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PARTIAL REPLACEMENT OF CEMENT WITH BREWERS DRY GRAIN ASH (*Sorghum Vulgare*) IN CONCRETE

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Abstract: The production of cement, one of the major binders in the construction industry has adverse effect on the environment, contributes to global warming, and leads to depletion of limestone. On the other hand, burning of Brewer dry grain (BDG) in the open pollutes the atmosphere with attendant health consequences. To overcome the adverse effect associated with cement production and the burning of waste material, the use Brewer dry grain ash (BDGA) as partial replacement of cement in concrete production was investigated. Cement was partially replaced with BDGA at 5 %, 10 %, 15 % and 20 % in concrete. A water-cement ratio and mix ratio of 0.61 and 1:1.5:3.2 was adopted. Chemical analysis test on the ash sample was carried out in accordance with ASTM C618 (1999). The consistency, initial and final setting time test was carried out in accordance with BS EN 196-3 (1994). Eighty-five cubes of the size of 150 ×150×150 mm were cast and tested for compressive strength at 7, 14, 28 and 56 days curing. The test was carried out in accordance with BS EN 12390-1(2000). For tensile strength test, twenty-five specimens of size 100 × 100 × 200 mm were cast and tested after 28 days curing. This test was carried out in accordance with ASTM C 496-11. BDGA had a 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. An increase in setting time was observed with BDGA addition. A maximum compressive strength of 36.4 MPa was attained at 10 % cement replacement with BDGA ash, and the result obtained was higher than the strength of plain concrete by 25.6 %. For tensile strength, a maximum compressive strength of 3.03 was obtained at 10% replacement. This was higher than the strength of plain concrete by 13.5 %.
Keywords: Brewers dry grain, pozzolans, compressive & tensile strength, Sorghum

1. INTRODUCTION

The use of locally available materials to replace cement in concrete productions is currently being researched upon, as the usage of such waste will aid in reducing the cost of producing concrete and also minimize the issues associated with Carbon dioxide (CO_2) emission during cement production. According to Babu and Rao (2008), about 7 % CO_2 is released into the atmosphere for every 1kg of cement that is produced. Also, the depletion of the limestone deposits is other disadvantages associated with cement production. However, investigations conducted by researchers showed that some waste on either grinding or burning to a specified temperature contains pozzolanic properties that make them suitable in concrete production. Okpalla (1987) reported that the addition of 40 % rice husk ash to cement resulted in the concrete of compressive strength equivalent to concrete produced from only cement. The attributed improvement in concrete strength to the addition of rice husk ash as a pozzolan. Pozzolans by definition are siliceous and aluminous materials that possess no cementitious properties, but in its ground 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 of stage of the chemical reaction. According to Aziz et al. (2004), the pozzolan remains dormant during the first seven days. During this period, cement reacts with water to form Calcium silicate hydrate (C-S-H) and Calcium hydroxide as by-product. The calcium silicate formed is responsible for strength gain in concrete.

Interestingly, pozzolans further improve the strength properties in concrete as the silica in the pozzolans reacts with the calcium hydroxide in concrete to also form calcium silicate hydrate. Other areas of 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 crops 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 colors 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 ground into powdered form and used in preparing traditional food meals (*Amala*, bread). They are also used for making local drinks popularly known as *Burukutu and kunu*. 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.

Brewers dry grain used in the research is a by-product from the production of local beer called *burukutu*. It is a solid residue obtained from the processing of the dried cereal grain for the production of beer. The brewers dry grain is also used as feeds for animals.

This research investigates the effect of blending Brewers dry grain ash (*Sorghum Vulgare*) with Ordinary Portland cement in concrete.

2. MATERIAL & METHODOLOGY

— Materials

The materials used in this research were Brewers dry grain, Ordinary Portland cement (OPC), crushed coarse aggregate (granite) and fine aggregate (sand). The Brewers dry grain samples were obtained from *burukutu* producers along Brewer road, in Makurdi local government area of Benue State, Nigeria. The coarse and fine aggregate was 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. Figure 1 and Figure 2 shows the Local drink extract (Brewers dry grain) and the local drink (*Burukutu*) after the production process.

Figure 1: Brewers dry grain

Figure 2: Produced local drinks in pans (*burukutu*)

— Preparation of Test Specimens

The brewers dry grain sample obtained in a wet state was sun-dried in an open space. The samples in its dry state were taken to Mechanical Engineering Workshop, Kwara State Polytechnic, Ilorin, Kwara State, and burnt in a lift out furnace at a controlled temperature of 650^{o}C for 6 hours (Jimoh et al. 2017). On cooling, the ash sample was then passed through sieve 75 μmm, and the fine particles that passed were used in this research. The coarse and fine aggregate was air-dried for about 1 hour until it attained its saturated surface dried state.

— Concrete Mix Design

The British department of environment (DOE) method of mix design was adopted for a conventional grade of 20 MPa, 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. Before testing for initial and final setting time, compressive strength and tensile strength, cement was partially replaced with brewers dry grain ash (BDGA) at 5 %, 10 %, 15 % and 20 %.

— Determination of Chemical Properties of Test Specimen

Brewers dry grain ash was tested for the presence of oxides in accordance with ASTM C618 (1999). The oxides includes; SiO_2, Al_2O_3, CaO, Fe_2O_3, MgO, Na_2O, SO_3, and K_2O. 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.

— Determination of the physical properties of test Specimens

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

— Consistency, Initial and Final Setting Time Test of Blended Cement Mortar

The test was carried out on plain cement mortar, and blend of the cement mortar with brewers dry grain ash. The test procedure was carried out in accordance with BS EN 196-3:1994. The cement mortar was replaced with the brewers dry grain ash sample at 5 %, 10 %, 15 % and 20 %.

— Slump Test

The test was carried out in accordance with BS 1881 – 102: 1983, which describes the procedure for the determination of slump in concrete using the cone method. A cone mould 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 was 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 indicated the workability of concrete mix.

— Compressive Strength Test

Plate III and IV show the curing and crushing process of concrete cubes. Specimens of cube size, 150 × 150 × 150 mm was tested for compressive strength. This was carried out in accordance with BS EN 12390 – 1 (2000) specification. Brewers dry grain ash sample was incorporated into the concrete mix at 5%, 10%, 15% and 20%. The concrete was demoulded after 24 hours and allowed to cure in water for 7, 14, 28 and 56 days. At the curing intervals, the cubes were tested using Universal Testing Machine with a load capacity of 2000KN. The force at failure obtained was recorded. Compressive strength was calculated using Equation (1).

$$S = \frac{L}{A} \quad (1)$$

where S = compressive strength (MPa), L = force at failure (kN), and A = Cross-sectional area of the cube (mm)

Figure 3: Curing process of cube specimen

Figure 4: Process of testing cube specimen

— Density Test

Specimens of cube size, 150 ×150 × 150 mm were used in determining the density in accordance with BS 373 (1973). The density was calculated using Equation (2)

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

where $\sigma = density of cube specimen$ (kg/mm³), M = mass of the cube specimen (kg) and V = volume of cube specimen (mm³).

— Tensile Strength Test

Split tensile test strength was carried out on concretes based on ASTM C 496-11 using 100 by 200 mm cylindrical cubes. A centerline was drawn on the opposite sides of the cube samples. During testing, the cylindrical sample was placed in position in the Tinus Olsen Testing Machine, which has a loading capacity of 2000 KN. Steel bars of 16 mm diameter, sealed on steel plates were placed on the center line drawn on the opposite sides of the cylinder samples. Compressive forces were applied along the two opposite center line, such that the splitting along these lines was caused by the principal tensile stress in the plane joining the loaded lines. Loading was applied continuously at the rate of 150 kN/minute over the entire load application area until fracture occurred. The split tensile strengths were then determined at curing ages of 28 days. Force obtained at failure was then used to calculate the tensile strength using Equation (3).

$$F = \frac{2p}{\pi LD} \tag{3}$$

where:
F = tensile strength (N/mm^2)
P = compressive load at fracture (N)
L = length of the cylindrical specimen
D = diameter of the cylindrical specimen

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 falls within the range of 2.6 – 2.8, specified in BS 812-2:1995. The coarse aggregate had an aggregate impact value of 15.7 %, less than 25 % specified in BS 812-112 (1990). Hence, the aggregate was suitable for usage in the research work. For brewers dry grain ash, it had a specific gravity and density of 2.43 and 473.4 respectively.

The results of particle size analysis of fine (sand) and coarse aggregate (granite) are shown in Table 1 and Table 2 respectively.

Table 1: Particle Size Analysis of Coarse Aggregate

Sieve (mm)	Weight of aggregate retained Determination no				% of total weight retained	Cumulative % of total weight retained	% passing
	1	2	3	Average			
16mm	53	52	3	35.72	3.57	3.57	96.43
8mm	769	762	765	764.68	76.46	80.03	19.98
4.75	167	175	223	188.33	18.83	98.83	1.13
Pan	12	9	13	11.33	1.13	100	0

Total weight of samples = 1000g

Table 2: Particle Size Analysis of Sand

Sieve size	Weight of aggregate retained (g) Determination No				% of total weight retained	Cumulative % of total weight retained	% passing
	1	2	3	Average			
8 mm	0	0	0	0	0	0	100
4.75 mm	5	6	7	6	0.6	0.6	99.4
2.36 mm	21	23	31	25	2.5	3.1	96.9
1.0 mm	113	119	133	121.67	12.17	15.27	84.73
0.5 mm	526	577	573	558.67	55.87	71.14	28.86
0.3 mm	229	192	183	201.33	20.13	91.27	8.73
0.15 mm	85	67	53	68.33	6.83	98.1	1.9
0.075 mm	4	3	5	4	0.4	98.5	1.5
Pan	17	13	15	15	1.5	100	0

Total weight of sample = 1000g

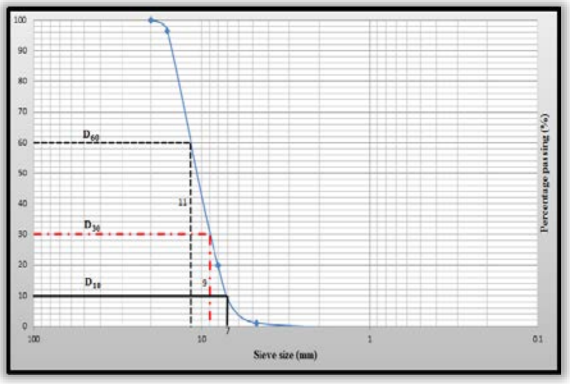

Figure 5: Sieve Analysis of Granite

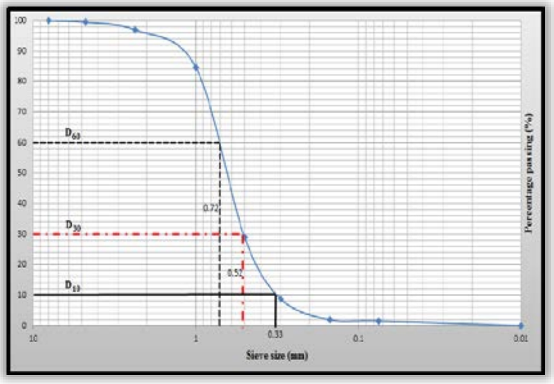

Figure 6: Sieve Analysis of Fine Sand

From Figure 5, for the coarse aggregate, a value of 1.58 obtained for the coefficient of uniformity (Cu) was less than four specified in the BS 882:1992. The result 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 6, for fine aggregate, a coefficient of uniformity of 2.18 obtained was less than 4 specified in BS 883:1992. The 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 was well graded.

The result of the chemical composition of the brewers dry grain ash (*Sorghum Vulgare*) is shown in Table 3. The ash had a silica content of 75.20 %. The summation of the elemental oxides of SiO_2, AlO_3, and Fe_2O_3 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. Break dawn of the classification is shown in Table 4.

Table 3: Chemical Composition of Brewers dry grain ash Sample

Elemental Oxides	SiO_2	Al_2O3	CaO	Fe_2O_3	MgO	Na_2O	SO_3	K_2O	LOI	% Ash
Brewers dry grain ash	74.20	1.32	3.33	0.82	3.44	0.24	0.50	7.29	4.21	2.96

Table 4: ASTM C618 Classification of Brewers dry grain ash (*Sorghum Vulgare*) as a Pozzolan

Chemical pozolanic properties	Admixture Class (ASTM C618, 8)	Sorghum waste Ash (Sorghum)
SiO_2 + AlO_3 +Fe_2O_3 (%)	≥ 50	76.34
SO_3	≤ 4	0.5
MgO	≤ 5	3.44
Loss of Ignition	≤ 10	4.21
Na_2O	≤ 1.5	0.24

As shown in Figure 7, the initial and final setting increased as the cement was partially replaced with the Brewers dry grain ash. The pattern of increase in setting time fell in line with the findings obtained by Ganesan et al (2008); Cooks (1986) and Bhanumathidas et al (2004) for rice husk ash in concrete production. The increase in setting time was influenced by the specific surface area of the brewers dry grain ash, since the ash has a greater surface area than cement content. Since BDGA contain SiO_2 which is dormant during its initial face of cementitious reaction, the heat of hydration is greatly reduced with BDGA addition. As such, the rate of strength gained is reduced and setting time increased (Ganesan et al. 2008). The results of initial and final setting time test satisfied the BS EN 196-3:1994 standard requirement for a material to regarded as cementitious.

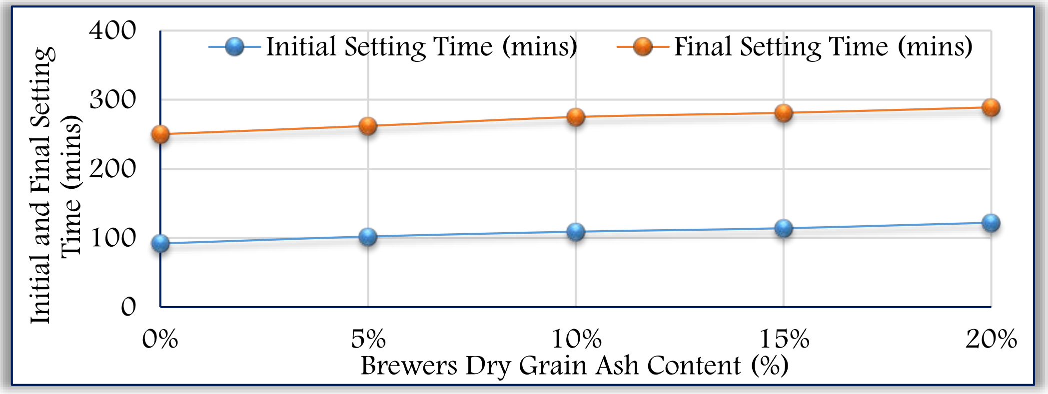

Figure 7: Initial and Final Setting Time of Brewers dry grain ash - cement Mortar

Consistency results of brewers dry grain ash (BDGA) in the cement paste increased with addition of BDGA sample content, as displayed in Figure 8. More water is required to achieve a consistent paste as cement is partially replaced with brewers dry grain ash.

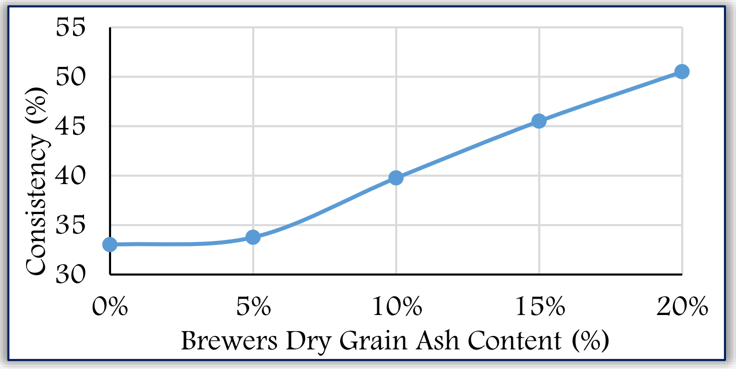

Figure 8: Consistency of the Mix with Ash Replacement

As shown in Figure 9, the water content demand in the mix increased with increase in BDGA ash content in concrete. This means 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.

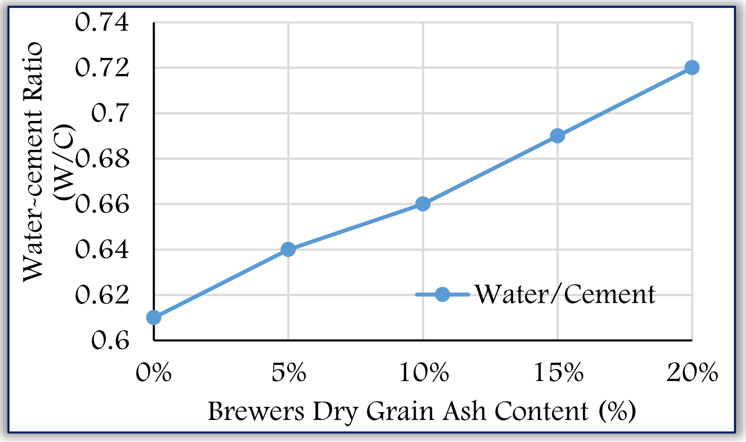

Figure 9: Rate of Change of Water-Cement Ratio with Cement Replacement

Table 7 shows the result of density. The results obtained falls within the range of 2300 – 2700 Kg/m³ specified in ASTM C 230 (2009) classification for a normal weight concrete. An increase in density of BDGA concrete was observed with curing age.

Table 7: Average Density and Compressive Strength of BDGA Concrete

Brewers dry grain ash (BDGA) (Average density kg/m³/ Compressive strength MPa)										
Testing age	0 %		5 %		10 %		15 %		20 %	
7	2506	20.8	2346	22.2	2548	20.3	2475	15.6	2312	14.9
14	2523	26.1	2391	28.8	2613	29.5	2504	20.0	2433	19.6
28	2618	28.6	2556	34.6	2685	36.3	2518	23.8	2469	23.4
56	2634	33.3	2549	37.8	2691	40.2	2555	29.6	2481	27.7

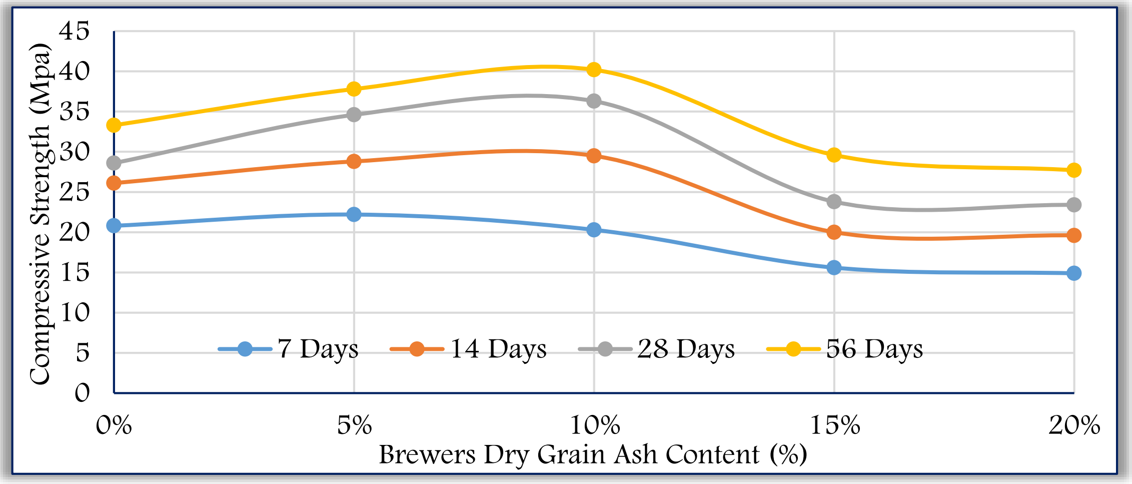

Figure 10: Rate of Strength Development with Cement Replacement

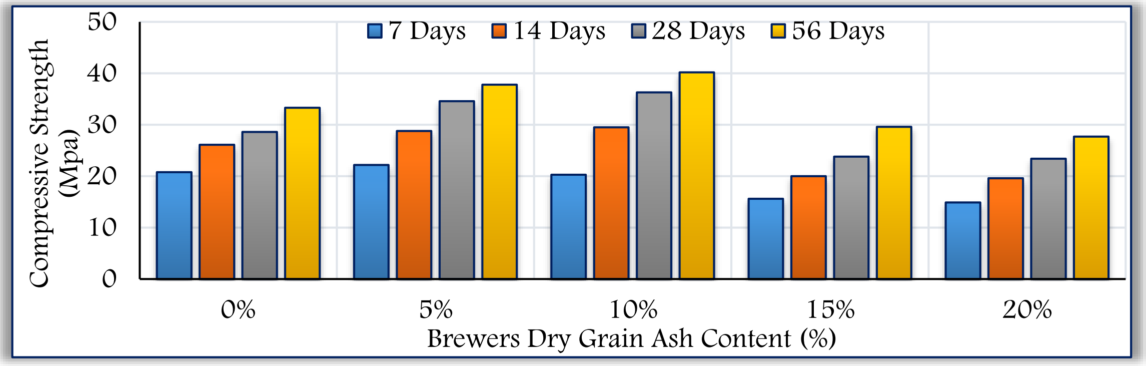

Figure 11: Rate of Strength Gain with Curing Age

As shown in Figure 10, the compressive strength of brewers dry grain ash concrete decreased as cement was replaced with the ash at the 7th day curing. Silica oxide in the BDGA does not undergo reaction at the early stage (Neville, 2011). Hence, 5 % cement reduction will result to a decrease in strength. At 28 day curing, the maximum strength was achieved at 10 % replacement. The maximum strength of 36.3 MPa obtained was higher than control strength of 28.6 MPa. An increase in compressive strength was noticed from 5 % to 10 %. Afterward, a drop in strength was observed from 10 % to 20 % ash replacement. Such a drop was as a result of the excess non-reactive ash, thus causing a reduction in strength. Voids also created as a result, will tend to act as weak breakage zones in the concrete (Ephraim et al. 2012).

Table 8 shows the result of tensile strength. As shown in Figure 12, an increase in tensile strength was observed up to 10 % replacement. The maximum tensile strength of 3.03 MPa obtained was higher than the strength of plain concrete by 13.5 %. Beyond 10 %, a drop in strength was noticed. The pattern of strength gain with ash addition tallied with the findings obtained by Krishna et al. (2016). The reason for the gain in strength with ash addition in concrete mix is due to the pozzolanic effect of silica oxide in the ash in enhancing cementitious reaction and also bonding effect of the silica content at the interface between aggregate and cement paste. Also, ash in concrete aids in reducing the voids present at the interfacial zone.

Table 8: Split Tensile Strength of BDGA Concrete

Ash Content (%)	0 %	5 %	10 %	15 %	20 %
Tensile strength (MPa)	3.05	2.56	3.03	2.19	1.79

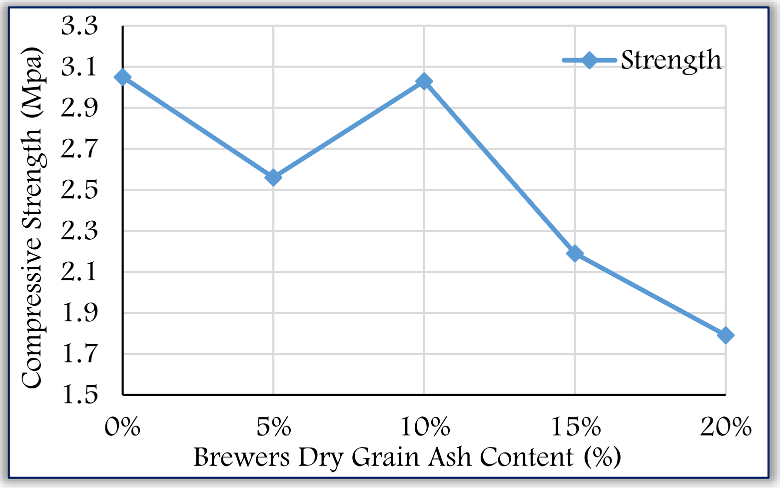

Figure 12: Rate of Change in Tensile Strength with Cement Replacement

4. CONCLUSION

From this study, brewers dry grain ash can be regarded as a pozzolan, and hence can be used in concrete production. The inclusion of brewers dry grain ash in cement mortar increased the initial and final setting time. The results obtained were also within the BS EN 196-3:1994 specification limits for a mortar to be considered a cementitious material. Blending of the ash with cement up to 10 % replacement can produce concrete of compressive strength, 27.4% greater than control strength. For tensile strength test, the maximum strength of 3.03 MPa is achieved at 10 % replacement and result obtained is greater than the strength of control by 13.5 %.

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