared with the normal curing concrete [22]. Loss in weight was decreased at the addition of 25% of fly ash and metakaolin. Weight loss was reduced by 25% and 67% at 20% and 25% replacement respectively compared to the conventional concrete. The compressive strength at 25% of fly ash and metakaolin showed lesser loss of strength compared to the nominal mix by 40%. Fig 5 and 6 shows the loss of weight and loss in compressive strength.

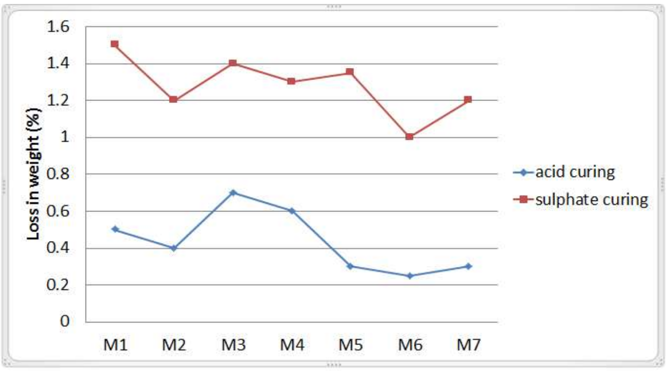

Fig.5 - Loss in weight by chemical curing at 180 Days.

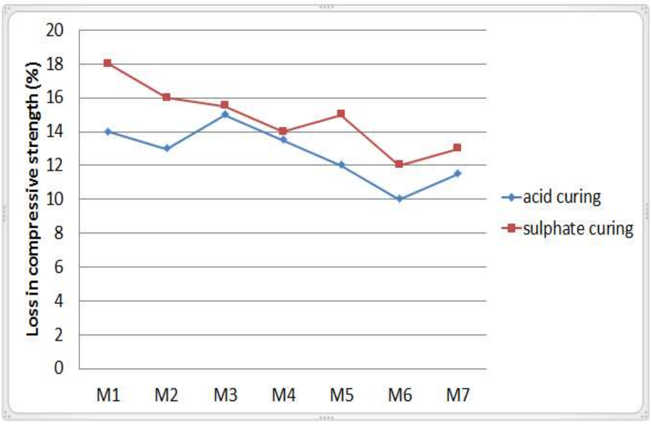

Fig.6 - Loss in compressive strength by chemical curing at 180 Days.

3.7 Sulphate attack test

The specimen 150x150x150 mm cube is immersed in 5% of sulphate solution mixed water for 180 days.

After curing, the cube is taken out from the solution and weight loss is noted which is compared with the weight of normal curing and are tested using compression testing machine to find the strength of the cube which is compared with the normal curing concrete [22]. SCC is susceptible to sulphate attack as compared to the acid curing. But compared with nominal mix, modified mix shows lower weight loss for all the mixes by 25%, 7%, 11%, 8% and 40% respectively due to the compact structure by the binders. And with 25% of fly ash and metakaolin, loss in compressive strength is lower. Compared to conventional concrete compressive strength loss was decreased by 12.5%, 13.2%, 15%, 13%, 50% and 25% respectively for all the mixes.

4. Conclusion

The conclusions are arrived based on the experimental results for various combinations of fly ash and metakaolin with the addition of fibers and results was being compared. From the observations of test results following conclusions are obtained,

1) The strength of the SCC mix with metakaolin and fly ash content was increased compared to the control mix and it was observed that the improvement in the strength was due to hydration in addition to pore filling property.

2) The compressive strength of SCC is increased compared to the control mix at all the ages and the optimum content is at 20% of metakaolin and fly ash at 180 days by 14.28% increase in strength compared to the conventional concrete.This is due to the compact microstructure of the mixes.

3) The split tensile strength of SCC is increased compared to the control mix at all the ages and the optimum content is at 25% of metakaolin and fly ash at 180 days by 12.5% increase compared to the conventional concrete because of the bridging property of fibers in micro pores and also due to the property of fly ash gaining strength at later age.

4) The flexural strength of SCC is increased compared to the control mix at all the ages and the optimum content is at 25% of metakaolin and fly ash by 13.4% compared to the conventional concrete due to the property of fibres to inhibit the cracks by stretching.

5) The mechanical properties of SCC incorporating metakaolin and fly ash found to be improved. The high fineness of fly ash supported the filler effect property and also improved the strength of SCC mixes.

6) The fresh concrete properties of SCC decrease with increase in the additive content due to lesser specific gravity. But all the mixes satisfy the filling and passing abilities.

7) By incorporating fly ash and metakaolin in self-compacting concrete, its water absorption was reduced at 180 days comparing to 28 and 56 days.

8) When curing at chemicals, the SCC are prone to acid and sulphate attack. At 25% addition of fly ash and metakaolin showed less loss in weight and loss in compressive strength compared to nominal concrete.

9) Self-compacting concrete is more ecological and it utilizes the waste materials like Fly Ash, metakaolin and glass fibers effectively thereby reducing the risk of their disposal which leads to hazardous environment.

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