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# Characteristic Studies on Partial Replacement of Cement with Metakaolin and Fine aggregate with Silica sand in SCC

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**ABSTRACT:** Self-compacting concrete (SCC) is a new type of concrete which can be placed in every corner of formwork under its weight without any segregation. On the other hand, the cost of SCC is high due to its expensive ingredients such as mineral and chemical admixtures and cement. Hence, with the aim of reducing the production cost of SCC without sacrificing on its strength and durability performances, the authors have attempted to produce SCC incorporating the waste materials such as Metakaolin (MK) and Silica sand (SS). In this study MK and SS are used in the production of SCC in varying percentage replacements. The fine aggregate is replaced at 0% and 30% by volume replacements of SS. Metakaolin is used in proportions of 0, 10, 20 and 30% by volume of cement. The experimental program of the study consisted of eight concrete mixes which reflect the key variables and their effects on the fresh, mechanical and durability properties of the produced SCC. The fresh properties test results for acceptance characteristics of SCC such as slump flow and slump flow T500 were conducted and the mechanical properties such as compressive strength test at various ages of 28 and 56 days and durability properties such as water absorption test and sulphate attack test were also determined and results are presented. The obtained results in all of the studied mixes indicate that the performance of SCC produced with MK and SS are comparable with that produced with natural aggregate.

**KEYWORDS:** Self compacting concrete, Metakaolin, Silica sand, Fresh properties, Compressive strength, Durability properties.

## I. INTRODUCTION

Self-Compacting concrete is a type of concrete which flows and compacts only under gravity. Usually, conventional concrete requires vibration for compaction but SCC does not require any vibration. SCC is suitable in areas where compaction of concrete is very difficult and also in case of congested reinforcement. The properties of SCC are improved by adding mineral and chemical admixtures in it. Self-compacting concrete usually possesses the following properties:

- (i) Filling ability: the ability of concrete to fill all the corners of the formwork.
- (ii) Passing ability: the ability of concrete to pass the reinforcement.
- (iii) Segregation resistance: the concrete should remain homogeneous before and after placing.

Lately, in the field of construction, there is an increase in the construction of large and complex structures, which often results in difficulty of placing the concrete. In congested reinforcements, the vibration of concrete is hard, and also results in segregation of concrete. The strength of concrete is affected due to segregation. In order to overcome this problem, the use of SCC is necessary. Countries like Japan, Britain and Sweden widely use SCC on a large scale but in India, the use of SCC is comparatively lesser. SCC contains powder material as constituent in addition to the traditional concrete materials. Therefore, in general, the density of SCC seems to be higher than the density of normal concrete.

Industrial by-products such as metakaolin, fly ash and silica sand can be used as mineral admixtures in SCC. By using these industrial by-products, the cost can be reduced and also environmental pollution is minimized.

Metakaolin (MK) is one type of calcined clay and it comes from the calcination of kaolin clay. It is a dehydroxylated form of the clay mineral kaolinite. Metakaolin is commonly used in the production of ceramics, but is also used as cement replacement in concrete.

## II. LITERATURE REVIEW

Hamdy [1] et al. (2017) carried out an experimental investigation on the mechanical behaviour of high strength concrete made with high percentages of Metakaolin and hybrid fibres with volume fractions of 0.25% and 0.5%. A total of 315 standard test specimens (189 cubes and 126 cylinders) were cast and divided into three groups each group consisted of 105 specimens and each data was based on the average results of 3 test specimens. The Metakaolin (MK) percentage was fixed in all groups (10%, 15%, 20%, 30%, 40% and 50%) as a percentage of cement weight.

Arulsivanantham [2] et al. (2017), has done a review paper on self-compacting concrete which is made using various admixtures and fibres. This paper discusses about the mix design of SCC and the tests to be conducted on fresh concrete, and their acceptance values. In this paper, the need for SCC and its importance is clearly explained. The properties of SCC are also discussed.

Kasini [3] et al. (2012) studied the influence of Metakaolin (MK) and Calcined Kaolin (CKs) on the compressive strength development of the concrete. The Metakaolin samples investigated were obtained from four different sources in Czech Republic. Portland cement was replaced with Metakaolin in the percentages of 5%, 10%, 15% and 20% for the production of concrete. For comparative basis, a plan mix without admixture was produced and compressive strength development of the concrete was evaluated at 3, 7, 28 and 90 days.

Ramezaniapour&Bahrami[4] (2012) studied the response of concrete mixtures containing local Metakaolin in terms of compressive strength, water penetration, absorptivity, salt ponding, Rapid Chloride Permeability Test (RCPT) and electrical resistivity subject to 7, 28, 90 and 180 days of curing. Portland cement was replaced with Metakaolin at 0%, 10%, 12.5% and 15% by mass. Mixes were designed based on w/c ratios of 0.35, 0.4 and 0.5 at a constant binder content of 400 kg/m<sup>3</sup>.

Ubojiekere E. Obunwo [5] et al (2018). study investigates the effects of metakaolin on the fresh state and compressive strength of high strength self-compacting concrete. The particle packing model (PPM) was adopted for the mix design of concrete constituents. The prime rational was to eliminate void in the self-compacting concrete (SCC).

## III. MATERIALS AND THEIR PROPERTIES

**3.1 Properties of Cement:** A cement is a binder material used in construction. Cement is mixed with water for hardening and binding the materials. The raw materials used for cement are lime (CaO), silica (SiO<sub>2</sub>), alumina (Al<sub>2</sub>O<sub>3</sub>) and gypsum. Ordinary Portland cement-43 grade conforming to IS: 8112 was used for the present study. Various tests are performed on cement to determine its quality and strength as per the guidelines provided in IS: 4031-1988.

**Table 1- Physical properties of cement**

Physical Properties	Value
Specific gravity	3.14
Fineness of cement	8%
Initial setting time of cement	52 min
Final setting time of cement	315 min

**3.2 Properties of Aggregate:** The aggregate which passes through 4.75 mm and retaining on 0.075 mm sieve is known as fine aggregate. Usually, river sand and m-sand are used as fine aggregate in concrete. The aggregates which are above 4.75 mm in size are called as coarse aggregate. Generally crushed stones are used as coarse aggregate in concrete. Depending on concrete grade and purpose, the size of the aggregate changes.

Table 2- Physical properties of Aggregates

Physical properties	Fine aggregate	Coarse aggregate
Specific gravity	2.59	2.73
water absorption (%)	1	0.7
Bulk density (kg/m <sup>3</sup> )	1375	1506
Fineness modulus	3.06	8.53

### 3.3 Properties of metakaolin & silica sand:

Table 3- Physical properties of metakaolin &amp; silica sand

Physical properties	Metakaolin	Silica sand
Specific gravity	2.6	2.3

## IV. EXPERIMENTAL METHODOLOGY

The experimental study is done in three stages. In stage-1 the mix design of M30 grade SCC is done based on trial-and-error method. In stage-2 the cement is then replaced with metakaolin by 10%, 20% and 30% variations and silica sand by 30% to increase the workability of SCC. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of Metakaolin and Silica sand on compressive strength and durability characteristics of self-compacting concrete so as to assess its feasibility for use in building structures. The experimental program consists of casting of specimens, curing and testing of controlled mix concrete specimen and concrete specimen incorporated with metakaolin and silica sand at different ages. For the mix design of SCC, there is no specific design procedure, but few guidelines are provided in IS 10262 (2019) and also in EFNARC code. So, our mix design is done based on these guidelines.

Table 4- Quantity of materials for 1m<sup>3</sup>

S No	Mix	Cement (kg/m <sup>3</sup> )	FA (kg/m <sup>3</sup> )	SS (kg/m <sup>3</sup> )	CA (kg/m <sup>3</sup> )	MK (kg/m <sup>3</sup> )	W/C (lit/m <sup>3</sup> )
1	MK0SS0	500	830	0	700	0	185
2	MK10SS0	450	830	0	700	50	185
3	MK20SS0	400	830	0	700	100	185
4	MK30SS0	350	830	0	700	150	185
5	MK0SS30	500	581	249	700	0	185
6	MK10SS30	450	581	249	700	50	185
7	MK20SS30	400	581	249	700	100	185
8	MK30SS30	350	581	249	700	150	185

Many different test methods have been developed in attempts to characterise the properties of SCC. So far, no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly, no single method has been found which characterises all the relevant workability aspects. So, each mix design should be tested by more than one test method for the different workability parameters. The fresh concrete tests in this test were performed according to the procedure given by EFNARC Committee. Compressive test was performed on hardened



concrete for 28 days and 56 days respectively. Water absorption test and sulphate test were performed to test the durability characteristics of the concrete.

## V. TEST RESULTS AND DISCUSSIONS

Various tests were performed on fresh concrete and hardened concrete and the results were analysed. The analysis of results provides clear perspective about the behaviour of concrete under various conditions. In the analysis, the obtained results are compared with each other to determine its behaviour. The results can be easily analysed with the help of graphs given below.

### 5.1 Slump flow test:

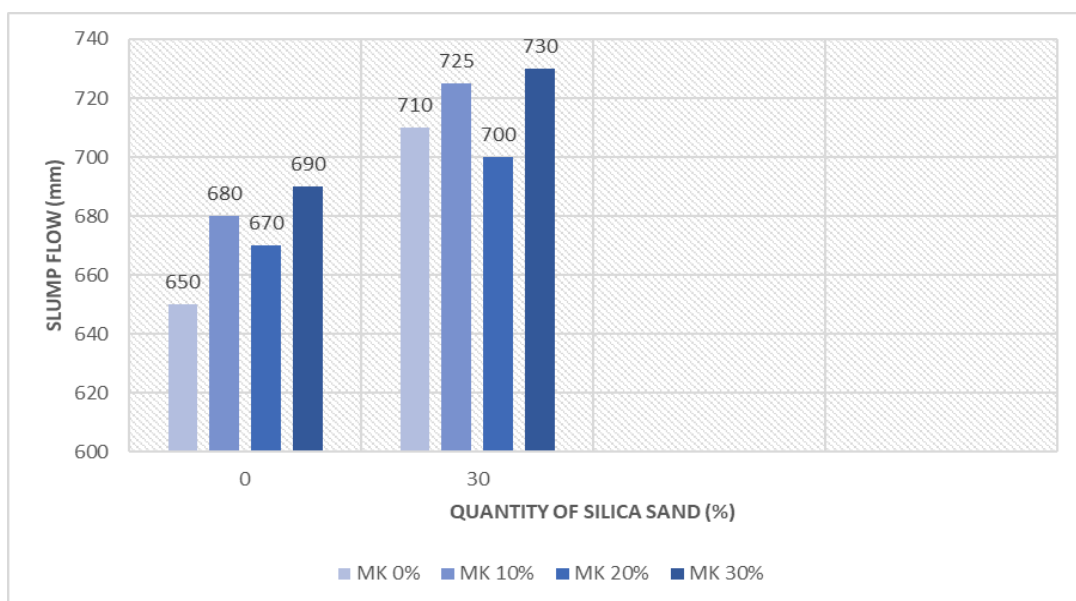


Fig 1- Variations of slump flow test

### 5.2 Slump flow at T50cm:

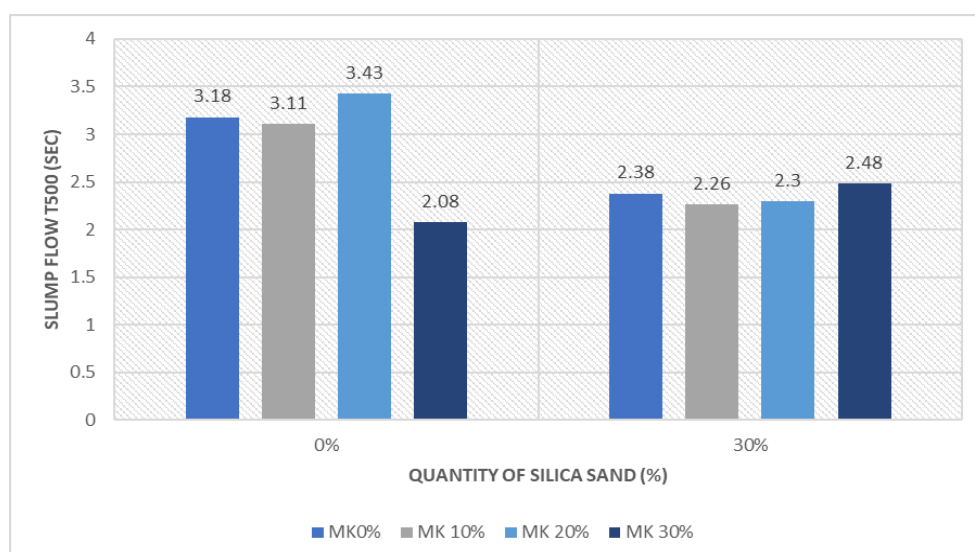


Fig 2- slump flow T500 for various SCC mixes

### 5.3 Compressive strength at 28 days:

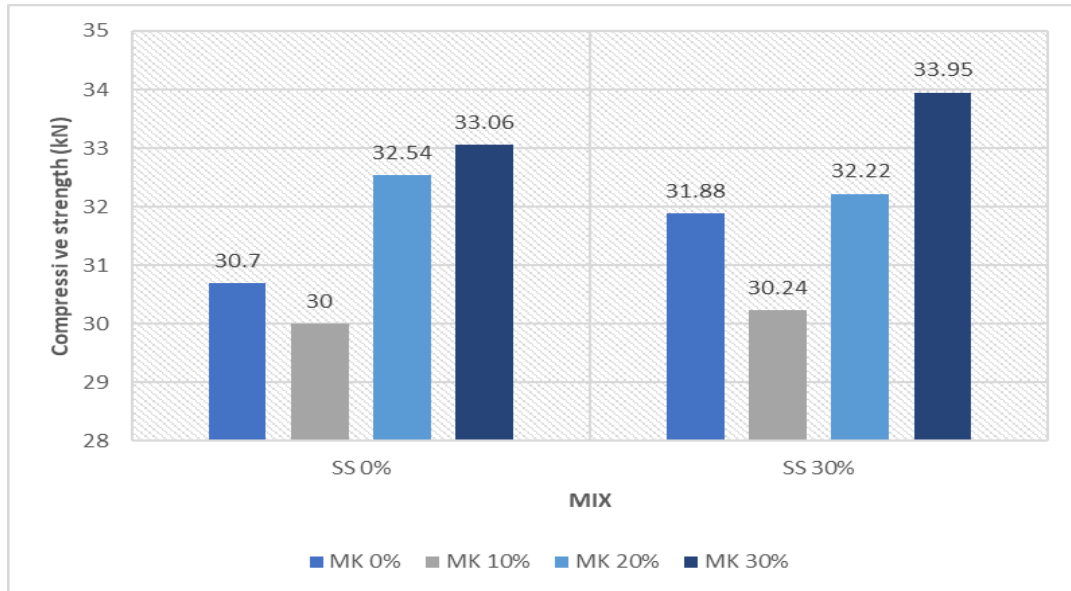


Fig 3- Compressive strength of SCC at 28 days.

### 5.4 Compressive strength at 56 days:

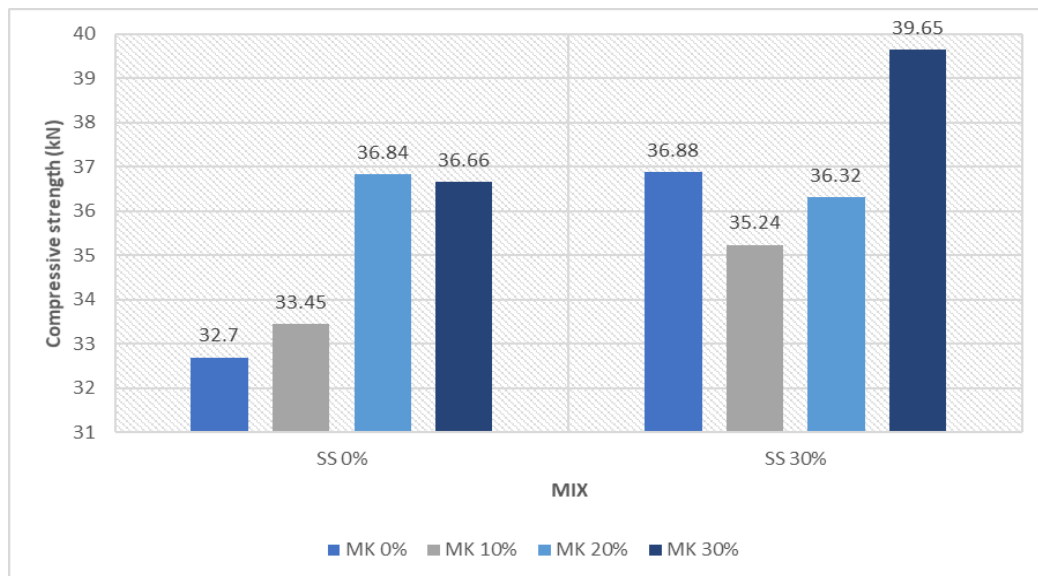
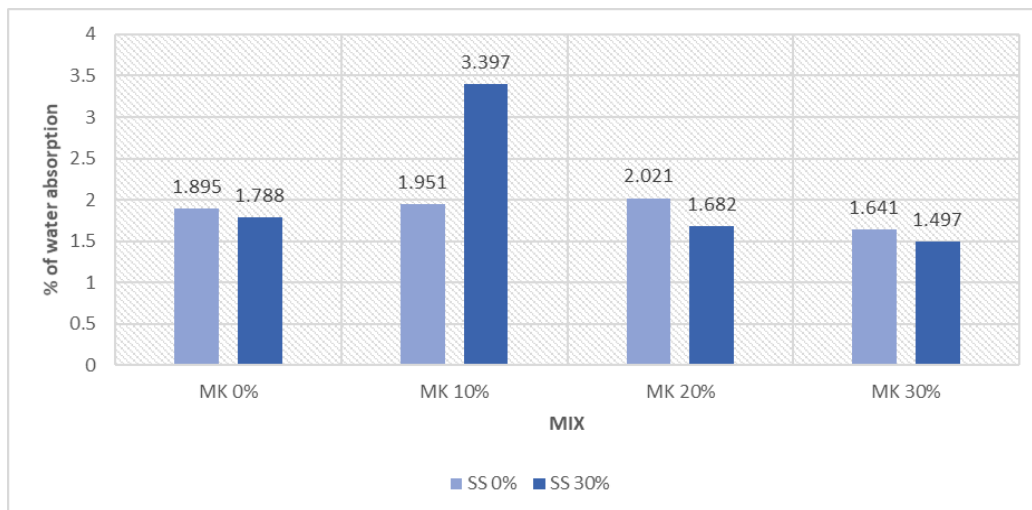


Fig 4- Compressive strength of SCC at 56 days.

The graph of the compressive strength in figure 3&4 depicts that the increase in percentage replacement of metakaolin and silica sand, the compressive strength of the cubes increases. Mix with 30% replacement of metakaolin and 30% replacement of silica sand is found to be optimum mix.

### 5.5 Water absorption test:

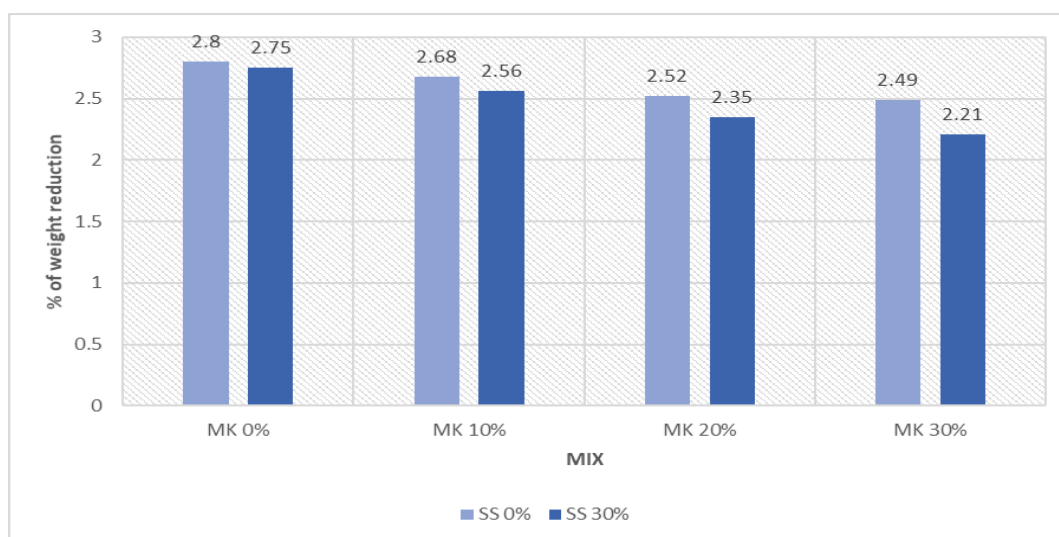


**Fig 5- Water absorption test at 28 days**

The water absorption test for 56 days is conducted for the casted specimen. Concrete cubes of 150mm size are casted and cured in potable water for 56 days from the day of casting. From the values obtained from the water absorption test, it is clear that as the percentage replacement of metakaolin and silica sand increases, the percentage of water absorption decreases. Mix with metakaolin replacement of 30% and silica sand replacement of 30% is observed as the mix with lowest percentage of water absorption with 1.497%.

### 5.6 Sulphate test:

The sulphate attack testing procedure was conducted by immersing concrete specimens of the size 100x100x100 mm over the specified initial curing in a water tank. Then, they were cured in 5% Sodium sulphate solution for 56 days. The degree of sulphate attack was evaluated by measuring the weight losses of the specimens at 56 days.



**Fig 6- Sulphate attack test on SCC**

From the sulphate attack test, it is observed that the percentage of weight reduction due to the attack of sulphate in concrete becomes lesser as the replacement of metakaolin and silica sand in concrete increases.

## VI. CONCLUSION

1. In this study, it has been found that with the increase in superplasticizer dosage, the workability is increased. So, the required slump value fulfilling the criteria of EFNARC can be obtained.

2. For 30% replacement of metakaolin and silica sand, the fresh properties observed were good as compared to 0%, 10% and 20% replacement. Hence, if we increase the metakaolin replacement of cement, we can have better workable concrete.

3. The results of mechanical properties (compressive strength) have shown significant performance differences, and the higher compressive strength has been obtained for 30% metakaolin and silica sand replacement. So, 30% replacement level could be of optimum consideration for flowability, mechanical properties and durability study.

4. From the results of the water absorption test, it is clear that as the percentage replacement of metakaolin and silica sand increases, the percentage of water absorption decreases.

5. Metakaolin, when added as a cement replacement in concrete enhances the sulphate resistance in concrete.

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