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Suitability of Aluminium Dross (ALD) as Partial Replacement of Fine Aggregates in Self-Compacting Concrete Blended with Metakaolin (MK)

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Abstract*: This study is aimed at experimenting, the suitability of aluminium dross as partial replacement of fine aggregates in self-compacting concrete blended with metakaolin. A tested approach such as particle parking model (PPM) was ratified for the mix design of concrete aggregates. Cement was replaced with 15% metakaolin for all mixes and water binder ratio say 0.25, 0.3, and 0.35 respectively. Fresh concrete mixes were subjected to workability tests such as slump flow, L- box, V-funnel and J-ring in accordance with the EFNARC 2005 specification. Hardened concrete specimens for compressive and split tensile strength tests were cured in fresh water for 7, 14 and 28 days. Laboratory experiment carried out based on the PPM mix design method reviewed it is a suitable method for preparing self-compacting concrete manufactured with industrial waste such as aluminium dross. All concrete mixes met the criteria stipulated in the (EFNARC, 2005) code. The compressive strength was 61.2MPa at 10% aluminium dross (ALD) inclusion blended with 15% metakaolin at 28 days water curing. While, the split tensile strength was 2.48N/mm^2 at 5% aluminium dross (ALD) addition combined with 15% metakaolin at 28 days water curing, a higher level 15 to 25% of aluminium dross (ALD) incorporation in the concrete will cause a reduction in strength properties and density. Also, it will increase the permeability nature of the concrete as a result of glut voids.

***Keywords*: Self-compacting concrete, Aluminium dross, Metakaolin, Compressive strength, Split tensile strength, Particle parking model, Water/Cement ratio.**

1. Introduction

The improvement of self-compacting concrete (SCC) additionally alluded to as "Self-Consolidating Concrete" has as of late been one of the most significant improvements in construction (Ahmad, Umar, & Masood, 2017). Self-compacting concrete (SCC) is an extraordinary solid that can settle into the intensely fortified, profound and restricted segments by its own weight, and can solidify itself without requiring inner or on the other hand outside vibration, and simultaneously keeping up its soundness without prompting isolation of constituents and draining of water. SCC requests a lot of powder content contrasted with regular vibrated cement to create a homogeneous and firm blend (Long, Gu, Liao, & Xing, 2017). The basic practice to acquire self-compatibility in SCC is to limit the coarse total substance and the most extreme size and to use lower water–powder proportions together with another age super plasticizers (SP) (Sharma & Khan, 2018). During the transportation and arrangement of SCC, the expanded flowability may cause isolation and draining which can be overwhelmed by giving the fundamental thickness, which is typically provided by expanding the fine total content; by constraining the most extreme total size; by expanding the powder content; or by using consistency changing admixtures (VMA) (Aslani, Ma, Yim Wan, & Muselin, 2018). One of the impediments of SCC is its expense, related with the utilization of concoction admixtures and utilization of high volumes of Portland concrete.

The high demand for concrete and its constituents leads to crucial problems relating to its mode of preparations and designs to finally achieve an economical, durable, and environmentally friendly product on short and long durations. Since most aggregates of concrete, sand and coarse are extracted from natural source such as rivers, seas, rocks, the process at which these materials are derived possess threats to the natural environment which includes collapse of rivers banks, degradations of rivers, erosions, danger to aquatic organism, collapse of marine structures (ports, jetties, platforms).

Aluminium dross (ALD) can be considered as a constituent of concrete by entirely or partially replacing it with sand. Aluminium dross (ALD) are derived from aluminium industries, or waster aluminium products like aluminium cans, scraps from automobile, foil papers, scraps from electrical products and scraps from building materials. They can be dissolved and reuse in the production of electrical equipment, electrical power lines, cars, aircraft carriers, strips), food packaging, kitchen utensils, etc.

Although a large amount of aluminium dross (ALD) is not suitable for recycling and these amounts to environmental pollutions. Hence, the use of aluminium dross (ALD) in concrete can be very efficient in the reduction of environmental pollution caused by aluminium industries. Aluminium dross (ALD) is not a biodegradable material meaning its usage in land reclamation/filling will take up to 700 years before degrading. Therefore, the usage of waste aluminium dross (ALD) in landfilling is practically not advised.

2. Literature review

M. Satish Reddy, (2014) has worked on an experimental investigation on the use of secondary aluminium dross in concrete. The objective of his research was to utilize the aluminium dross in the natural cycle by using it as an engineered material and to investigate the mechanical properties of the new concrete type obtained by adding aluminium dross. The results of this study indicate that aluminium dross can be used as an ingredient of up to 5% to improve expanded concrete.

N. Y. Galat (2017) examined the performance of concrete using aluminium dross. His project aimed to investigate the potential use of dross in concrete products such as non-aerated concrete, concrete cube. The main advantage if this type of concrete over the conventional ones is the reduction in the number of raw materials.

Nesibe G. O, (2014) conducted a study on the effect of aluminium dross on mechanical and corrosion properties of concrete. They investigated the mechanical and chemical behavior of new concrete type obtained by adding aluminium dross. They concluded that up to a certain limit, aluminium dross could improve expanded concrete and corrosion resistivity of concrete.

Shaik M. H, (2016) has worked on "An Experimental Investigation on Use of Secondary aluminium Dross in Cement Concrete." They studied mechanical properties of the new concrete type obtained by adding aluminium Dross, which is an impure aluminum mixture, obtained from metals melting and mixing with flux. The result of this study indicates that aluminum dross can be used as an ingredient of up to 5% to improve expanded concrete.

Gireesh M, (2016) carried out a study on the investigation of concrete produced using recycled aluminum dross for hot weather concreting conditions. He examined the utilization of reuse aluminum dross in producing concrete, which is suitable for hot weather concreting condition. The observed result showed that initial setting time of the recycled aluminum Dross concrete extended by about 30min at 20% replacement level.

As stated above it seems that the use of Aluminum dross (ALD) as alternative fine aggregate in self-compacting concrete is one of the good alternatives to overcome the problem of waste management, reduction of cost of construction and introduction of a new innovation concrete material.

Self-Compacting Concrete (SCC) is a species of concrete that does not require external or internal vibration for placing and consolidation; instead, it gets consolidated under its self-weight. Some unique features of SCC, which make it special in construction are resistance to segregations, flowability, deformability, filling capacity, unrestrained shrinkage, and permeability. The involvement of SCC promotes the new ideology of concrete in the construction industry. Although, many researchers have contradicted the use of Self-Compacting Concrete (SCC) due to its ability to decrease employability of skilled laborers. Nevertheless, it can cause a reduction in the standard price of in situ solid concrete construction. This type of concrete is highly sensitive to produce, considering its mix and determination of its constituents, sand, cement, coarse, and natural minerals (superplasticizers).

Obunwo et al. (2018) studied the effects of metakaolin on the fresh state and compressive strength of high strength self-compacting concrete. In the research, the particle parking model (PPM) was initiated for the mix design of concrete aggregate. In their research, metakaolin was used to replace cement in the ratios of 5%, 10% and 15% at different water to cementitious ratios say 0.25, 0.30, 0.35 and 0.40. Concrete mixes were prepared to meet the criteria state in (EFNARC, 2005. Laboratory experiment were executed to determine the on both fresh and hardened concrete properties such as slump flow, L- box, V-funnel and J-ring and compressive strength. The hardened concrete specimens were subjected for comprehensive strength test after curing in fresh water for 7, 14 and 28days. The results showed that the particle parking model used in the mix design was suitable for producing SCC. All fresh state properties satisfied criteria (EFNARC, 2005). The highest compressive strength of 69.6 MPa was obtained for concrete using metakaolin.

Gopala Krishna Sastry & Asha Deepthi Deva, (2015) studied the difference in mechanical properties of regular vibrated concrete and Self-Compacting concrete. The samples were cast by M30 grade of concrete. They examined the upshot of different proportion of Fly Ash 30 % & Silica Fume 10% in concrete. NVC of M30 grade was designed in accordance with the IS code-10262:2009 and obtained a compressive strength of 39.52 N/mm^2 at 28 days. SCC with 30% FA addition produced approximately the same strength of NVC of the same grade. SCC with 10% SF addition gives nearly the same strength of NVC of the same grade. SCC containing 30% FA & 10% SF obtained maximum compressive strength, split tensile strength & flexural strength. The percentage increase in compressive strength, split tensile strength and flexural strength at 30% FA & 10% SF for SCC M30 grade is 23.89%, 18.77%, 20.31% more than that of SCC without mineral admixture.

Chandra Mohan G (2015) studied the properties of Self-Compacting and Self-Curing Concrete. The specimens were cast by M40 grade of concrete. The SCC was cured in three different curing conditions being normal curing (NC), membrane curing (MC) and self-curing (SC). The compressive strength of the self-compacted self-curing concrete is more than other curing methods like typical and membrane curing types. The compressive strength of self-compacting concrete is getting more than conventional concrete. It is found that the ratio of gain in strength is almost the same or even better than that of conventionally vibrated concrete.

3. Materials and methods

A. Cement

The ordinary Portland cement used in the preparation of concrete specimens in this research is the Dangote 3X Portland limestone c (PLC) of grade 42.5N this cement is locally available in Nigeria produced in bags of weight 50kg. The cement was tested in accordance with the BS EN 196.1 (2016), Methods of Testing Cement, Determination of Strength. British Standard Institute, London, United Kingdom.

B. Fine Aggregate

The fine aggregate used in this research were obtained from Choba River in Emouha, Local Government Area, Rivers State Nigeria. The sand was first served through 4.75mm sieve to eliminate any particle greater than 4.75mm. The acceptance of the fine aggregate used in this research is due to its concordance with the BS 882 (1992), Specification for Aggregates from Natural Sources for Concrete. British Standards, Institute, London,

C. Aluminium Dross

aluminium dross (ALD) used in this research are in the form of thin, flexible and small strips of variable sizes the aluminium dross (ALD) were obtained from making and usage of aluminium alloys for engineering applications basically in construction of residential building elements such as windows, doors, facades, guard rails. The Aluminium chips were gotten from aluminium fabrication shops around Okereke Street, Ojoto Street and Afikpo Street all in Diobu, Port Harcourt, Rivers State, Nigeria. The Aluminium dross (ALD) was added to the concrete at different percentages ranging from 5 to 25% by weight of fine aggregate (sand).

D. Coarse Aggregate

The course aggregate applied in this research were crushed grander and rough-textured granite obtained from crushed rock industry Nigeria limited, Akankpa in cross Rivers state Nigeria. Its maximum size was 10mm considering its use for SCC production the selection of coarse aggregate for this research is under EN 12620.

E. Mineral Admixture

The admixture used in this research is metakoalin. Metakaolin is an anhydrous calcined form of the clay mineral kaolinite, they are found in abundance in some parts of Nigeria such as Edo State, Kogi State, and Northern parts of Nigeria. A certain amount of researchers has conducted researches on natural pozzolanas such as Metakaolin. Irrespective of the pozzolanic nature of metakaolin, they are not highly reactive. Highly reactive metakaolin is made by water processing to remove unreactive impurities to make 100% reactive pozzolan. High reactive metakaolin shows high pozzolanic reactivity and reduction in $Ca(OH)_2$ even as early as one day. Metakaolin undergoes densification which enhances strength and permeability of concrete when they are used as mineral admixtures in concrete. The mechanism considerably limits the water demand in flowable concrete.

F. Casting and Curing

Before casting, the molds were cleaned and oiled properly. The molds were firmly tight to achieve concrete of regular shape (cubic and cylindrical). Proper care was taken to make sure there were no leakages for possible passage of slurry. After casted specimens have hardened, they were retrieved from the mold and cured in fresh water for the curing process. The concrete specimens were cured for 7, 14 and 28 and subjected to percentage water absorption, compressive and split tensile strength test.

Experiment for this study was administered within the structural laboratory of Rivers State University, Port Harcourt, Nigeria, and an extensive description on this study is procurable in Orime et al., (2018).

4. Mix design procedure

The mix design method adopted in this research is the Particle Packing Method (PPM). The PPM method guarantees compatibility amount aggregate of SCC concrete and also helps to reduce void concrete on conduct (Tigiri et al. 2018). In the course of developing an SCC with excellent properties such as flowability, segregation resistance, and filling ability, the optimum size of coarse aggregates is limited 10mm. The three proportions of coarse and fine aggregate applied are as follows; 60:40, 55:45 and 52:48 for coarse and fine aggregates, respectively. Hence, the evaluation of compacted bulk density and the specific gravity of concrete aggregate were carried out. The properties of coarse and fine aggregate that produced the least amount of void were then adopted (Tigiri, et al. 2018).

The bulk density, packing density (PD), and void content (VC) were experimented and computed using the relationship below conforming to the required standard (ASTM29 or EN 1097-1998).

$$\text{Parking Density (P.D)} = \sum \left(\frac{\textit{Bulk Density X Weight Fraction}}{\textit{Specific Gravity}} \right) \quad (1)$$

$$\text{Void content} = 1 - \sum \left(\frac{\textit{Bulk Density X Weight Fraction}}{\textit{Specific Gravity}} \right) \quad (2)$$

However, the Void Content (VC) can also be deduced by subtracting Packing Density (PD) in equation (1) from one (1).

$$\text{Void content} = 1 - \text{PD} \quad (3)$$

The paste derived from cementious materials and water is

Table 1
Aggregate Combination for Particle Packing Method

Mould Number	Aggregate Combination Fine Aggregate + Granite (%)	Average Specific Gravity (Gs)	Average Bulk Density (g/cm^3)
MD1	40 + 60	2.31	2.11
MD2	45 + 55	2.30	2.09
MD3	48 + 52	2.41	2.21

Table 2
Specific Gravity and Bulk Density of the Concrete Constituents

Constituents	Specific Gravity (Gs)	Bulk Density (g/cm^3)
Portland Cement	3.01	2.630
Metakaolin	1.96	1.005
River Sand	3.016	1.940
10mm Granite	2.780	2.138
Aluminum Dross	1.35	0.7709
Super Plasticizer	1.06	1.09
Pure Water	1.0	1.0

expected to fill voids and provide the required compatibility. Since the self-compacting concrete blended with metakaolin is manufactured to establish a 2/3 properties of workability and strength, an excess paste of 10% was allowed for coating of aggregates. The primary paste can be estimated using the Koehler & Fowler 2007 equation.

$V_{p\ \text{volume of paste}} = V_{\text{Excess volume of paste}} + V_{\text{void volume of void of compacted aggregate blend in concrete}}$ (4)

Where,
V_p = Volume of paste (%)
V_{Exp} = Excess volume of paste (%)
V_{void} = Volume of void of compacted aggregate blend in concrete (%)

A. Mix Design Procedure

- Aggregate gradation (determination of void content in compacted aggregates)
- Compaction of packing density
- Evaluation of volume of primary paste

$V_p = V_{Exp} + V_{void}$
Evaluation of Volume of aggregates
$V_{Aggregates} = 1 - VC$ (5)

Evaluation of total volume of solid aggregate

$$V_{\text{Solid Aggregates}} = \sum\left(\frac{\text{Weight Fraction of Aggregates}}{\text{Specific Gravity}}\right) \quad (6)$$

Determination of aggregate weight

$$= \left(\frac{\text{Volume of Aggregate}}{\text{Total Volume of Solid}}\ X\ \text{Weight Fraction}\ X\ 1000\right) \quad (7)$$

If W/B ration = N x C

Total Paste Content = C+ W+S.P

$$\frac{C}{\text{Specific Gravity of Cement}} + \frac{C}{\text{Specific Gravity of Water}} + \frac{C}{\text{Specific gravity of S.P}} \quad (8)$$

$$\text{Cement Content} = \frac{\text{Total Voids Contents}}{\text{Total Paste Content}}\ x\ 1000 \quad (9)$$

Water Content = W/B x Cement Content. (10)

B. Mix Design

The mix design method adopted in this research is the Particle Parking Method (PPM) for Self-Compacting Concrete.

Step-1:

For **MD1** Aggregate Combination (Fine Aggregate + Gravel) of 40 and 60% respectively.

$$\text{Void content in percent volume} = \frac{\text{Specific Gravity} - \text{Bulk Density}}{\text{Sprcific Gravity}}\ X\ \frac{100}{1} \quad (11)$$

$$\text{Void content in percent volume} = \frac{2310-2110}{2310}\ X\ \frac{100}{1}$$

Void content in percent volume = 8.658%

For **MD2** Aggregate Combination (Fine Aggregate + Gravel) of 45 and 55% respectively.

$$\text{Void content in percent volume} = \frac{2300-2090}{2300}\ X\ \frac{100}{1}$$

Void content in percent volume = 9.130%

For **MD3** Aggregate Combination (Fine Aggregate + Gravel) of 42 and 48% respectively.

$$\text{Void content in percent volume} = \frac{2410-2210}{2410}\ X\ \frac{100}{1}$$

Void content in percent volume = 8.290%

Since the void content in MD3 is lesser compared to MD1 and MD2, we have to adopt the combination of 42 and 48% for fine aggregate and granite respectively.

Step-2:

Packing Density (P.D) = $\sum\left(\frac{Bulk\ Density\ X\ Weight\ Fraction}{Specific\ Gravity}\right)$

Packing Density (P.D) of 10mm Granite = $\frac{2138\ x\ 0.52}{2780}$

Packing Density (P.D) of 10mm Granite = 0.3999kg/m^3

Packing Density (P.D) of Fine Aggregate = $\frac{1940x0.48}{3016}$

Packing Density (P.D) of Fine Aggregate = 0.3087kg/m^3

Total packing Density = Packing Density of Fine aggregate + Packing Density of Granite

Total packing Density = 0.3086 + 0.3999

Total packing Density = 0.7086kg/m^3

Void Content (VC) = 1-P.D

Void Content (VC) = 1-0.7086

Void Content (VC) = 0.2914kg/m^3

Assuming, excess paste content of 10% due to voids.

Therefore,

$\frac{10}{100}\ x\ 0.2914\text{kg/m}^3$ = 0.02914kg/m^3

Total paste content = 0.2914 + 0.02914

Total paste content = 0.32054kg/m^3

Step-3:

In the production of SCC, the volume of paste is larger compared to that of a conventional concrete. The essence of the large amount of paste is to fill in void between other constituents (Fine and Coarse Aggregate) of the concrete.

V_{exp} = Volume of Excess Paste

V_p = Volume of Primary Paste Needed to fill Voids

V_{voids} = Volume of voids in the compacted aggregate combination.

$V_p = V_{exp} + V_{voids}$

V_p = 0.32054 + 0.0829

V_p = 0.4034kg/m^3

From equation (5) above,

$V_{Aggregates}$ = 1 -VC

Volume of aggregate = 1- 0.40344kg/m^3

Volume of aggregate = 0.59656kg/m^3

Making reference to equation (6) above,

$V_{Solid\ Aggregates} = \sum\left(\frac{Weight\ Fraction\ of\ Aggregates}{Specific\ Gravity}\right)$

Total of $V_{Solid\ Aggregates}$ = $\frac{Weight\ Fraction\ of\ Fine\ Aggregates}{Specific\ Gravity\ of\ Fine\ Aggregagte} + \frac{Weight\ Fraction\ of\ Granite}{Specific\ Gravity\ of\ Granite}$

Total of $V_{Solid\ Aggregates} = \frac{0.52}{2.780} + \frac{0.48}{3.016}$

Total of $V_{Solid\ Aggregates}$ = 0.3462kg/m^3

Step-4:

From equation (7)

Aggregate Weight =

$$\left(\frac{Volume\ of\ Aggregate}{Total\ Volume\ of\ Solid}\ X\ Weight\ Fraction\ X\ 1000\right)$$

Weight of Granite (10mm) = $\frac{0.59656}{0.3462}\ x\ 0.52\ x\ 1000$

Weight of Granite (10mm) = 896.04kg/m^3

Weight of Fine Aggregate = $\frac{0.59656}{0.3462}\ x\ 0.48\ x\ 1000$

Weight of Fine Aggregate = 827.11kg/m^3

Step-5:

Since, the volume of coarse and fine aggregate needed has been computed, it is important to calculate the amount of cementious material, super plasticizer and water to be used in each of the mix proportion considering three (3) W/B ratios of 0.25, 0.3 and 0.35 respectively.

At 0.25 W/B ratio.

$\frac{W}{B} = 0.25$

W = 0.25B

Using Super plasticizer of 1.3% (0.013) by weight of cementious material,

Specific gravity of water = 1.0

Specific Gravity of Super plasticizer = 1.06

Table 3
Summary of Aggregate content required for the various Water Binder Ratios and Mix Proportions

Mixes	W/B Ratio	Mix Ratio	Cement content	Fine Aggregate	Coarse Aggregate	Water Content	Super Plasticizer Content
Mix1	0.25	1.0:1.22:1.32:0.25	678.66	827.11	896.04	169.66	8.82
Mix2	0.30	1.0:1.32:1.32:0.30	625.87	827.11	896.04	187.762	8.13
Mix3	0.35	1.0:1.42:1.54:0.35	580.82	827.11	896.04	203.28	7.55

Specific Gravity of cement = 3.01

From equation

Total Paste Content = C+ W+S.P

$$\frac{C}{Specific\ Gravity\ of\ Cement} + \frac{C}{Specific\ Gravity\ of\ Water} + \frac{C}{Specific\ gravity\ of\ S.P}$$

That implies that,

$$\frac{1}{3.01} + \frac{0.25}{1.0} + \frac{0.013}{1.06}$$

Total Paste Volume = 0.59656kg/m^3 (12)

Equating equation (3.8) to (3.12) we have the result below as;

$$\frac{1}{3.01} + \frac{0.25}{1.0} + \frac{0.013}{1.06} = 0.59656C$$

Solving the equation for cement content (C)

$$C = \frac{0.40344}{0.59446}$$

Hence, weight of cement becomes;

$$C = \frac{0.40344}{0.59446}\ x\ 1000$$

C = 678.66kg/m^3

Therefore, from equation (10) the amount of water required is deduced as;

Water Content = 0.25 x 678.66kg/m^3

Water Content = 169.66kg/m^3

Super Plasticizer Content = 1.3% of 678.66kg/m^3

$$\text{Super Plasticizer Content} = \frac{1.3}{100}\ x\ 678.66$$

Super Plasticizer Content = 8.823kg/m^3

The Mix Ratio becomes;

$$\frac{Aggregate}{Cement\ Content}$$

For Cement

$$\frac{678.66}{678.66} = 1.0$$

For Fine Aggregate

$$\frac{827.11}{678.66} = 1.22$$

For Coarse Aggregate

$$\frac{896.04}{678.66} = 1.32$$

Mix ratio then becomes 1:1.22:1.32:0.25

Similarly, for mix2 and Mix3 of 0.3 and 0.35 W/B ratios respectively.

Step-6:

Using A cube mould of 100x100x100mm and a cylinder mould of 150x300mm for compressive and split tensile strength specimens respectively.

For each concrete mix, a total of 9 cubes and 3cylinders would be cast hence, the volume of mould can be computed as shown below.

Volume of 1 cubes for a mix = d x d x d = d^3

Volume of 1 cubes for a mix = 0.1x0.1x0.1

Volume of cubes 1 for a mix = 0.001m^3

Therefore, for 9 concrete cubes we have a volume of 9x10^{-3}

$$\text{Volume of 1 cylinder for a mix} = \frac{\pi d^2}{4} \times H$$

$$\text{Volume of 1 cylinder for a mix} = \frac{\pi \times 0.15^2}{4} \times 0.3$$

Volume of 1 cylinder for a mix = 5.301x10^{-3}

Therefore, for 3 concrete cylinders we have a volume of 0.01590m^3

Volume of concrete for one mix = 9x10^{-3} + 0.01590

Volume of concrete for one mix = 0.0249m^3

Table 4
Proportions of Concrete Constituents for Self-Compacting Concrete

W/B Ratio	Mix Ratio	Variation of Cement and metakaolin CM:MK	Variation of River Sand and Aluminum Dross RS:ALD	Cement (CM) (kg)	Metakaolin (MK) (kg)	Fine Aggregate (RS) (kg)	Aluminum Dross (ALD) (kg)	Coarse Aggregate (Granite) (kg)	Water (l)	Super Plasticizer (l)
0.25	1:1.22:1.32:0.25	100:0	100:0	18.59	0	22.65	0	22.54	4.64	0.24
		85:15	95:5	15.81	2.78	21.52	1.13	22.54	4.64	0.24
		85:15	90:10	15.81	2.78	20.39	2.26	22.54	4.64	0.24
		85:15	85:15	15.81	2.78	19.26	3.39	22.54	4.64	0.24
		85:15	80:20	15.81	2.78	18.13	4.52	22.54	4.64	0.24
		85:15	75:25	15.81	2.78	17.00	5.65	22.54	4.64	0.24
0.30	1:1.32:1.32:0.0.3	100:0	100:0	17.14	2.57	22.65	0	22.54	5.14	0.22
		85:15	95:5	14.57	2.57	21.52	1.13	22.54	5.14	0.22
		85:15	90:10	14.57	2.57	20.39	2.26	22.54	5.14	0.22
		85:15	85:15	14.57	2.57	19.26	3.39	22.54	5.14	0.22
		85:15	80:20	14.57	2.57	18.13	4.52	22.54	5.14	0.22
		85:15	75:25	14.57	2.57	17.00	5.65	22.54	5.14	0.22
0.35	1.0:1.42:1.54:0.35	100:0	100:0	15.90	0	22.65	0	22.54	5.57	0.20
		85:15	95:5	13.52	2.38	21.52	1.13	22.54	5.57	0.20
		85:15	90:10	13.52	2.38	20.39	2.26	22.54	5.57	0.20
		85:15	85:15	13.52	2.38	19.26	3.39	22.54	5.57	0.20
		85:15	80:20	13.52	2.38	18.13	4.52	22.54	5.57	0.20
		85:15	75:25	13.52	2.38	17.00	5.65	22.54	5.57	0.20

Consider 10% void in excess

$\frac{10}{100}\ x\ 0.0249 = 0.000249\text{m}^3$

Total volume of concrete needed for one mix becomes;

Total volume of concrete = 0.02739m^3

Hence,
To convert the amount of each constituent from kg/m^3 required to produce 9 concrete cubes and 3 concrete cylindrical specimens, each constituent will be multiplied by the 0.02739m^3.

Note:
CM = Cement, MK = Metakaolin, ALD = Aluminum Dross, and RS = River Sand

5. Results and discussion

A. Slump Flow Test

The slump flow of trial mixes have been measured and displayed in figure 1. The spread diameter (Slump flow) of ALD self-compacting concrete blended with 15% metakaolin decreased as the percentages of water/binder ratio and aluminium dross increases. The reason is that the water present in the concrete for maintaining workability decreases due to absorption of water over the high specific surface area of metakaolin and aluminium dross. Although all concrete mixes maintain the properties of a self-compacting concrete excluding the concretes produced from 15, 20 and 20% of ALD at 0.30 and 0.35 W/B ratio conveyed diameters of the spread less than the acceptable EFNARC 2005 standard of 650mm to 800mm.

The result observations from this research are in line with preceding findings of Mailar, Gireesh & Naganna (2016) who concluded that the slump flow decreases as the percentages of recycled aluminum dross increased from 0 to 30%.

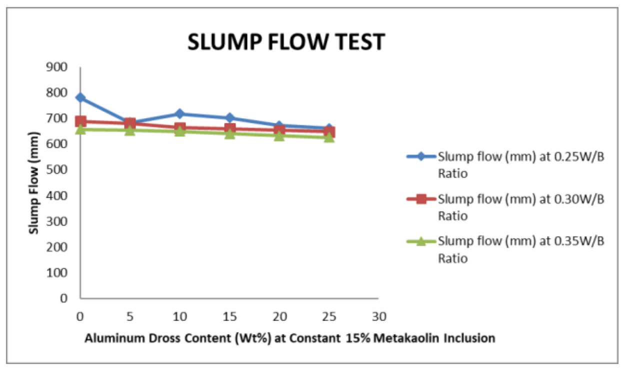

Fig. 1. Slump flow (mm) difference against percentages of Aluminium Dross (ALD) and W/B Ratios

B. J-Ring test

J-Ring test is a medium used to assess the passing ability of a concrete mix through massive reinforcement without separation. Standard J-Ring equipment present in the structures laboratory in the department of civil engineering, Rivers State University made according to BS specifications is used to perform the test. The result from this test is shown in figure 2 below. After the necessary experiment, it illustrated that the diameter of spread for all mixes was reducing as the percentages of ALD increased from 0 to 25%. Also, the time was recorded for the test to deduce the duration of concrete spread. However, all the concrete mixes were within the EFNARC (2005) standard.

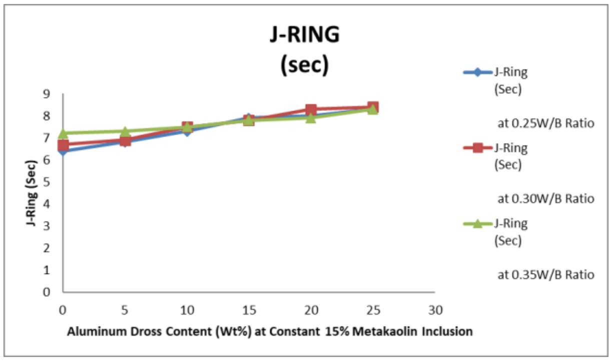

Fig. 2. J-Ring (Sec) differences against percentages of aluminium Dross (ALD) and W/B Ratios

C. V-Funnel Test

V-funnel flow time for each mixture is illustrated in Figure 3 concerning EFNARC (2005). However, V-funnel flow time of combinations showed the almost same trend with T50 slump flow time. Enhancing the Aluminum dross content also systematically increased the V-funnel flow time at all concrete mixtures. The V-funnel flow times deduced from the different concrete mixtures were between 6.2 and 8.5s. Notwithstanding, the results gotten from V-funnel flow times indicated that the produced concrete provides the self-compacting concrete criteria regarding EFNARC (2005). This result is in line with the study of Marie et al. (2007).

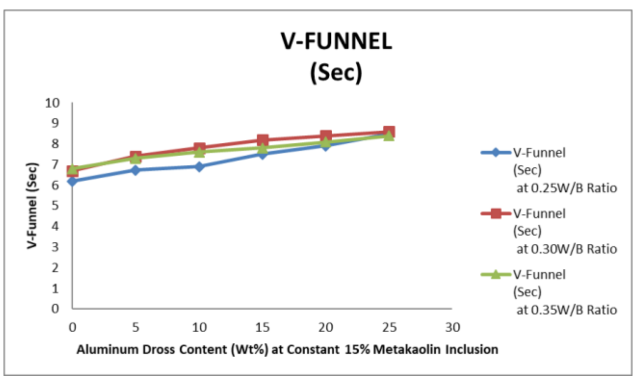

Fig. 3. V-Funnel difference against percentages of aluminium Dross (ALD) and W/B Ratios.

D. L-Box Test

The L-box value is a ratio of h2/h1 ratio. This test was conducted to specify the passing ability of the produced ALD Self-Compacting concrete. The L-box height ratio must be equal to or greater than 0.8 to agree and satisfy that the self-compacting concrete has the required passing ability, as stated in the EFNARC (2005). According to table 4.4 and Fig. 4.7, all mixtures satisfy the EFNARC limitation for the given L-box height ratio. The L-box height ratio value for the control mixture was 0.94, 0.91 and 0.84 or 0.25W/B, 0.30W/B and 0.35W/B ratios respectively. As the percentages of ALD increased from 0 to 25%, the H2/H1 L-Box values decreased.

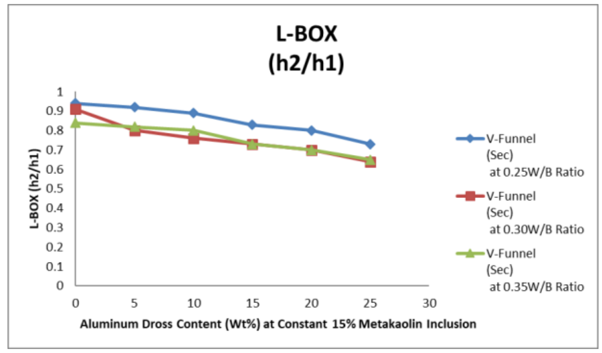

Fig. 4. L-Box (h2/h1) difference against percentages of aluminium Dross (ALD) and W/B Ratios.

E. Density of Concrete

Figure 5 represent the variation of aluminium dross self-compacting concrete densities blended with 15% metakaolin. The results posit that the increase in aluminium dross contents decreases the density of concrete composite. The control mix (0% ALD) had the highest densities of 2800, 2830, and 2600 for 0.25, 0.3 and 0.35W/B Ratios respectively. Effect of aluminium dross was highly noticeable on density, which was due to low specific gravity of the aluminium dross as compared to fine and coarse aggregates.

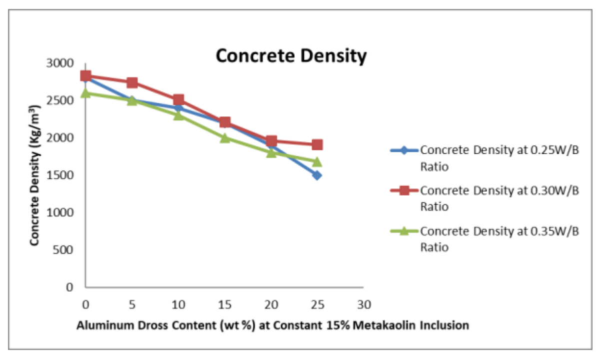

Fig. 5. Variation of Concrete Densities of aluminium Dross SCC blended with Metakaolin Produced with varying W/B Ratio.

F. Water Absorption

The water absorption test was carried out at the age of 28 days as per standard procedure ASTM C642 (2001). The water absorption test was carried out at the age of 28 days in accordance with the standard procedure of ASTM C642 (2001) on the standard test specimen, 100 x 100 x 100 mm concrete cubes produced at different W/B ratios to measure the percentage of water absorption of the concrete.

The effect of aluminium dross and metakaolin content on the water absorption capacity of concrete samples can be discerned in Figure 6. In figure 6, it can be seen that as the aluminium dross content increased from 10 to 25%, permeability values of concrete samples increase proportionally. At 0.25W/B ratio with 5% and 10% aluminium dross and 15% metakaolin incorporation in the concrete, the permeability level reduced. This may be attributed to the metakaolin addition that enhanced the bonding strength of constituents of the concrete as well as reduced the void in the concrete. The finding is in agreement with that of Foti, Dora & Lerna (2019) who studied the mechanical characteristics and water absorption properties of blast-furnace slag concrete with fly ashes or micro silica additions. In their study, it was concluded that the permeability capacity of the concrete reduced compared to the control specimens when blast-furnace slag concretes, fly ashes and micro-silica were added to the concrete.

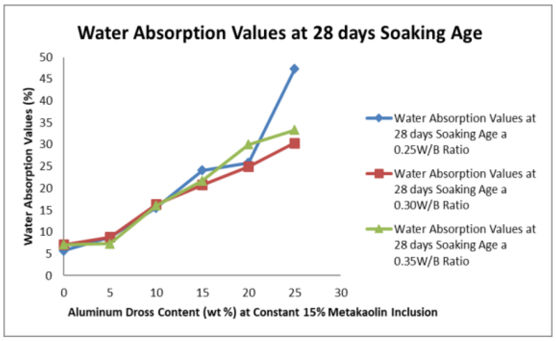

Fig. 6. Variation of 28 days soaking Water Absorption values for Aluminium Dross SCC blended with Metakaolin and W/B Ratio

G. *Comprehensive Strength*

From figure 6, we can see the compressive strength for 0.25 W/B ratio of the Aluminium Dross SCC blended with Metakaolin fluctuate from 29.7, 43.2, 44.7, 33.5, 24.8 and 18.9 Mpa at 0, 5, 10, 15, 20 and 25% Aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at seven (7) days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at seven (7) days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 44.7Mpa noting around 6.8% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 13.1%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin, and it is void filling ability. While the decrease may be as a result of the high amount of aluminium dross present in the concrete, which further reduced the agglomeration between aggregates in the concrete and causing more voids.

Figure 6, shows the compressive strength for 0.30 W/B ratio of the Aluminium Dross SCC blended with Metakaolin changes from 27.4, 37.5, 38.9, 30.4, 20.6 and 16.8 MPa at 0, 5, 10, 15, 20 and 25% Aluminium dross incorporation and 15% metakaolin addition. It can be seen that as the percentages of ALD increased from 5 to 10%, the compressive strength at seven (7) days increased compared to 15, 20 and 25% ALD addition of ALD which further decreased the compressive strength at seven (7) days pure water curing. The maximum increase was recorded at 10% ALD incorporation with a value of 38.9Mpa noting around 4.7% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 13.6%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin, and it is void filling ability while the decrease may be as a result of the high amount of aluminium dross present in the concrete, which further reduced the agglomeration between aggregates in the concrete and causing more voids.

From figure 6, we can see the compressive strength for 0.35 W/B ratio of the aluminium Dross SCC blended with Metakaolin changes from 27.0, 36.4, 38.3, 24.3, 20.2and 15.3 Mpa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It can be seen that as the percentages of ALD increased from 5 to 10%, the compressive strength at 7 days increased compared to 15, 20 and 25% ALD addition of ALD which further decreased the compressive strength at seven (7) days pure water curing. The maximum increase was recorded at 10% ALD incorporation with a value of 38.3Mpa noting around 11.1% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 11.9%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin, and its void filling ability. While, the decrease may be as a result of the high amount of aluminium dross present in the concrete, which further reduced the agglomeration between aggregates in the concrete and causing more voids.

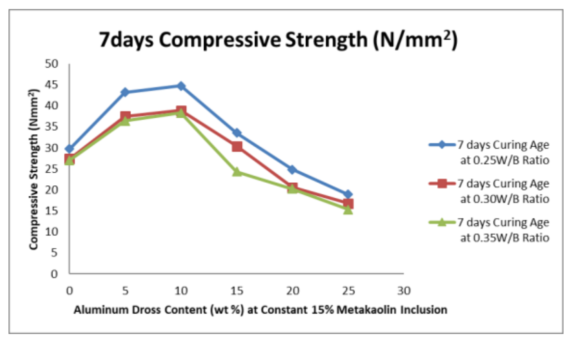

Fig. 7. Variation of 7 days Compressive Strength of Aluminium Dross SCC blended with Metakaolin Produced with varying W/B Ratio

From figure 7, we can see the compressive strength for 0.25 W/B ratio of the aluminium Dross SCC blended with Metakaolin fluctuate from 38.3, 52.4, 53.9, 36.8, 25.49 and 20.7 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 14 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 14 days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 53.9Mpa noting around 12.7% increase in compressive strength. While, the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 20.5%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability. While the decrease may be as a result of the high amount of aluminium dross present in the concrete, which further reduced the agglomeration between aggregates in the concrete and causing more voids.

In figure 7, we can see the compressive strength for 0.30 W/B ratio of the aluminium Dross SCC blended with Metakaolin fluctuate from 34.2, 46.4, 48.9, 32.6, 21.4 and 20.7 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 14 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 14 days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 48.9Mpa noting around 10.6% increase in compressive strength. While, the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 17.6%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability. While, the decrease may be as a result of the high amount of aluminium dross present in the concrete which further reduced the agglomeration between aggregates in the concrete and causing more voids.

From figure 7, we can see the compressive strength for 0.35 W/B ratio of the aluminium Dross SCC blended with Metakaolin fluctuate from 30.6, 43.8, 45.7, 26.4, 22.8 and 19.2 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 14 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 14 days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 45.7Mpa noting around 11.5% increase in compressive strength. While, the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 15%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability. While, the decrease may be as a result of the high amount of aluminium dross present in the concrete which further reduced the agglomeration between aggregates in the concrete and causing more voids.

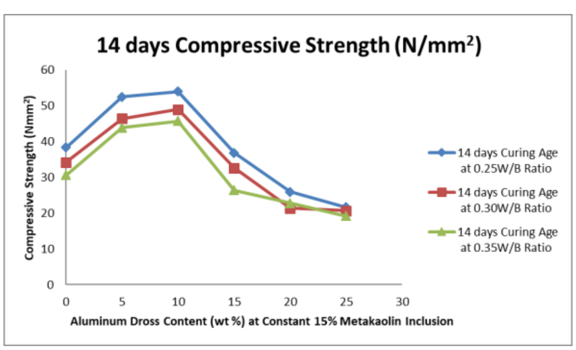

Fig. 8. Variation of 14 days Compressive Strength of aluminium Dross SCC blended with Metakaolin Produced with varying W/B Ratio

Figure 8 shows the compressive strength for 0.25 W/B ratio of the aluminium Dross SCC blended with Metakaolin fluctuate from 43.2, 58.9, 61.2, 44.3, 29.7 and 24.3 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 14 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 14 days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 61.2Mpa noting around 18% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 18.9%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability while the decrease may be as a result of the high amount of aluminium dross present in the concrete which further reduced the agglomeration between aggregates in the concrete and causing more voids.

From figure 8, we can see the compressive strength for 0.30 W/B ratio of the aluminium Dross SCC blended with metakaolin fluctuate from 39.4, 55.2 56.7, 38.9, 23.8 and 23.6 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 14 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 14 days pure water curing. The maximum increase was recorded at 10% ALD inclusion with a value of 56.7Mpa noting around 15.8% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 21.1%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability while the decrease may be as a result of the high amount of aluminium dross present in the concrete, which further reduced the agglomeration between aggregates in the concrete and causing more voids.

From figure 8, we can see the compressive strength for 0.35 W/B ratio of the aluminium Dross SCC blended with Metakaolin fluctuate from 37.6, 49.4, 54.3, 30.1, 26.5 and 22.8 MPa at 0, 5, 10, 15, 20 and 25% aluminium dross incorporation and 15% metakaolin addition. It was observed that as the percentages of ALD increased from 5 to 10%, the compressive strength at 28 days appreciated compared to 15, 20 and 25% ALD inclusion which further reduced the compressive strength at 28 days pure water curing. The maximum increase was recorded at 5% ALD inclusion with a value of 54.3Mpa noting around 16.7% increase in compressive strength. While the maximum decrease in compressive strength was recorded at 25% ALD addition to the concrete with a value of 14.8%. The initial increase in strength is due to the high pozzolanic nature, fineness of the metakaolin and its void filling ability.

While the decrease may be as a result of the high amount of aluminium dross present in the concrete which further reduced the agglomeration between aggregates in the concrete and causing more voids.

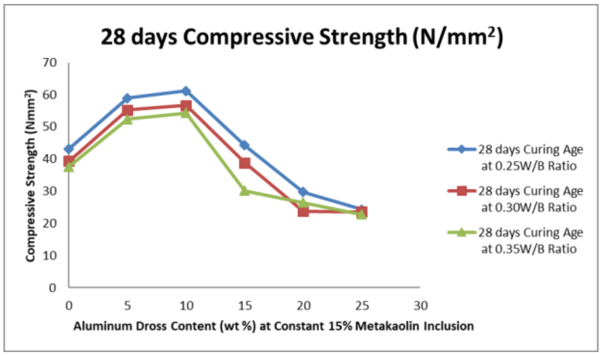

Fig. 9. Variation of 28 days Compressive Strength of Aluminum Dross SCC blended with Metakaolin Produced with varying W/B Ratio

H. Split Tensile Strength

The variations of splitting tensile strength at 28 days with different percentage of aluminium dross with ratio are shown in Figure 9. From the experimental results, it can be observed that the maximum splitting tensile strength is obtained for a mix with 5% replacement of river sand by aluminium dross blended with 15% metakaolin. We can also witness that the splitting tensile strength increases with the increase in ALD content up to 5%; beyond this, the tensile strength decreases gradually. The increase in the tensile strength of the concrete produced by replacing 5% aluminium dross is because of the distinct densification of the concrete caused by the metakaolin. The maximum increase in tensile strength was 2.48N/mm^2 at 0.25W/B ratio.

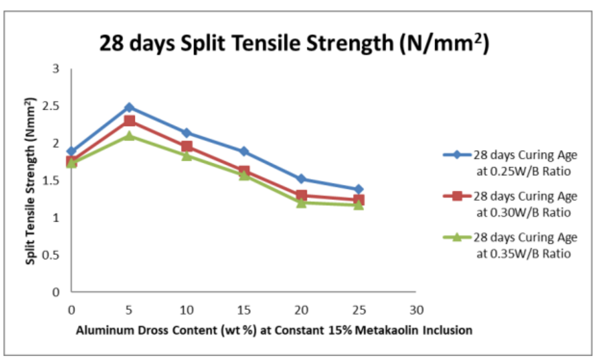

Fig. 10. Variation of 28 days Split Tensile Strength of aluminium Dross SCC blended with Metakaolin Produced with varying W/B Ratio

6. Findings and conclusion

The study was aimed at investigating the suitability of aluminium dross as partial replacement of fine aggregate in self-compacting concrete blended with metakaolin to obtain an economical, durable and environmentally friendly concrete and establish a strength predictive model to forecast compressive and split tensile strength of aluminium dross self-compacting concrete blended with metakaolin using nonlinear regression analysis. A preliminary test was carried out on concrete constituents including; Specific gravity, particle size distribution, and bulk density. Workability tests (Slump flow, J-Ring, V-Funnel, L-Box, and T50 tests) were conducted on fresh concrete while compressive and split tensile strength was carried out on hardened concrete specimen. A total of 162 concrete cubes and 162 concrete cylinders were casted for 1:1.22:1.32:0.25, 1:1.32:1.32:0.30 and 1:1.42:1.54:0.35 concrete mix proportion. All experiments were administered by their acceptable standards.

The following conclusions were drawn from experimental and numerical results;

- The particle parking method for mix design was adopted in the preparation of mixes. This method deals with fewer trial mixes and enhances void elimination, which renders concrete durable by dandifying its microstructure. Through this method of mix design, a compressive and split tensile strength was obtained as 61.2Mpa and 2.48N/mm^2 at 0.25W/B ratio at 10% ALD and 5% ALD respectively as compared to the control mix.
- The preliminary tests conducted on the aluminium dross revealed that it is a lightweight material with a shallow specific gravity of 1.35.
- The water absorption percentage increases as the percentages of ALD increased from 0 to 25%.
- The workability tests (Slump flow, J-Ring, V-Funnel, and L-Box) conducted on fresh concrete produced from 1:1.22:1.32:0.25, 1:1.32:1.32:0.30 and 1:1.42:1.54:0.35 showed that at 0.25W/B ratio, the range of Slump flow, J-Ring, V-Funnel, and L-Box was 661-780 (mm), 6.4-8.3 (Sec), 6.2-8.5 (Sec), and 0.73-0.94 respectively. Also, at 0.3W/B ratio, the range of Slump flow, J-Ring, V-Funnel, and L-Box was 648-689 (mm), 6.7-8.6 (Sec), 6.7-8.6 (Sec), and 0.64-0.91 respectively. Lastly, at 0.35W/B ratio, the range of Slump flow, J-Ring, V-Funnel, and L-Box was 626-658 (mm), 7.2-8.3 (Sec), 6.8-8.4 (Sec), and 0.65-0.84 respectively. About the EFNARC (2005) specification for SCC, we can be dissolved that all mixes flaunt the characteristics of an SCC, which includes; filling ability, resistance to segregation, and passing ability.
- The test conducted on the hardened concrete specimens showed that as the percentages of aluminium dross increased from 5-10%, the compressive and tensile strength increased. Also, the strength of compressive and tensile strength decreased when the proportions of aluminium risen from 15-25%. The maximum compressive and tensile strength was obtained at 0.25W/B ratio (1:1.22:1.32:0.25 mix proportion). The compressive strength was 61.2Mpa at 10% ALD inclusion blended with 15% metakaolin at 28days water curing. While the split tensile strength was 2.48N/mm^2 at 5% ALD addition combined with 15% metakaolin at 28days water curing, a higher level (15-25%) of ALD incorporation in the concrete will cause a reduction in strength properties and density. Also, it will increase the permeability nature of the concrete as a result of glut voids.

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