



## Effects of Shredded Polyethylene Terephthalate (PET) Waste as Partial Substitute for Conventional Fine Aggregates on the Engineering Properties of Concrete

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### Abstract

This work assesses the possibility of using shredded PET waste as partial replacement of conventional fine aggregate in concrete at 0 %, 5 %, 10 %, 15 % and 20 % replacements. The workability, density, water resistance and compressive strength of PET-modified concrete were investigated and compared with a control mix concrete containing 0% PET. These properties were determined according to the recommended British standard codes. Concrete was produced using a mix ratio of 1:2:4 and water-cement ratio of 0.5 which served as the control mix. The slump test results show decreasing slump with addition of PET flakes, with 20% PET content having the least slump of 30mm, implying that addition of PET increases the harshness of concrete. Also, it follows that density of concrete reduces with increasing PET content, with 20% PET showing the lowest density of 2334.81kg/m<sup>3</sup>. However, water absorption test shows decrease in water resistance with addition of PET flakes but 5 % PET gave highest water absorption capacity of 2.15%. On the other hand, compressive strength test assessed at curing ages of 7, 14 and 28 days shows that strength reduces with addition of PET at each curing duration and also, increases with curing duration. Concrete with PET content not higher than 5% yielded compressive strength of 23.6 N/mm<sup>2</sup> at 28 days of curing which is very suitable for structural applications. The study suggests that PET wastes instead of creating environmental problems should be used in concrete production to promote green and sustainable construction.

**Keywords:** Compressive strength; water resistance; workability; concrete; Environment; shredded PET waste fibers.

### 1. Introduction

The high usage of plastic materials all around the world has increased the amount of plastic waste dumped in the environment. This huge quantity of waste plastic can be reduced either by recycling or reuse. Reuse of plastic waste to produce construction materi (Oliveira et al. 2020)). About 9% of this quantity has been recycled while 12% has been incinerated (The Economist n.d.)). In 2023, the annual production of plastic is a staggering 430 million tons, two-thirds of which are short-lived products that soon become waste (Blas 2022). However, Nigeria is ninth among the countries with the biggest contribution to plastic pollution, producing over 2.5 million tons of plastic waste annually. Unfortunately, over 88% of the plastic waste generated in Nigeria is not recycled, instead a lot is disposed in water bodies like rivers, lakes, drains and lagoons (Sogbanmu 2022).

Plastics last for a relatively long period in the environment since they are non-biodegradable and break down very slowly when exposed to typical atmospheric weathering conditions. As a result, problems are encountered in safe disposal of these plastic wastes. The most common methods of disposal are recycling, incineration or in landfills. The ecosystem is impacted by the large volume of plastic waste that is disposed of, as it causes soil contamination through landfilling, marine pollution through ocean dumping and air pollution through open dumping (Mourshed et al. 2017). Moreover, common outcomes of ineffective plastic waste management systems include clogged sewers, flooding, sterility in the soil and water poisoning (Carpenter and Wolverton 2017). The majority of lightweight plastic goods and packaging materials,

which are often used once, make up 50% of all plastics produced (Moore 2025).

Polyethylene terephthalate (PET), is a thermoplastic polymer resin and a member of the polyester family of polymers (Hahladakis and Iacovidou 2018). PET is a transparent, robust and lightweight plastic that is widely used in the food and beverage sector as a packaging material. Its application is significantly increased when the final user's convenience is considered, and it is crucial in packaging food, water and soft drinks. It is also used as fiber for clothing, thermoforming for manufacturing and in combination with glass fiber for engineering resin.

Global output of plastic drinking bottles, or PET bottles, was estimated to be 485 billion in 2016, and it was expected to reach 583.3 billion by 2021 (Statista 2025) . However, an estimated 1 billion plastic bags and PET bottles are produced annually in Nigeria (Kehinde et al. 2020).

Concrete is the most commonly used building material worldwide. It is a non-homogeneous mixture of cement, water, and aggregates, with or without admixtures. When it comes to material consumption, concrete is second only to water in terms of human use (Onyechere et al. 2021). However, the rate of urbanization and development has increased over time, which has resulted in overuse and depletion of natural resources needed to produce concrete (Bhardwaj and Kumar 2017). The aggregates used in concrete production are commonly obtained from processes such as; quarrying and mining of natural resources, which negatively affects the environment and the ecosystem. According to their diameters, these aggregates are separated into two main groups; Coarse

aggregates, which have particle sizes less than or equal to 80 mm but more than 4.75 mm, and Fine aggregates, which have particle sizes less than or equal to 4.75mm (Onyechere et al. 2021). Compressive strength, porosity, density, workability, durability, rate of setting and hardening and other characteristics are crucial for both fresh and hardened concrete but concrete quality is frequently assessed based on the strength (Onyechere 2022). However, a majority of these properties are attributed to the aggregates, which make up between 65% and 80% of any concrete volume (Faraj et al. 2020). The resources from which aggregates are produced are abundant but finite and the absence of viable alternatives has led to overdependence on these conventional aggregates, causing a considerable increase in their prices and in turn, has led to increase in cost of concrete production and execution of construction projects.

Thus, in order to solve the problem of depletion of natural resources and soil erosion caused by over dependence on natural sand as fine aggregates in concrete, there is a continuous search for suitable substitutes for sand in concrete. Kirthika, Singh, and Ajay, (2020), studied the engineering properties of concrete produced using several substitutes for fine aggregates. Mohammed et al., (2024) studied the suitability of some viable alternatives to river sharp sand such as; Recycled bricks fine aggregates, bricks fine aggregates, stone fine aggregates, etc. In their work, they observed that the compressive strength of concrete increases when natural river sharp sand is replaced by stone fine aggregates and bricks fine aggregates. The use of waste glass as substitute for natural river sand in concrete was studied by. In their work, they observed that replacing natural sand with 5 – 10% of crushed waste glass produces concrete with higher workability, durability and strength. Supar et al. (2021) presented a review on the use of waste materials like; rubber ash, sawdust, stone dust, cinder sand, crumb rubber, seashells, copper slag, etc. In their work, they observed that when sand was replaced with stone dust up to 25% and with a combination of seashell and cocoonut fiber up to 50%, the compressive strength increased.

In this research, waste PET bottles instead of creating environmental problems were used to partially substitute the natural river sharp sand as fine aggregates in concrete. This will proffer a lasting solution to the problems of depletion of natural resources, distortion of river eco-system caused by continuous mining of river sharp, soil erosion caused by over dependence on natural sand as fine aggregates in concrete, and the environmental hazards caused by waste PET bottles and hence promote green and sustainable construction.

## 2. Materials and Methods

The basic constituents of concrete and waste PET bottles which constitute the materials used in this work were taken to the Civil Engineering laboratory for the various analysis.

### 2.1 Materials.

The materials used for this research include:

- (i) Potable water.
- (ii) Dangote brand of Ordinary Portland Cement grade 42.5
- (iii) River Sharp Sand as fine aggregates obtained from Otammiri River close to Federal University of Technology, Owerri.
- (iv) Crushed granite as coarse aggregates of 19mm maximum size obtained from a rock quarry site at Ishiagu, Ebonyi State.
- (v) Shredded waste Polyethylene terephthalate (PET) bottles. The waste PET bottles were picked from refuse dumps within the

premises of Federal University of Technology Owerri, thoroughly washed and then taken to the shredding machine.

### 2.2 Methods.

The various laboratory analysis employed in this study are explained in this section.

#### 2.2.1 Sieve Analysis.

This test was done in accordance to the recommendations of (BS 812-103:1995. n.d.). Apparatus for this test includes electronic weighing balance (with accuracy of 0.01g), electric sieve shaker, sieves (with sizes 4.75mm to 31.5mm for coarse aggregate, and 75µm to 4.75mm for fine aggregate), pan, stopwatch. The results from this test for the fine and coarse aggregate and the PET flakes shows that the aggregates were poorly graded. The coefficient of uniformity ( $C_u$ ) and coefficient of curvature ( $C_c$ ) are expressed mathematically as;

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{D_{30}^2}{D_{10}D_{60}} \quad (2)$$

Where  $D_{10}$ ,  $D_{30}$  and  $D_{60}$  are the particle sizes corresponding to 10%, 30% and 60% finer materials on the cumulative particle size distribution curve, respectively. The fineness modulus (F.M) is mathematically defined as:

$$F.M. = \frac{\text{Sum of \% the sample retained}}{100} \quad (3)$$

#### 2.2.2 Casting of Concrete Cubes.

Concrete mixes were prepared using concrete mix ratio of 1:2:4 and water-cement ratio of 0.5. Two concrete cubes were cast for each PET content of 0%, 5%, 10%, 15% and 20% and for each curing duration of 7, 14 and 28 days, yielding a total of thirty (30) concrete cubes, which were cast in 150mm x 150mm x 150mm mould. These cubes were de-moulded after 24 hours and cured by totally submerging them in a water curing tank.

#### 2.2.3: Slump Test

To determine the workability of the concrete, slump test was carried out on each of the concrete batches following specifications of (BS en 12350-2-2019-1 n.d.). A 300 mm height, 200 mm bottom diameter, and 100 mm top diameter slump cone was used for the test. After mixing, the fresh concrete was poured into the cone in three layers, with 30 blows delivered to each layer using a tamping rod. The cone was withdrawn upwards, without any lateral movement and slump obtained by measuring the height difference between the fresh concrete and the cone.

#### 2.2.4: Density of hardened concrete

After curing of concrete cubes, the cubes were brought out of the tank and allowed to dry, and weighed and the mass recorded. The density,  $\rho$  of the hardened concrete is expressed mathematically as:

$$\rho = \frac{M}{V} (Kg/m^3) \quad (4)$$

Where;  $M$  represents the mass of the concrete cube,  $V$  represents the volume of the cube.

#### 2.2.5: Water Absorption Test

This test was done following specifications of (BS 1881: Part 122: 1983). By deducting the sample's original weight before curing

(M1) from its end weight after curing (M2) and dividing the result by the sample's starting weight, the water absorption (W.A.) was calculated, implying that the water absorption of concrete is reported as a percentage of the sample's starting or original weight. Concrete is said to be more water-resistant and long-lasting when it has lower water absorption rate. Water absorption (W.A.) is expressed mathematically as:

$$W.A. = \frac{M_2 - M_1}{M_1} \times 100 \quad (5)$$

2.2.6: Compressive Strength Test

The compressive strength test was done following specifications of (BS EN 12390-3 2022) using a 1000KN universal testing machine. The test was carried out after curing ages of 7, 14 and 28 days for each percentage of PET content. The sample, after being placed on the test machine, was subjected to gradually applied load without shock until failure occurred. The load at failure was read off and compressive strength computed by dividing the failure load (P) by the area of the cube (A).

$$\sigma = \frac{P}{A} \quad (6)$$

The results of Equation 6 are presented in Tables 6, 7, and 8.

3.0 Result and Discussion

In this section is contained the results of the various laboratory analysis carried out in this work and their discussions.

3.1 Sieve Analysis Results.

Table 1: Sieve Analysis Test Results of River Sand

Sieve Size (mm)	Ws (g)	Wsa (g)	Mr (g)	CmR (g)	CpR (%)	CpP (%)
4.000	546.81	553.30	6.49	6.49	1.27	98.73
2.360	535.68	549.30	13.62	20.11	3.92	96.08
1.180	365.46	442.04	76.58	96.69	18.85	81.15
0.600	359.28	506.60	147.32	244.01	47.56	52.44
0.300	343.28	558.60	215.32	459.33	89.53	10.47
0.150	339.02	385.28	46.26	505.59	98.55	1.45
0.075	337.39	339.40	2.01	507.60	98.94	1.06
Pan	299.02	304.46	5.44	513.04	100.00	0.00

Weight of sample = 513.04g

Legend: Ws = Weight of Sieve; Wsa = Weight Sieve+sample; Mr = Mass retained; CmR = Cumulative mass retained; CpR = Cumulative Percentage retained; CpP = Cumulative percentage passing.

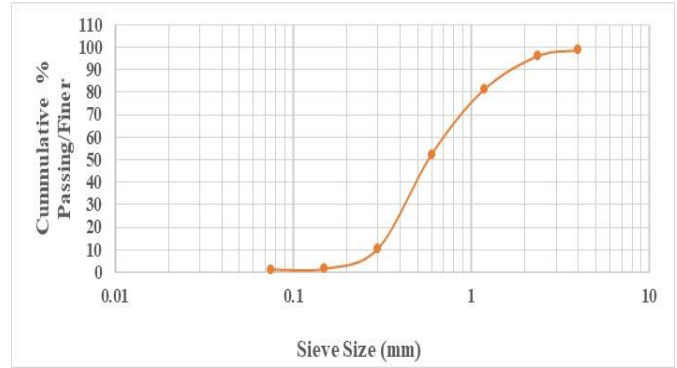


Figure 1: Particle Size Distribution Curve of River Sand

D10 = 0.292 mm, D30 = 0.440mm and D60 = 0.753mm

From equations 3.1 and 3.2, Cc and Cu for river sand are obtained as; Coefficient of Curvature, Cc = 2.580, Coefficient of Uniformity, Cu = 0.880 and from equation 3.3, F.M = 3.58

Table 2: Sieve Analysis Test Results of Granite

Ss (mm)	Ws (g)	Wsa (g)	Mr (g)	CmR (g)	CpR (%)	CpP (%)
19	800.00	960.0	160.0	160.0	16.0	84.0
16	780.00	780.0	160.0	320.0	32.0	68.0
13.2	770.00	770.0	210.0	530.0	53.0	47.0
12.5	780.00	880.0	100.0	630.0	63.0	37.0
11.2	840.00	990.0	150.0	780.0	78.0	22.0
9.5	700.00	800.0	100.0	880.0	88.0	12.0
6.3	720.00	840.0	120.0	1000.0	100.0	0.0
Pan	299.41	299.4	0.0	1000.0	100.0	0.0

Weight of Sample = 1000g

Legend: Ss = Sieve Size; Ws = Weight of Sieve; Wsa = Weight Sieve+sample; Mr = Mass retained; CmR = Cumulative mass retained; CpR = Cumulative Percentage retained; CpP = Cumulative percentage passing.

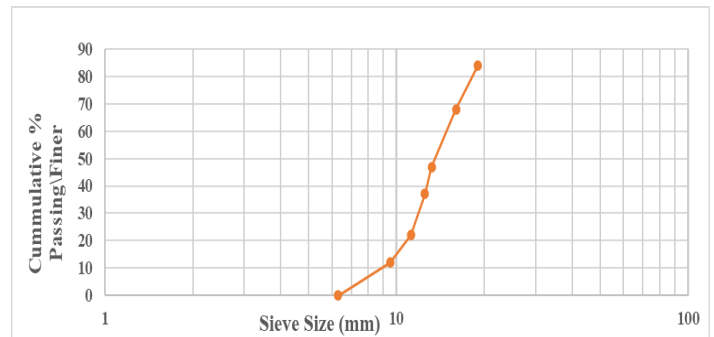


Figure 2 Particle Size Distribution Curve of Granite

D60 = 14.93, D30 = 11.89, D10 = 8.97

From Equations 1 and 2, Cc and Cu for granite are obtained as; Coefficient of Curvature, Cc = 1.66 and Coefficient of Uniformity, Cu = 1.06

Table 3 Sieve Analysis Test Results of PET Flakes

Ss (mm)	Ws (g)	Wsa (g)	Mr (g)	CmR (g)	CpR (%)	CpP (%)
4.000	547.54	591.02	43.48	43.48	17.39	82.61
2.360	536.38	688.70	152.32	195.80	78.32	21.68
1.180	365.96	415.94	49.98	245.78	98.31	1.69
0.600	359.74	362.27	2.53	248.31	99.32	0.68
0.300	343.70	344.48	0.78	249.09	99.64	0.36
0.150	339.63	340.01	0.38	249.47	99.79	0.21
0.075	337.63	337.76	0.13	249.60	99.84	0.16
Pan	299.41	299.81	0.40	250.00	100.00	0.0

Weight of Sample = 250g

Legend: Ss = Sieve Size; Ws = Weight of Sieve; Wsa = Weight Sieve+sample; Mr = Mass retained; CmR = Cumulative mass retained; CpR = Cumulative Percentage retained; CpP = Cumulative percentage passing.

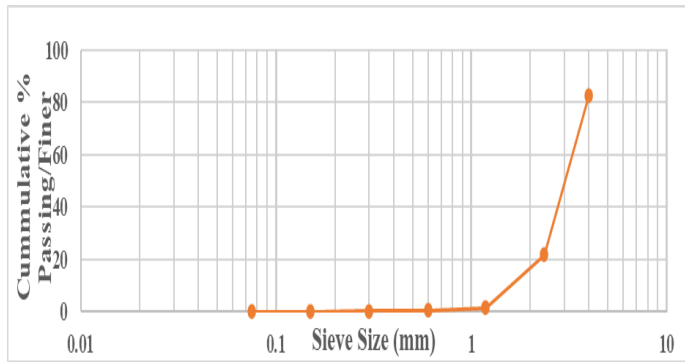


Figure 3 Particle Size Distribution Curve of PET Flakes  
D60 = 3.39, D30 = 2.58, D10 = 1.67

From equations 1 and 2, Cc and Cu for PET flakes are obtained as; Coefficient of Curvature, Cc = 2.03 and Coefficient of Uniformity, Cu = 1.18

Tables 1, 2 and 3, shows the results of sieve analysis, and from these results, it can be deduced that the river sand, granite and PET flakes are poorly graded on the basis of their coefficient of uniformity and coefficient of curvature, according to BS 882:1992, (1992), although the gradation curve of the fine aggregate may indicate a well-graded soil. Figures 1, 2 and 3, shows the gradation curve of river sand, granite and PET flakes, respectively.

3.2 Slump Test Results

Table 4: Slump Test Results of Concrete Samples

%PET	0	5	10	15	20
Slump (mm)	85	65	55	40	35

Table 4: shows the results of the slump test of the concrete samples for the different percentages of PET content. Table 4 shows decrease in workability with increase in the amount of PET present in the concrete. This result is in line with the findings of Al-Luhybi and Qader (2021). The reduced slump of concrete with addition of PET flakes is because of the rough and angular edges of the flakes which inhibits the flow of the concrete.

3.3: Density Results

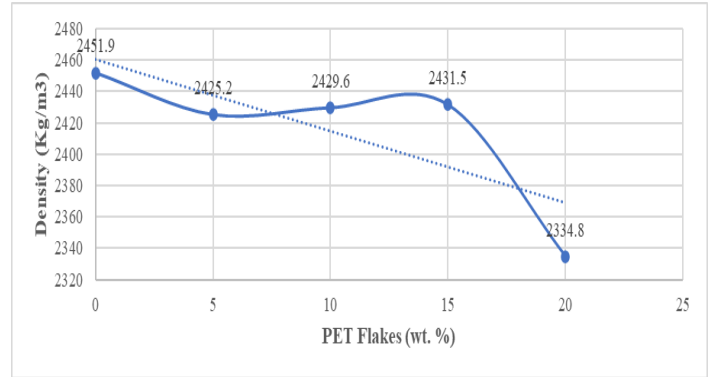


Figure 4: Variation of Density for different PET Content

The variation of density against PET content is shown in Figure 4. The trend of the graph shows a reduction in density with increase in percentage PET content. 0% PET content gives a density of 2451.9kg/m3 and this reduces to value of 2425.2kg/m3 at 5% PET. However, the density increases gradually to 2429.6kg/m3 and 2431.5kg/m3 at 10% and 15% PET content respectively and then decreases abruptly to a value of 2334.81kg/m3 at 20% PET content. These results are in line with the findings of Black (2020). The reduced density with increase in PET content is predicted to be due to the weight of PET being less than that of river sand.

3.4 Water Absorption Test Results

Table 5 shows the test results and the variation of water absorption of the concrete samples for the different PET content. At 0% PET content the table shows a water absorption of 1.27% and spikes to 2.15% at 5% PET. The value of water absorption reduces to 1.5% at 10% PET content and increases gradually to value of 2.03% at 20% PET content.

Table 5: Water Absorption Test Results of Concrete Samples.

PET (%)	0	5	10	15	20
M <sub>2</sub> (Kg)	8.38	8.36	8.32	8.58	8.04
M <sub>1</sub> (Kg)	8.28	8.19	8.20	8.42	7.88
Water Absorption	1.27	2.15	1.50	1.85	2.03
W.A. (%)					

Legend: Wa = Water absorption; M<sub>1</sub> = Mass of specimen before curing; M<sub>2</sub> = Mass of specimen after curing

3.5 Compressive Strength Results

Table 6 Compressive Strength Test of Concrete Samples at 7 days Curing age.

PET (%)	0	5	10	15	20
Crushing Load (KN)	326.25	285.75	302.00	225.00	184.50
Compressive Strength (MPa)	14.50	12.70	13.42	10.00	8.20

Table 7. Compressive Strength Test of Concrete Samples at 14 days Curing age.

PET (%)	0	5	10	15	20
Crushing Load (KN)	488.70	495.00	443.70	354.60	229.50
Compressive Strength (MPa)	21.70	22.00	19.72	15.74	10.20

Table 8. Compressive Strength Test of Concrete Samples at 28 days Curing age

PET (%)	0	5	10	15	20
Crushing Load (KN)	549.00	531.00	398.70	364.50	320.40
Compressive Strength (MPa)	24.40	23.60	17.72	16.20	14.24

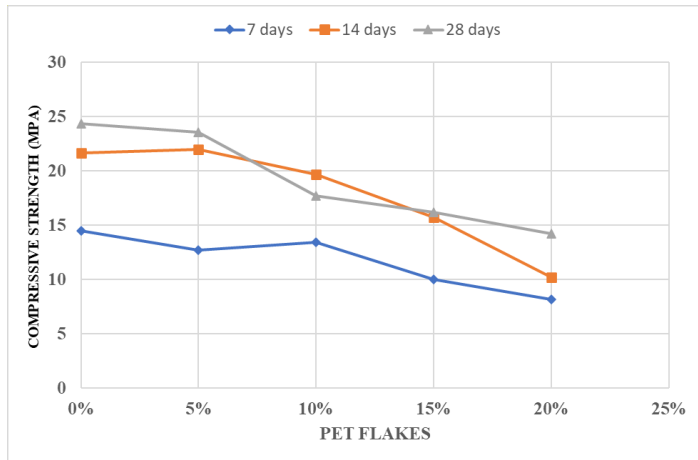


Figure 5: Variation of Compressive Strength for different PET Content at varying Curing ages.

The variation of compressive strength for different PET content at curing ages of 7, 14 and 28 days is shown in Tables 6, 7 and 8 and in Figure 5. For each curing duration, the results indicate decrease in compressive strength with increase in the percentage of PET content and a relative increase in compressive strength with increase in curing duration. At 7 days curing age, concrete of 0 % PET content gives a compressive strength of 14.5MPa, which reduces gradually to 12.70 MPa at 5% PET and increases to 13.42 MPa at 10 % PET content. However, compressive strength drops to a value of 10 MPa at 15 % PET and further decreases to 8.20 MPa at 20 % PET. The trend of compressive strength against PET content is similar for 14 and 28 days curing ages. However, at 28

days, concrete containing 0 % PET gave a compressive strength of 24.4 MPa and reduces gradually to 23.60 MPa, 19.72 MPa, 16.2 MPa and finally to 14.24 MPa at 5 %, 10 %, 15 % and 20 % PET content, respectively. Furthermore, at 14 days curing age, concrete of 0 % PET content gave a compressive strength of 21.7 MPa, increasing to a value of 22 MPa at 5 % PET content and drops to 10.2 MPa at 20 % PET. These results are in accordance with the findings of Lasiyal et al. (2016) as well as Mastan and Asadi (2017). The reduction in strength with increase in PET content is reported to be due to reduction in adhesion or binding forces between cement and the aggregates with addition of PET.

**4.0. Conclusion**

Based on the data obtained from the series of laboratory test carried out, deductions can be made on the workability, water absorption, density and compressive strength of PET-modified concrete. The following conclusions were made from the results obtained:

- i. Addition of PET flakes decreases the workability of concrete. This implies that concrete containing high PET content are more suitable for concrete sections with medium or moderate reinforcement like in casting of damp proof courses (DPC) reinforced with BRC mesh.
- ii. Incorporation of PET flakes in concrete did not improve the water resistance or waterproofing properties of concrete. As a result, concrete containing high PET content is not suitable for structures frequently exposed to water because the rebar within this concrete will corrode due to water intake, causing failure.
- iii. The use of PET flakes in concrete helps to reduce the weight and density of the concrete. concrete containing 20 % PET content yielded the least density of 2334.81kg/m<sup>3</sup>. This means that PET modified concrete can be used in the construction of building elements such as in-situ or precast roof fascia and precast partition walls because of its low density and weight, assisting in reducing the load on a structure.
- iv. Concrete containing up to 5% waste PET in place of natural river sand can be used in constructing normal load-bearing concrete structures. Higher content of PET in place of natural sand is only recommended for concrete structural elements bearing lower loads such as; lintels, pedestrian walkways, roof parapets, pavements, etc. Addition of waste PET in concrete negatively impacts the strength of concrete but concrete containing not higher than 5% PET gives compressive strength most suitable for structural applications.

**Declaration Statement.**

The authors hereby declare that this work is original and that they all agree to publish this work in SEET Engineering and Technology Journal.

**Conflict of Interest.**

There is no conflict of interest.

**Authors Contributions.**

(1) I. C. Onyechere; Conceptualized the study, supervised the work and wrote the original and revised draft of the manuscript (2) L. U. Ezeamaku; Developed the methodology and supervised the work.

(3) U. P. Okoro; Analyzed the data, discussed the results and wrote the original draft of the manuscript. (4) B. O. Anyachie; Conducted the laboratory experiment and collected the data. (5) N. S. M. Ogbonna; Edited the work and interpreted the results. (6) O. C. Ukachukwu; Internal review and result interpretation.

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### Influence of Metakaolin on the Engineering Properties of Self-Compacting Concrete.

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#### Abstract

This research studied the effects of Metakaolin pozzolan on the engineering properties of self-compacting concrete (SCC) in which Complast sp40 was used as a superplasticizer. Laboratory tests were conducted on the Metakaolin and the aggregates to determine their properties. Different fine aggregate / coarse aggregate (FA/CA) mix proportions for SCC with a target strength of 35 N/mm<sup>2</sup> were used to produce concrete cube specimens of sizes 150mm x 150mm x 150mm by mixing the aggregates, water, complast sp40 and partially replacing cement with 0%, 5%, 10%, and 15% metakaolin. The fresh concrete for each batch was tested for workability using slump test. The concrete cubes prepared were cured in water for 28, 60 and 90 days, after which the density and the compressive strength of the hardened concrete were determined. The slump test results showed a decrease in the workability of fresh concrete as the percentage Metakaolin increases. The results showed a reduction in the density of concrete as Metakaolin content in concrete increases. It was observed from the results that the compressive strength of the concrete increases as the curing age increased from 28 to 90 days. Aggregate proportioning significantly impacted strength, with optimal fine aggregate to coarse aggregate (FA/CA) ratios of 0.45/0.55 yielding the highest strength for all curing ages. 10% Metakaolin replacement level exhibited the highest strength compared to 5% and 15% replacement levels.

**Keywords:** Compressive strength; Self-compacting concrete; Metakaolin, Pozzolan; Aggregates.

#### 1. Introduction

Concrete is probably the most widely used material in the construction of infrastructures in the world (Anyu et.al., 2024). Also, modern Civil Engineering construction tends to progress towards more economic, design and construction of structures through gradually improved methods of design and the use of higher strength materials (Gana and Okoye, 2015). One constituent of concrete that determines its strength is coarse aggregate, which takes about 50 and 60 percent of the concrete volume depending on the mix proportion adopted (Onyechere et.al., 2021). Several studies and research have been done and are still in progress on the effect of aggregate shape, type and size on the strength properties of concrete (Eme and Nwaobakata 2019). Structures constructed with normal-strength concrete mostly fail in compression by separation of the aggregates when excessive load is exerted on them, but in high-strength concrete structures, there is higher bonding force between the aggregates and the binding agent so that under the action of very high compressive loads, the structure does not fail.

Self-compacting concrete (SCC) being a high-performance concrete has the ability to flow under the influence its self-weight to fill the form without segregating even in a concrete section with congested reinforcements and compacts itself without the help of a mechanical vibrator. Concrete of such a model enhances its placement and compaction, thus reducing the labour cost for placement, compaction, reducing the environmental pollution caused during concreting and producing hardened concrete with

better finishes. SCC is recommended for mass concreting and while casting concrete in sections with some restrictions and insufficient work area for compaction hence, enabling the engineer to sufficiently satisfy the specifications of a given project. The main features of SCC include; ability of the fresh concrete to flow easily under its own weight in sections with highly congested reinforcements without requiring vibration and being able to maintain the uninformed homogenous nature of the concrete without segregation. To successfully produce a self-compacting concrete, water reducers are employed to lower the yield stress to a level to accommodate the free-flowing features of the concrete, thereby striking a balance between yield stress and the flowability of the concrete paste (Shetty, 2005). Aggregate gradation is a very important part of concrete production hence the need to combine coarse aggregate with fine aggregate in its simplest form. An improperly graded aggregate structure can have undesirable effects on the properties of concrete as it can produce weak, stiff or porous concrete (Ukala, 2019). The techniques employed in the batching of self-compacting concrete include using less portions of coarse aggregates and using larger portions of fillers or employing concrete admixtures to modify the viscosity of the concrete produced so as to easily fill the formworks without segregation and sufficiently compact itself without requiring any mechanical compactor (Promsawat et.al. 2020). Among the several important factors that influence the proportions of the constituents of a concrete mixture is the grading of the aggregate. It is well known

that aggregate grading directly influences concrete mix proportions and that satisfactory concrete can be produced with aggregates whose grading does not fall entirely within normal specifications or conform to typical grading curves. In developing countries, such aggregates are often the only ones locally available or within economic distance, and the concrete manufacturer has no choice but to select the most suitable mix proportions. Since more than one-third of concrete volume is occupied by coarse aggregate, variations in the proportioning of coarse aggregates will affect the strength and shear properties of the concrete (Rozalija and Darwin 1997).

According to Dinakar, Pradosh and Sriram (2013), From the previous studies, it can be noted that concrete strength depends upon the water-cement ratio and the materials used that are used other than the conventional materials such as cement, fine aggregate, coarse aggregate, and water (Li et.al., 2020). Most studies are basically on aggregate gradation effect on workability with little focus on the extensive influence of alternating the fine and coarse aggregate proportion.

Furthermore, the manufacturing of high-strength and performance concrete is somewhat different from conventional concrete preparation by utilizing additional materials such as mineral and chemical admixtures and use of techniques like re-vibration and seeding (Samimi et.al., (2017). Supplementary materials such as mineral admixtures or burnt ash or calcined kaolin etc. are added. For maintaining such quality in the HPC and HSC, many pieces of research are carrying out throughout the world (Priya, and Raja, 2021).

On the other hand, Among the components of concrete, the aggregate accounts for approximately 60–70% of the total volume of concrete; thus, it has a significant impact on concrete properties. In general, concrete aggregate can be classified as fine aggregate (FA) or coarse aggregate (CA). The workability and mechanical properties of concrete vary depending on the physical properties and mix proportions of the different aggregates. In some regions, three or more types of aggregates are used because of the quality characteristics of the aggregates produced in those regions. As the number of aggregates used in a concrete-mix increases, the influences of each aggregate on the properties of the concrete become increasingly complicated. Therefore, to optimize the basic properties of concrete, including workability and strength, significant attention needs to be paid to the proportions of aggregates used in the concrete mix (Lee, et.al, 2021).

In general, the properties of an aggregate that affect the strength of concrete include the strength, shape, surface texture, maximum size, and particle size of the aggregate (Alexander and Mindess, 2005). It is notable that the compressive strength of concrete depends on the water-to-cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate (Rocco and Elices, 2009). Concrete can be visualized as a multi-phase composite material made up of three phases; namely the mortar, mortar/aggregate interface, and the coarse aggregate phase. The coarse aggregate in normal concrete are mainly from rock fragments characterized by high strength. The aggregate interface is not a limiting factor governing the strength requirement (Beshr, Almusallam, and Maslehuddin 2003). The onset of failure is manifested by crack growth in the concrete. For normal concrete the crack growth is mainly around the cement paste or at the aggregate/cement paste interfacial zone. The strength of concrete

at the interfacial zone essentially depends on the integrity of the cement paste and the proportioning of the aggregate.

The main constituents of SCC include; coarse aggregates (mainly within size range of 10 – 20mm, though sometimes, bigger sizes could be used if the reinforcements in the sections are not congested), fine aggregates (containing more of fines), Ordinary Portland Cement (grade 43 – 53), Potable water, chemical admixtures (superplasticizers are used to contribute the required workability and viscosity of the fresh concrete without segregation) and mineral admixtures which enhances the quality of the concrete and makes the concrete more durable (Shetty, 2005).

Therefore, this research studied the effects of Metakaolin pozzolan on the engineering properties of self-compacting concrete produced using a chemical admixture (Complast sp40) as a superplasticizer. The Kaolin was obtained from a natural deposit and then converted to Metakaolin by calcining the kaolin within a temperature range of 4000C to 8000C under a controlled supply of oxygen.

## 2. Materials and Methods

The Kaolin was obtained from a natural deposit and first raised to a temperature of about 4000C, thereafter, it was grinded and was heated further continuously to a temperature of 8000C using logs of piled up woods in a furnace for about nine to ten hours. The fine calcinated kaolin was placed inside a stainless-steel basin and the top was covered with another second stainless-steel basin. An infrared thermometer was used to monitor the temperature of the heated calcinated kaolin, the colour of the calcinated kaolin was observed to change from white to a cementitious colour at 800 degrees Celsius. Heating was stopped and the calcinated kaolin was allowed to gradually cool to room temperature.

Sieve analysis was carried out on both the fine and coarse aggregates used, in accordance with the recommendations of BS 812: Part103.1:1985 to determine their grain size distribution. Specific Gravity and Bulk Density tests were conducted on the aggregates following the recommendations of ASTM C127-07, 2007.

The physical properties of the Metakaolin were determined using the procedures prescribed by ASTM C618-15, (2015). X-ray diffraction method was used for the chemical analysis of the Metakaolin to determine its chemical compositions.

Concrete mixes were prepared for concrete grade 35 using the various combinations of different proportions of coarse aggregate (CA) and fine aggregate (FA) shown in Table 1. Where; “C” designates control samples at 0% Metakaolin, “N1” designates samples at 5% replacement of cement with Metakaolin, “N2” designates samples at 10% replacement of cement with Metakaolin, and “N3” designates samples at 15% replacement of cement with Metakaolin.

**Table 1: Mix Combination at Different aggregate volume ratios**

MN	W/C	C	Aggregate volume ratio			FA ratio	CA ratio
			Total VA	CA	FA		
C <sub>11</sub>	0.65	1	0.704	0.4020	0.3020	0.65	0.55
C <sub>12</sub>	0.65	1	0.704	0.4020	0.3020	0.60	0.40
C <sub>13</sub>	0.65	1	0.704	0.4020	0.3020	0.55	0.45
C <sub>14</sub>	0.65	1	0.704	0.4020	0.3020	0.50	0.50
C <sub>15</sub>	0.65	1	0.704	0.4020	0.3020	0.45	0.55
N <sub>11</sub>	0.64	1	0.716	0.4654	0.2506	0.65	0.55
N <sub>12</sub>	0.64	1	0.716	0.4654	0.2506	0.60	0.40

N <sub>13</sub>	0.64	1	0.716	0.4654	0.2506	0.55	0.45
N <sub>14</sub>	0.64	1	0.716	0.4654	0.2506	0.50	0.50
N <sub>15</sub>	0.64	1	0.716	0.4654	0.2506	0.45	0.55
N <sub>21</sub>	0.63	1	0.719	0.4674	0.2517	0.65	0.55
N <sub>22</sub>	0.63	1	0.719	0.4674	0.2517	0.60	0.40
N <sub>23</sub>	0.63	1	0.719	0.4674	0.2517	0.55	0.45
N <sub>24</sub>	0.63	1	0.719	0.4674	0.2517	0.50	0.50
N <sub>25</sub>	0.63	1	0.719	0.4674	0.2517	0.45	0.55
N <sub>31</sub>	0.61	1	0.725	0.4713	0.2538	0.65	0.55
N <sub>32</sub>	0.61	1	0.725	0.4713	0.2538	0.60	0.40
N <sub>33</sub>	0.61	1	0.725	0.4713	0.2538	0.55	0.45
N <sub>34</sub>	0.61	1	0.725	0.4713	0.2538	0.50	0.50
N <sub>35</sub>	0.61	1	0.725	0.4713	0.2538	0.45	0.55

Legend: MN = Mix number; W/C = Water/Cement ratio; VA = Volume of Aggregate; CA = Coarse Aggregate; FA = Fine Aggregate; C = Cement.

For each fresh concrete mix, slump test was conducted according to the procedures outlined in BS 1881: Part 102: (1983), to determine the workability of the concrete. Also for each concrete mix, concrete cubes of size 150x 150 x 150 mm<sup>3</sup> were prepared for compressive strength test in accordance to the guidelines enshrined in BS 1881: Part 108: (1983). After 24 hours of casting, the cubes were demoulded and cured by immersion in water for a period of 28 days, 60 days and 90 days. After curing, the cubes were brought out of water, and air-dried. Thereafter, the density of the concrete were determined in accordance to the recommendations of BS 1881: Part 114: (1983). The density is thus given by the expression;

$$\rho = \frac{Mass(kg)}{Volume(M^3)} \quad (1)$$

The cubes thereafter were tested for compressive strength using a 2000KN Universal Testing Machine adopting the procedures enshrined in BS 1881: Part 115, (1983). The compressive strength (CS) is given as;

$$CS = \frac{Crushing\ Load(N)}{Cross - sectional\ Area(mm^2)} \quad (2)$$

### 3.0 Result and Discussion

The results for the research work are presented in this section for both material characterization and the engineering properties of concrete.

Table 2: Summary of Physical Characteristics of Sample Material

Description/ Material	Fine Agg.	Coarse Agg.	Metakaolin (MK)	Cement (OPC)
Bulk Density (g/cm <sup>3</sup> )	0.299		0.547	1.116
Specific Gravity	2.650	2.705	2.064	3.150
Fineness Modulus (%)	2.90	-	3.60	2.00
Aggregate Impact Value (%)	-	8.0	-	-

A critical study of the physical properties of the concrete materials (aggregates, cement and Metakaolin) shown in Table 2 reveals that

both the bulk densities and specific gravities of the Metakaolin used are less than those of OPC, this implies that the concrete produced with Metakaolin will be of lighter weight, this will thus, reduce the self-weight of a superstructure produced with this concrete and hence, requiring less cost for construction of foundations to carry the superstructure. The specific gravity of the fine aggregate used agreed with the typical value 2.65 for natural sand (Shetty, 2005).

Table 3: Results of the Sieve Analysis of Fine Aggregate

Sieve size (mm)	Retained mass (gm)	%Retained (%)	Cumulative percentage retained (%)	Passed percentage (%)
4.750	6.50	1.30	1.30	98.70
2.360	13.80	2.76	4.06	95.94
1.180	44.30	8.86	12.96	87.08
0.600	92.20	18.44	31.36	68.64
0.425	100.00	20.00	51.36	48.64
0.150	221.40	44.28	95.64	4.36
0.075	17.10	3.42	99.06	0.94
PAN	4.70	0.94	100.00	0.00

Table 4: Results of the Sieve Analysis of Coarse Aggregate

Sieve size (mm)	Retained mass (g)	Mass Retained (%)	Cumulative percentage retained (%)	Percentage Passing (%)
25.00	836.3	55.75	55.75	44.25
19.00	531.4	35.43	91.18	8.82
9.50	112.5	8.17	99.34	0.66
4.75	9.8	0.66	100.00	0.00
Pan	0.0	0.00	0.00	0.00

From the Tables, it is observed that the grading results for both the fine and coarse aggregates complies with to the recommendations of BS 882 for heavy duty concrete.

Table 5: Chemical composition of the Metakaolin

S/N	Chemical Component	Mass %
1	SiO <sub>2</sub>	59.11
2	Al <sub>2</sub> O <sub>3</sub>	16.18
3	Fe <sub>2</sub> O <sub>3</sub>	6.82
4	CaO	1.44
5	MgO	1.43
6	K <sub>2</sub> O	1.53

The results of the Metakaolin with respect to chemical composition in Table 5 shows the sum of the percentage composition of the major oxides [Silica (SiO<sub>2</sub>), Aluminum Oxide (Al<sub>2</sub>O<sub>3</sub>), Iron (III)

oxide (Fe<sub>2</sub>O<sub>3</sub>) and Potassium Oxide (K<sub>2</sub>O)] for Metakaolin to be 84.26% which is above the stipulated minimum index of 70% as reported by Ettu et al. (2016), to be minimum percentage for a perfect pozzolan. Also, the combined sum of the percentages of the Silica (SiO<sub>2</sub>), Aluminum Oxide (Al<sub>2</sub>O<sub>3</sub>) and Iron oxide (Fe<sub>2</sub>O<sub>3</sub>) is 82.11%, this value is far above the minimum value of 70% prescribed for pozzolan by ASTM C618-06. This higher pozzolan index can be attributed to the suitability of the mineral deposit as well as quality of calcining and milling to fine powder process. Thus, the calcined kaolin used in this research is a satisfactory pozzolan.

Table 6: Slump Test Result

% Metakaolin replaced	Slump of concrete (mm)
0%MK	89
5% MK	70
10% MK	68
15% MK	60

A critical study of Table 6 reveals that as the Metakaolin content in concrete increases, the workability of concrete reduces. Thus, Metakaolin is recommended in concrete mixes that requires less workability. Also, when Metakaolin – cement blended concrete are to be used in concrete sections with congested reinforcements, superplasticizers are required to enhance the workability of the concrete produced.

Table 7: Density of Concrete After 90 Days Curing (Kg/m<sup>3</sup>)

FA/CA	Density of Concrete after Curing in Water (Kg/m <sup>3</sup> )				
	0.65/0.35	0.60/0.40	0.55/0.45	0.50/0.50	0.45/0.55
% MK	5	40	45	0	.55
0	2320.97	2364.44	2350.05	2313.74	2302.4
5	2305.84	2363.93	2348.72	2223.10	2291.0
10	2304.52	2352.99	2344.97	2222.92	2278.6
15	2289.66	2348.64	2323.81	2219.75	2272.9

From Table 7, it is evident that density of concrete reduces as the Metakaolin content in the concrete increases. This is further supported by the fact that Metakaolin has lower bulk density and lower specific gravity than cement.

Table 8: Compressive Strength of Concrete at 28 Days Curing Period.

FA/CA	Compressive Strength at 28 days (N/mm <sup>2</sup> )				
	0.65/0.35	0.60/0.40	0.55/0.45	0.50/0.50	0.45/0.55
% MK	0	5	10	15	
0	38.67	38.67	40.34	40.96	42.30
5	38.12	38.67	40.74	41.56	42.00
10	39.30	39.85	42.30	42.00	42.59
15	38.81	39.19	35.41	40.89	41.26

Table 9: Compressive Strength of Concrete at at 60 Days Curing Period.

FA/CA	Compressive Strength at 60 days (N/mm <sup>2</sup> )				
	0.65/0.35	0.60/0.40	0.55/0.45	0.50/0.50	0.45/0.55
% MK	0	5	10	15	
0	39.85	39.85	41.93	41.56	43.11
5	39.26	39.70	41.69	42.52	43.01
10	40.52	42.31	43.33	43.41	44.89
15	39.26	39.70	40.37	41.33	42.00

FA/CA	0.65/0.35	0.60/0.40	0.55/0.45	0.50/0.50	0.45/0.55
% MK	0	5	10	15	
0	38.89	38.89	40.74	41.33	42.59
5	38.37	38.96	41.26	42.15	42.44
10	39.93	40.58	43.04	42.22	43.26
15	38.96	39.48	40.13	41.33	41.63

Table 10: Compressive Strength of Concrete at 90 Days Curing Period.

FA/CA	Compressive Strength at 60 days (N/mm <sup>2</sup> )				
	0.65/0.35	0.60/0.40	0.55/0.45	0.50/0.50	0.45/0.55
% MK	0	5	10	15	
0	39.85	39.85	41.93	41.56	43.11
5	39.26	39.70	41.69	42.52	43.01
10	40.52	42.31	43.33	43.41	44.89
15	39.26	39.70	40.37	41.33	42.00

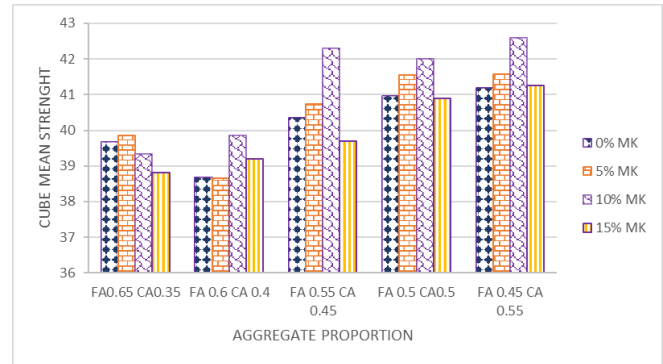


Figure 1: Compressive Strength of Concrete after 28 days of curing for all percentages of cement replacement.

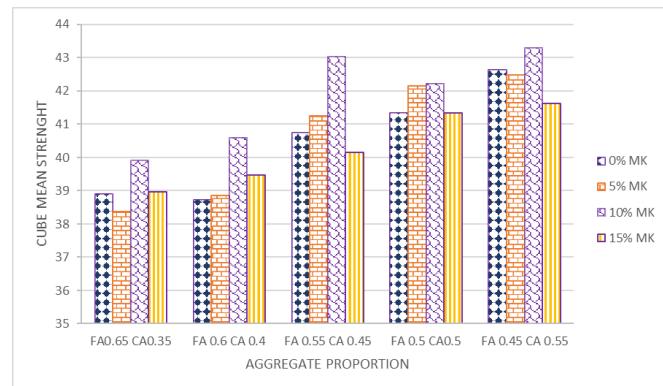
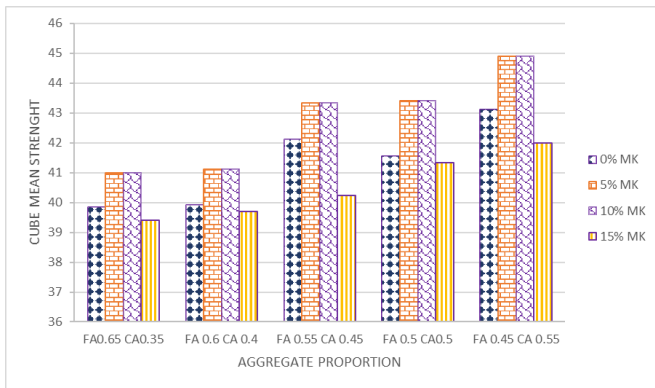


Figure 2: Compressive Strength of Concrete after 60 days of curing for all percentages of cement replacement.



**Figure 3: Compressive Strength of Concrete after 90 days of curing for all percentages of cement replacement.**

From the results presented in Tables 8 – 10 and Figures 1 - 3, it is observed that the compressive strength of the samples with 100% Ordinary Portland Cement and super plasticizer with 0% Metakaolin pozzolan meets and exceeded the stipulated designed cube mean of 35 N/mm<sup>2</sup> thus validating the mix design used in this research. It is observed that for all the curing ages and for all the percentage replacement of OPC with Metakaolin, the Fine aggregate / Coarse aggregate (FA / CA) proportioning of 0.45 / 0.55 produced concrete with the highest compressive strengths. This shows that increase in the proportion of coarse aggregate in a concrete mix increases the compressive strength of the concrete produced. Furthermore, as OPC was replaced with the Metakaolin pozzolan up to 5%, the compressive strength reduces minimally but increases rapidly beyond 5% with a maximum strength recorded at 10% replacement of OPC with Metakaolin pozzolan, as more cement was replaced with the pozzolan up to 15%, the strength improvement for all proportion of FA to CA ceased progressing. Thus, for all the curing ages and FA/CA proportioning considered, concrete produced with 10% Metakaolin replacement with OPC yielded the highest compressive strength even greater than the compressive strength of the control mix (concrete made with 100% OPC). This shows that from this research, 10% replacement is the optimum percentage for replacement of OPC with Metakaolin. Also, as the curing age increases, the compressive strength of the concrete produced increases. For all the curing ages and FA/CA proportioning considered, 90 days curing age produced the highest compressive strength.

### Conclusion.

From the results of the laboratory analysis carried out in this research, it was observed that metakaolin has a high pozzolanic index. Also increase in metakaolin content in concrete leads to increase in the workability and decrease in the density of the concrete produced, this is because, metakaolin has a lower bulk density and specific gravity than cement. For all the curing ages and all the percentage replacement of OPC with Metakaolin, the Fine aggregate / Coarse aggregate (FA / CA) ratio of 0.45 / 0.55 produced concrete with the highest compressive strength. It was observed from the study that metakaolin can replace Ordinary Portland Cement in Concrete up to 10% for optimum results.

From the results of the various laboratory analysis conducted in this research, the following conclusions can be drawn. Results of chemical analysis of Metakaolin show that Metakaolin has a high pozzolanic index. Increase in Metakaolin content in concrete leads to decrease in the workability of the concrete produced. As the Metakaolin content in concrete increases, the density of the concrete produced reduces. This is so because, Metakaolin has a lower bulk density and specific gravity than cement.

For all the curing ages and all the percentage replacement of OPC with Metakaolin, the Fine aggregate / Coarse aggregate (FA / CA) ratio of 0.45 / 0.55 produced concrete with the highest compressive strengths.

Metakaolin can be used to substitute Ordinary Portland Cement up to 10% for optimum results.

### Declaration Statement.

The authors hereby declare that this work is original and that they all agree to publish this work in SEET Engineering and Technology Journal.

### Conflict of Interest.

There is no conflict of interest.

### Authors Contributions.

(1) J. C. Ezeh; Conceptualized the study and supervised the work. (2) O.M Ibearugbulem; Developed the methodology and supervised the work. (3) I. C. Onyechere; Analyzed the data, discussed the results and wrote the original draft of the manuscript. (4) C. D. Okolie; Conducted the laboratory experiment and collected the data. (5) A. U. Igbojiaku; Edited the work and interpreted the results.

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