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# Performance of Self Compacting Concrete Incorporating Ground Granulated Blast furnace Slag and Metakaolin

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**Abstract.** The experimental study of two supplementary cementitious material on self-compacting concrete was investigated. Three mixes were designed, the control mix without the supplementary cementitious material, second mix with metakaolin (MK) and third mix with ground granulated blast furnace slag (GGBFS) both at 5, 10, 15, 20 and 25% respectively. After each mix preparation, workability test was carried out and specimens of the three mixes were cast and cured in water for 7, 14, 21 and 28 days respectively. Tests on hardened concrete were carried out to know the compressive strength of the three-mix designs. The test results showed that a replacement of 5% of both admixtures GGBFS and Mk increased in the compressive strength compared to the control mix. Also observed was the presence of mineral admixtures that had a significant on the strength loss due to the sodium, calcium and magnesium sulphate attack. The best resistance was obtained for 5% MK and GGBFS at 28 days curing.

**Keywords:** self-compacting concrete, metakaolin, ground granulated blast furnace slag, curing and compressive strength.

## 1. Introduction

A concrete that flow under its own weight, fill the form work, enclose the reinforcement while maintaining homogeneity and consolidate without the need for vibration or compaction is known as self-compacting concrete (SCC). In construction industry, development of this type of concrete is a desirable achievement in overcoming problems associated with cast in-situ concrete. Self-compacting concrete is not affected by reduction in skilled labourer, shape of form work and amount of reinforcement. This concrete can be pumped at longer distance due its high fluidity and segregation resistance, this type of concrete was proposed by Professor Okamura Hajime in 1986 but its prototype was developed in japan by [6]. SCC was developed at the time to improve the durability of concrete structures. All over the world investigations have been carried out on SCC used in partial structures. The advantage for employment of SCC include compaction of confined zone, shorten the construction period and eliminate vibration noise. Self-compacting concrete consist of cement, aggregate, water with addition of chemical and mineral admixtures. High range water reducers (superplasticizer) and viscosity modifying agent which change the rheological properties of the mix while mineral admixtures are used as partial replacement with cement and at times with fine aggregate. In this research the cement content was partially replaced with mineral admixture, metakaolin which improves the following and strengthen characteristic of the concrete. It is obtained by calcination of pure or refined kaolin clay at a temperature between 650 and 850°C, followed by grinding to achieve a fineness of 700m<sup>2</sup>/kg to 900m<sup>2</sup>/kg. The resulting material has high pozzolanicity. The metakaolin



used is manufactured from pure raw material to strict quality standard. From the blast furnace, iron slag is quenched and kept in water to produce a glassy granular product which is grounded and then dried into fine powder to produce ground granulated blast furnace slag (GGBS). [1] it was observed that concrete made with GGBS set more slowly than concrete made with ordinary Portland cement. [5] Studied effect of blending Portland cement with GGBS slag on the properties of concrete. They concluded that GGBS in replacement of cement increased the workability and compressive strength can be increased to the strength of NCC. [10] investigated GGBF and metakaolin effect on the mechanical properties of SCC, he reported that varying percentage of metakaolin mix increase the temperature of the mix and the filling and flowability of the mixes decreased. [10] also reported that the mix with 6% metakaolin and 15% GGBS exhibited maximum mechanical properties while the chloride permeability of the mix decreased as the percentages of the metakaolin and GGBS increased. The bond strength of SCC is more compared to ordinary concrete. Self-compacting concrete should have lesser coarse aggregate content and hence high cement content. [8] assessed the strength properties of cassava peel ash concrete. Cassava peel ash was used to partially replace cement at varying percentages and curing days. It was seen that the concrete can be used for light construction works where high strength is not a major requirement, but durability is a major concern. [4] examined the mechanical behaviour of concrete mix grade of M20 and M30 replaced with marginal product of RHA and GGBS to minimize the cost of cement and concluded that replacing the cement at varying percentage with both mineral admixtures gave good strength without altering much strength of the concrete. [11] studied the strength parameter of geopolymer concrete with GGBS and Metakaolin, they reported that the geopolymer concrete workability decrease as metakaolin content and increases with GGBS. For mechanical properties, metakaolin in concrete show increase trend. 30% metakaolin and 70% GGBS seem to have good compressive, split and flexural strength. [7] researched concrete durability of palm oil fuel ash at 14, 28 and 90 days of water absorption on the specimen also tested for acid and sulphate resistance, from the result it is observed mixes with ash had low resistance to the acid and sulphate test compared to SCC with palm oil fuel ash which had high values. [1] studied improving the performance of concrete by also reducing the amount of cement and quantify the strength of concrete by using GGBS as cement replacement for M35 grade. Specification, production method and degree of effectiveness of each replacement are studied to achieve high performance and sustainable concrete. At curing age of 28 days replacement of 20% GGBS achieved increase in strength and degree of workability of concrete was normal. [9] used statically analysis to determine the dataset on predictive compressive strength models of SCC. They concluded that water cement ratio, aggregate combination, superplasticizer and binder combination are variables that affect compressive strength for 7, 28 and 90 days. The objective of this study is to find out the influence of mineral admixtures on the hardened and fresh properties of SCC. The performance is observed by the fresh concrete tests using the L-box and V-funnel; and on the hardened concrete tests.

#### **Requirement of Self Compacting Concrete are;**

Filling ability: complete filling of concrete in the form work while maintaining homogeneity, this is measured by T50cm slump while the flow ability is measured by the slump flow test of concrete. It the horizontal and vertical flow of concrete mix with in form work and encapsulating of reinforcement.

Passing ability: narrow section, complex shape of formwork, closely spaced reinforcement etc. are filled with SCC mix passing through the obstacles without blocking caused by interlocking of the aggregate particles; this is measured by the L-Box.

Resistance to segregation: dynamic and static stability of concrete during placement, casting and mixing refers to the resistance of segregation and bleeding of self-compacting concrete mix.

**Table 1:** Properties of Portland Cement and Mineral Admixtures

Property	Cement	GGBFS	Metakaolin
Chemical Composition (%)			
Loss on Ignition	2.0	0.89	0.70
SiO <sub>2</sub>	20	35.1	52.24
Fe <sub>2</sub> O <sub>3</sub>	0.6	0.7	0.60
Al <sub>2</sub> O <sub>3</sub>	4.85	12.9	43.18
CaO	62.56	40	1.03
MgO	2.5	10.1	0.61

## 2. Experimental Procedure

### 2.1 Materials.

Ordinary Portland cement of grade 42.5 was used and the properties shown in table 1 in accordance to [12]. River sand that has been screened and washed to remove all the organic and inorganic components that are likely to be present in it was used, sieved with 5mm test sieve to filter out large and unwanted organic wastes. Locally available crushed angular coarse aggregate having the maximum size of 12.5mm conforming to IS 383-1970 was used. The specific gravity of the coarse aggregate was 2.71, water cement ratio of 0.5 was used. The maximum size of the coarse was restricted to avoid the blocking effect in self-compacting concrete. The supplementary cementitious materials (Metakaolin) were sourced along Abeokuta-Ajebo Road, Abeokuta, Ogun state (789400 N, 548209 E). The deposit was located at a depth ranging from about 10 meters from the ground level. The collected clay was later processed to produce metakaolin. Its physical and chemical properties is shown in table 1 and 2 and conform to standards as stipulated in [2] requirement for pozzolans. GGBFS used for this research study was sourced locally from a steel manufacturing plant with its properties identified and found to be in conformity with European guidelines for supplementary cementitious materials. Conplast SP430 was used as superplasticizer for the mix, as it reduces water content up to 25% and prevent segregation in the mix. Portable water was used for both mixing and curing. [2] that increase in the viscosity of SCC mix results in high quantity of fine fillers/additives in this way, the stability of the mix is maintained, bleeding is reduced, and separation of coarse aggregates is avoided.

**Table 2** Physical properties of Materials.

MATERIAL	BULK DENSITY (kg/m <sup>3</sup> )	SPECIFIC GRAVITY
Cement	1470	3.15
GGBS	585	2.3
Metakaolin	1100	2.54
Coarse aggregate(20mm)	1662.50	2.77
Fine Aggregate	1580	2.65

## 2.2 Mix Proportion

The European federation specialist [3] of chemicals and concrete system provided guideline for development of SCC, but no method of mix design specifying the grade of concrete in SCC. This study attempts to produce high strength SCC by adopting trial and error approach of mix proportioning. Preferred mix proportion obtained for this study is listed in table 3.

**Table 3:** Mixture Proportions for GGBS and metakaolin of Self-Compacting Concrete (kg/m<sup>3</sup>)

Materials	Control	GGBS 5%	GGBS 10%	GGBS 15%	GGBS 20%	GGBS 25%
Cement	600	570	540	510	480	450
GGBS	-	30	60	90	120	150
Water/Powder	0.5	0.5	0.5	0.5	0.5	0.5
Sand	750	750	750	750	750	750
Coarse Aggre.	600	600	600	600	600	600
Superplasticizer	2%	2%	2%	2%	2%	2%

## 2.3 Workability Test

The varying mixes of both metakaolin and GGBFS where tested for flow, filling, passing ability and resistance to segregation using the slump flow, T<sub>50cm</sub>, V-funnel and L-box test and the results reported in Table 4

**Table 4** Limitations specified [4]

Test methods	Units	Minimum	Maximum
Slump flow	mm	650	800
T50	Sec	0	7
L box	H2/H1	0.8	1
V funnel	Sec	0	10

## 2.4 Casting, Curing and Testing

After the workability test on fresh concrete, the mix were cast in concrete cubes of 150x150x150 mm at varying percentages 5, 10, 15, 20 and 25. Cube moulds used for this experimental procedure were kept clean and oiled before pouring fresh concrete into the mould. Cast cubes of both metakaolin and GGBFS are kept for 24hours, removed and placed in the curing tank for 7, 14, 21 and 28days.

## 3. Results and discussion

### 3.1. Properties of fresh concrete

The results of the fresh properties of the SCC mixes are shown in table 5 and figure 1 at varying percentages of GGBFS and Metakaolin at 5, 10, 15, 20 and 25%. The figure 1 shows the properties of the

slump flow and it was observed that 25% GGBFS replacement mix, had a slump of 770mm while that of metakaolin at 25% replacement had a slump flow of 731mm. This indicates a good deformability. Also, for both admixtures at 5% GGBFS and metakaolin, there was a gradual increase in the slump.

The  $T_{50}$  slump flow which is the time to reach the 50cm diameter showed a result within the range of 2-5s, the mixes were less than 5secs as compared to the control with 3secs; 25% replacement showed a good workability of blocking ratio and filling ability as per EFNARC. In addition to the  $T_{50}$  and slump flow tests, the V-funnel test was carried out to assess the filling ability and stability. The SCC sample is poured from the top and the flap of the outlet opened and then the time taken for the concrete to flow out is being measured.

The L-box assessed the placing-ability as the SCC samples were poured into the box with the slide lifted up the concrete has to flow horizontal and the difference between the levels  $h_2/h_1$  is measured and it is between 0.8 and 1.00. The L-box result is shown in table 5, all the mixes results were within the satisfactory range of EFNARC standard.

**Table 5** Fresh properties of self-compacting mixes

Mix No.	Slump flow(mm)	V-funnel (sec)	L-Box ( $h_2/h_1$ )	$T_{50}$ (sec)
Control	660	6.0	0.89	3
GGBFS 5%	705	6.8	0.96	2
GGBFS 10%	720	7.2	0.94	2
GGBFS 15%	736	7.8	0.90	3
GGBFS 20%	755	8.7	0.87	3
GGBFS 25%	770	9.3	0.82	3
MK5%	704	9.2	0.95	2
MK10%	709	8.5	0.90	2
MK15%	722	8.1	0.89	2
MK20%	728	7.9	0.85	3
MK25%	731	7.2	0.82	3

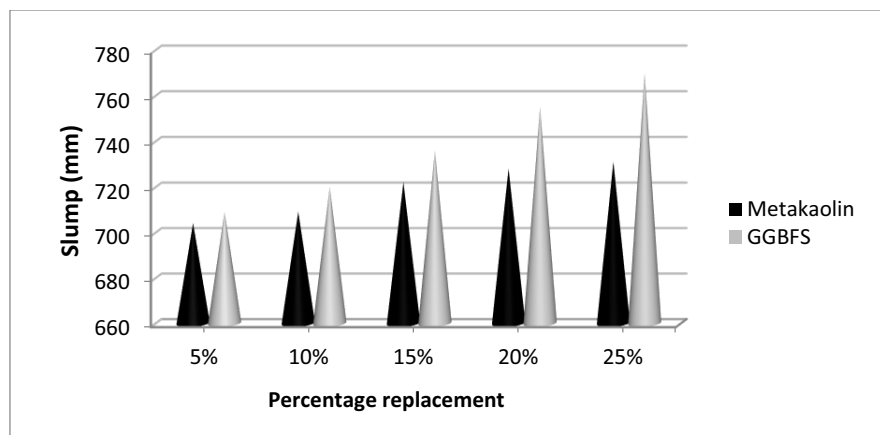


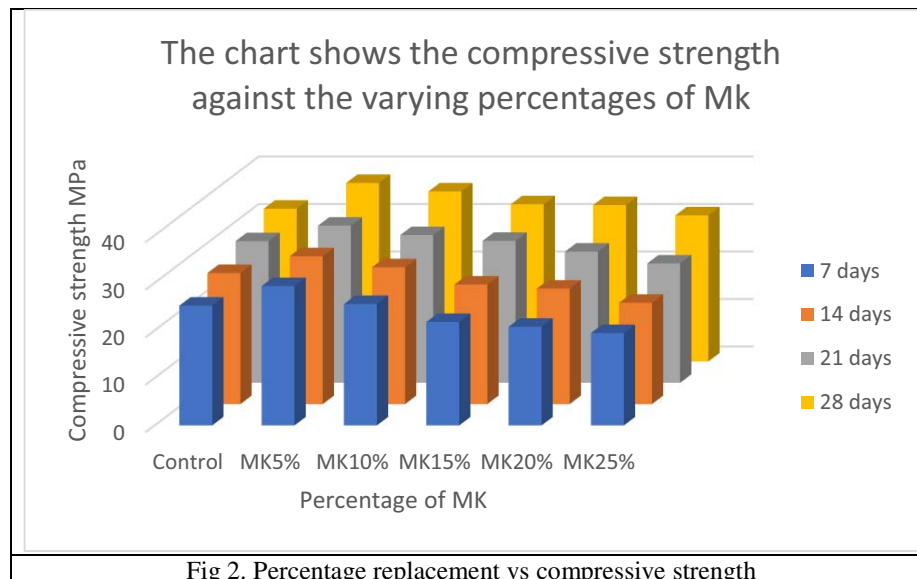
Fig 1. Slump flow of self-compacting concrete with GGBFS and metakaolin.

### 3.2 Compressive strength test

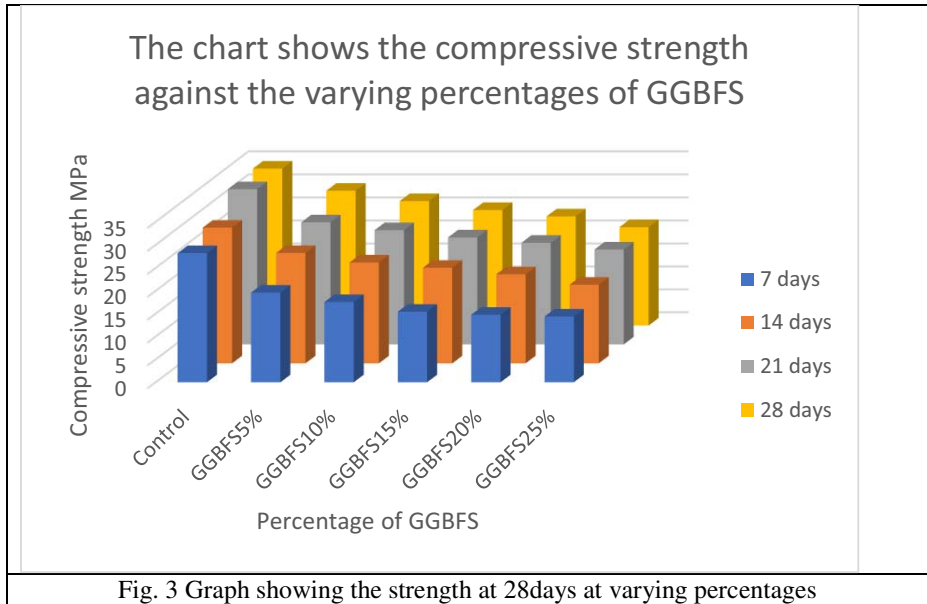
The compressive test for the admixtures at 7, 14, 21 and 28 days is presented in table 6. It shows the average mean of all the samples. It can be seen for the table that 5% MK had a value of 29.32 MPa greater than the strength of the control mix 25.22 at 7 days. The highest value of 37.55 MPa was at 28 days for 5% MK while the lowest compressive strength value was 19.45MPa at 7 days for 5% Mk which showed a gradual strength gain. The fineness of Mk in SCC mix, the chemical reaction of the cement hydration increased. At 28 days, GGBFS sample had the highest strength 29.34MPa while the lowest strength value was 14.39MPa at 7 days, 25% replacement. For the GGBFS samples, the control at 28 days had a value of 34.15MPa which was greater than all the other mixes at varying percentages and days. This is due to the pozzolanic reactions of GGBFS was not sufficient to speed up the reaction of the paste that could increase the compressive strength. The GGBFS acts like an inert filler reducing the voids in the matrix. At the early days, Mk showed significant performance.

**Table 6** Compressive strength test results for GGBFS and metakaolin.

Mix	Compressive Strength									
	Metakaolin					GGBFS				
	7 days	14 days	21 days	28 days	Mix	7 days	14 days	21 days	28 days	
Control	25.22	27.60	29.81	32.15	Control	25.22	27.60	29.81	32.15	
MK5%	29.32	31.11	33.06	37.55	GGBFS5%	19.60	24.11	26.62	29.34	
MK10%	25.56	28.81	31.09	35.79	GGBFS10%	17.55	22.05	24.93	27.09	
MK15%	21.77	25.16	29.87	33.08	GGBFS15%	15.43	20.90	23.35	25.15	
MK20%	20.76	24.30	27.60	32.90	GGBFS20%	14.76	19.47	22.18	23.77	
MK25%	19.45	21.33	25.11	30.75	GGBFS25%	14.39	17.21	20.72	21.43	



**Fig 2.** Percentage replacement vs compressive strength





#### 4. Conclusions

From the experiments carried out to determine the fresh and hardened properties of SCC mixtures the following were the inference drawn:

- From both mineral admixtures used, the best performance was obtained for MK with better workability. The evaluation of the slump flow, T<sub>50</sub>, V-funnel and L-box for both admixtures were within the specified range.
- The performance of self-compacting was improved by the use of mineral admixtures and superplasticizer as shown in figure 3 and 2 for the two types of mineral admixture.
- Also, it was observed that the compressive strength increased with age at curing. For all curing days of GGBFS the highest strength was obtained from the mix with 5% GGBFS at 28days and increase in strength as the GGBFS increased in percentage of the mix.
- For metakaolin, the highest strength was observed at 5% of the mix which had an increase in strength of 28% from 7 to 28 days of curing. In addition, metakaolin had higher compressive strength compared to GGBFS as compared to the control mix while for the mix with GGBS the control had higher strength than the varying percentage with GGBFS mix.

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