

# Effects of Sesame Straw Ash as a Substitute for Cement on Strength Characteristics of Concrete

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## ORIGINAL RESEARCH ARTICLE

**Abstract-** Concrete is broadly used as a building material across the globe, and its use is raising the need of cement in the construction industries. High price of cement and environmental debasement are the driving problems forcing the researchers to come up with alternative materials from large volumes of agricultural wastes as a partial replacement for cement. This study aims at recycling agricultural waste ash (i.e. Sesame straw ash) as a substitute for cement in the production of sustainable and environmentally friendly greener concrete. Preliminary tests on constituent materials were conducted in order to find out their physical properties. Influences of sesame straw ash (SSA) on cement paste were looked into for addition of 0, 5, 10, 15, 20 and 25 % by weight of cement. The Compressive and flexural strengths as well as the slump of concrete made with different portions of SSA (i.e., 0 – 25 %) were investigated. A 100 mm cubes and 100 mm X 100 mm X 450 mm beams of SSA-concrete were tested for compressive and flexural strengths at 3, 7, 28, 56 and 90 days of curing in line with procedure outlined in BS 1881-116: (1983) and BS 1881-118: (1983) respectively. The outcomes of the workability test show that as the portion of SSA increases the workability a fresh concrete decreases, but consistency, setting times, and soundness of SSA-cement paste increase as the portion of SSA increases. However, the strengths of SSA-concrete increase as the duration of curing increases, and decrease as the portion of SSA increases. It was detected that the strength of concrete produced with 10 % SSA content was beyond the designed strength of 20 N/mm<sup>2</sup> at 28 days of curing. In addition, the densities of SSA-concrete samples fall within the limits of 2200 kg/m<sup>3</sup> to 2600 kg/m<sup>3</sup>. Finally, it was concluded that the maximum amount of SSA to be used should not exceed 10 % replacement in concrete production.

**Keywords-** Sesame straw ash, Cement, workability, compressive strength, flexural strength and concrete.

## 1 INTRODUCTION

Agricultural waste materials are increasingly being used as an alternative for cement in concrete and mortar with a view of improving the properties of concrete or mortar and reduce the usage of cement in the formation of mortar or concrete as well as reducing the environmental impact. High inflation in the prices of cement in many of the growing countries has contributed to a step-up in the cost of building and other civil engineering works. To cut down the cost of cement, buildings and civil engineering works to a low-cost rate, lots of studies were targeted towards usage of low-priced and local materials such as wastes from the agricultural and industrial sector as an alternative for cement in infrastructure construction (Ogork and Ayuba 2014).

The use of supplementary cementing materials (SCM) in concrete is very essential where there is a demand to modify the characteristics of concrete. The selection to assess the use of Sesame straw ash (SSA) and rice husk ash (RHA) as cementing materials in the concrete formation with the view of enhancing the farmers' economic standard by employing the waste materials as a less expensive alternative to that of normal admixtures, with a view of reducing the cost of buildings and other civil engineering construction and a way of dealing the environmental pollution made by the assemblage of uncontrollable waste.

However, there is few available studies or literatures on the use of Sesame straw ash (SSA) in concrete, but related literatures on the use of agricultural wastes ashes are also reported. A study conducted by Orame *et al.*, (2020) claimed that Sesame plant Mucilage (SPM) has a combined SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> composition of 25.58 %. The results of their findings showed that at 28 days of curing, concrete made with different percentages of Sesame mucilage have higher compressive strength than the control mix with 33.2 N/mm<sup>2</sup>, 31. N/mm<sup>2</sup>, and 30.8 N/mm<sup>2</sup> for 1.0 %, 1.5 %, and 2.0 % Sesame mucilage content respectively. They concluded that the addition of sesame mucilage content increased flexural and split tensile strength and their values obtained are more than that of the control specimen at all curing periods.

According to a study carried out on the effect of adding Sesame stalks fibre (SSF) to the concrete mixture by Elmardi *et al.*, (2021) claimed that the strengths of SSF-concrete decreased as the percentage of sesame stalks fibre (SSF) increased, however, the addition of (SSF) increases the concrete resistance against crack growth. Sulaiman *et al.*, (2020) stated that addition of sesame straw ash (SSA) decreased the flow and compressive strength of mortar. On the other hand, the soundness, setting times, and consistency of SSA-cement paste were enhanced when various portions of SSA were added. The compressive strength of SSA-mortar was enhanced as the curing period increased. Sulaiman *et al.*, (2020) claimed that incorporating GSA-SDA decreases the workability of concrete but increases the setting times and soundness GSA-SDA-cement paste. Moreover, the compressive strength of concrete was enhanced as the curing age increased, it also increases up to 10 % at 28 days of curing and then decreases when percentage of GSA-SDA increases. They concluded that the maximum percentage

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of GSA-SDA to be used should not be more than 10%.

Ndububa and Aburime (2021) stated that incorporation of Guinea corn husk ash (GCHA) as an alternative for cement does not enhance the flexural strength of concrete. They concluded that GCHA had a high silica content that makes it to be a high grade pozzolana. Ettu *et al.*, (2016) reported that incorporating RHA and SDA as alternatives for cement in the formation of concrete decreased the split tensile strength of concrete. They concluded that RHA-SDA can be utilised as an alternative material for cement in reinforced and unreinforced concrete works where time of loading is not critical. According to Abubakar (2018), it is seen from the literature that the optimum replacement level of RHA with cement is about 10 – 20 % and with a longer curing duration, as there is a sharp decline in mechanical properties beyond this level. The addition of rice husk ash (RHA) beyond 7 % declined the workability (Adinna *et al.*, 2019). Hassan *et al.*, (2020) discovered that flexural and compressive strengths of mortar were delayed at early periods of 2 days and 7 days when Plantain peel ash (PPA) was added as an admixture. They concluded that the maximum percentage to be used should not be more than 1.0 %.

Research performed by Lawan *et al.*, (2020) shows the highest strength of concrete was detected to be 40.2 N/mm<sup>2</sup> and 46.02 N/mm<sup>2</sup> at 28 days and 120 days of curing and 2 % nanoparticles and 15 % Metakaolin respectively. Ogork *et al.*, (2015) looked into the influence of GHA mixed with rice husk ash in concrete, the results revealed that GHA is less reactive than RHA with summation of Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub>, as 26.06 % and 80.33 % respectively. Ofuyatan *et al.*, (2018) worked on assessment of strength characteristics of cassava peel ash (CPA) and their findings showed that the compressive strength, and its resistance and durability to sulphuric acid have been enhanced at 10 % replacement. They concluded that cassava peel ash (CPA) can be used for the formation of light concrete especially when durability is the main concern. According to Gunduz and Kalkan, (2019) the usage of RHA has drastically enhanced the strength of mortar at the 20% substitute level at the curing age of 90 days. The objective of this research study is to evaluate the influence of sesame straw ash as a substitute for cement in concrete.

## 2 MATERIALS AND METHODS

### 2.1 MATERIALS

#### 2.1.1 Cement

The Portland limestone cement (PLC) used was Dangote BlocMaster, grade: 42.5R, having a moisture content of 1.81 % and specific gravity of 3.16.

#### 2.1.2 Fine Aggregate

The fine aggregate used was obtained from Zaria Local Government Area, Kaduna State, Nigeria, with a silt content of 2 %.

#### 2.1.3 Coarse Aggregate

The coarse aggregate used was obtained from Samaru Zaria, Kaduna State, Nigeria. It has a specific gravity of 2.68 and bulk density of 1425 kg/m<sup>3</sup>.

#### 2.1.4 Sesame Straw Ash

The Sesame straw ash (SSA) used was obtained by burning the sesame straw (SS) sourced from Jigawa State, Nigeria. The straw was obtained after removing the sesame seed from sesame plant. SSA has a moisture content of 1.95 %, a specific gravity of 2.69, and an LOI of 0.3 %.

#### 2.1.5 Water

The water used was potable, sourced from Department of Civil Engineering laboratory of ABU, Zaria, Kaduna State, Nigeria.

### 2.2 METHODS

#### 2.2.1 Tests on Physical Properties Constituent Materials

The specific gravity, fineness and moisture content tests of cement, SSA, fine and coarse aggregate were carried out according to BS 812, Part 2, (1975), BS EN 196-6:2005 and BS EN 1097-5:2008 respectively. While crushing and impact value tests were also conducted on coarse aggregate according to their respective standard presented in Table 4 respectively.

#### 2.2.2 Consistency, Setting Times, and Soundness Test of SSA-Cement Paste

The setting times, consistency and soundness tests conducted on SSA-cement paste were in conformity with BS EN 196-3 (1995).

#### 2.2.3 Mix Proportions and Concreting for SSA-Concrete

The mix proportions used are highlighted in Table 1. Design of Experimental (DOE) method was used to calculate the concrete mix proportions for grade 20 concrete. The mixing of concrete was done according to BS 1881-125:1986. While the batching was carried out by weight.

Table 1. Mix Proportion of SSA-Concrete

Mix	Cement (kg/m <sup>3</sup> )	SSA (kg/m <sup>3</sup> )	Fine Aggregate (kg/m <sup>3</sup> )	Coarse Aggregate (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	W/C
T0	320	0	723	1231	176	0.55
T5	304	16	723	1231	176	0.55
T10	288	32	723	1231	176	0.55
T15	272	48	723	1231	176	0.55
T20	256	64	723	1231	176	0.55
T25	240	80	723	1231	176	0.55

#### 2.2.4 Slump of Fresh Concrete

The slump test performed on fresh concrete was carried out in accordance with BS 1881:102 (1983).

#### 2.2.5 Compressive Strength of SSA-Concrete

The strength test on SSA- concrete was conducted in accordance with BS 1881-116: (1983). Concrete samples were cast and cured in potable water, and a total of 3 cubes were considered for an average for each curing regime 3, 7, 28, 56 and 90 days using the Avery-Denison Universal testing machine.

#### 2.2.6 Flexural Strength of SSA-Concrete

The flexural strength test on SSA-concrete beams was conducted according to BS 1881-118: (1983). Beams were

cast and cured in water, and 3 samples were tested for a mean for each curing regime 3, 7, 28, 56, and 90 days using the Avery-Denison universal testing machine. The flexural strength of concrete was calculated using the equation (1).

$$f_b = \frac{1.5 PL}{b^3} \tag{1}$$

Where:  $f_b$ = flexural strength of concrete (N/mm<sup>2</sup>),  $b$  = cross sectional dimension,  $L$  = prism span,  $P$  = failure load

### 3 RESULTS AND DISCUSSIONS

#### 3.1 PHYSICAL CHARACTERISTICS OF CEMENT AND SSA

The results of physical characteristics (i.e., specific gravity, moisture content, fineness, loss on ignition) of cement and SSA were presented in Table 2. It has been noticed that the specific gravity of cement is 3.16 greater 3.12 obtained by Mohammed *et al.*, (2022) and SSA had a specific gravity of 2.69 which less than 2.1 obtained by Sulaiman *et al.*, (2020). It was observed that the SSA has the lowest LOI of 0.3 % which is much lower than that of Cement with LOI of 1.89 %. The results of LOI for all the samples fall within the acceptable not more than 10 % as highlighted by ASTM C618 for Class N pozzolana.

Table 2. Physical Characteristics of Cement and SSA

Property	Cement	SSA
Specific Gravity	3.16	2.69
Moisture Content (%)	1.81	1.95
Fineness (% passing B.S sieve 100 $\mu$ m)	98.5	96.4
Loss on Ignition (LOI) (%)	1.89	0.3
Colour	Dark Grey	Light Grey

#### 3.2 OXIDE COMPOSITION OF CEMENT AND SSA

The results of the XRF test performed on cement, SSA are displayed in Table 3. The oxide composition of SSA indicates that the sum total of aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), iron oxide (Fe<sub>2</sub>O<sub>3</sub>) and silicon oxide (SiO<sub>2</sub>) is 28.92 % which is less than the lower limit of 70 % specified by ASTM C 618 for pozzolana. The CaO content of 45.42 % in SSA shows that it possesses some cementing characteristics.

Table 3. Oxide Composition of Cement, SSA and RHA

Oxide	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	SO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	Cl	BaO	K <sub>2</sub> O	CaO	TiO <sub>2</sub>	Cr <sub>2</sub> O <sub>3</sub>
Cement (%)	0.18	1.05	2.83	21.43	1.42	-	-	0.01	0.62	68.02	0.17	-
SSA (%)	1.08	3.55	1.82	20.83	2.52	6.96	1.01	-	8.02	45.42	1.47	0.01

Oxide	Mn <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	ZnO	V <sub>2</sub> O <sub>5</sub>	SrO
Cement (%)	0.03	2.77	0.39	0.02	-
SSA (%)	0.15	6.27	0.37	-	0.49

#### 3.3 PHYSICAL CHARACTERISTICS OF FINE AGGREGATE AND COARSE AGGREGATE

The results of the physical characteristics of fine aggregate and coarse aggregate are presented in Table 4. It was observed that all the values obtained are within the acceptable limit as specified by their standard codes as presented in Table 4. This shows that the materials are fit for usage in the production of concrete.

Table 4. Physical Characteristics of Coarse Aggregate and fine aggregate

Property	Fine Aggregate	Coarse Aggregate	Limits	Standard Code
Specific Gravity	2.72	2.68	2.6 – 2.9	ASTM C136 (1978)
Bulk Density (kg/m <sup>3</sup> )	1737	1425	1200 – 1750	ASTM C29
Aggregate Crushing Value (ACV) %	-	33.61	≤ 45	BS 882 (1992)
Aggregate Impact Value (AIV) %	-	23.81	≤ 45	BS 882 (1992)
Water Absorption (%)	2.56	0.89	-	-
Silt Content (%)	2	-	< 6	BS 882 (1992)

#### 3.4 SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

The results of particle size distributions of fine and coarse aggregates are displayed in Figure 1. It was observed that the fine aggregate used belongs to zone 1 in line with BS 882 (1992) for grading limits for fine aggregate. The fine aggregate has a silt content of 2 which is less than the maximum of 6.0 and specific gravity of 2.72. While the coarse aggregate used has a bulk density of 1425 kg/m<sup>3</sup> and specific gravity of 2.68. It was noticed that the coarse aggregate was well-graded. This proves that the fine aggregate (sand) and coarse aggregate can be used in the production of concrete.

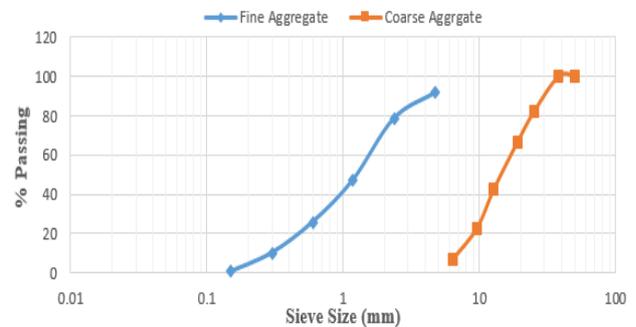


Fig. 1: Particle Size Distribution of Fine and Coarse Aggregates

#### 3.5 CONSISTENCY OF SSA-CEMENT PASTE

The result of the consistency test carried out on SSA-cement paste is demonstrated in Figure 2. It was discovered that as the amount of SSA increased the value of consistency increased. This trend shows that SSA-cement paste required more water to get the desired consistency as the additional amount of SSA was added. The increment in water requirement may be due to the high porosity of SSA when compared to cement, the findings are consistent with the work of (Sulaiman and Aliyu 2020; Sulaiman *et al.*, 2020). This might also be owing to a lower specific gravity of SSA and RHA compared to Cement (PLC).

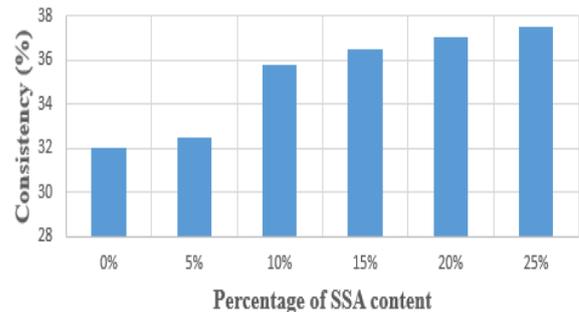


Fig. 2: Relationship between Consistency and percentage of SSA Content

### 3.6 SETTING TIMES OF SSA-CEMENT PASTE

The relationship between the initial setting and final setting time of SSA-cement paste as a portion of SSA is presented in Figure 3. It was discovered that the initial setting time and final setting time went up as the portion of SSA stepped up. Thus, the increment might be because of the presence of potassium oxide that impedes the complete combination of lime and causes setting negative influence on the setting, consistent with (Sulaiman *et al.*, 2020). The slowdown in the setting time might be ascribed to the reduction in the amount of C3S in the paste (Abubakar, 2018).

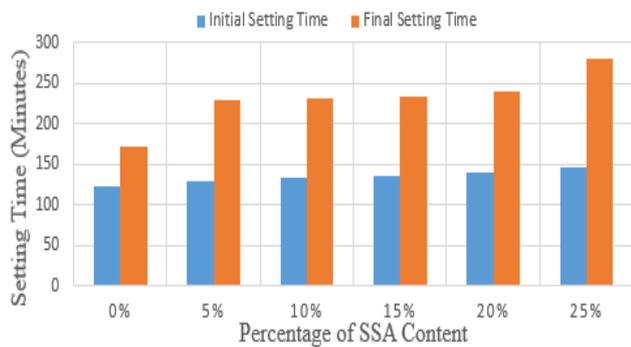


Fig. 3: Relationship between Setting Times and percentage of SSA Content

### 3.7 SOUNDNESS OF SSA-CEMENT PASTE

The results of the soundness test performed on SSA-cement paste were demonstrated in Figure 4. It disclosed that the soundness of SSA-cement pastes ballooned as the percentage of SSA increased. However, all the values found at each level of replacement (i.e., from 0.1 mm to 3.4 mm) were within the acceptable limits as highlighted by BS EN 196-3 (1995) justified that cement is good if its soundness value spans from 0 - 10 mm and not sound beyond 10 mm. The same pattern was observed by (Sulaiman and Aliyu, 2020).

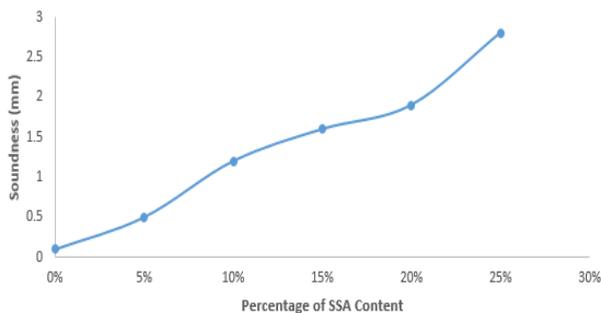


Fig. 4: Relationship between Setting Times and percentage of SSA Content

### 3.8 SLUMP OF FRESH SSA-CONCRETE

The results of slump carried out on fresh SSA-concrete with different proportions of SSA i.e., 0%, 10 %, 15 %, 20 %, 25 % and 30 % were presented in Figure 5. The outcomes of the slump test revealed that the slump values decreased as the portions of SSA increased. This depicted that as the quantity of SSA increases the less workable the fresh concrete becomes. This behaviour affirms that SSA absorbs water then the cement and it is in agreement with the result of the consistency test conducted on SSA-cement paste. The highest value of slump was detected to

be 23 mm at 0 % of SSA content while the lowest was 3 mm at 25 % of SSA. The decrement in a slump maybe because of the higher surface area of SSA this explanation is in line with Sulaiman *et al.*, (2020). It may also be imputed to the fact that the density of the SSA is lower than that of cement and the finer of the particle size. Similar behaviour was reported by Sulaiman and Aliyu (2020).

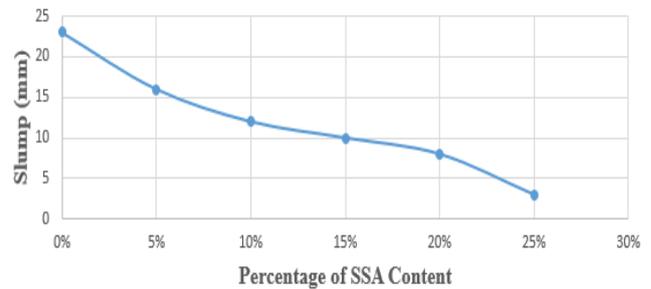


Fig. 5: Relationship between Slump and percentage of SSA Content

### 3.9 COMPRESSIVE STRENGTH OF SSA-CONCRETE

The strength of concrete is the most crucial characteristics of concrete, and it is the property that is mostly employed for the design of structural concrete. The results of the strength of SSA-concrete were demonstrated in Figure 6. It has been discovered that the strength of SSA-concrete diminishes as the portion of SSA raises. The highest value of the strength found was 27.4 N/mm<sup>2</sup> at 0 % SSA and 90 days of curing, while the lowest value was recorded as 8.57 N/mm<sup>2</sup> at 25 % and 3 days of curing in fresh potable water. From another point of view, the strength of SSA-concrete increases as the curing period escalates. However, it was noticed that at 28 days of curing, the strength of concrete made with 10 % SSA overstepped the target design strength of 20 N/mm<sup>2</sup>. However, the cut down in the strength of concrete as the portion of SSA increased maybe as a result of the cut down in the quantity of cement for the hydration (Sulaiman *et al.*, 2020). The establishment of C-S-H gel because of the pozzolanic response of SSA is less strong than that of cement hydration and this behaviour led to the cut down in the strength of concrete having 5 % SSA and above. It may also be due to the dilution consequences of cement (Sulaiman *et al.*, 2020; Ogork and Ayuba 2014). Finally, the increment in compressive strength as the curing span went up is because of the hydration of cement and SSA.

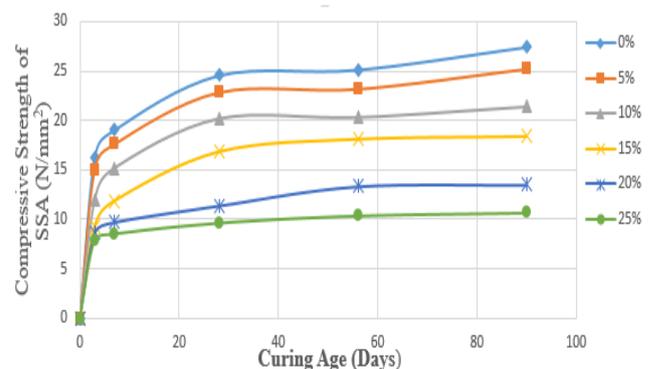


Fig. 6: Relationship between Compressive Strength and Curing Age

### 3.10 FLEXURAL STRENGTH OF SSA-CONCRETE

The results flexural strength of concrete produced with various percentages of SSA content are depicted in Figure 7. It has been noticed that the strength of concrete produced with various percentages of SSA declined as the percentage of SSA content increased, and it increases as the curing age increases. It has been discovered that the flexural strength of concrete recorded spanned from 3.9 N/mm<sup>2</sup> at 0 % SSA and 90 days of curing to 1.70 N/mm<sup>2</sup> at 25 % SSA and 3 days of curing. The raising in the strength of concrete as the curing span raised was because of the cement hydration and the pozzolanic reaction of SSA, consistent with the explanation given by Ogork and Uche (2014). The decline in flexural strength with an increase in the portion of SSA might be owing to the reaction mechanism of SSA, in which the influence of dilution of cement and less strength development from the pozzolanic reaction was responsible for the cut down in strength (Sulaiman *et al.*, 2020). However, Ettu *et al.*, (2021) reported a similar pattern.

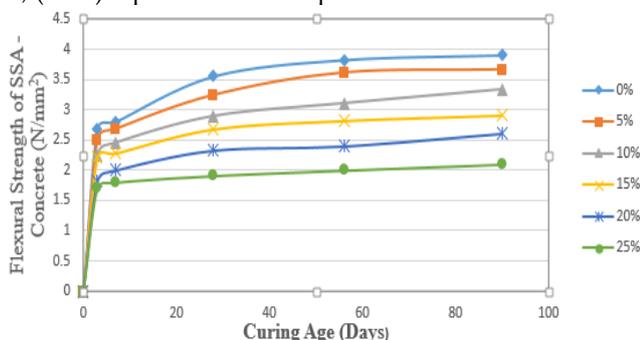


Fig. 7: Relationship between Flexural Strength and Curing Age

### 3.11 DENSITY OF SSA-CONCRETE

The densities of concrete produced with different portions of SSA as a substitute for cement are shown in Figure 8. It shows that all the densities of SSA-concrete fall within the limits of 2200 kg/m<sup>3</sup> to 2600 kg/m<sup>3</sup>.

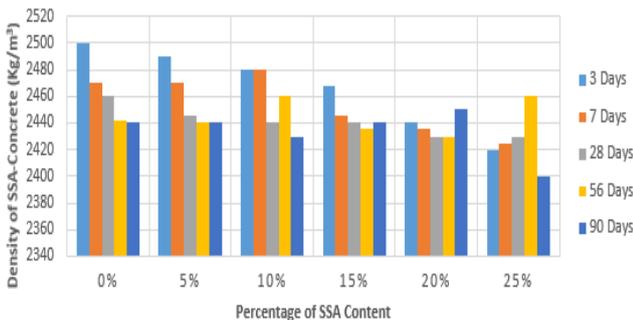


Fig. 8: Relationship between Density of SSA-Concrete and Percentage of SSA Content

### 4 CONCLUSIONS

Based on the tests performed, the following decisions were outlined;

- Sesame straw ash (SSA) has a sum total of aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), silicon oxide (SiO<sub>2</sub>) and iron oxide (Fe<sub>2</sub>O<sub>3</sub>) as 28.92 % which is less than the lower limit of 70 % highlighted by ASTM C 618 for pozzolana and concluded to be a low reactive pozzolana.
- Addition of SSA increased the consistency, soundness, initial and final setting times of SSA-cement paste.
- Addition of SSA portions decreased the workability of

fresh SSA concrete

- The compressive and flexural strengths of SSA-concrete increase as the curing age increases and decrease as the percentage portion of SSA content increases.
- It was concluded that up to 10 % SSA content is recommended for the production of concrete.

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