

INFLUENCE OF METAKAOLIN AND SILICA FUME ON RHEOLOGICAL AND MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE

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ABSTRACT

Self Compacting Concrete may be defined as a flowing concrete that can be cast into place without the use of vibrators to form a product free of honeycombs and bugholes. Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Stone that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume. Silica Fume or condensed silica is another material that is used as an artificial pozzolanic admixture. This study investigates the effects of replacement by weight of cement or sand by metakaolin and silica fume. It has been found that the rheological behavior of Self Compacting Concrete is affected by the incorporation of metakaolin and silica fume. The compressive strength is increased significantly and a similar trend is observed at increased replacement levels. A lower but still noticeable improvement in split tensile strength is also found. However the rheological and Mechanical behavior of concrete produced by replacement by weight of cement was found to be more efficient than replacement by weight of sand.

KEYWORDS: Self Compacting Concrete, Meta kaolin, Silica Fume, Rheology, Compressive Strength, Split Tensile Strength

INTRODUCTION

Concrete is defined as “high- strength” solely on the basis of compressive strength at a given age. In the late 1970s before the advent of super plasticizers, concrete mixtures that showed 40MPa or more compressive strength at 28 days were called high-strength concrete. Later, when 60 to 120 MPa concrete mixtures came commercially available, in 2002 the ACI Committee on High Strength Concrete revised the definition to cover mixtures with a specified design strength of 55MPa or more.

Although conventional practice is to specify the concrete strength based on the 28 day test result, there is a growing movement to specify the 56 or 90 day strength because many structural elements are not fully loaded for periods as long as two to three months or even longer. The use of high-strength concrete mixtures, with dense steel reinforcement, has successfully met the need of the construction industry for stronger and more ductile structures. However the constructability of highly congested reinforced concrete elements require the fresh concrete mixtures to be very fluid. Even then the use of flowing concrete mixtures presents the risk of bleeding, segregation and settlement, which by weakening the interfacial transition zone between the cement paste and aggregate, would have an adverse effect on the mechanical

properties as well as on the durability of concrete. Thus Self Compacting Concrete may be defined as a flowing concrete that can be cast into place without the use of vibrators to form a product free of honeycombs and bug holes.

SCC may be used in pre - cast applications or for concrete placed on site. It can be manufactured in site batching plant or in a ready mix concrete plant and delivered to site by truck. It can be manufactured in a site batching plant or in a ready mix concrete plant and delivered to site by truck. It can then be placed either by pumping or pouring in to horizontal or vertical structures.

BRIEF REVIEW OF LITERATURE

Sfikas et al investigated the effect of replacement of cement or limestone powder by metakaolin. It was found that rheological behavior of Self Compacting Concrete is affected by the incorporation of metakaolin. Compressive strength is significantly enhanced and a similar increasing trend was observed at higher replacement levels. Hafez et al studied the effect of various filler types on the fresh and hardened properties of self-compacting concrete (SCC) and Flow-able concrete. For this purpose, two groups of fillers were selected. The first group was pozzolanic fillers (silica fume and met kaolin) while the second group was non-pozzolanic fillers (limestone powder, granite dust and marble dust). The test results showed that filler type and content have significant effect on fresh concrete properties where non-pozzolanic fillers improve segregation and bleeding resistance. Generally, filler type and content have significant effect on unitweight water absorption and void ratio. In addition, non pozzolanic fillers have significant effect on unit weight, water absorption and voids ratio. In addition, non-pozzolanic fillers have insignificant negative effect on concrete compressive strength. Srivastava et al quoted that the use of supplementary cementitious materials is fundamental in developing low cost construction materials for use in developing countries. By addition of some pozzolanic materials, the various properties of concrete viz, workability, durability, strength, resistance to cracks and permeability can be improved. Silica fume is known to improve both the mechanical characteristics and durability of concrete. Bijelijie et al studied the possibility of use of calcined clay as a partial substitute for cement. The key characteristics of SCC are based on its fresh properties. In this paper, fifteen mixes including different Metakaolin contents (0-20% by weight of cement) with three water/binder ratio of .32, .38, .45 were designed. The fresh concrete test results revealed that by substituting optimum level of metakaolin in SCC, satisfactory workability and rheological properties can be achieved. Metakaolin inclusion significantly increases the compressive strength of SCC within first 14 days up to 27%. Hassan and Lakheim investigated the rheological properties of self-consolidating concrete (SCC) containing metakaolin (MK) and compared with those of SCC containing silica fume (SF). The results showed that the plastic viscosity and the yield stress increased with the increase percentage of MK. On the other hand, the addition of SF did not affect the viscosity of the SCC mixture but a sharp increase in the yield value was detected as the percentage of SF was increased. The results also demonstrated a correlation between the slump flow diameter and the yield stress as well as a correlation between the viscosity and the slump flow time.

EXPERIMENTAL INVESTIGATION

Materials and Mix Proportion

In the present study coarse aggregate of size passing through 12.5 mm and retaining on 10mm sieve, aggregates passing through 10mm and retaining on 6 mm aggregates were used. The sieve analysis of the aggregate were carried out as per IS: 2386 (Part 1)-1963. The important properties of the coarse aggregate were fineness modulus =2.461, water absorption = 0.5%, crushing value = 30.12%, and specific gravity = 2.673.

Fine aggregate used in the investigation was Manufactured Sand (M-Sand). The properties of fine aggregate found as per IS 383-1970. The important properties of the fine aggregate were fineness modulus =3.446, water absorption = 9%, and specific gravity = 2.66. The gradation of fine aggregate (Zone II) was maintained.

Met kaolin for the present investigation was obtained from English India Pvt. Ltd, Thiruvananthapuram. Silica fume for the experiment was obtained from BSS Chemicals Pvt. Ltd, Ernakulam. The physical and chemical properties of Silica fume and metakaolin has been given in Table 1.

Table 1: Physical and Chemical Properties of Metakaolin and Silica Fume

Physical	Silica Fume	Metakaolin
Specific Gravity	2.23	2.52
Main grain size (µm)	0.15	2.54
Specific area (cm ² / gm)	150000-300000	150000-180000
Colour	Dark to light grey	Dark grey
Chemical		
Silicon Dioxide (SiO ₂)	85	60-65
Aluminium Oxide (Al ₂ O ₃)	-	30-34
Iron Oxide (Fe ₂ O ₃)	-	1
Calcium Oxide (CaO)	0.2-0.8	0.2-0.8
Magnesium Oxide(MgO)	0.2-0.8	0.5-1.2
Sodium Oxide(Na ₂ O)	0.5-1.2	-

The binder used in this investigation was 53 grade OPC (Deccan Cement). The properties of the cement was determined in accordance with IS 8112-1989 were Consistency = 30%, Initial Setting time = 75 minutes, Specific gravity = 3.125, Final Setting time = more than 180 minutes.

For the present study mix design for M110 grade of concrete was carried out using the above coarse aggregate, fine aggregate and the binder. Table 2 shows the Mix id abbreviation for various mixes used in the experimental investigation , Table 3 shows the Mix proportions for mixes when the replacement is done by weight of cement

Table 2: Mix Id Abbreviation

Mix ID	Abbreviation
M ₀ S ₀	Metakaolin 0% Silica fume 0%
M ₁₀ S ₈	Metakaolin 10% Silica fume 8%
M ₁₀ S ₁₀	Metakaolin 10% Silica fume 10%
M ₁₀ S ₁₂	Metakaolin 10% Silica fume 12%

Table 3: Quantity of Materials per M³ of Concrete (M110) with Admixtures during Cement Replacement

Mix ID	Cement (Kg)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	Met kaolin (Kg)	Silica Fume (Kg)	Water (L)
M ₀ S ₀	639.84	864.72	765.68	-	-	166.36
M ₁₀ S ₈	524.67	864.72	765.68	63.98	51.19	136.42
M ₁₀ S ₁₀	511.88	864.72	765.68	63.98	63.98	133.09
M ₁₀ S ₁₂	499.08	864.72	765.68	63.98	76.78	127.27

Table 4 shows mix proportions for mixes when the replacement is done by weight of Sand. The replacement is done with the mineral admixtures, met kaolin and silica fume The dosage of met kaolin being fixed as 10% and silica fume being fixed from 8%, 10% to 12%.

Table 4: Quantity of Materials per M³ of Concrete (M110) with Admixtures during Sand Replacement

Mix ID	Cement (Kg)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	Met Kaolin (Kg)	Silica Fume (Kg)	Water (L)
M ₀ S ₀	639.84	864.72	765.68	-	-	166.36
M ₁₀ S ₈	639.84	864.72	627.87	76.56	61.25	166.36
M ₁₀ S ₁₀	639.84	864.72	61.26	76.56	76.56	166.36
M ₁₀ S ₁₂	639.84	864.72	597.24	76.56	91.88	166.36

Test Procedures

The proportion of the materials by weight was 1:1.196:1.35 (Cement: Fine Aggregate: Coarse Aggregate) in this investigation a comparative study on the effect of met kaolin and silica fume on rheological and mechanical properties of self compacting concrete for replacement by weight of cement and replacement by weight of sand was done. Cement only specimens were casted for checking the compressive strength at 28th & 56th days. Specimens were cast for different variation of Silica Fume with Met kaolin dosage being fixed as 10%. Percentage replacement by weight of cement and sand with Silica Fume is varied by 8-12%. Rheological property test such as Slump flow, V-funnel time, L-Box test were carried out. Mechanical properties such as Compressive strength, Flexural strength, Split tensile strength at 28 days and 56 days were carried out. For determining the compressive strength, cube specimens of size 150 x 150 x 150mm were cast. For the determination of Split tensile strength cylinder, specimens of 150 x 300mm were cast. The flexure test was carried out on beam specimens of 100 x 100 x 500mm, since the maximum size of aggregate used for casting the specimens were less than 20mm.

RESULTS AND DISCUSSIONS

- Rheological Behaviour Study**

Fresh properties of different mixes with replacement of sand and cement are tabulated in Table 5 and Table 6

Table 5: Fresh Properties of SCC Due to Replacement by Weight of Cement

Mix ID	Silica Fume Dosage (%)	Slump Flow (Mm)	T ₅₀₀ (Sec)	V Funnel Time (Sec)	Passing Ability
M ₀ S ₀	0	720	4	11	0.91
M ₁₀ S ₈	8	685	4.5	14	0.88
M ₁₀ S ₁₀	10	615	6	21	0.83
M ₁₀ S ₁₂	12	570	9	23	0.8

Table 6: Fresh Properties of SCC Due to Replacement by Weight of Sand

Mix ID	Silica Fume Dosage (%)	Slump Flow (Mm)	T ₅₀₀ (Sec)	V Funnel Time (Sec)	Passing Ability
M ₁₀ S ₈	8	669	5.9	19	0.85
M ₁₀ S ₁₀	10	585	8.6	24	0.78
M ₁₀ S ₁₂	12	554	9	26	0.72

From Table 5 and Table 6 it can be inferred that addition of mineral admixtures decreases the workability of concrete with increase in replacement level of admixture. Water demand increases in proportion to the amount of micro silica added. Additions of mineral admixtures make concrete sticky and hard to handle. Thus it can be also seen from the graph that replacement by weight of sand makes the concrete stiffer than replacement by weight of cement and sand. This

may be attributed to the increased fineness of mix happening due to replacement by weight of sand. Thus the results show that all mixes satisfy the requirements of SCC. This variation illustrates the effect of addition of mineral admixtures on the workability of concrete. Mineral admixtures being finer than cement particles, the water demand to wet the surface of these fine particles increases, thus reducing the amount of water available for cement particles and making the concrete stiffer. But this drawback has been overcome by the use of polycarboxylic ether contained super plasticizers.

MECHANICAL PROPERTY

- **Compressive Strength**

Cement only specimens were casted for checking the compressive strength at 28th & 56th days. Specimens were cast for different variation of Silica Fume with Met kaolin dosage being fixed as 10%. Percentage replacement by weight of cement and sand with Silica Fume is varied by 8-12%. Thus the optimum dosage was found at met kaolin dosage 10% and silica fume dosage 10%. Figure 1 and Figure 2 shows the comparison between the 28th day and 56th day compressive strength obtained from replacement by weight of cement and replacement by weight of sand.

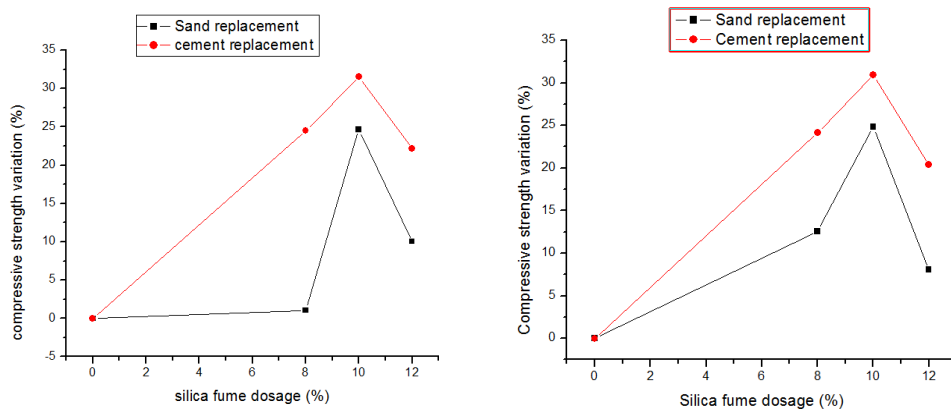


Figure 1: 28th Day Compressive Strength Variation Figure 2 56th Day Compressive Strength Variation

From the Figure 1 and Figure 2, it was inferred that incorporation of Metakaolin and Silica Fume increases the compressive strength of concrete; however the optimum combination was found out to be 10% of Metakaolin and 10% of Silica Fume. This is due to the reaction of calcium hydroxide produced as a by product of cement hydration with silica present in the mineral admixtures. Compressive strength of cube specimens increased up to 28.9% when the replacement was done by weight of cement and 22% when the replacement was done by weight of sand. Thus replacement by weight of cement gives better results than replacement by weight of sand from the perspective of compressive strength of cube specimen. Thus the reason for the increase is due to the optimum reaction between mineral admixture dosage and calcium hydroxide formed during the hydration process. In the increased replacement level there is reduced formation of calcium silicate hydrate, thus resulting in formation of weaker interfacial transition zone and weaker packing of the matrix compared to the mix in the optimum replacement level.

- **Split Tensile Strength**

Specimens were cast for different variation of Silica Fume with Metakaolin dosage being fixed as 10%. Percentage replacement by weight of cement and sand with Silica Fume is varied by 8-12%. Thus the optimum dosage was found at metakaolin dosage 10% and silica fume dosage 10%. Fig 3 and Fig 4 shows the variation of split tensile strength at 28th

and 56th day test results.

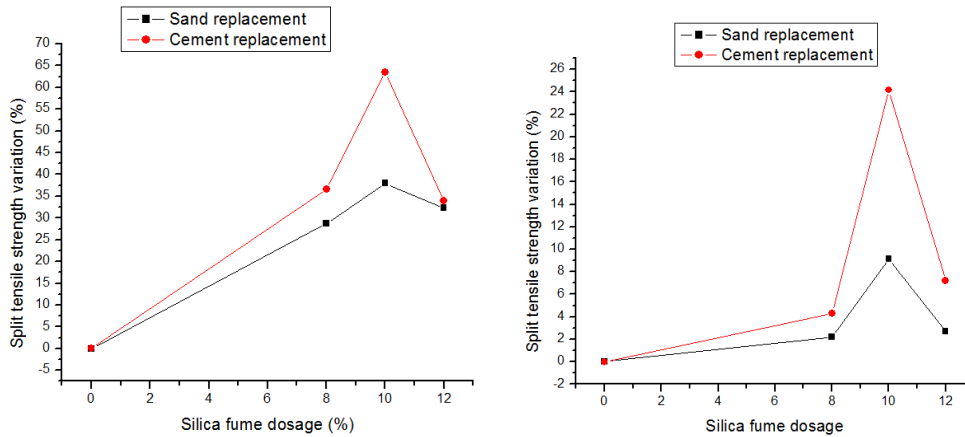


Figure 3: 28th Day Split Tensile Strength Variation Figure 4 56th Day Split Tensile Strength Variation

• Flexural Strength

Specimens were cast for different variation of Silica Fume with Metakaolin dosage being fixed as 10%. Percentage replacement by weight of cement and sand with Silica Fume is varied by 8-12%. Fig 5 and Fig 6 shows the variation of flexural strength at 28th and 56th day test results. From the Fig 3, Fig 4, Fig 5 and Fig 6, it can be inferred that incorporation of Metakaolin and Silica Fume increases the tensile strength of concrete, however the optimum combination was found out to be 10% of Metakaolin and 10% of Silica Fume. The modulus of rupture as per Codal provision was found out to be 7.34N/mm². However split tensile strength showed a lower value than the requires strength, but values obtained from flexural strength satisfy the minimum required strength. Split tensile strength of cylinder specimens increased up to 23% when the replacement was done by weight of cement and 21% by weight of sand. Flexural strength of beam specimens increased up to 32% when the replacement was done by weight of cement and 14.75% when the replacement was done by weight of sand. The decrease in the split tensile strength of concrete during replacement by weight of sand may be attributed to increase in the fineness of the mix.

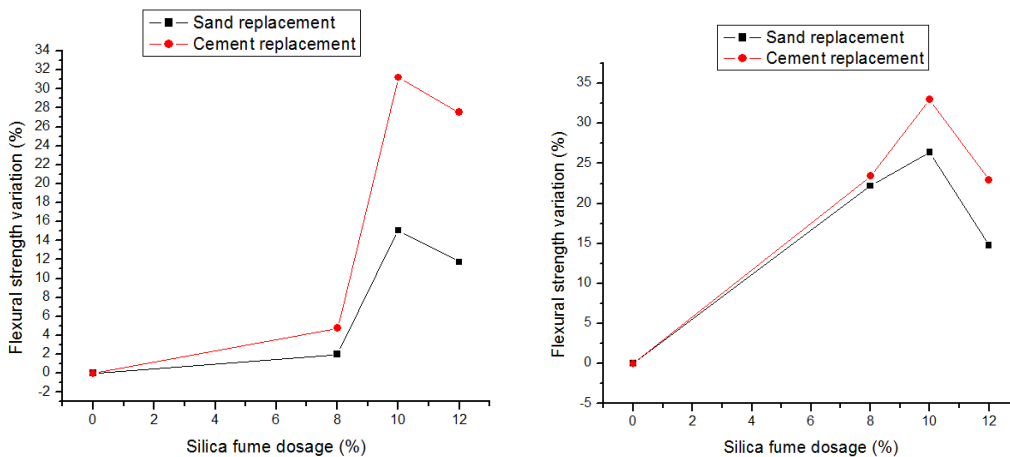


Figure 5: 28th Day Flexural Strength Variation Figure 6 56th Day Flexural Strength Variation

CONCLUSIONS

In this work, it is attempted to study the scope of using supplementary cementitious materials to obtain high strength Self Compacting Concrete. Study has been carried out to do a comparison between replacement of the admixtures by weight of cement and replacement by weight of sand.

Based on the experimental investigation

- Three tests were carried out to determine the flow ability, viscosity, passing ability through the following tests namely Slump flow, V-funnel time and L-Box test respectively.
- From the test on rheological properties it was inferred that addition of mineral admixtures reduces the Slump flow and passing ability of the concrete mix but increases the viscosity of the mix.
- Replacement of admixtures by weight of cement is more efficient than replacement by weight of sand.
- The reduction in workability of the mix may be attributed to increased stiffness of the mix due to the increase in fineness because of the presence of mineral admixtures.
- From the comparative study on hardened properties of the concrete it was inferred that replacement by weight of cement gave more strength when compared to replacement by weight of sand.
- The Compressive strength of cube specimens increased up to 29% when the replacement was done by weight of cement and 22% when the replacement was done by weight of sand.
- A lower but considerable increase in Split tensile strength of concrete was found with the incorporation of mineral admixture. Split tensile strength of cylinder specimens increased up to 23% when the replacement was done by weight of cement and 21% by weight of sand

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