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Evaluating The Impact of Partially Replacing Cement with Rice Husk Ash and Metakaolin on the Rheological Behavior and Mechanical Strength of Self-Compacting Concrete

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Abstract: Although self-compacting concrete (SCC) is a unique concrete that can spread and fill formwork without the need for mechanical vibration, researchers are now using supplementary cementitious materials (SCMs) to partially replace cement in SCC production because of the high cement content required to produce SCC. Based on the aforementioned, the rheological and strength properties of SCC admixed with Rice Husk Ash (RHA) and Metakaolin (MK) at 0.4, 0.5, and 0.6 water-cement (W/C) ratios was investigated. The materials used in the study are cement, water, fine aggregate, coarse aggregate, Metakaolin (MK), Rice Husk Ash (RHA), and superplasticizer. Mechanical tests were conducted on the cement, fine and coarse aggregate, RHA and MK. SCC was produced by partially replacing cement with RHA and MK separately and in blend at 2.5, 5, 7.5, 10, 12.5, and 15 %, yielding a total of four hundred and twenty (420) concrete cubes, and all cubes were cured for 3, 7, 14, 28, 56, 90, and 120 days before crushing. The Marsh cone test was adopted to determine the optimum superplasticizer (SP) content, while the rheological tests conducted on the fresh SCC are the slump test, V-funnel test, L-Box test, and J-Ring test, whereas the mechanical tests conducted on the hardened SCC are the compressive, flexural, and split tensile strength test. Results from the findings showed that the rheological properties of SCC admixed with RHA and MK separately and in blend at 0.9 % superplasticizer content, exhibits adequate workability and flowability at 0.4, 0.5, and 0.6 water-cement ratios. Also, at 0.4, 0.5, and 0.6 W/C ratios, the maximum compressive strength of SCC was achieved at 5-10 % for RHA, and 5-15 % for MK, and was achieved at 10 % when MK and RHA was used in blend. More also, the maximum 28 days split tensile strength was achieved at 7.5-10 % for RHA, and 10 % for MK, and was achieved at 10 % when MK and RHA blend replaced cement. Furthermore, the maximum 28 days flexural strength was achieved at 12.5-15 % for RHA, and 15 % for MK, and was achieved at 12.5 % when MK and RHA blend replaced cement. Hence it was concluded that the workable rheological, and maximum strength properties of SCC can be achieved when blend of RHA and MK replaces cement between 10 – 12.5 %.

Keywords: *Compressive strength; Flexural strength; Metakaolin (MK); Rheology; Rice Husk Ash (RHA); Self-Compacting Concrete (SCC); Split tensile strength.*

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I. INTRODUCTION

➤ *Background of the Study*

Concrete that is very flowable and can spread and fill formwork under its own weight without the need for mechanical vibration is called self-compacting concrete (SCC), sometimes referred to as self-consolidating concrete [1-3]. It is perfect for building projects where standard compaction methods are difficult because of its ability to flow readily into confined places, around dense reinforcement, and around intricate shapes [4-6]. Similar to traditional vibrated concrete, SCC is made up of cement, aggregates, water, and chemical and mineral admixtures. The reduction of coarse aggregate content and the increase in powder amounts provide SCC its passing ability and segregation resistance. The high fluidity of the concrete mix is caused by superplasticizers (high rangewater reducers), whilst the

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powder and viscosity modifying agents improve stability and cohesiveness by lowering bleeding and mix segregation [7].

However, due to the higher cement content involved in the production of SCC [8-10], which contributes to increased carbon emissions, and raises environmental concerns [8, 11-13], researchers have turned to producing SCC with supplementary Cementitious Materials (SCMs) as a partial replacement of cement in SCC production. More also, these SCMs are often obtained as industrial or agricultural wastes which causes environmental problems if not duly utilized [14]. In order to maintain a safe and clean environment, the majority of recent research efforts have focused on potential methods of recycling these pollutants for future use [15]. Because they use a lot of earthen materials every year, the transportation, construction, and environmental sectors have the most potential for reuse. This phenomenon also helps to lower the cost of cement for a given project when the amount of cement required is to be supplemented by these wastes rather than disposed of, which reduces pollution in the environment [16].

This, along with other factors, has prompted the hunt for cement substitutes. Fly ash, ground granulated blast-furnace slag, silica fume, rice husk, glass powder, Metakaolin, and other industrial and agricultural by-products have been utilized primarily, and it has become common practice to use these industrial by-products to partially replace cement in concrete [17, 18]. In addition to minimizing the associated CO_2 emissions, employing such industrial by-products as cement substitutes also has the benefit of lessening the environmental impact of garbage and landfills. By minimizing the consumption of scarce resources, recycling industrial by-products further prevents the exploitation of natural resources and has both economic and environmental benefits through cost savings [19, 20]. One of such agricultural waste, and industrial by-product is Rice Husk Ash (RHA) and Metakaolin (MK), which are the SCMs considered in this study to partially replace cement in the production of SCC.

These SCMs (i.e. RHA and MK) were considered in this study since in Nigeria, the demand for rice (Oryza sativa) increased steadily in the last decades [21], and it is anticipated that 6.4 million metric tonnes of rice are produced annually [22]. Bran, broken rice, and rice after milling make up around 78% of the paddy's weight. They are given the husk, which makes up the remaining 22% of the weight of the rice. Rice husk is a type of agricultural debris that is removed from the outer layer of rice grains during the milling process. The ash that is created during the burning process from the roughly 75% organic volatile components that were present in this husk is known as rice husk ash (RHA). It is a naturally occurring waste product that is frequently used in concrete [23].

On the other hand, metakaolin is a highly reactive pozzolanic material obtained by calcining natural kaolin clay at elevated temperatures, and is abundant in Nigeria in places like Okpella in Edo state [24], Kankara inKatsina state [25, 26], Alkaleri in Bauchi state [27], etc. Metakaolin enhances the workability, strength, and durability of concrete by promoting pozzolanic processes that produce more cementitious compounds. Metakaolin can be added to concrete mixtures to enhance the material's long-term performance by enhancing microstructural characteristics and reducing permeability (Pillay *et al.*, 2022), and self-compacting concrete (SCC). Hence this study was conducted to investigate the rheological and strength properties of SCC admixed with RHA and MK separately and in blend at 0.4, 0.5, and 0.6 water-cement ratios.

More also, this study intends to fill the gap in existing literatures since previous recent studies have been conducted on the properties of concrete produced by replacing cement with Rice Husk Ash (RHA) [28-33], and metakaolin [34-38] individually, whereas few studies had been conducted on the properties of concrete produced by replacing cement with RHA and MK blend [39-45].

However, with regards to the few studies conducted on the use of RHA and MK blend on properties of SCC, Vaid and Bansal [43] used ternary blend (i.e. metakaoline, silica fume and rice husk), Sharma and Gupta [41] also used ternary blend (i.e. metakaolin, GGBFS and rice husk ash), Adeshokan and Arum [40] adopted alkaline-activator and only studied the compressive strength, whereas Verma, et al. [39] also used an alkali activator in geopolymer concrete. From the aforementioned, there are scarce literatures that address the rheological and strength properties of SCC admixed with RHA and MK" at various W/C ratios, which is why this study was undertaken to fill the gap in existing literature.

II. MATERIALS AND METHODS

➢ *Materials*

The materials used are cement, water, fine aggregate, coarse aggregate, Metakaolin (MK), Rice Husk Ash (RHA), and superplasticizer.

- *Cement*

Cement obtained from an open market in Zaria-Kaduna State, Nigeria was used for the experiment.

- *Water*

Water fetched at Civil Engineering Laboratory of Ahmadu Bello University (ABU) Zaria was used in producing the concrete mixture for this study.

- *Fine Aggregate*

Fine aggregate obtained from a dealer in Zaria was sieved through a BS 4.75mm sieve to remove some of the contained coarse aggregates was used in this study.

- *Coarse Aggregates*

Coarse aggregate obtained from crushed granite was used in this research, and it was obtained from an open market in Zaria-Kaduna State, Nigeria.

- *Metakaolin*

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Kaolin was obtained from Kankara local government in Katsina state. It was subjected to the beneficiation process to remove the large particle size and break the lumps to obtain a fine particle size.

- *Rice Husk*

Rice husk was obtained from rice mill in Zaria. It was calcinated at 750°C for 3 hours to obtain the rice husk ash (RHA). The RHA was then sieved through sieve size 75um. This was done to obtain a very fine particle size that can easily fill up the voids.

- *Super-plasticizers*

Konkrete carbonoxlylic super plasticizer was used. The superpasticizer was in liquid form and it meets the requirement of ASTM-C494 [46] type F standard specification for chemical admixtures for concrete.

➢ *Methods*

- *Preliminary tests on cement*

✓ *Consistency of cement*

Consistency of cement was done in line with BS-EN-196-3 [47], at concrete laboratory of Ahmadu Bello University Zaria.

✓ *Setting time of cement*

Setting time test was done in line with BS-EN-196-3 [47].

✓ *Soundness of cement*

Soundness test was done as described in BS-EN-196-3 [47].

✓ *Specific gravity of cement*

Specific gravity of cement was done as described in BS-EN-196-3 [47].

- *Preliminary tests on aggregate*

✓ *Sieve Analysis of Fine and Coarse Aggregates*

The gradation of fine and coarse aggregate was done in line with BS-882:2 [48].

✓ *Specific Gravity of Aggregates*

Coarse and fine aggregates specific gravity tests were conducted as described in BS-812:2 [49].

✓ *Bulk Density of Aggregate*

Bulk density on the fine and coarse aggregates were done as described in BS-812:2 [49].

✓ *Aggregate Impact Value Test*

Aggregate impact value test was done as described in BS-812-110 [50].

✓ *Aggregate Crushing Value*

Aggregate crushing value test was done in line with BS-812-110 [50] specification.

✓ *Fineness Modulus*

The fineness modulus of the fine and coarse aggregates was determined in line with ASTM-C33 [51]

➢ *Tests on Pozzolanas*

- *X-ray Fluorescence Analysis (XRF)*

The X-ray Fluorescence Analysis (XRF) was conducted to determine the oxide composition of the MK and RHA, and was done in accordance to ASTM-C618 [52] at the Department of Chemical Engineering, Ahmadu Bello University, Zaria.

- *Specific Surface*

The specific surface of the RHA and MK used in this study was determined at Ahmadu Bello University Civil Engineering concrete laboratory, in accordance with BS:4359-1 [53].

➢ *Experimental Procedure*

- *Mix Design*

Trial mix design of the concrete was conducted to obtain 28 days target strength of 20, 30 and 40 N/mm^2, at w/c ratios of 0.4, 0.5, and 0.6 respectively. The absolute volume mix design method was adopted in ratio 1:2:4 by weight of cement, fine, and coarse aggregates.

- *Sample Preparation*

Cement was partially replaced with RHA and MK separately and in blend at 2.5, 5, 7.5, 10, 12.5, and 15 % respectively, as shown in Table 1. All cubes were cured for 3, 7, 14, 28, 56, 90, and 120 days before crushing.

- *Design of Experiment*

The design the experiment of concrete produced by replacing cement with RHA and MK separately and in blend was done manually, and the mix design/proportioning is shown in Table 1.

Table 1 Design of Experiment

Experiment	Cement	RHA	MK
Control (0.4 W/C)	100	0	0
A	97.5	2.5	0
B	95	5	0
C	92.5	7.5	0
D	90	10	0
E	87.5	12.5	0
F	85	15	0
Control (0.5 W/C)	100	0	0

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G	97.5	0	2.5
H	95	0	5
I	92.5	0	7.5
J	90	0	10
K	87.5	0	12.5
L	85	0	15
Control (0.6 W/C)	100	1.25	1.25
M	97.5	2.5	2.5
N	95	3.75	3.75
O	92.5	5	5
P	90	6.25	6.25
Q	87.5	7.5	7.5

The experimental design from Table 1 indicates there is a total of 20 experiments runs at various percentage replacements of RHA and MK. Also, the cubes are cast in triplicates which were crushed at 3, 7, 14, 28, 56, 90, and 120 days, making the total number of cubes per experiment, twenty-one (21). Hence, a total of four hundred and twenty (420) concrete cubes were cast for compressive, flexural, and split tensile strength properties.

- *Marsh Cone Test*

The marsh cone test was conducted to determine the optimum superplasticizer (SP) content to be adopted in the mix in accordance to ASTM-C939 [54]. The test was conducted by adding superplacticizers at 0.5, 1.0, 1.5, and 2% to the design mix at various water-cement ration (i.e. 0.4, 0.5, and 0.6), after which the optimum SP dosage was adopted based on the flow time and saturation.

➢ *Tests on Fresh Concrete*

- *Slump Test*

This was done as specified in BS-EN-12350;2 [55].

- *V-Funnel Test*

V-funnel test was done in accordance with BS-EN-12350;2 [55] and EFNARC [56].

- *L-Box Test*

L-Box test was done in accordance with BS-EN-12350;2 [55].

- *J-Ring Test*

The test determines the passing ability of SCC. For blockage prevention, the height difference should not exceed 10 mm [56]. This is in line with BS-EN-12350;2 [55].

➢ *Tests on Hardened Concrete*

- *Compressive strength test*

The compressive strength test of the hardened concrete was determined after the required curing days of 3, 7, 14, 28, 56, 90, and 120 days in accordance with BS-EN-12390-3 [58].

- *Flexural strength test*

The flexural strength test was performed on a 150mm x 150mm x 450mm concrete beam specimen, and it was a three point bending test conducted in line with ASTM-C78 [59].

- *Split Tensile Test*

The splitting tensile strength was performed on a 100mm x 300mm concrete cylinder specimen in accordance with ASTM-C496 [60] standard test method.

III. RESULTS AND DISCUSSION

➢ *Preliminary Test Result of Materials*

Tests were conducted on the cement, aggregates, MK, and RHA, to ascertain their conformity to BS and ASTM codes, as presented in Table 2.

Table 2 Material Physical and Mechanical Properties

Description of Test	**Results**	**Standard**	**Code**
Cement			
Consistency (%)	28.0	26-33%	BS-EN-196-3 [47]
Initial setting time (mins)	155	≥45	BS-EN-196-3 [47]
Final setting time (mins)	222	≤ 600	BS-EN-196-3 [47]
Soundness (mm)	0.5	≤ 10mm	BS-EN-196-3 [47]
Specific gravity	3.14	3.1 – 3.16	BS-EN-196-3 [47]
Fine Aggregates			
Specific Gravity	2.65	2.5 – 2.8	BS-812:2 [49]
Bulk density	1435	<1520	BS-812:2 [49]
Fineness modulus	5.24	mm	BS-EN:12620 [61]
Coarse Aggregate			
Specific gravity	2.78	2.5 – 2.8	BS-812:2 [49]
Bulk density	1300	<1520	BS-812:2 [49]
Fineness modulus	7.53	mm	BS-EN:12620 [61]

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Aggregate Crushing Value	26.88	25 – 30%	BS-812-110 [50]
Aggregate Impact Value	27.33	25 – 30%	BS-812-110 [50]
Metakaolin (MK)			
Specific Gravity	2.5		BS-812:2 [49]
Specific surface	84608	m^2/kg	BS:8615-1 [62]
Rice Husk Ash (RHA)			
Specific Gravity	2.13		BS-812:2 [49]
Specific surface	7189	m^2/kg	BS:8615-1 [62]

Since the consistency (28%), initial setting time (155 minutes), total setting time (222 minutes), soundness (0.5 mm), and specific gravity (3.14), all satisfied British Standard (BS) code requirements, the result from Table 2 demonstrate that the cement used in this study is sufficient for producing concrete.

Additionally, the study's fine aggregate is deemed suitable for making concrete because its specific gravity (2.65) and bulk density (1435 kg/m3) fall within the range suggested by BS-812:2 [49]. Specific gravity, bulk density, aggregate crushing value, and aggregate impact values of 2.78, 1300 kg/m3, 26.78%, and 27.33%, respectively, for the coarse aggregate all satisfied code requirements of BS-812:2 [49], and BS-812-110 [50], confirming its adequacy for concrete production.

Additional findings revealed that the MK and RHA had specific gravities of 2.7 and 2.13, respectively, greater than the cement's (3.14) and the fine aggregate's (2.65), which were used in this investigation. Furthermore, the specific surface of the RHA is 7189, which is less than that of the MK, which is 84608. The implication of the findings of this study is that concrete produced with RHA and MK having lower specific gravity that cement and fine aggregate will be lighter [63] and less workable [64] since the specific surface" of MK is high.

- *Gradation of Fine and Coarse Aggregate*

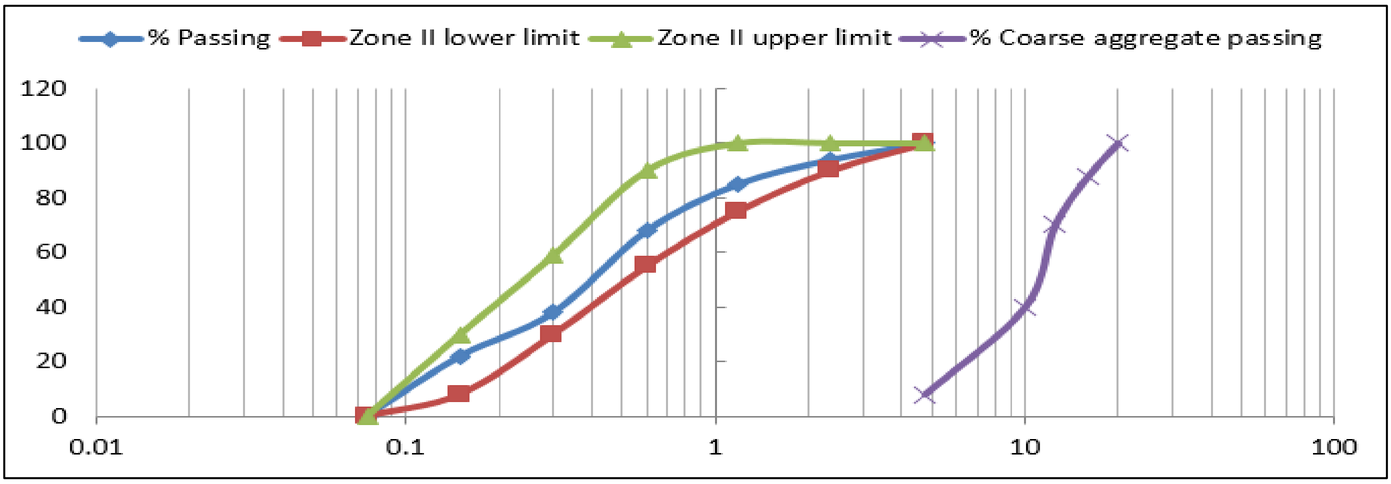

Fig 1 Gradation of Fine Aggregate

The fine aggregate's particle size analysis results are displayed in Figure 1, and it was categorized as zone II based on the lower and upper limit values that fit into the envelope (25 percent finer than 600 µm and 75 percent coarser than 600 µm). This demonstrates that the fine aggregate may be used to make concrete and is consistent with research findings from Mubaraki, et al. [65], Morales Fournier, et al. [66]. Also, the coarse aggregate used in this study was uniformly grade from 10 – 20mm sized aggregate.

- *Oxide Composition of RHA and MK*

This section of the chapter presents result of the oxide composition of the MK and RHA used in this study using the X-ray fluorescence (XRF) method.

Table 3 RHA and Mk Oxide Composition

Oxides	Metakaolin	Rice Husk Ash
Na_2O	0.36	0.056
MgO	0.21	2.721
Al_2O_3	**35.2**	**2.363**
SiO_2	**55.0**	**80.722**
K_2O	1.18	2.341
CaO	0.66	1.394

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TiO_2	0.08	0.203
CuO	0.09	
Fe_2O_3	**0.82**	**1.103**
P_2O_5		8.109
SO_3		0.675
Cl		0.023
Cr_2O_3		0.002
Mn_2O_3		0.233
LOI	6.4	0.055

The oxide composition result from Table 3 shows that the combination of SiO_2, Al_2O_3 and Fe_2O_3 of MK and RHA is approximately 91.0 % and 84.2 % respectively, which is an indication that the MK and RHA used in this study is a good reactive pozzolana [52]. Additionally, a detailed comparison of the MK and RHA reveals that the former is rich in iron oxide and aluminum oxide but lacking in silicon oxide, while the latter is extremely rich in silicon oxide, which will make up for the MK's lack of silicon oxide. Concrete's strength and durability are increased by the high silicon oxide's reaction with calcium hydroxide ($Ca(OH)_2$), which is created during cement hydration, to generate more calcium silicate hydrate (C-S-H) [67-69].

➢ *Self-Compacting Concrete Paste Design*

The optimum superplasticizer (SP) dosage was determined by varying different superplasticizer content and water-cement ratios on the mix as shown in Figure 2.

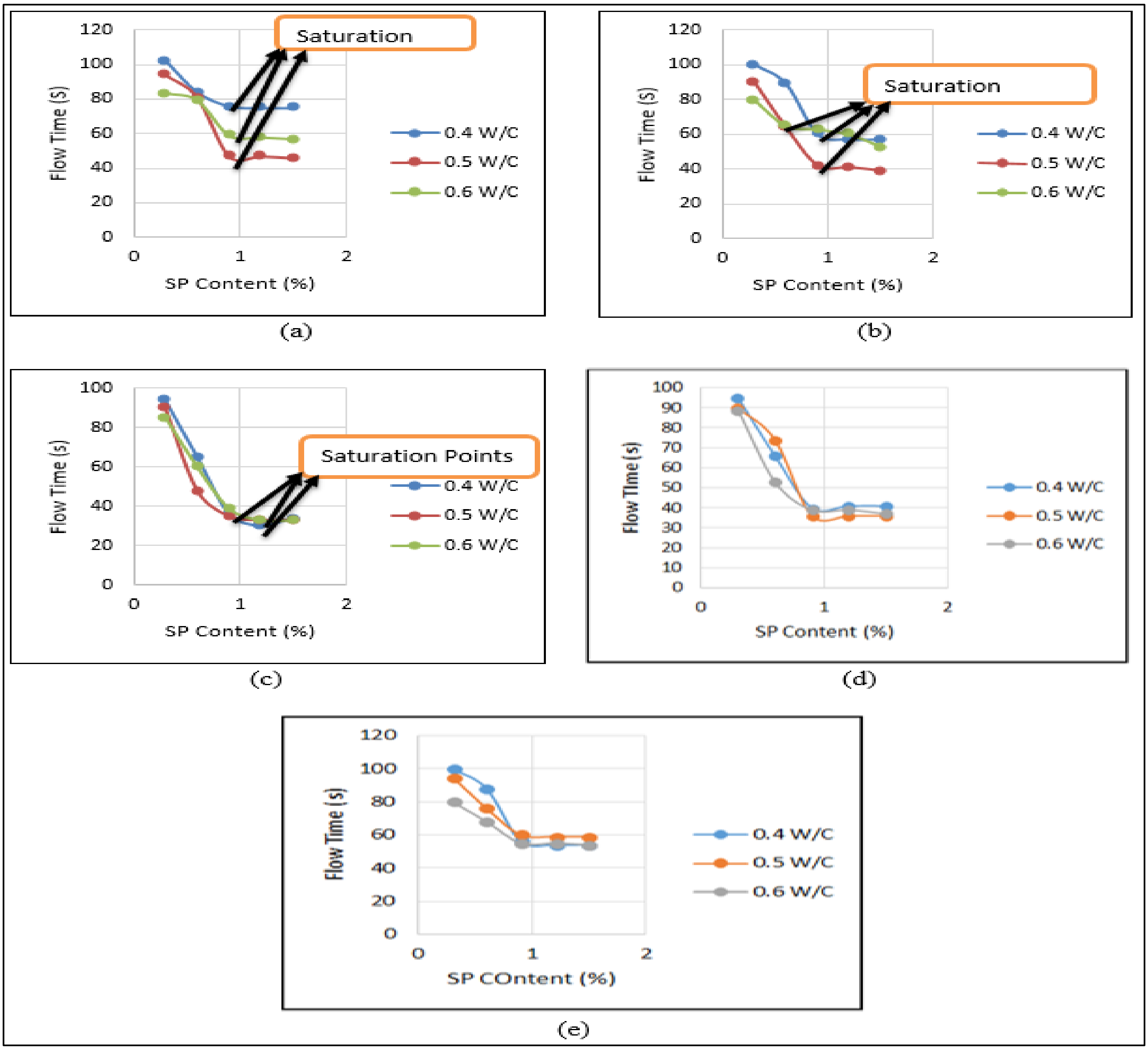

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Fig 2 Optimum SP Content with Different W/C Ratio for (a) Control; (b) 5%RHA and MK; (c) 10%RHA and MK; (d) 15%RHA and MK; and (e) 20%RHA and MK

Figure 2 (a-e), it can be seen that the optimum SP dosage for "W/C 0.4, 0.5 and 0.6 was achieved as 0.9%. Also, increasing the W/C as well as increasing the SP content increased the flow time using marsh cone. This might be explained by the fact that there is less free water available for lubrication, which increases particle friction. Consequently, the paste's viscosity rises and its flowability through the marsh cone decreases which was also explained by Bouras [70]

Furthermore, increasing the quantity of RHA and MK in the paste, increase in the flow time. This could be as a result of the water absorption ability of RHA and MK, but increasing the W/C and SP content reduces flow time. This might be because RHA and MK have a higher specific surface area than cement, as well as because they require a lot of water and have a big surface area. This thus reduces the cohesiveness of the paste and the pressures required to scatter the particles as explained by Lowke [71]. Additionally, it can be linked to improved steric and electrostatic repulsion between the cement particles that come into contact with SP, which results in a superior de-flocculation of the particles in the paste and lowers the plastic viscosity. From Figure 2, the saturation points for W/C 0.4, 0.5 and 0.6 was location at 0.9% SP.

From Figure 2 (d), the saturation points for 15% RHA and MK is 0.9% for W/C 0.4, 0.5 and 0.6. This shows that, for paste containing RHA and MK, the W/C doesn't have an effect on the saturation point. The same effect was observed for 20% RHA and MK as seen in from Figure 2(e). Based on the outcome of the SCC paste design, an optimum SP dosage of 0.9 was adopted for use in production of the concrete.

➢ *Rheological Properties of MK and RHA Concrete*

The rheological properties of the concrete were investigated at 0.4, 0.5, and 0.6 water-cement ratios, and at 0.9 % SP content. The fresh concrete properties investigated are slump, V-funnel, L-box, and J-ring properties of the fresh concrete.

- *Slump Test of MK and RHA Concrete*

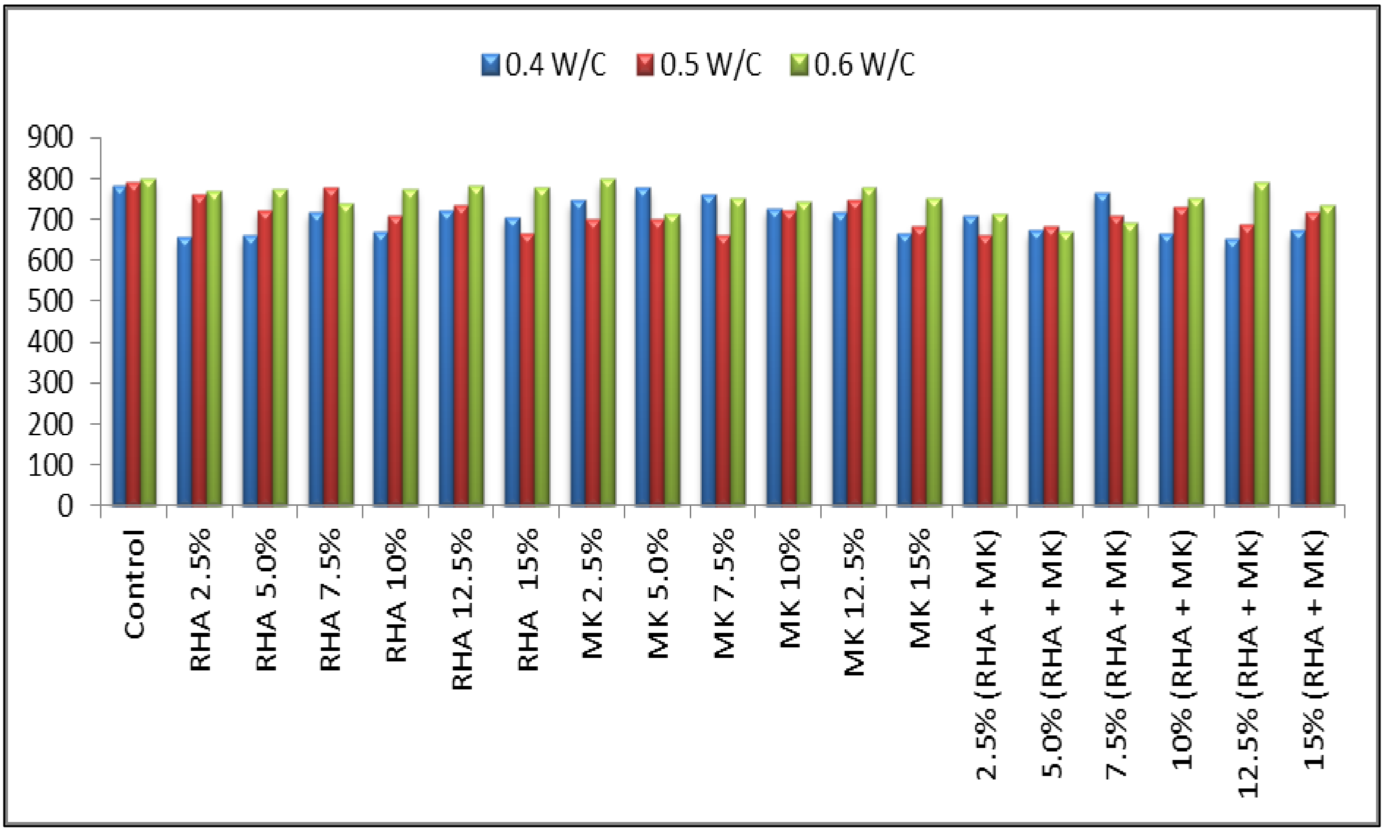

Fig 3 Concrete Slump at 0.4 – 0.6 W/C Ratios

The result from Figure 3 showed that the slump at 0.4, 0.5, and 0.6 W/C ratios ranges from 651 – 783 mm, 660 – 793 mm, and 670 – 799 mm respectively, when RHA and MK is used as partial replacement of cement separately, and in combination. However, the slump value of the control concrete is mostly higher than the experimental concrete at various W/C ratios, and can be attributed to the high specific surface of the MK and RHA (Table 2) which necessitates increase in water to maintain workability, hence the reduction in slump of the fresh experimental concrete compared to the control concrete.

However, the slump values of the control and experimental ranges from 650 – 800 mm which satisfies the

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requirements of BS-EN-12350;2 [55] and EFNARC [72]. Hence, indicating the mixes are adequate for concrete production.

- *V-Funnel Test of RHA and MK Concrete*

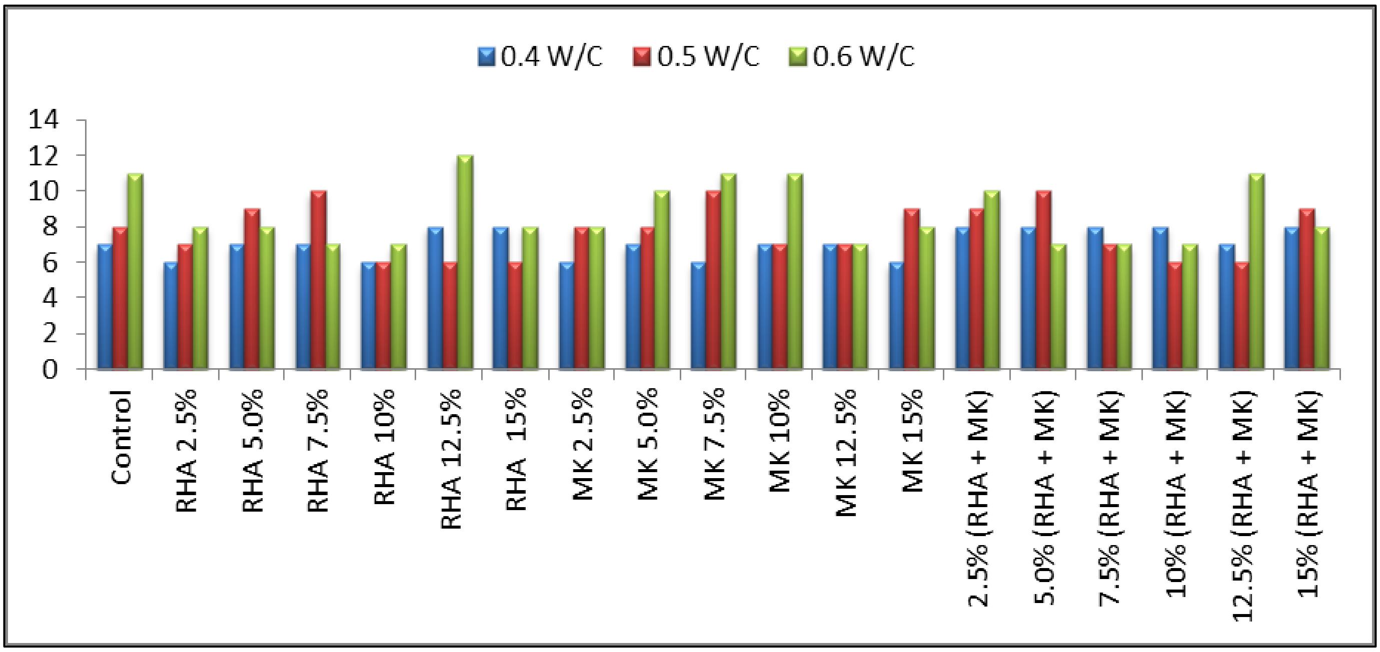

Fig 4 V-Funnel at 0.4 – 0.6 W/C Ratios

The result from Figure 4 showed that the V-funnel values of the fresh concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 6-8 secs, 6-10 secs, and 7-12 secs respectively, when RHA and MK is used as partial replacement of cement separately, and in combination. Also, all the experimental concretes including the control concrete have V-funnel values within 6 – 12 seconds as specified by EFNARC [72]. This implies that majority of the bio-self compacting concrete have good flowability and resistance to segregation [72].

- *L-Box Properties of RHA and MK concrete*

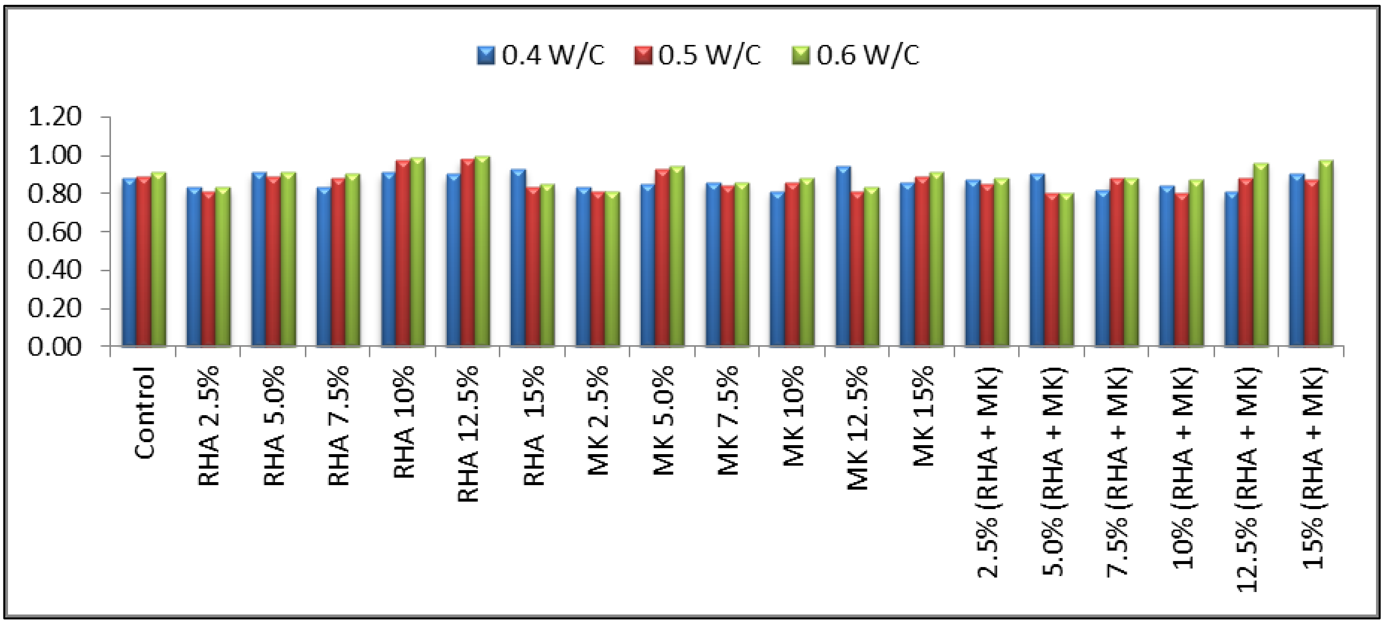

Fig 5 V-Funnel at 0.4 – 0.6 W/C Ratios

The result from Figure 5 showed that the L-Box values of the fresh concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 0.81-0.94, 0.80-0.98, and 0.80-1.00 respectively, when RHA and MK is used as partial replacement of cement separately, and in combination. However, both the experimental and control concrete have values within 0.8 –

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1.0 (h_2/h_1) as specified by EFNARC [72]. This implies that self-compacting concrete with addition of MK and RHA separately and in combination exhibits good filling ability, and passing ability of SCC between steel bars in congested steel arrangements.

- *J-Ring Properties of RHA and MK concrete*

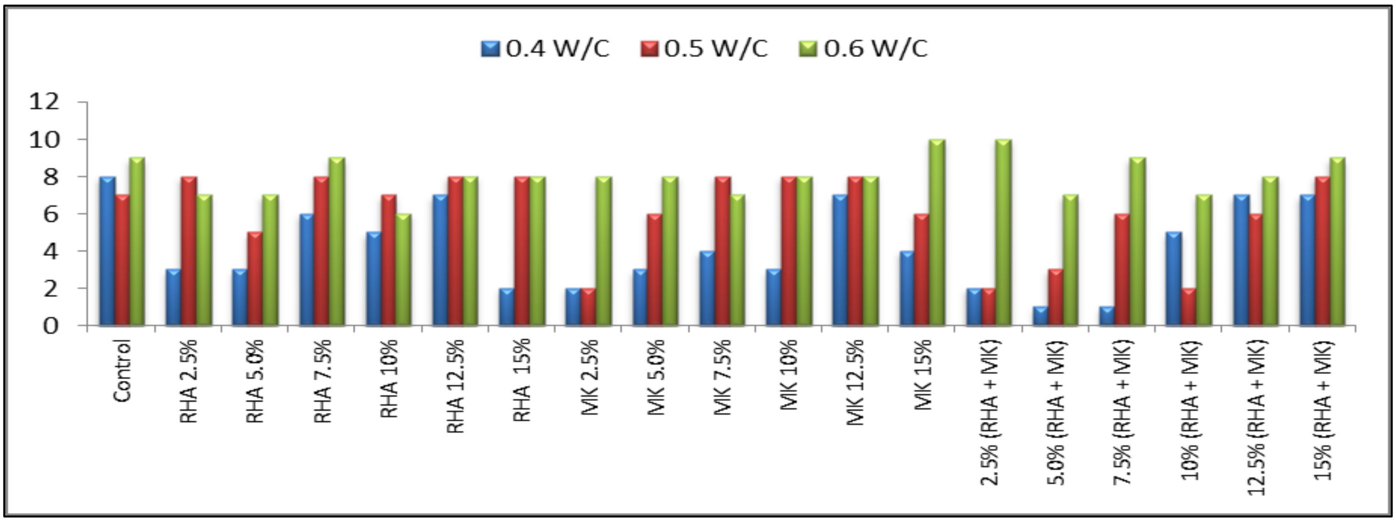

Fig 6 J-Ring of Fresh Concrete at 0.4 – 0.6 W/C Ratios

The result from Figure 6 showed that the J-ring values of the fresh concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 1-8, 2-8, and 6-10 mm respectively, when RHA and MK is used as partial replacement of cement separately, and in combination. Also, both the experimental and control concrete have values within 0 – 10 mm as specified by EFNARC [72] and BS-EN-12350;2 [55], which is an indication that the superplasticizer dosage of 0.9 % adopted in this study is adequate for producing SCC with satisfactory flowability and workability.

➢ *Strength Properties of MK and RHA SCC*

This section presents results on the compressive strength, flexural strength, and split tensile strength of SCC produced by partially replacing cement with RHA and MK separately, and in combination at 0.4, 0.5, and 0.6 W/C ratios.

- *Compressive strength of RHA and MK SCC*

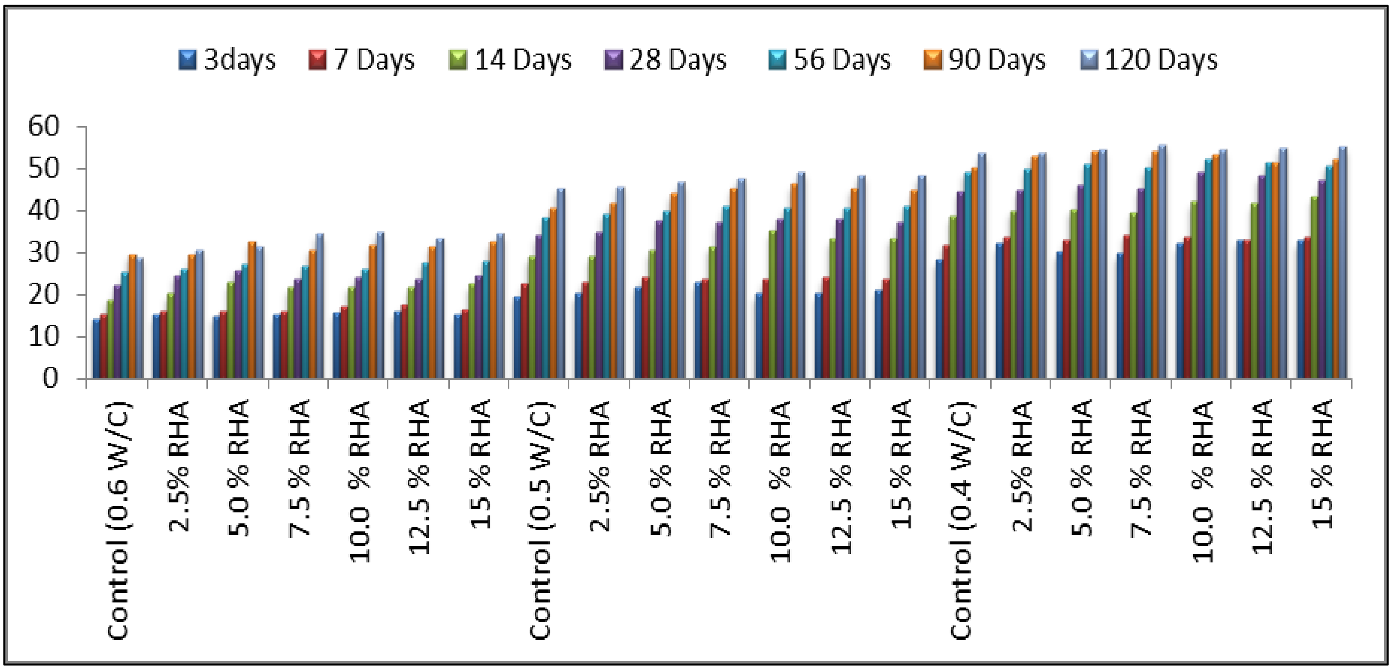

Fig 7 Compressive Strength of RHA Concrete at Various W/C Ratios

The result from Figure 7 showed that, as curing days "increases, the concrete compressive strength increases, and the 3-120 days compressive strength of the control concrete at 0.6, 0.5, and 0.4 W/C ratio ranges from 14.3 – 28.9, 19.7 – 45.3, and 28.3 – 53.6 N/mm^2 respectively, Also, the 3-120 days compressive strength of the control concrete at 0.6, 0.5,

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and 0.4 W/C ratio ranges from 14.9 – 34.9, 20.1 – 49.2, and 29.9 – 55.5 N/mm^2. However, at 28 days, the highest compressive strength of the experimental concrete at 0.6, 0.5, and 0.4 W/C ratios was achieved as 25.85, 38.1, and 49.2 N/mm^2, when cement was partially replaced with 5, 10, and 10 % RHA respectively.

The outcome of the findings of this study showed that concrete produced by replacing cement with 5 – 10 % RHA had 28 days compressive strength higher than the control concrete. This can be attributed to the chemical reaction between the RHA and cement, since RHA contains a high amount of amorphous silica (Table 3) [73, 74], which produces more calcium silicate hydrate (C-S-H) when it combines with calcium hydroxide, a result of cement hydration, increasing the concrete's strength and durability [68, 75-77]. Similar findings were reported by Agboola, et al. [78], Xi, et al. [79], Subramaniam and Sathiparan [80], Hasan, et al. [81].

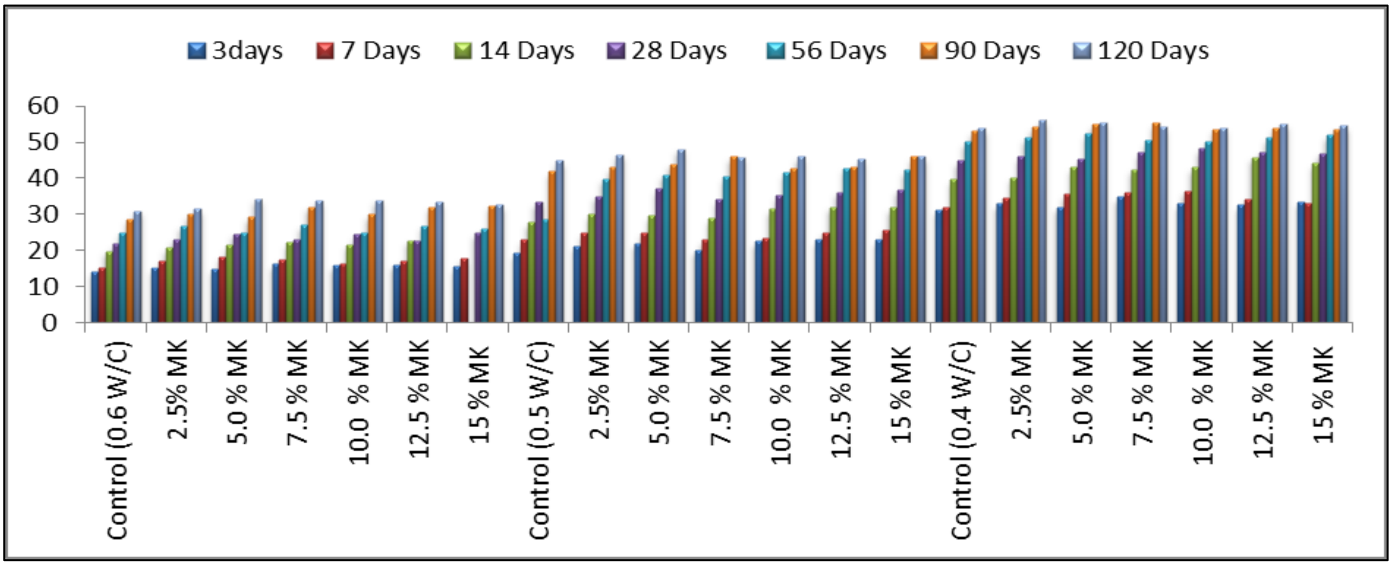

Fig 8 Compressive Strength of MK Concrete at Various W/C Ratios

The result from Figure 8 also showed that, as curing days increases, “the concrete compressive strength increases when cement is partially replaced with MK, and the 7-120 days compressive strength of the control and experimental concrete at 0.6, 0.5, and 0.4 W/C ratio ranges from 14.2 – 34.3; 19.3 – 48.1; and 31.4 – 56.1 N/mm^2 respectively, with the control concrete having lower compressive strength compared to the experimental concrete.

However, at 28 days, the compressive strength of the control concrete at 0.6, 0.5, and 0.4 W/C ratios is 21.9, 33.4, and 40.0 N/mm^2 respectively, whereas the highest 28 days compressive strength of the experimental concrete at 0.6, 0.5, and 0.4 W/C ratios was achieved as 24.9, 37.1, and 48.2 N/mm^2, when cement was partially replaced with 15, 5, and 10 % RHA respectively. The outcome from these findings showed that compared to RHA concrete, maximum compressive strength was achieved when MK was used to replace cement at 5-15% at various W/C ratios, similar findings were reported by [82-85].

This gain in compressive strength can be attributed to the high content of alumina (Table 3), which when combined with cement creates more calcium aluminate hydrate (C-A-H) when it combines with calcium hydroxide, increasing the concrete's strength [86-90]. Also, the high specific surface of the MK (Table 2), which fill voids between cement particles, leading to a denser and more compact concrete matrix, and improves the particle packing” leading to higher compressive strength [91].

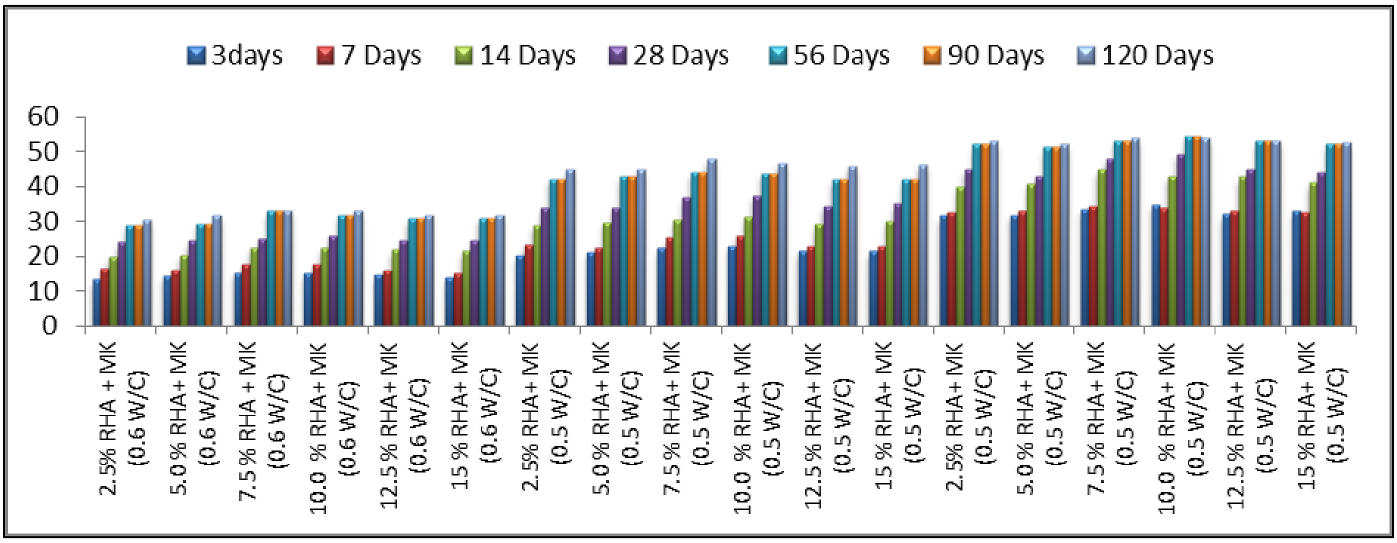

Fig 9 Compressive Strength of MK and RHA combined at Various W/C Ratios

The result from Figure 9 also showed that, as curing day's increases, the concrete compressive strength increases, and as "W/C ratio decreases, compressive strength increases. However, the 3-120 days compressive strength of the experimental concrete at 0.6, 0.5, and 0.4 W/C ratio ranges from 13.3 – 33.1; 20.1 – 47.9; and 31.7 – 54.5 N/mm^2 respectively. The maximum 28 days compressive strength of the concrete at 0.6, 0.5, and 0.4 W/C ratios is 25.9, 37.5, and 49.3 N/mm^2 respectively, and was achieved when cement was partially replaced with blend of 10% (RHA + MK), Similar findings were reported by Uche [90], Farsana and Vivek [92]. The outcome from these findings showed that 10% combination of RHA and MK (i.e. 5% RHA and 5% MK) as partial replacement of cement yielded the maximum 28 days concrete compressive strength at 0.4, 0.5, and 0.6 W/C ratios, which is higher compared to 28 days compressive strength of RHA and MK concrete when used to replace cement separately" as shown in Figure 10.

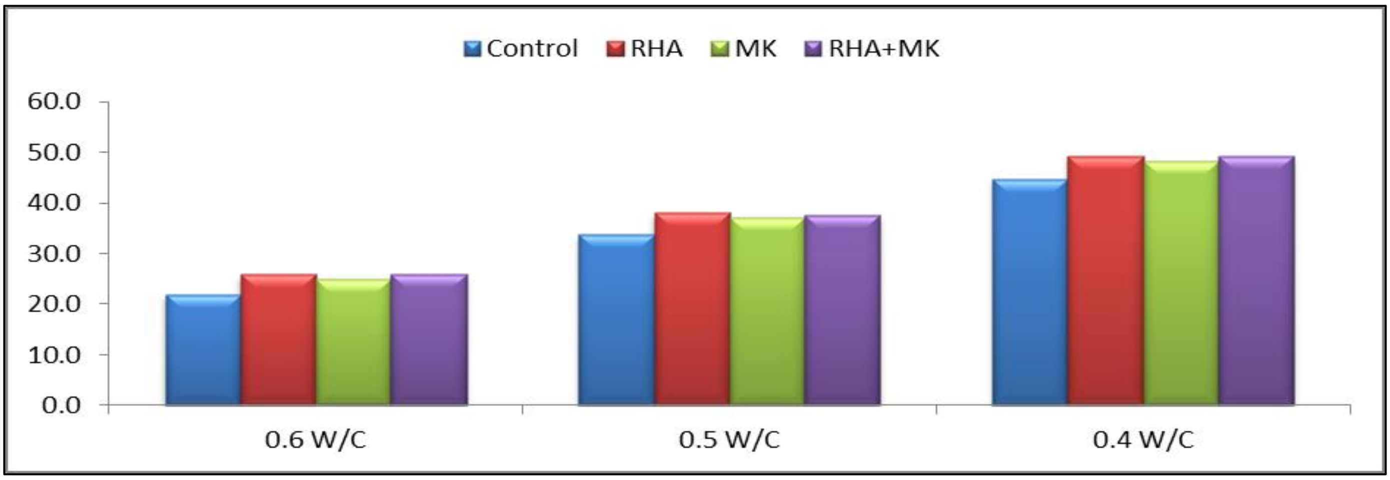

Fig 10 28 days Compressive Strength of Control, RHA, MK and RHA + MK Concrete

As can be seen from Figure, 10, the control concrete had the least compressive strength at 28 days compared to the experimental concretes. Also, at 0.6 W/C ratio, the highest 28 days compressive strength was achieved when cement is replaced with 10 % blend of RHA and MK (25.9 N/mm^2), at 0.5 W/C ratio, the highest 28 days compressive strength was achieved when cement is replaced with 10 % RHA (38.1 N/mm^2), followed by 10 % blend of RHA and MK (37.5 N/mm^2), whereas at 0.4 W/C ratio, the highest 28 days compressive strength was achieved when cement is replaced with 10 % blend of RHA and MK (49.3 N/mm^2), followed by 10 % RHA (49.2 N/mm^2).

The findings from this study showed that combination of RHA and MK at 10% replacement of cement yielded the highest 28 days compressive strength compared to the control concrete, followed by concrete produced by replacing cement with 10 % RHA.

- *Split tensile strength of RHA and MK SCC*

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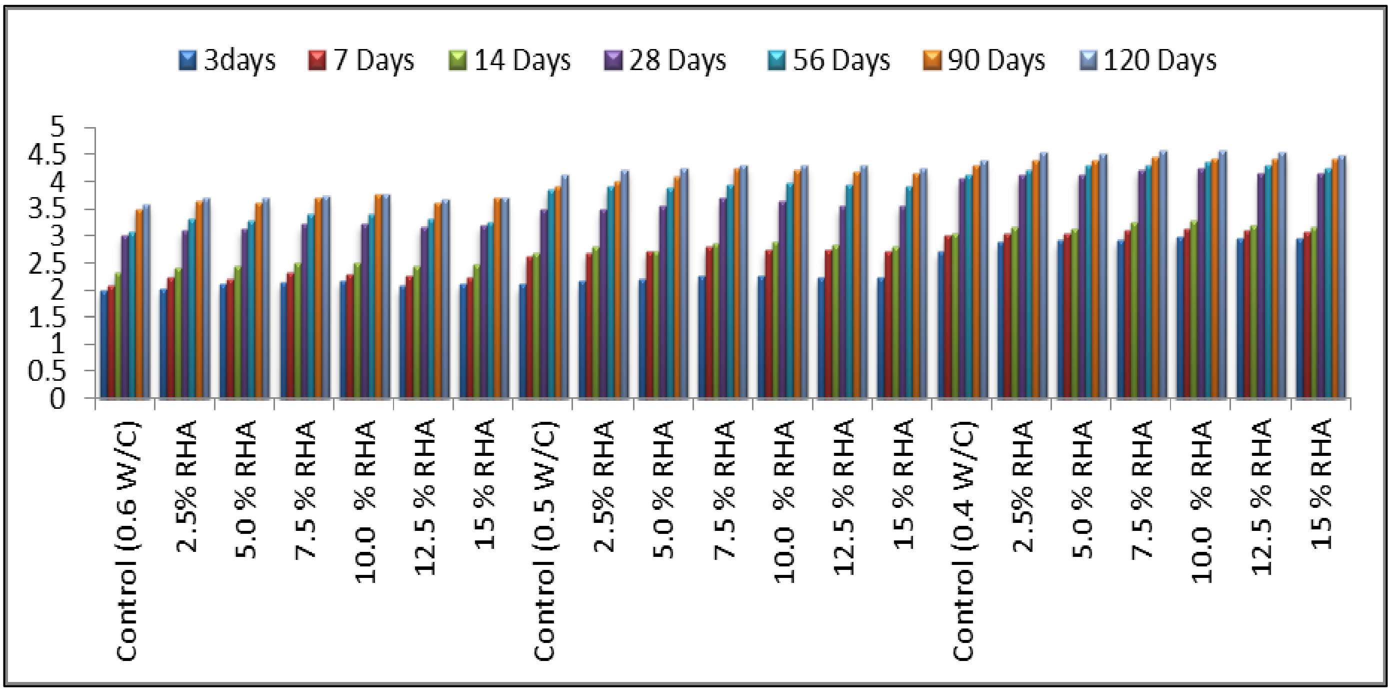

Fig 11 Split Tensile Strength of RHA Concrete at Various W/C Ratios

The result from Figure 11 showed that the control RHA concrete split tensile strength from 3 – 120 days at 0.6, 0.5, and 0.4 W/C ratios ranges from 1.98 – 3.59; 2.16 – 4.22; and 2.89 – 4.53 N/mm^2 respectively, whereas the experimental concrete split tensile strength from 3 – 120 days at 0.4, 0.5, and 0.6 W/C ratios ranges from 1.98 – 3.59; 2.16 – 4.22; and 2.89 – 4.53 N/mm^2 respectively. Also, the maximum 28 days split tensile strength of the control concrete at 0.6, 0.5, and 0.4 W/C ratios is 3.02, 3.50, and 4.11 N/mm^2 respectively, and the maximum 28 days split tensile strength of the experimental concrete at 0.6, 0.5, and 0.4 W/C ratios is 3.23, 3.70, and 4.23 N/mm^2, and was achieved when cement was partially replaced with RHA at 10, 7.5, and 10 % respectively. The implication of these findings showed that to achieve maximum concrete split tensile strength, cement should be replaced with 7.5 – 10.0 % RHA, similar findings were reported by Ali, et al. [93], Shupta, et al. [94].

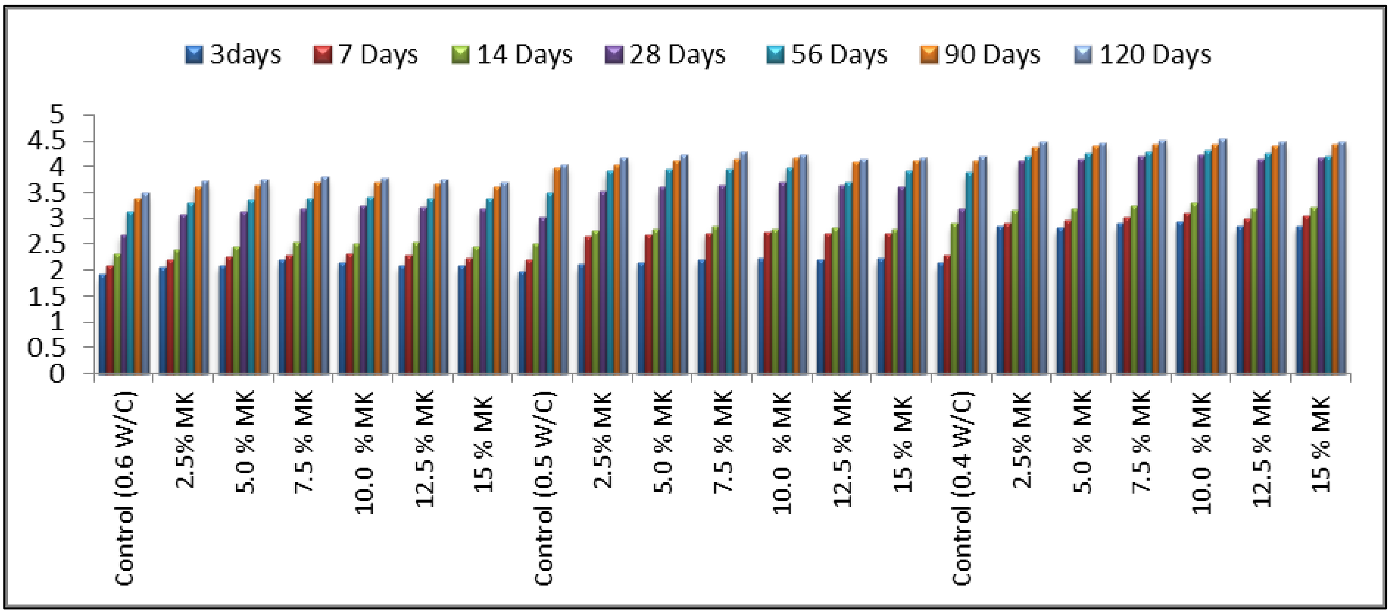

Fig 12 Split Tensile Strength of MK Concrete at Various W/C Ratios

The result from Figure 12 showed that the "split tensile strength of control MK concrete from 3 – 120 days at 0.6, 0.5, and 0.4 W/C ratios ranges from 1.98 – 3.59; 2.16 – 4.22; and 2.89 – 4.53 N/mm^2 respectively, whereas the experimental concrete split tensile strength from 3 – 120 days at 0.4, 0.5, and 0.6 W/C ratios ranges from 2.05 – 3.80; 2.11 – 4.29; and 2.81 – 4.53 N/mm^2 respectively. Also, the maximum 28 days split tensile strength of the MK control concrete at 0.6, 0.5, and 0.4 W/C ratios is 2.69, 3.01, and 3.19 N/mm^2 respectively, and the maximum 28 days split tensile strength of the MK experimental concrete at 0.6, 0.5, and 0.4 W/C ratios is 3.24, 3.70, and 4.22 N/mm^2, and were all achieved

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when cement was partially replaced with RHA at 10 % respectively. Similar findings where 10 % MK replacement" yielded the maximum split tensile strength were reported by Nanda, et al. [95], Agboola, et al. [96]

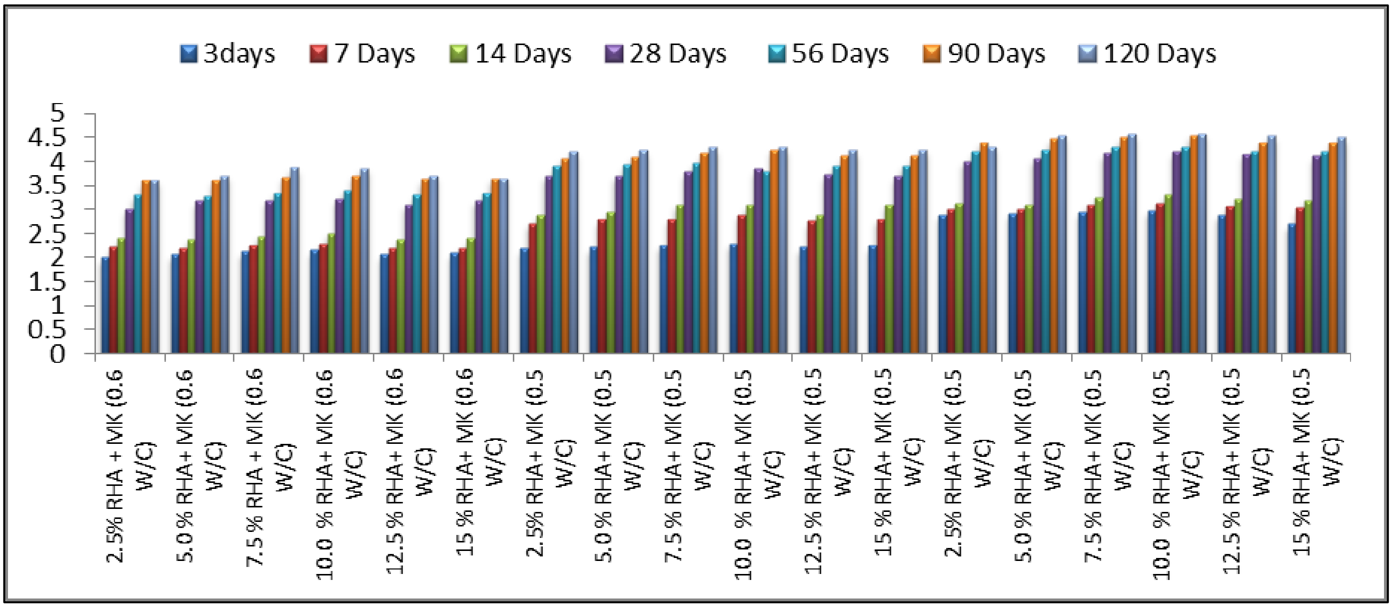

Fig 13 Split Tensile Strength of RHA and MK Blend at Various W/C Ratios

The result from Figure 13 showed that the 3-120 days split tensile strength of the experimental concrete at 0.6, 0.5, and 0.4 "W/C ratio ranges from 2.01 – 3.88; 2.18 – 4.30; and 2.70 – 4.58 N/mm^2 respectively.

The maximum 28 days split tensile strength of the concrete at 0.6, 0.5, and 0.4 W/C ratios is 3.22, 3.84, and 4.20 N/mm^2 respectively, and was achieved when cement was partially replaced with blend of 10% (RHA + MK). The outcome from these findings showed that 10% combination of RHA and MK (i.e. 5% RHA and 5% MK) as partial replacement of cement yielded the maximum 28 days concrete split tensile strength at 0.4, 0.5, and 0.6 W/C ratios, as obtained in the compressive strength of concrete (Figure 9).

- *Flexural Strength of RHA and MK SCC*

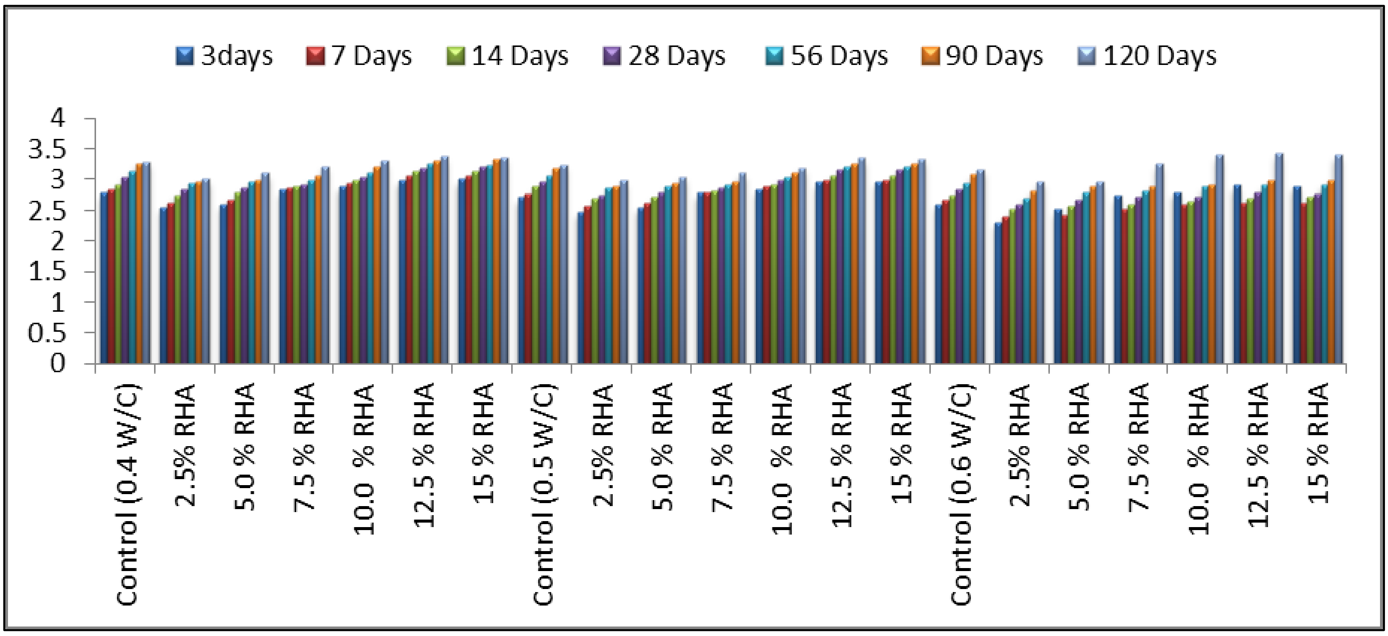

Fig 14 Flexural Strength of RHA Concrete at Various W/C Ratios

The result from Figure 14 showed that the 3-120 days flexural strength of the RHA concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 2.55 – 3.37; 2.48 – 3.35; and 2.31 – 3.42 N/mm^2 respectively. The maximum 28 days flexural strength of the control concrete are 3.04; 2.96; and 2.83 N/mm^2, at 0.4, 0.5, and 0.6 W/C ratios respectively, whereas the 28 days flexural strength of the experimental concrete at 0.4, 0.5, and 0.6 W/C ratios is 3.20, 3.16, and 2.78 N/mm^2 respectively, which was achieved when cement was partially replaced with RHA at 15%, 15%, and 12.5% respectively. The outcome

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from these findings showed that the maximum flexural strength of RHA concrete was achieved" at 12.5 – 15%. Similar findings were reported by Nemeyabahizi [97], Ahmed [98], Narayana, et al. [99]

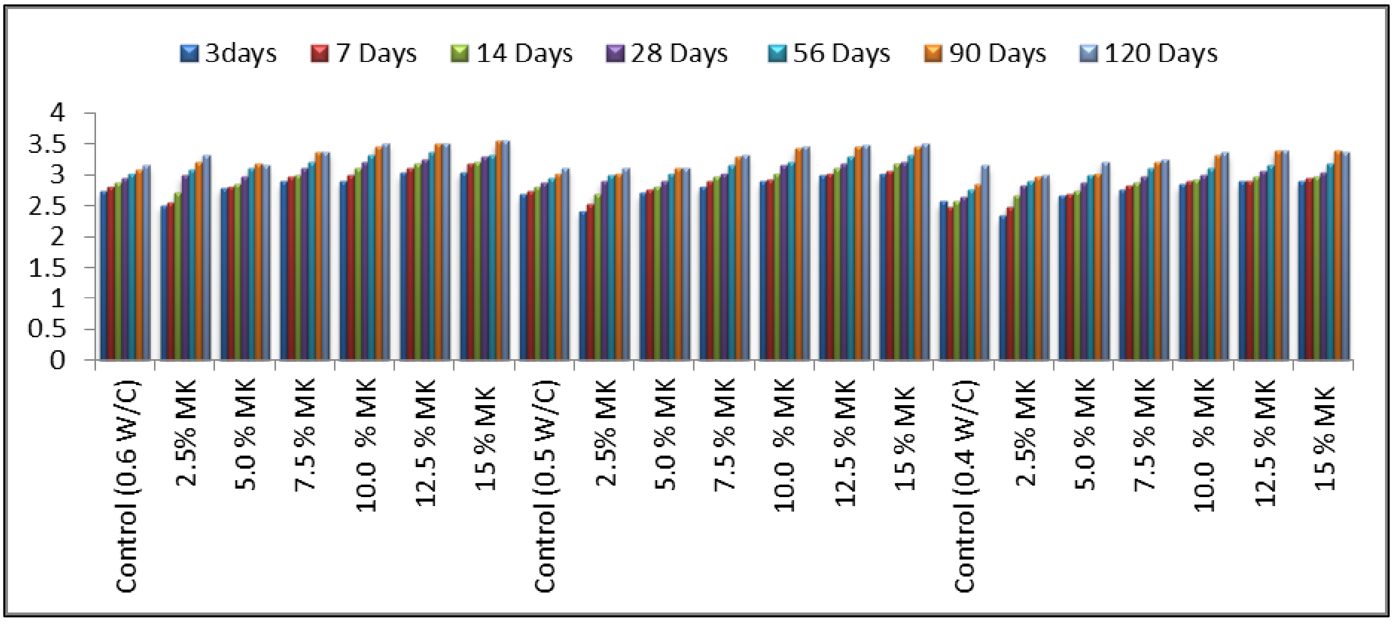

Fig 15 Flexural Strength of MK Concrete at Various W/C Ratios

The result from Figure 15 showed that the 3-120 days flexural strength of the MK concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 2.51 – 3.36; 2.41 – 3.51; and 2.33 – 3.40 N/mm^2 respectively. The maximum 28 days flexural strength of the MK control concrete are 2.94; 2.88; and 2.64 N/mm^2, at 0.4, 0.5, and 0.6 W/C ratios respectively, whereas the 28 days flexural strength of the MK experimental concrete at 0.4, 0.5, and 0.6 W/C ratios is 3.30, 3.20, and 3.06 N/mm^2 respectively, which were all achieved when cement was partially replaced with MK at 15%. The outcome from these findings showed that the maximum flexural strength of MK concrete was achieved when cement is replaced with 15% MK. Similar findings were reported by Mohanraj and Senthilkumar [34], Saand, et al. [84], Mahmoud, et al. [100], Oraka and Sajedi [101].

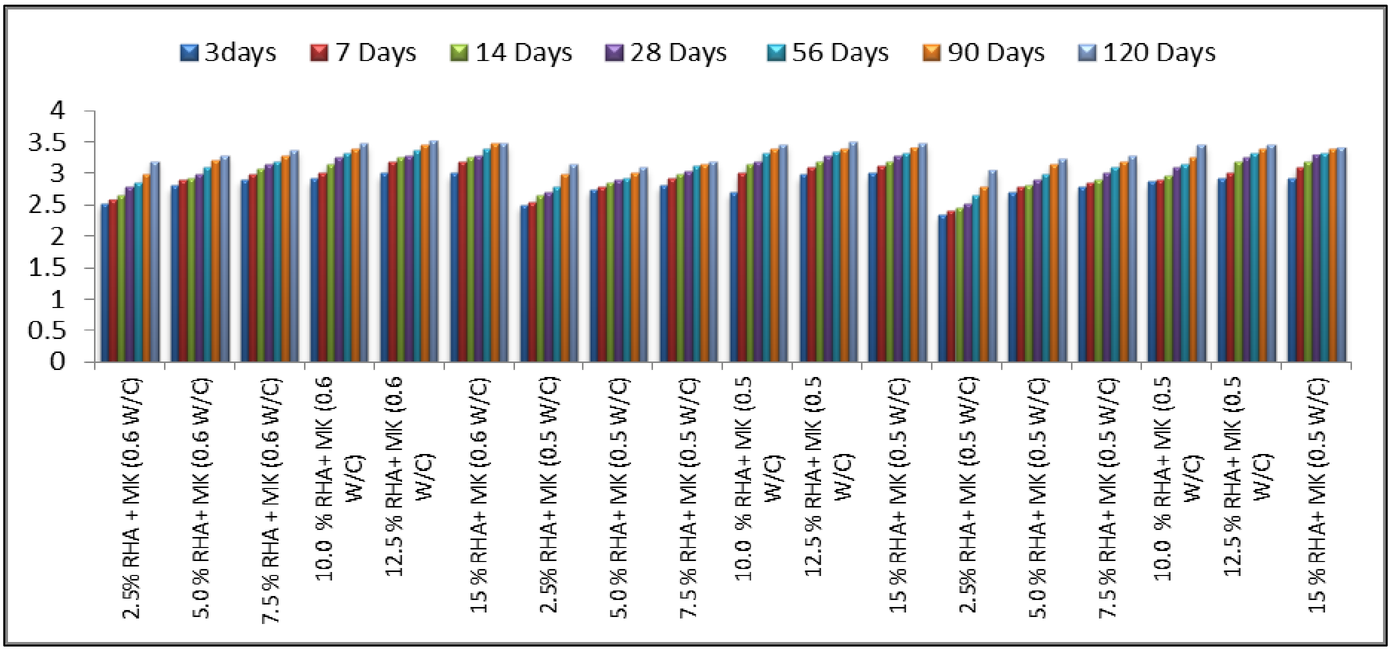

Fig 16 Flexural Strength of RHA and MK Blend at Various W/C Ratios

The result from Figure 16 showed that the 3-120 days flexural strength of the RHA + MK blend of concrete at 0.4, 0.5, and 0.6 W/C ratios ranges from 2.52 – 3.52; 2.50 – 3.50; and 2.35 – 3.46 N/mm^2 respectively. The maximum 28 days flexural strength of the concrete at 0.4, 0.5, and 0.6 W/C ratios is 3.29, 3.29, and 3.30 N/mm^2 respectively, which were all achieved when cement was partially replaced with 12.5% blend of RHA + MK (i.e. 6.25% of MK and RHA each). Similar findings were reported by Saifullah, et al. [102], Marwoto, et al. [103], Safitri, et al. [104], Safitri, et al. [105].

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IV. CONCLUSION

At the end of the result obtained from the findings of this study, it was concluded that the rheological properties of the SCC with addition of MK and RHA separately and in combination, and at 0.9 % superplasticizer content, exhibits adequate workability and flowability at 0.4, 0.5, and 0.6 water-cement ratios. The maximum 28 days compressive strength of the SCC at 0.4-0.6 W/C ratios was achieved at 5-10 %, and 5-15 % when RHA and MK was used separately respectively, and was achieved at 10 % when MK and RHA blend replaced cement. Also, the maximum 28 days split tensile strength was achieved at 7.5-10 %, and 10 % when RHA and MK was used separately respectively, and was achieved at 10 % when MK and RHA blend replaced cement. The maximum 28 days flexural strength was achieved at 12.5-15 %, and 15 % when RHA and MK was used separately respectively, and was achieved at 12.5 % when MK and RHA blend replaced cement. Hence, the maximum compressive, split, and flexural strength of SCC produced by partially replacing cement with blend of RHA and MK was achieved at 10 %, 10 % and 12.5 % replacement respectively.

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