Comparative study on Compressive strength of Self-compacting Concrete Blended with metakaolin and microsilica

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Abstract

This research work examines the performance of metakaolin and microsilica as partial replacement of cement in the production of self-compacting concrete. The mix design was carried out using absolute volume method (A.V.M). Metakaolin and microsilica was used to replace cement at 0%, 5%, 10% and 15% at various water/ cementitious ratios of 0.25, 0.30, 0.35 and 0.40, while superplasticizer dosage was kept constant for all mixtures The results indicated that the mix design adopted was appropriate for the production of self-compacting concrete for both metakaolin and microsilica compressive strength 83.3mpa and 79.7mpa respectively. Metakaolin and microsilica enhanced significantly to the development of strengths. Comparatively, the increase in compressive strength of concrete mixes containing metakaolin were slightly greater than those containing microsilica at equal percentage of replacement of cement.

Introduction

Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demolding and faster use of elements and structures (EFNARC, 2005).
Sivakumar *et al.* (2017) carried out a study on SCC and suggested fiber reinforced self-compacting concrete (SCC) are more stable for efficient buildings, and also reported that the effects of Metakaolin (MK) and Alkali resistant glass fibers were investigated. And in addition, rheological properties such as (L-Box, slump flow, T50), and mechanical properties (compressive, splitting tensile and flexural strength), and durability properties (chloride ion penetration and water absorption) were investigated. The results show that the presence of both MK and GF in optimal percentages, can improve the mechanical properties and durability of self-compacting concrete significantly.

2. Literature Review

Muduli and Mukharjee (2019) examined the usage of metakaolin as a supplementary cementitious material for improving the properties of concrete mixes, containing varying percentages of recycled coarse aggregates (RCA). In this study, a total of fifteen concrete mixes were prepared by replacing natural coarse aggregates (NCA) with 0%, 50% and 100% RCA and cement with 0%, 5%, 10%, 15% and 20% metakaolin. Nine different properties of concrete including workability, compressive strength (3, 7 and 28 days) of curing ages, splitting tensile strength, flexural strength, ultrasonic pulse velocity, rebound number, water absorption, density and volume of voids have been experimented to examine the effect of metakaolin and RCA on the properties of concrete. From the study, it was also observed that the workability becomes higher with higher percentage of RCA. However, the use of metakaolin in RAC significantly reduces the water absorption and volume of voids. The optimum replacement percentage of metakaolin is found to be 15% as the RAC mixes shows best performance at this replacement level. Furthermore, the properties of concrete mix containing 100% RCA and 15% metakaolin are similar to that of normal concrete. Therefore, it is feasible to produce sustainable concrete by using maximum waste concrete i.e. 100% RCA and 15% metakaolin without much affecting the strength criteria.

Gill and Siddique (2018) carried out an experimental investigation to examine the durability and micro-structural properties of self- compacting concrete (SCC) blended with metakaolin (MK) and rice husk ash (RHA). For this purpose, metakaolin (MK) was used to replace cement by weight in three different proportions of 5, 10 and 15% and fine aggregates were replaced by rice husk ash (RHA) in proportion of 10%. A total of four mixes, including the control mix, were designed. Slump flow, L-box, U-box, and V-funnel tests were conducted in concrete's fresh state. Testing of specimen in hardened state was carried out at age of 7, 28, 90 and 365 days and was tested for compressive strength and durability properties such as water absorption, porosity, sulphate resistance and rapid chloride permeability test (RCPT). Further SEM & XRD tests were also conducted. Result shows that, all the mixes fulfilled all workability criteria according to EFNARC. Furthermore, hardened stage tests results were also positive. Durability properties showed significance improvement with the use of MK and RHA. Micro-structural analysis further confirmed the positive trend of results.

Akcay and Tasdemir (2018). Examined the performance of silica fume and metakaolin with identical finesses in self-compacting and fiber reinforced concrete. Partial replacement of cement by metakaolin (MK) increases the strength of concrete, but since the properties of MK are important parameters, it is not entirely clear whether MK is more effective than silica fume (SF) in enhancing the properties of concrete. In this study, high-performance self-compacting concretes (SCC) with two different water/binder (w/b) ratios (0.28 and 0.35), cement was replaced by MK or SF at the weight fraction of 10%. the pozzolans with similar particle sizes were used. Result shows that both MK and SF had an increasing effect on autogenous shrinkage of paste with 0.35 w/b ratios, while at 0.28 w/b ratio the mixtures with MK showed a lesser amount of autogenous shrinkage at 48 hours. CH consumption was found to be slightly higher in the pastes containing MK compared to those with SF. The long-term autogenous shrinkage of SCCs with MK was lower than those with SF. The use of MK and SF as mineral additives caused a decrease in fracture energies of concretes, and this effect is more pronounced in SF blended concretes, while no significant change was observed in the compressive strength developments of the mixtures. Fiber reinforced concretes containing MK were found to have much higher fracture energy than that with SF, indicating that the MK addition improves the matrix/steel fiber bonding properties.

Gholhaki *et al*. (2018) investigated engineering properties of self-compacting concrete (SCC) incorporating water and silica fume, metakaolin, rice husk ash and fly ash (10% and 20% by weight of cement). The fresh state properties were investigated by means of slump flow, T50, V-funnel, L box and visual stability index (VSI). At hardened state, compressive strength was evaluated at the ages of 7 and 28 days and also tensile strength of the concrete were measured at 28-day. splitting tensile strength development and also durability characteristics of concrete were tested for water absorption test at the age of 28 days. Results indicate that magnetic water and pozzolanic materials in SCC can improve the self-compatibility criteria in terms of flowability and viscosity.

3. Materials and methods

3.1. Materials

The following materials were used in carrying out this research.

i. Crushed granite (coarse aggregate) with a maximum grade size of 10mm (conforming to EN 12620). From Akamkpa in Cross-rivers State, Nigeria
ii. Fine aggregate (river sand) conforming to EN 12620. Sourced from mile 3 market, Rivers State, Nigeria.
iii. Metakaolin conforming to (EN 934-2) which is obtained from kaolin, metakaolin is one of the most natural abundant minerals. Which is found in Kogi, Edo state and other Northern parts of Nigeria.
iv. Microsilica conforming to EN 934-2. Sourced from Jacio international company limited, Lagos State, Nigeria.
v. Portland Limestone Cement (PLC) manufactured by Dangote cement conforming to NIS 444 (Grade 42.5). Sourced from Dangote cement depot, Port Harcourt Rivers State
vi. Water conforming to EN1008. Sourced from the Rivers State University water mains obtained from the civil engineering laboratory
vii. Superplasticizer dosage (SP): For developing a flowable self-compacting concrete, poly carboxylate ether (PCE) based superplasticizer was used. Based on the manufacturer's prescription, the dosage level should be between 1% to 1.3% of the total cementitious or powder content of superplasticizer conforming to EN 934-2.

3.2 Experimental Plan

For self-compacting concrete, coarse aggregate maximum size of 10mm was selected to ensure flowability. Three combinations of coarse and fine aggregate were selected with the following ratios: 60:40, 55:45 and 52:48. Followed the determination of compacted bulk density and specific gravity of aggregates. The aggregates combination that provided the least void was selected.

Table 3. Experimental Plan

S/N	Experiment	Mix proportion (Water/B+MK) Ratio 0.25 W/B 0.30 W/B 0.35 W/B 0.40W/B 1:1.33:1.44:0.2 1:1.45:1.57:0.3 1:1.55:1.69:0.35 1:1.67:1.81:0.40	No of samples	Total number	parameters	standards	
1	Specific Gravity test	A B A A B B A B		3 9 3		BS 812:1999 BS1377:197	
2	Particle size distribution of coarse and fine aggregate			3			BS 882:1992
3	Mix design						ASTM C29 or EN 1097-3; 1998.
4	Slump flow test, J-ring test, V-funnel and L-box test	Fresh Concrete			Workability		EFNARC 2005
5	Compressive Strength test for 7, 14 and 28days	18 54 18 54 18 54 18 54		288	Compressive strength		BS 1881:199
6	Split Tensile test for 7, 14 and 28 days	6 18 6 18 6 18 6 18		96	Tensile Strength	BS 1881:199	

3.3 Mix design method

3.3.1 Absolute Volume Method

absolute volume mix design was adopted for the preparation of concrete mix in this study in accordance to BS8110. In this method, a suitable water/cement ratio is assumed to determine the target strength based on the curing age as presented below.

i. Equation 3.1 provided by (Lydon, 2002) is employed to compute the target compressive strength at a specified water/cement ratio.

$$f_c = \frac{140.44}{(10.92)^{w/c}}$$

Where f_c = target strength and w/c = water-binder ratio.

ii. An estimated water content is obtained based on the expected slump value. For the purpose of strength, the water content is taken to be 134 kg/m^3.

iii. Cement content is obtained from the division of the water content by water/cement ratio.

iv. Concrete density was obtained from the specific gravity of aggregates.

v. The volume of aggregates are computed.

vi. The aggregate/cement ratio is computed.

vii. The fine aggregate (sand) and coarse content is determined.

viii. The mixed proportions by weight are determined.

3.3.2 Mix Design Computation

For water-binder ratio of 0.25:

Target strength is given as

$$f_c = \frac{140.44}{(10.92)^{0.25}} = 77.26 \text{ N/mm}^2$$

For water content of 134 kg/m^3, cement content is given as;

$$\text{Cement weight} = \frac{134}{0.25} = 536 \text{ kg/m}^3$$

Assuming 2% air void, void content becomes;

$$= \frac{2}{100} \times \frac{1000}{1} = 20 \text{ m}^3$$

Total volume of mix = 1000 m^3

Volume of cement (V_c) = $\frac{536}{3.10}$ = 172.90 m^3

Volume of water (V_w) = $\frac{134}{1.0}$ = 134 m^3

Volume of superplasticizer (V_{SP}) = $\frac{\frac{1.2}{100}\times 536}{1.06}$ = 6.07 m^3

Volume of paste (V_{paste}) = $V_c + V_w + V_{SP}$ = 172.90 +134 + 6.07 = 312.97 m^3

Primary paste volume required for filling ability = total volume – void volume

= 1000 – 20 = 980 m^3.

Total volume of aggregate (V_g) = 980 – 312.97 = 667.03 m^3

Aggregate ratio for fine and coarse aggregates are 42% and 58% respectively.

Therefore,

Weight of fine aggregate = 0.42 × 667.03 × 2.50 = 700.38 kg/m^3

Weight of coarse aggregate = 0.58 × 667.03 × 2.54 = 982.67 kg/m^3

Mix ratio with respect to cement is given as 1:1.31:1.83:0.25

TABLE 3.1: Concrete Mixture Proportion

Mix	Percentage replacement	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Course aggregate (kg/m^3)	Metakaolin/Microsilica (kg/m^3)	water (kg/m^3)	Superplasticizer (%)
0.40	0%	335	882.52	1083.44	0	134	4.02
	5%	318.25	882.52	1083.44	16.75	134	3.82
	10%	301.50	882.52	1083.44	33.5	134	3.62
	15%	284.75	882.52	1083.44	50.25	134	3.42
0.35	0%	382.86	719.63	1060.16	0	134	4.59
	5%	363.72	719.63	1060.16	19.14	134	4.36
	10%	344.58	719.63	1060.16	38.28	134	4.13
	15%	325.43	719.63	1060.16	57.43	134	3.91
0.30	0%	446.68	733.49	1029.12	0	134	5.36
	5%	424.35	733.49	1029.12	22.33	134	5.36
	10%	402.02	733.49	1029.12	44.66	134	4.82
	15%	379.68	733.49	1029.12	67.00	134	4.56
0.25	0%	536	700.32	982.67	0	134	6.43
	5%	509.20	700.32	982.67	26.80	134	6.11
	10%	482.40	700.32	982.67	53.60	134	5.79
	15%	455.6	700.32	982.67	80.40	134	5.47

3.3.3 Particle Size Distribution

The particle size distribution, a sieve analysis is a basic test which consists of sieving a measured quantity of soil through a series of successively smaller sieve, the sieve sizes are given in terms of number of opening per millimeter. The number of openings per millimeter is equal to the square of the sieve (BS 812 part 103.1 (1985).

The weight retained on each sieve is then expressed as a percentage of the total sample in accordance to BS812, specification of the sieve used are designated as 19.0mm, 13.2mm, 9.50mm, 6.70mm, 4.75mm, 2.36mm,1.18mm, 600mm, 300mm,150mm,75mm and pan.

3.4 Test on Concretes

This section presents some of the tests that were carried out on concretes prepared in the laboratory. The test carried out on fresh and hardened concretes include workability test, compressive strength test and split tensile strength test.

3.4.1 Workability

i. The workability of self-compacting concrete is much higher than the higher class of traditional vibrated concrete and can be characterized by the following properties:

ii. filling ability
iii. passing ability
iv. segregation resistance

Table 3.2 Standard Criteria for Self-Compacting Concrete (SCC)

	Method	Unit	Typical range of values	
			Minimum	**Maximum**
1	Slumpflow by Abrams core	Mm	650	800
2	T_{50} slumpflow	Sec	2.0	5.50
3	J-ring	Mm	0	10.0
4	V-funnel	Sec	6.0	12.0
5	V-funnel at $T_{5minutes}$	Sec	0	+3
6	L-box	$(h_2/h_{1)}$	0.8	1.0
7	U-box	(h_2/h_1)mm	0	30.0

Source: EFNARC, 2002

3.4.2. Specimen Preparation and Testing Methods

All concrete constituents were properly mix using rotary drum mixers with maximum capacity of 50kg. In order to achieve the desire homogeneity and uniformity in all mixtures priority was given to mixing sequence and duration. Firstly, the dry constituents were combined and mix briefly. This is followed by the addition of wet constituents (water and superplasticizers), all the constituents were thoroughly mixed until a homogeneous mixture was achieved in all cases.

The self-compacting concrete was designed to fulfill all specifications/recommendation of EFNARC committee (2002). The workability tests conducted in the following sequence:

3.4.3 Slump Flow Test and T_{50cm} Test

The slump flow value is the first primary test carried out. It is used to investigate the flowability of a fresh concrete in unconfined conditions. Based on this, it is usually designed to meet a slump flow of 650+ 25mm according to EFNARC.

T_{50} time is the measured time for flowing of concrete to a diameter of 500mm based on EFNARC specification. It provided more information about segregation resistance and uniformity of the SCC. This is achieved by virtual inspections during test.

T_{50} time test also provide further information on the rate of flow relating to viscosity. However, it cannot be used to measure the direct viscosity of the SCC.

The fresh concrete was obtained from the mixer and placed in the slump cone, fill to the brim and allowed to spread on the T_{50} board of dimension 1000X500 mm. the center of the board was marked and a radius of 250mm was measured on it. The concrete was poured from the slump cone and allowed to spread. It was virtually inspected until it spread to T_{50} mark on the board

The test set-up for slump flow and T_{50} test

3.4.4: J-Ring Test

The flow diameter and difference in concrete height inside and outside J-ring (h2-h1). The J-ring is designed using a cage of rebar that is arranged around the slump cone. The slump flow test is run both with and without the J-ring in place and the passing ability is the difference in slump flow

The test set-up for J-ring

3.4.5: V-funnel Test and V-funnel Test at $T_{5minutes}$

This is a measured of the time taken by concrete to flow through V-funnel after 10seconds (T_{10sec}) time and also time taken by concrete to flow through V-funnel after 5mins (T_{5mins}). The V-funnel test is used to determine the filling ability (flow ability) usually for concrete for concrete with a maximum aggregate size of 20mm. the funnel is designed to accommodate about 12kg of concrete and the time taken for it to flow through it is measured.

The flow time will be delayed significantly if the concrete is experiencing problem relating to segregation.

The V-shaped funnel is used to measure the V-funnel flow time, the fresh concrete produced is to fill and allow to flow out from the funnel, the elapsed time of the fully flowing is recorded as the V-funnel flow time.

The test set-up for V-funnel test and V-funnel test at $T_{5minutes}$

3.4.6: L-box Test Method

L-box test is designed to measure the passing ability of the fresh concrete mixture to flow through a confined spaces and narrow openings such as areas of congested reinforcement without experiencing segregation, loss of uniformity and the risk of blocking.
A calculated volume of fresh concrete is allowed to flow in a horizontal direction via the gaps between vertical, smooth reinforcing bars and the height of concrete beyond the reinforcement is measured. The passing ability classification with respect to the L-box height ratio are measured and compare to the EFNARC specifications.

3.5: Compressive Strength

For design purpose, the principal criterion for the compressive strength of the concrete is the 28days strength when the limit of compressive strength is reached. The concrete cube is crushed.
In this study, compressive strength is measured at various ages of 7, 14 and 28 days. Specimens were removed from water and dried a day to the testing age
The compressive strength test was performed on three cube specimens (150x150x150mm) and the result was computed based on the average of the three specimens.
The compressive strength test was conducted based on ASTM C39

4. Results and Discussions

This chapter presents the test results and discussions on the result obtained. The test results are presented in tables and plots; firstly, results on physical properties are presented then, the result of workability. Followed by the results of the hardened state properties

4.1 Workability

The mixes of Self-Compacting concrete prepared with varying dosages of Metakaolin (MK) and Microsilica (MS) were designed to meet two-fold requirement of self-compatibility and strength.
Slump flow test was used to examine the flowability while T_{50} slump flow time and V-funnel flow time test were used to determine the viscosity. It is expected that the fresh state properties should satisfy these criteria for self-compatibility as highlighted in chapter three.
The results from the various tests carried out on both metakaolin and microsilica blended concretes are presented in Tables 4.1 and 4.2.

Table 4.1: Laboratory Test Results from the Workability Tests Metakaolin-Blended Self-compacting Concretes

W/B ratio	%Replacement (Kg/m3)	Slump Flow (mm)	T_{50cm} Slump Flow (sec)	J-ring flow (mm)	J-ring (sec)	V-funnel (sec)	L-box (h_2/h_1)
0.40	0	710	5.3	635	6.8	6.27	0.93
	5	656	5.6	614	7.4	7.68	0.91
	10	641	5.9	567	7.7	8.2	0.90
	15	591	7.0	528	8.4	8.9	0.88
0.35	0	680	5.5	625	7.0	7.1	0.91
	5	639	6.0	611	7.3	8.07	0.86
	10	616	6.6	545	8.2	8.53	0.78
	15	558	7.9	499	9.9	10.76	0.73
0.30	0	613	5.8	612	7.4	7.29	0.89
	5	605	6.4	583	7.9	8.31	0.81
	10	575	7.5	520	9.7	10.38	0.70
	15	554	10.5	445	12.3	11.33	0.51
0.25	0	587	6.2	597	7.8	8.12	0.84
	5	579	7.2	547	8.4	8.53	0.69
	10	564	8.5	494	11.1	9.6	0.53
	15	552	12.7	407	13.9	11.62	0.3

Table 4.2: Laboratory Test Results from the Workability Tests Microsilica-Blended Self-compacting Concretes.

W/B ratio	%Replacement (Kg/m3)	Slump Flow (mm)	T_{50cm} Slump Flow (sec)	J-ring flow (mm)	J-ring (sec)	V-funnel (sec)	L-box (h_2/h_1)
0.40	0	710	5.3	635	6.8	6.27	0.93
	5	661	5.5	615	7.0	7.35	0.92
	10	645	5.8	568	7.4	7.5	0.91
	15	594	6.9	529	8.1	7.9	0.89
0.35	0	680	5.5	625	7.0	7.1	0.91
	5	641	5.9	615	7.4	7.27	0.88
	10	618	6.5	578	9.3	8.33	0.82
	15	560	7.8	532	12.0	9.46	0.79
0.30	0	613	5.8	612	7.4	7.29	0.89
	5	609	6.3	588	7.6	8.08	0.86
	10	581	7.4	524	9.6	9.08	0.79
	15	562	10.4	448	12.1	11.14	0.63
0.25	0	587	6.2	597	7.8	8.12	0.84
	5	582	7.1	551	8.1	8.23	0.76
	10	567	8.4	498	10.7	9.35	0.63
	15	554	12.6	412	13.6	11.43	0.42

Slump Flow (mm) Test

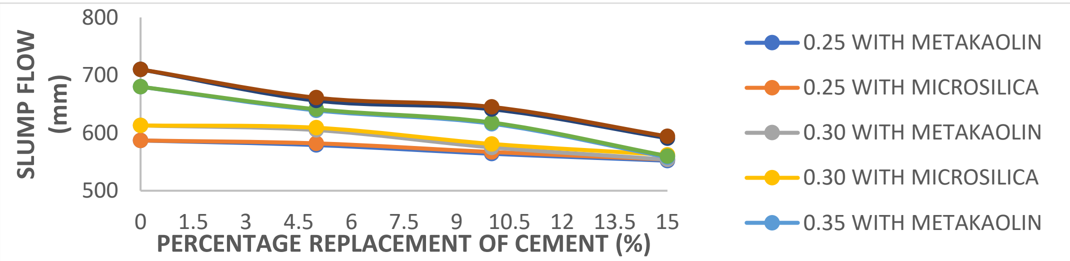

Figure 4.1: Variation of Slump Flow (mm) against Percentage Replacement of Cement Metakaolin and Microsilica at Varying Water-Binder Ratios

The slump flow variation with percentage replacement of cement with metakaolin and microsilica is shown in Figure 4.1 above. From the plot, it is observed that at the various water-binder ratios, the slump flow decreases with increase in the increase in percentage replacement of cement. Also, it was observed that the decrease is slightly greater in microsilica-blended concrete than the metakaolin-blended concrete

T_{50cm}Slump Flow

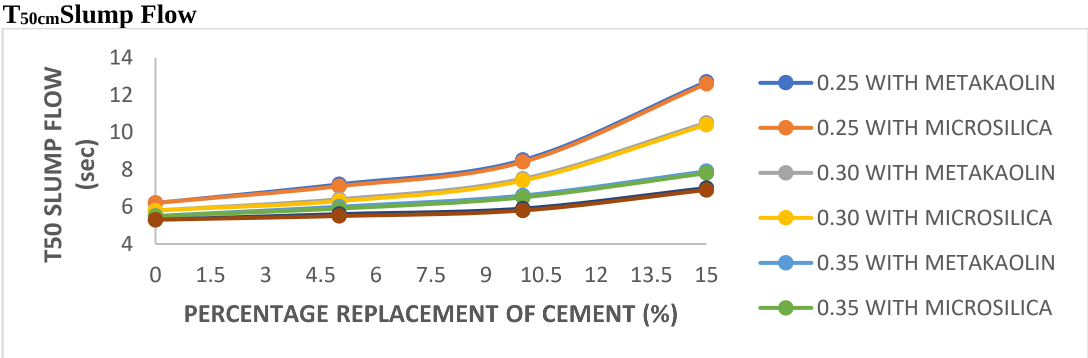

Figure 4.2: Variation of T50 Slump Flow Time with Percentage Replacement of Cement with Metakaolin and Microsilica

The T_{50} result is presented in figure 4.2 as shown above, the T_{50} flow times were measured in the range of 5.2 - 12.5 for all mixes. The reference (control) mix showed the lowest flow time across water-binder ratios. Whereas, at partial replacement of cement by 15% of supplementary cementitious materials exhibit the highest flow with those of metakaolin blended concrete slightly greater than their corresponding mixes with microsilica. The maximum flow time was observed for 0.25 water-binder ratio.

4.2 J-Ring Flow Test

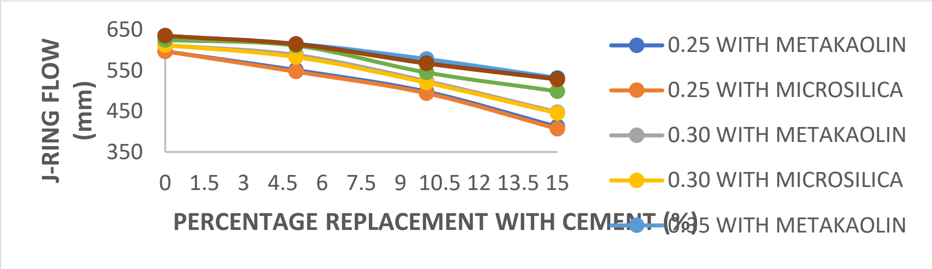

Figure. 4.3: Variation of J-Ring Flow (mm) against Percentage Replacement of Cement

The J-ring flow test and the J-ring tests were implemented on the prepare concrete to determine the passing ability of the various mixes. Figure 4.3 and figure 4.4 respectively show the plot of J-ring flow (mm) and J-ring flow time against percentage replacement of cement across various water-binder ratios.
From Figure 4.3, it was observed that the J-ring flow decreased as the percentage replacement of cement increased across water-binder ratios. Similarly, it reduced as the water binder ratio reduces.

4.3 The J-Ring Time (Secs)

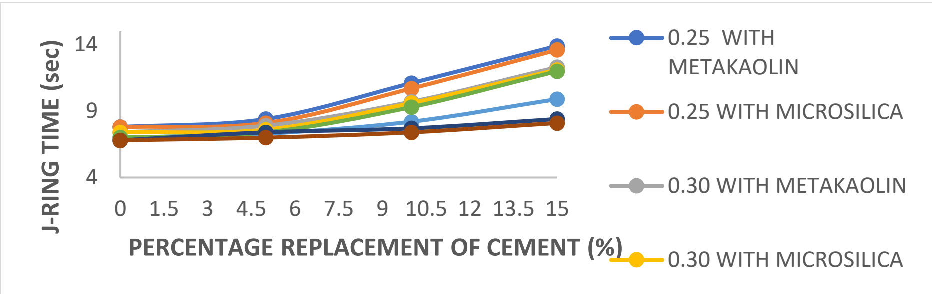

Fig 4.4: Variation of J-Ring Time (sec) against Percentage Replacement of Cement

The J-ring time plot shown in Fig 4.4 reveals that the time of flow in the J-ring test increased steadily as the percentage replacement of cement with Metakaolin and Microsilica increased. However, the increments are observed to be slightly greater in metakaolin-blended concrete than in the microsilica-blended concretes

4.4 V-Funnel Test

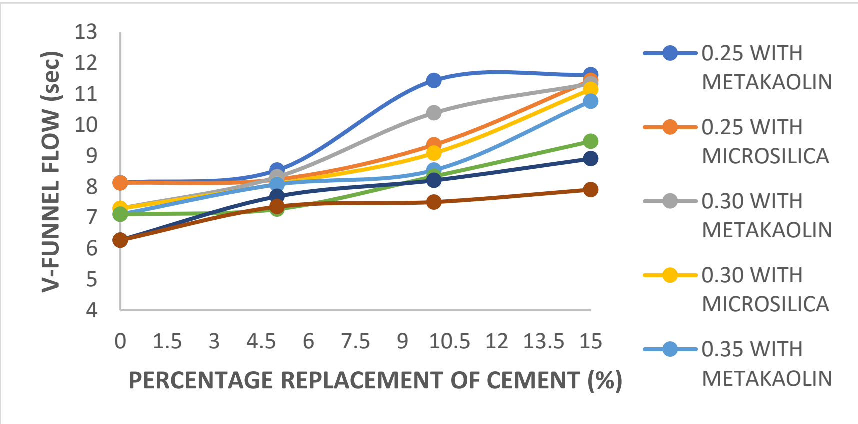

Fig. 4.5: Variation of V-Funnel time (sec) against Percentage Replacement of Cement
Figure 4. shows that the v-funnel flow time increases with increment in the amount of supplementary materials in the mixtures with greater increment observed for metakaolin-blended concrete.

4.5 Blocking Ratio (L-Box Test)

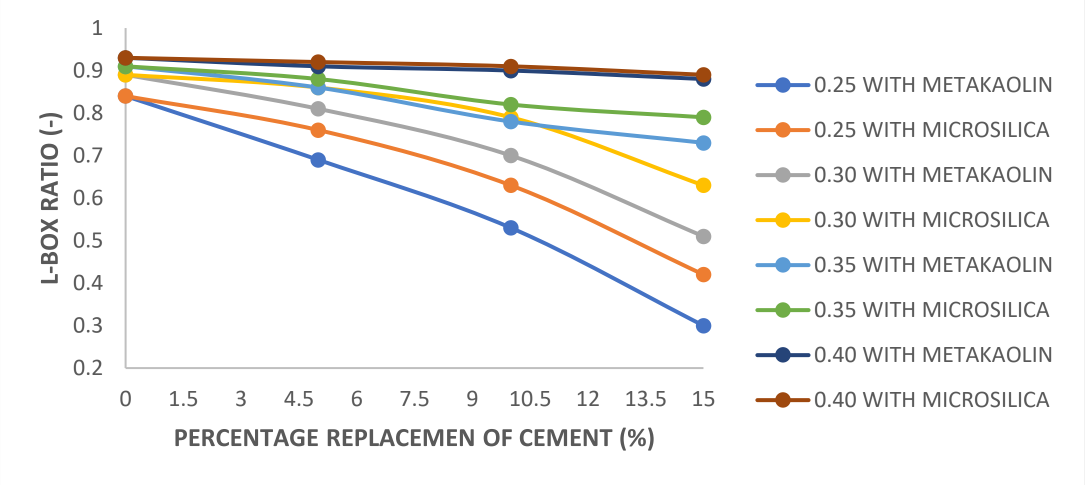

Fig. 4.6: Variation of L-Box (h_2/h_1) against Percentage Replacement of Cement

Figure 4.6 shows the variation of L Box (h_2/h_1) against percentage replacement of cement. It can be observed that as the percentage of metakaolin and microsilica increases, the L-Box (h_2/h_1) ratio of the concrete reduces. This is as a result of the reduction in workability of the fresh concrete.

4.6 Compressive Strength for Metakaolin (MK) and Microsilica Blended Concrete

Table 4.3: Compressive Strength of Control, Metakaolin Blended SCC at various curing ages (Mpa)

W/B ratio	Duration of Wet Curing	0% METAKAOLIN (CONTROL)	5% METAKAOLIN	10% METAKAOLIN	15% METAKAOLIN
0.4	7	37	39.7	41.7	42.7
	14	41	50	51.3	54.3
	28	48	53.3	55.3	57.3
0.35	7	50.3	53	57	60
	14	54.3	56	61.7	64.3
	28	58.3	62	65.7	68.7
0.3	7	56.3	61	65.3	69.3
	14	60.3	65.7	69	73
	28	65.7	69.3	73	76.7
0.25	7	63.7	68	72.7	75.3
	14	67.3	71.3	75	79
	28	72.3	76	79.7	83.3

Table 4.4: Compressive Strength of Control and Microsilica Blended SCC at various curing ages (Mpa)

W/B ratio	Duration of Wet Curing	0% MICROSILICA (CONTROL)	5% MICROSILICA	10% MICROSILICA	15% MICROSILICA
0.4	7	37	39	40	40.3
	14	41	44	46.7	51.7
	28	48	52	54.3	56
0.35	7	50.3	51.7	53.3	54.3
	14	54.3	55	58.3	62
	28	58.3	60	62.3	63
0.3	7	56.3	58	61.3	69.3
	14	60.3	62	64.7	73
	28	65.7	67.3	70.3	76.7
0.25	7	63.7	65.3	68	72.7
	14	67.3	69	72	75
	28	72.3	74	76.3	79.7

From Tables 4.3 and 4.4 above, it is observed that there is progressive increment in the compressive strength of the self-compacting concretes on increase amount of replacement of limestone cement with metakaolin and microsilica respectively. Comparatively, the increase in compressive strength of concrete mixes containing metakaolin were slightly greater than those containing microsilica at equal percentage of replacement of cement. Both materials resulted in improvement of compressive strengths due to their pozzolanic and filling effects. Compressive strengths were increased as voids were filled up by the supplementary cementitious materials.
Maximum compressive strength of 83.3 MPa was achieved for metakaolin blended self-compacting concrete at 15% replacement of cement and at 0.25 water-binder while at same replacement level and water-binder ratio, maximum compressive strength for microsilica blended self-compacting concrete is 79.7 MPa. The greater strength observed for metakaolin blended concrete compared to the microsilica blended concrete is due to the finer sizes of metakaolin particles. Also, it is observed that the compressive strength decreased with increase in the water-binder ratio.

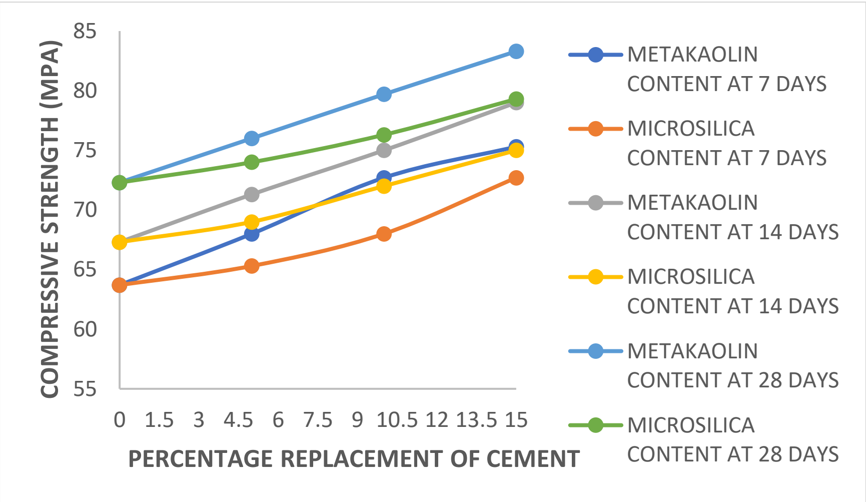

Fig. 4.7: Variation of Compressive Strength (MPa) with Metakaolin and Microsilica Content at 0.25 Water-Cement Ratio across Curing Ages

From Tables 4.3 and 4.4 and figure. 4.10, it is observed that at 7 days curing, the inclusion of metakaolin and microsilica resulted in 6.75%, 14.13%, 18.21% and 2.51%, 6.75%, 14.13% increase in compressive strength at 5%, 10% and 15% replacement of cement with metakaolin and microsilica respectively. In same manner, at 14 days curing, the incorporation of 5%, 10% and 15% of metakaolin and microsilica respectively yielded increase in compressive strength in proportions of 5.94%, 11.44%, 17.38% and 2.53%, 6.98%, 11.44% for metakaolin and microsilica blended concretes respectively. Also, at 28 days curing, the strength increment for metakaolin and microsilica at 5%, 10% and 15% replacement of cement are observed to be 5.12%, 10.24%, 15.21% and 2.30%, 5.53%, 9.68% respectively for metakaolin and microsilica blended concrete.
From the above, it is observed that greater increment are obtained from the partial replacement of cement with metakaolin than with microsilica. However, both resulted in positive increment in compressive strength at all levels of replacement

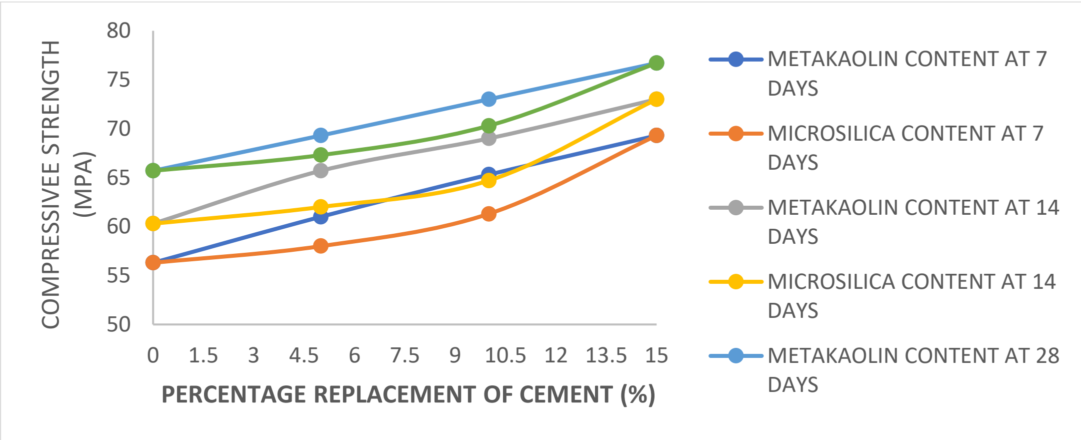

Fig. 4.8: Variation of Compressive Strength (MPa) with Metakaolin and Microsilica Content at 0.30 Water-Cement Ratio across Curing Ages

From Tables 4.4 and 4.5 and figure. 4.8, it is observed that at 7 days curing, the inclusion of metakaolin and microsilica resulted in 8.35%, 16.00%, 23.09% and 3.02%, 8.88%, 23.09% increase in compressive strength at 5%, 10% and 15% replacement of cement with metakaolin and microsilica respectively. In same manner, at 14 days curing, the incorporation of 5%, 10% and 15% of metakaolin and microsilica respectively yielded increase in compressive strength in proportions of 8.96%, 14.43%, 21.06% and 2.82%, 7.30%, 21.06% for metakaolin and microsilica blended concretes respectively. Also, at 28 days curing, the strength increment for metakaolin and microsilica at 5%, 10% and 15% replacement of cement are observed to be 5.48%, 11.18%, 16.74% and 2.44%, 7.00%, 16.74% respectively for metakaolin and microsilica blended concrete.
From the above, it is observed that greater increment are obtained from the partial replacement of cement with metakaolin than with microsilica. However, same level of increase are observed for both binders incorporation at 15% replacement.

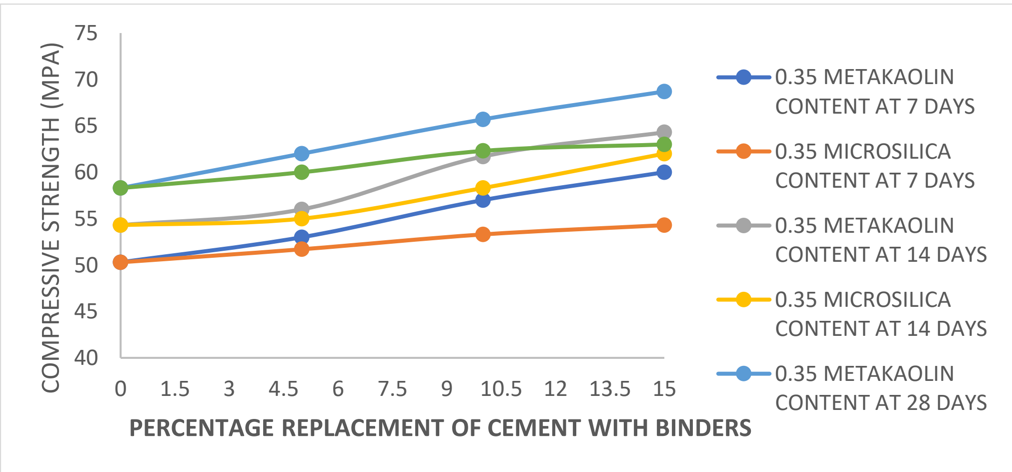

Figure. 4.9: Variation of Compressive Strength (MPa) with Metakaolin and Microsilica Content at 0.35 Water-Cement Ratio across Curing Ages

From Tables 4.3 and 4.4 and figure. 4.9, it is observed that at 7 days curing, the inclusion of metakaolin and microsilica resulted in 5.37%, 13.32%, 19.28% and 2.78%, 5.96%, 7.95% increase in compressive strength at 5%, 10% and 15% replacement of cement with metakaolin and microsilica respectively. In same manner, at 14 days curing, the incorporation of 5%, 10% and 15% of metakaolin and microsilica respectively yielded increase in compressive strength in proportions of 3.13%, 13.63%, 18.42% and 1.29%, 7.37%, 14.18% for metakaolin and microsilica blended concretes respectively. Also, at 28 days curing, the strength increment for metakaolin and microsilica at 5%, 10% and 15% replacement of cement are observed to be 6.35%, 12.69%, 17.84% and 2.92%, 6.86%, 8.06% respectively for metakaolin and microsilica blended concrete.
From the above, it is observed that greater increment are obtained from the partial replacement of cement with metakaolin than with microsilica. However, both resulted in positive increment in compressive strength at all levels of replacement.

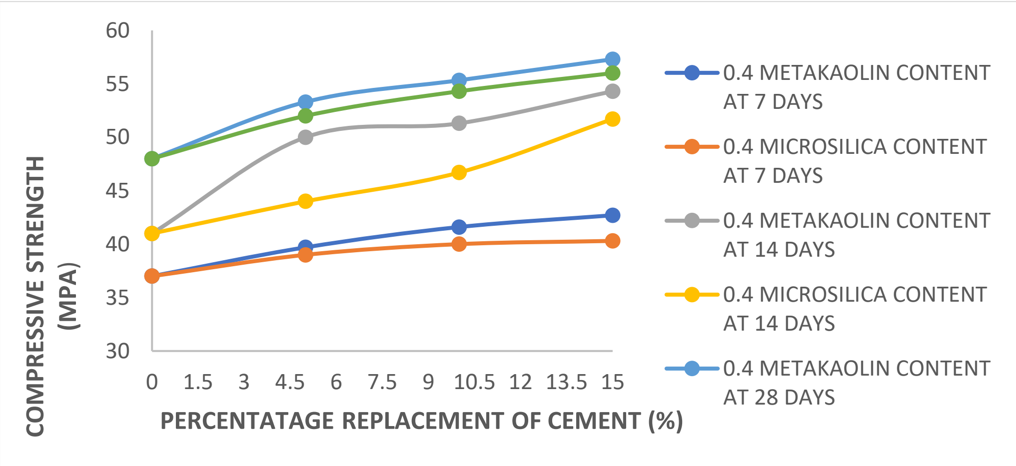

Fig. 4.10: Variation of Compressive Strength (MPa) with Metakaolin and Microsilica Content at 0.40 Water-Cement Ratio across Curing Ages

From Tables 4.3 and 4.4 and fig. 4.10, it is observed that at 7 days curing, the inclusion of metakaolin and microsilica resulted in 7.30%, 12.70%, 15.41% and 5.41%, 8.12%, 8.92% increase in compressive strength at 5%, 10% and 15% replacement of cement with metakaolin and microsilica respectively. In same manner, at 14 days curing, the incorporation of 5%, 10% and 15% of metakaolin and microsilica respectively yielded increase in compressive strength in proportions of 21.95%, 25.12%, 32.44% and 7.32%, 13.90%, 26.10% for metakaolin and microsilica blended concretes respectively. Also, at 28 days curing, the strength increment for metakaolin and microsilica at 5%, 10% and 15% replacement of cement are observed to be 11.04%, 15.21%, 19.38% and 8.33%, 13.13%, 16.67% respectively for metakaolin and microsilica blended concrete.
From the above, it is observed that greater increment are obtained from the partial replacement of cement with metakaolin than with microsilica. However, both resulted in positive increment in compressive strength at all levels of replacement.

5. Findings and Conclusion

This study is aimed at comparing the cementitious efficiency of metakaolin and micro-silica on fresh and hardened states properties of Self-Compacting Concrete.
In this study, the absolute volume mix design was adoped. The adopted mix design resulted in improved workability and mechanical properties of the prepared metakaolin and microsilica blended self-compacting concretes.
The workability test results from both metakaolin-blended and microsilica-blended concretes conformed to the criteria provided for self-compacting concrete by EFNARC. Slump flow and J-ring tests which were used in testing for flowabiliy, showed that microsilica-blende concrete have slightly greater flowability than the metakaolin-blended concretes. Whereas, the V-funnel flow time and T_{50}tests were implemented to determine the level of viscosity of the concrete mixes. Greater values were observed for metakaolin-blended concrete mixes than their corresponding microsilica mixes, indicating greater visosity in metakaolin based concrete than in the

microsilica based concretes. However, both metakaolin and microsilica improved the workability of self-compacting concrete.
Compressive strength test showed that there was progressive increment in the compressive strength of the self-compacting concretes on increase amount of replacement of limestone cement with metakaolin and microsilica respectively. Comparatively, the increase in compressive strength of concrete mixes containing metakaolin were slightly greater than those containing microsilica at equal percentage of replacement of cement. Both materials resulted in improvement of compressive strengths due to their pozzolanic and filling effects. Compressive strengths were increased as voids were filled up by the supplementary cementitious materials.Maximum compressive strength of 83.3 MPa was achieved for metakaolin blended self-compacting concrete at 15% replacement of cement and at 0.25 water-binder while at same replacement level and water-binder ratio, maximum compressive strength for microsilica blended self-compacting concrete is 79.7 MPa. The greater strength observed for metakaolin based concrete compared to the microsilica based concrete is due to the finer sizes of metakaolin particles and the greater cohesion in metakaolin based concrete compared to microsilica based concrete. Similar trend is observed for splitting tensile strength.

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