

Effect of the Blend of Cement - Sorghum Waste Ash (*Sorghum Vulgare*) on the Flexural Strength Properties of Concrete

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Abstract

The continuous depletion of lime stone deposits during cement production is increasingly posing a challenge in the construction industry. Other disadvantage associated with cement production includes CO₂ emission into the atmosphere and its negative effect on global warming. As a result, the research was geared towards at proffering alternatives to use of cement with impairing on the overall performance of concrete. Investigating the effect of Sorghum waste ash (SWA) - ordinary Portland cement blends on the flexural strength properties of concrete formed the bases for this study. Ordinary Portland cement was partially replaced with sorghum waste ash at an interval of 5, 10, 15 and 20 %. A water-cement ratio and mix ratio of 0.61 and 1:1.5:3.2 were adopted respectively. Chemical analysis test carried out on the ash sample was done in accordance with ASTM C618 (1999). Sorghum waste ash had silica content of 74 %, which was above the minimum of 50% specified in ASTM C618 (1999) for any material to be classified as a pozzolan. Twenty five beam specimens of size of 100 × 100 × 500 mm were cast and test for flexural strength after 28 days curing period. This was done in accordance with BS EN 12390-1(2000). Validation of experimental results was done using ANSYS 15.1 finite element software. A peak flexural strength of 6.079 N/mm² was gotten at 10 % cement level with ash. The strength result of plain concrete was 7.304 N/mm².

Keywords

Sorghum waste grain, pozzolans, flexural strength, concrete

1. Introduction

Concrete is one of the most used construction materials worldwide and its usage has also led an increase in the demand of cement, being a constituent material. As a result, emission of Carbon dioxide during the production process is also on an increase. The ruling argument is that the production of 1kg of cement which is the main ingredient of concrete generates 0.8 - 0.9 kg of CO₂ emission (Adama and Jimoh, 2011). In order to limit the usage of Portland cement and the negative effects associated with its production, research are currently being carried out to discover supplementary waste material for cement without impairing concrete performance. (Nielson and Glavind, 2007). Also, the depletion of lime stone deposits are other disadvantages associated with cement production.

Okpalla (1987) discovered that the addition of 40 % rice husk ash to cement resulted in concrete strength value equivalent to concrete produced from only cement. He attributed the improvement in concrete strength to the addition rice husk ash as a pozzolan. Pozzolans are siliceous and aluminous materials that possess no cementitious properties, but in its grinded state and in the presence of water reacts with lime to form cementitious compounds. When used as partial replacement of cement in concrete, they do not usually partake in the first stage of chemical reaction. According to Aziz et al (2004), the pozzolan reacts with Calcium hydroxide, a by-product of concrete, hence further improving strength properties in concrete. Other improvement recorded by researchers included better resistance to chemical attack, reduced heat of hydration responsible for thermal shrinkage, reduction of bleeding in concrete and greater impermeability (Seeley 1993).

Guinea corn (*Sorghum Vulgare*) is one of the most produced cereals crop in Nigeria. They are produced mostly in the middle belt and northern part of Nigeria (Tashikalma et al., 2010). The seeds are small, round and have varieties of colours such as; brown, black, red and white. Harvesting period of guinea corn ranges from September to January. Guinea corn forms a stable

diet and can be grinded into powdered form for preparing traditional food meals (*Amala*, bread). They are also used for making local drinks popularly known as *Burukutu* and *kunu*. Furthermore, USAID (2009) observed that Kaduna is the highest producer of guinea corn, with an annual production of 610100 metric tons. This accounts for 12.1 % of Nigeria's production. The top four regions (Zamfara, Borno, Kano and Niger) account for 52.30 %. Nigeria total production is estimated at 5,039,210 metric tons.

Sorghum waste grain used in the research is a byproduct of the production of local beer (*burukutu*). They are solid residue left over after the processing of the dried cereal grain for the production of beer. The sorghum waste grain is also used as feeds for animals. This research work was aimed at determining the effect of the blend of sorghum waste ash with ordinary Portland cement on the flexural strength properties of concrete.

2. Materials and Methodology

2.1 Materials

The materials used in this research were Sorghum waste grain (*Sorghum vulgare*), Ordinary Portland cement (OPC), crushed coarse aggregate (granite) and fine aggregate (sand). The Sorghum waste grain samples were obtained from *burukutu* drink producers along Brewer road, in Makurdi local government area of Benue State, Nigeria. The coarse and fine aggregate were obtained from a project construction site at University of Ilorin, Ilorin, Kwara State, Nigeria. The Ordinary Portland Cement (OPC) was obtained from a trader at Oke-odo, in Ilorin, kwara state.

2.1 Preparation of Test Specimens

The sorghum waste grain sample obtained was sun dried in an open space. The samples in its dry state was then taken to Mechanical Engineering Workshop, Kwara State polytechnic, Ilorin, Kwara State and burnt in a lift out furnace at a controlled temperature of 650⁰C for 6 hours (Jimoh et al. 2017). On cooling, the ash samples were then passed through sieve 75um and the fine particles that passed was used in this research. The coarse and fine aggregate obtained was opened dried for about 1 hour until it attained it saturated surface dried state.

2.3 Concrete Mix Design

The British department of environment (DOE) method of mix design was adopted for a conventional grade of 20 N/mm², and a water/cement ratio and mix ratio of 0.61 and 1:1.5:3.2 obtained from the calculation was used in the investigation. For the flexural strength test, cement was partial replaced with sorghum waste ash (SWA) at 5, 10, 15 and 20 %.

2.4 Determination of Chemical Properties of Test Specimen

Sorghum waste ash was tested for the presence of oxides in accordance to ASTM C618 (130). The oxides tested for includes; SiO₂, Al₂O₃, CaO, Fe₂O₃, MgO, Na₂O, SO₃ and K₂O. The test was conducted at the Industrial Chemical Department, University of Ilorin. The oxides were determined using Energy Dispersive X-ray Spectrometer (EDX) method. The element detected at high sensitivity and the detection lines gave results of the various oxides.

2.5 Determination of the physical properties of test Specimens

Physical property test were conducted for fine aggregate, coarse aggregate and sorghum waste ash sample. The test carried out for aggregate includes; specific gravity, particle size distribution and aggregate impact value test. The various test procedures was carried out in accordance to BS 812-2 (1995), BS 812-103,1 (1985), BS 812-112 (1990) and BS 812-109 (1990). Sorghum waste ash was tested for specific gravity and bulk density.

2.6 Slump Test

The test was carried out in accordance to BS 1881 – 102: 1983, which describes the procedure for determination of slump in concrete using the cone method. A cone of dimension 200 mm at the base, 100 mm at the top and 300 mm in height was firmly held against the surface and filled in three layers. For each layer, it was tampered with 25 strokes using a tamping rod. The same procedure was repeated for the remaining layers.

The mould was gently removed from the concrete and the slump value measured to the nearest 5 mm. the difference in height between the height of the mould and the drop in concrete was measured. The result obtained gave an indication of the workability of concrete mix.

2.7 Flexural Strength Test

The flexural strength under one point loading was done in accordance with BS EN 12390-5 (2000). 25 beams of size 100 × 100 × 500 mm were cast and cured in water for a period of 28 days. The flexural strength test was done using universal testing machine.



Figure 1: Curing process of beam



Figure 2: flexural strength test of beam

2.9 Density Test

Specimens of cube size, 150 × 150 × 150 mm were used in determining the density in accordance with BS 812 – 1 (1995). The density was calculated using Equation (2)

$$\sigma = \frac{M}{V} \quad (2)$$

Where σ = density of cube specimen (kg/mm^3), M = mass of the cube specimen (kg) and V = volume of cube specimen (mm^3).

3. Result and Discussion

The result of average specific gravity of the granite (coarse aggregate) and fine sand were 2.67 and 2.65 respectively. The specific gravity result fell within the range of 2.6 – 2.8, specified in BS Standard. The coarse aggregate had an aggregate impact value of 15.7 %, less than 25 % specified in BS Standard. Hence, the aggregate was suitable for usage in the research work. For sorghum waste ash, it had a specific gravity and density value of 2.43 and 473.4 respectively.

From Figure 3, for the coarse aggregate, the value of 1.58 obtained for coefficient of uniformity (Cu) was less than 4 specified in the BS 882:1992. Results of 1.05 obtained for the coefficient of curvature lied between 1 and 3 also specified in BS 882:1992. Hence, the coarse aggregate is well graded. From figure 4, for fine aggregate, the value obtained for coefficient of uniformity was 2.18, less than 4 specified in BS 883:1992. Coefficient of curvature value obtained was 1.14, which lies between 1 and 3 specified in BS 882:1992. From the result obtained, the fine aggregate is also well graded.

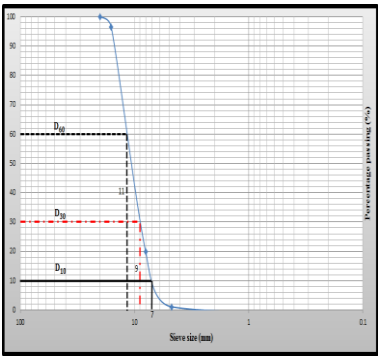


Figure 3 Sieve analysis of granite.

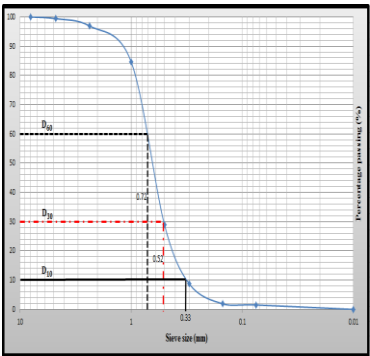


Figure 4 Sieve analysis of sand

The result of chemical composition of the sorghum waste ash (*Sorghum Vulgare*) is shown in Table 3. The ash had a silica content of 75.20 %. The summation of the elemental oxides of SiO₂, AlO₃, and Fe₂O₃ gave a result

value of 76.34 %. This was greater than the minimum of 50 % specified in ASTM C618-78 for a material to be regarded as a pozzolan. A break down of the classification is shown in Table 4.

Table 3 Chemical composition of sorghum waste ash sample

Elemental Oxides	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	Na ₂ O	SO ₃	K ₂ O	LOI
Sorghum waste ash	74.20	1.32	3.33	0.82	3.44	0.24	0.50	7.29	4.21

Table 4 ASTM C618 Classification of Sorghum waste Ash (*Sorghum Vulgare*) as a Pozzolan

Chemical pozzolanic properties	Class (ASTM C618, 8)	SWA
SiO ₂ + AlO ₃ + Fe ₂ O ₃ (%)	≥ 50	76.34
SO ₃	≤ 4	0.5
MgO	≤ 5	3.44
Loss of Ignition	≤ 10	4.21
Na ₂ O	≤ 1.5	0.24

Result of slump test is shown Table 6. The water required to make the mix consistent increased with increase in ash content.

Table 5 Result of slump test

Sorghum waste Ash (SWA)							
% ash	Weight of ash (A) Kg/m ³	Weight of cement (C) Kg/m ³	Weight of sand (FA) Kg/m ³	Weight of Granite (CA) Kg/m ³	Moisture content Kg/m ³	Mix ratio (C:A:FA:CA)	W/C Slump values (mm)
0 %	-	369	544	1212	230.00	1:1.5:3.28	0.61 45
5 %	18.45	350.55	544	1212	238.00	1:0.05:1.55:3.46	0.64 44
10 %	36.90	332.10	544	1212	241.80	1:0.11:1.64:3.65	0.66 37
15 %	55.35	313.65	544	1212	253.80	1:0.18:1.73:3.86	0.69 51
20 %	73.80	295.20	544	1212	266.0	1:0.25:1.84:4.11	0.72 58

This therefore meant that more water is needed to coat the surface of the sample and allow for workability in the fresh concrete mix. Ephraim et al. (2012) also confirms the influence of pozzolans on workability of concrete.

The change in flexural strength with respect to SWA addition is shown in Table 6. An increase in the flexural strength of sorghum waste ash concrete up to 10 % cement replacement was noticed. Beyond 10 %, a reduction in strength was noticed. Optimum flexural strength of 6.079 MPa obtained was lower than strength of 7.304 MPa obtained for plain concrete. The improvement in strength was due to the positive effect of silica oxide present in the ash. SWA has a silica oxide content of 75.2 %. The interfacial zone in concrete becomes stronger as the silica helps in fostering bonding between the cement paste and aggregate.

Table 6: Flexural strength of sorghum waste ash beam samples

Sorghum Waste Ash (SWA)				
% Ash Replacement	Density (Kg/m ³)	Peak Force (KN)	Peak Deflection (mm)	Flexural Strength (MPa)
0 %	2341	9071.5	1.887	7.304
5 %	2340	6820	1.644	5.933
10 %	2401	7910	2.254	6.079
15 %	2345	7806	3.714	5.854
20 %	2332	7204	3.349	5.403

Figure 5 presents the flexural load deflection curve for sorghum waste ash concrete beams. As shown in Table 6, the peak load of 7910 N was attained at 10 %, with a resultant deflection of 2.254 mm. The deflection was greater than the deflection for plain concrete beam by 19.5 %.

Results of the statistical analysis of flexural strength of Sorghum waste ash concrete are shown in Table 7. A peak mean value of 6.08, coefficient of variation of 5.67 and standard deviation of 0.34 is attained at 10 % replacement. Also, the desire confidence level of 95 % and 99 % of the flexural strength properties falls within the range of the true population.

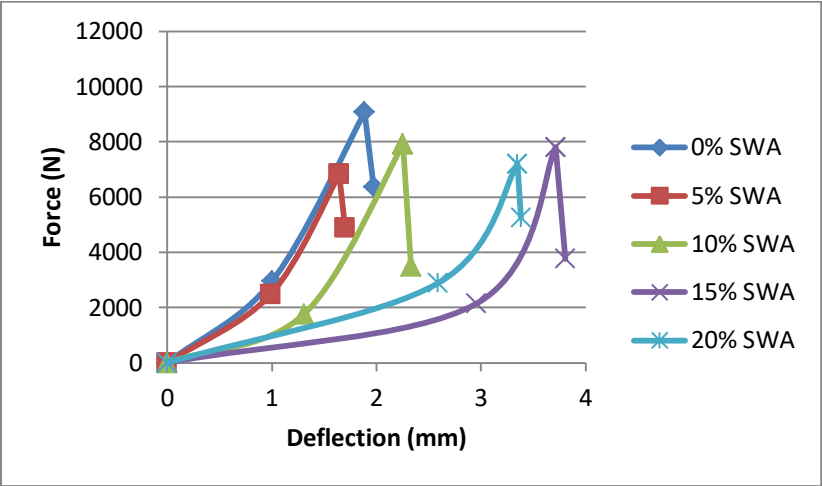


Figure 5 Flexural load deflection curve for sorghum waste ash (SWA) in concrete beams

Table 7 Result of statistical analysis of flexural strength of sorghum waste ash in concrete

Ash repl. (%)	Min	Mean	Max	S.D	C. of V	L.C.L	U.C.L
5	5.53	5.93	6.30	0.34	5.67	5.51	6.34
10	5.99	6.08	6.15	0.08	1.31	5.963	6.16
15	5.79	5.85	6.25	0.18	2.98	5.72	6.16
20	5.90	5.98	5.97	0.14	2.25	5.81	6.15

The results of the flexural strength of the test sample beams obtained using ANSYS 15.0 finite element analysis software are presented in Figures 4.20 – 4.31. The ANYSY flexural strengths results were compared with experimental flexural strengths in Table 8.

Table 8 Comparison between ANSYS flexural strengths and experimental flexural strengths

Ash Rep(%)	Experimental Flexural Strength (N/mm ²) (F _E)	ANSYS Flexural Strength (N/mm ²) (F _A)	$\frac{F_A}{F_E}$
0%	7.304	7.906	1.0
5%	5.833	5.906	1.0
10%	6.079	6.440	1.0
15%	5.704	5.718	1.0
20%	5.403	5.516	1.0

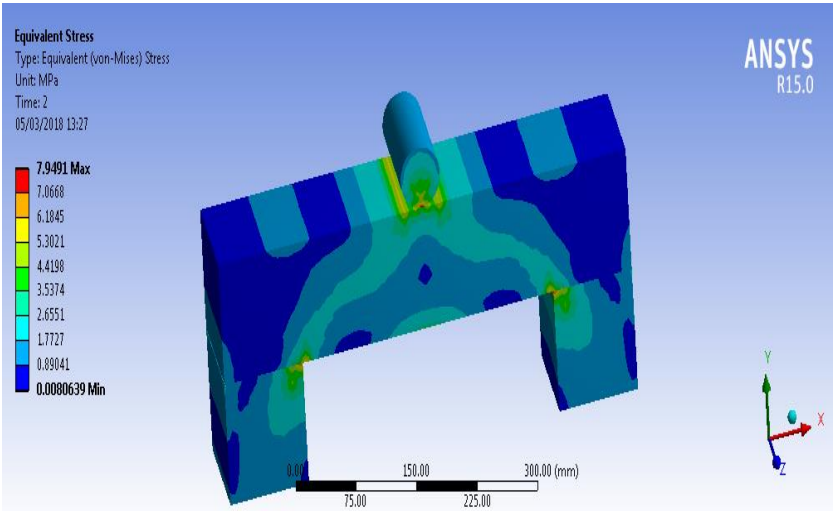


Figure 6 Stress for 0 % SWA

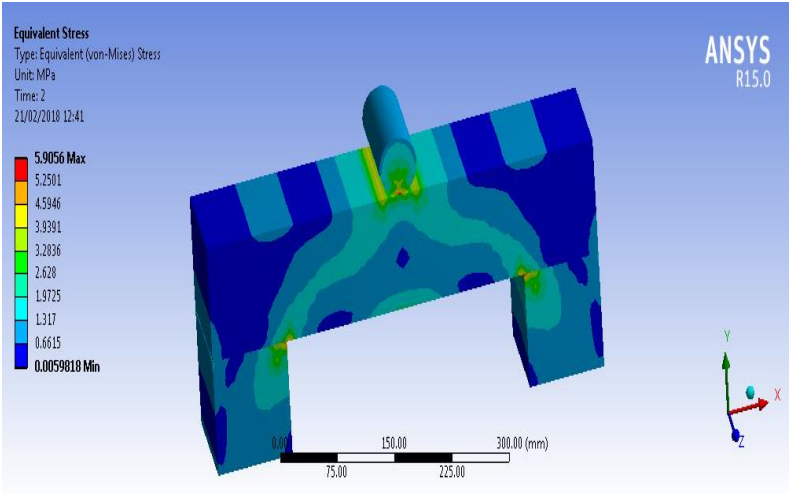


Figure 7 Stress for 5 % SWA

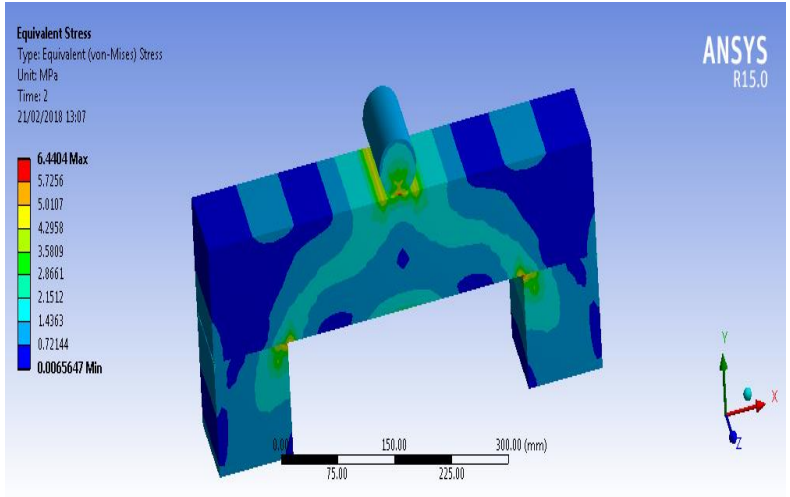


Figure 8 Stress for 10 % SWA

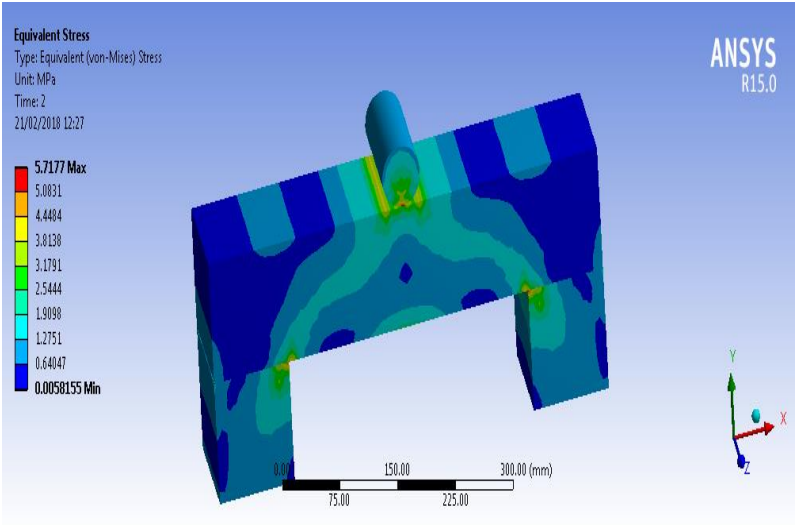


Figure 9 Stress for 15 % SWA

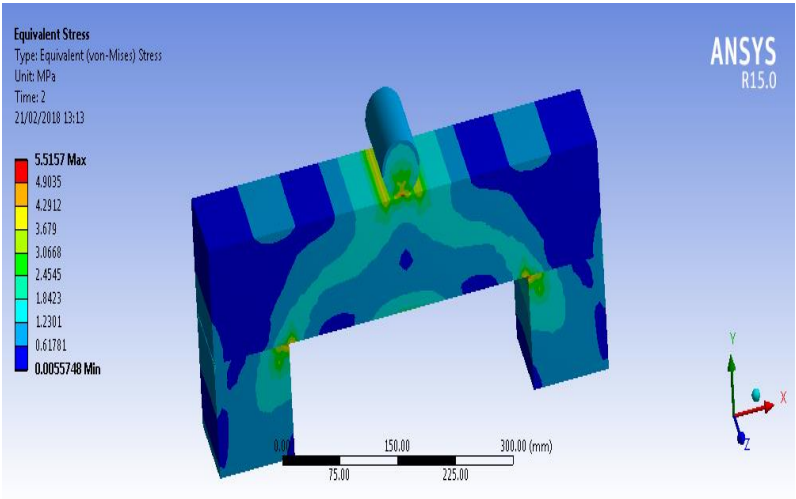


Figure 10 Stress for 20 % SWA

3. 1. Validation of Flexural Strength

The flexural strength of Sorghum waste ash concrete beam specimens was modeled in ANSYS 15.1 using the standard geometry of the specimens. The input parameters were the Poisson ratio (0.087), modulus of elasticity and density results, obtained from laboratory results. Triangular supports were modeled and fixed at 25 mm from the ends so as to have a clear span of 450 mm. Centre point load was applied at the middle of the clear span in the negative y-axis.

4. Conclusion

From this study, sorghum waste ash can be regarded as a pozzolan and hence can be used in concrete production. Blending of the ash with cement up to 10% replacement can produce a concrete of flexural strength, 6.42% lower than control strength. Result obtained from finite element analysis was greater than the experimental result by 5.93%.

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