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MECHANICAL PROPERTIES OF BREWERS DRIED GRAIN ASH-HYDRATED LIME IN CONCRETE

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Abstract

Ordinary Portland cement (OPC), the world most used binder in concrete production is adjudged a non - environmental friendly material due to the CO2 gas that is emitted into the atmosphere during its production process. Also, with the future generation in mind, limestone resource needs to be adequately preserved and managed. Previous studies on the search for alternative binders had centred mostly on the use of Agro - waste pozzolans in concrete, with little emphasis on the use of the pozzolans with additives that may further enhance reaction in concrete. Hence, this paper explores the possibility of using OPC with brewers dried grain ash-hydrated lime (BDGA-HL) in concrete. Prior to testing for initial and final setting time, compressive, flexural and tensile strength; cubes, beams and cylindrical specimens containing BDGA-HL at 5, 10, 15 and 20 % cement replacement were cast (in a ratio of 1:1.5:3.2 and w/c of 0.61) and cured in water for 7, 14, 28, and 56 days. Based on the findings, a decrease in setting time of the paste was noticed when OPC was partially replaced with BDGA-HL. Also observed was an improvement in flexural and tensile strength up to 10 %; while the maximum compressive strength was attained at 15 %. The results obtained for BDGA-HL concrete were higher than that of plain concrete. It was concluded that BDGA-HL has an excellent pozzolanic potentials improving the properties of concrete

Keywords: Brewers dried grain ash, hydrated lime, pozzolan, strength, concrete.

1.0 INTRODUCTION

The utilisation of cement as a binding agent in concrete production is popularly used among construction engineers and builders. Due to its wide range of structural applications from mortar, sandcrete, to concrete production, the demand for cement is also on the increase. With such a rapid increase in cement demand, the depletion of limestones deposit, CO2 gas emitted into the atmosphere during the cement production process and its negative effect on the ecosystem and environmental sustainability remains a concern to researchers. However, investigations are currently ongoing, to discover alternatives and supplements to cementitious materials. According to Okpalla (1987), some Agro-waste material when burnt to a required temperature contains a certain percentage of silica oxide which enhances cementitious reaction in concrete. The silica oxide contributes to strength development in concrete when it comes in contact with lime in the presence of water to form calcium silicate hydrate (C-S-H).

The degree of reaction of the waste material ash with lime to a large extent depends on the fineness of the grinded ash and the quantity reactive silica oxide present. Langan et al. (2002) recommended that ash samples that pass through 75 µm sieve size are most suitable for usage in concrete production. The common agro waste ash pozzolans that have been researched in concrete include; rice husk ash.

Brewers dried grain are by-products obtained from the production of a local drink called burukutu. The drink taken by the locals is produced in the savannah belt of Nigeria and West Africa. The brewers dried grain is disposed of in large amount as waste after the local drink is produced. The process of extracting the brewers dried grains entails; malting and mashing of the guinea corn (Sorghum Vulgare). As reported by Tuleun et al. (2018), Brewers dried grain (BDGA) in it ash state when tested for chemical properties falls within the ASTM C 618 class N for a material to be regarded as a pozzolan, and also has a silica oxide content of 74.4 %. They also observed an improvement in compressive strength when BDGA was used as partial replacement of cement in concrete, with the maximum compressive strength attained at 15 % cement replacement with ash; and the result obtained was higher than the strength of plain concrete. Figure 1 shows an image of the extracted brewers dried grain while Figure 2 shows an imaged process of making the local drink (burukutu)

Figure 1 Brewers dried grain after processing (Tuleun *et al.,* 2018)

Figure 2 Process of making a local drink (*burukutu*)

Hydrated lime (Calcium carbide residue) or carbide lime sludge is obtained when pure calcium carbide reacts with water to form acetylene gas and hydrated lime as by-product. The hydrated lime is whitish, colourless and odourless. The acetylene gas is widely used in lighting, metal cutting, the ripening of fruits in agriculture, and in welding industries. In developed countries like China, they are used in the production of industrial fuel and polyvinyl chloride (PVC). In Nigeria, it is popularly used by welders and panel biters.

Calcium carbide residue is alkaline, with a PH value higher than 12. Such property makes it useful in concrete production when pozzolans are used as additives. This is so because the durability and strength development of concrete containing pozzolans is enhanced in the presence of calcium hydroxide. Jaturapitakkul and Roongreung, (2003) discovered that the calcium carbide residue could be used to make cementitious materials when blended with rice husk ash and their findings were validated by Somna et al. (2014). Krammart et al. (1996), also discovered that the blend of calcium carbide residue with fly ash mixture (30:70) could accelerate pozzolanic reactions with significant improvement in the mechanical properties of the concrete. Also, according to Jaturapitakkul and Roongreung (2003), for a cementitious mortar, the highest compressive strength of 15.6 MPa was achieved when rice husk ash was blended with calcium carbide residue in a ratio of 50:50 by weight. The use of calcium carbide waste (hydrated lime) in concrete at 5 % cement replacement level resulted to concrete of maximum compressive strength 4.2 % higher than that of the plain concrete (Tuleun and Jimoh, 2018). According to Tuleun, et al. (2019), Provided adequate water curing is maintained, the partial replacement of cement with rice husk ash and hydrated lime (50:50) at 5% percent replacement results to a concrete of an improved compressive strength, 14.1% higher than a plain concrete.

The study aims to investigate the effect of using Brewers dried grain ash (BDGA) with hydrated lime (HL) as partial replacement of cement in concrete production. The specific objectives are to evaluate the;

i. consistency, initial and final setting time of BDGA-HL cement paste
ii. Workability of concrete with BDGA-HL
iii. Density of BDGA-HL concrete
iv. Mechanical properties (compressive, flexural and tensile strength) of BDGA-HL concrete.
v. Load - deflection of Concrete beam with BDGA-HL

2.0 MATERIALS AND METHODS

The constituent materials used in this research work includes; Ordinary Portland cement (OPC), Brewers dried grain ash (BDGA), Hydrated Lime (HL), Fine aggregate (Sharp sand), Coarse aggregate (Granite) and Portable water

2.1 Source And Treatment Of Materials

Brewers dried grain was sourced from Makurdi town, in Makurdi local government area of Benue state, Nigeria. The samples obtained in its wet state were sundried for 48 hours. The dried samples were burnt in a lift out furnace at a temperature of 650 oc for 6 hours as shown in Figure 3 (Jimoh, A.A. et al., 2017). This was carried out with the aim of obtaining the ash in an amorphous state. Afterwards, the ash sample was sieved through a BS sieve size of 75 µm. The Hydrated lime was obtained from panel biters at Okeodo, Tanke, Ilorin, Kwara state, Nigeria. The hydrated lime obtained in its wet state was sundried for 24 hours to remove the moisture content present. The dried sample was then passed through a 75µm sieve size and materials that passed through was used in the research work. Granite and sand used as the coarse and fine aggregate were obtained from Arafins contractors, at University of Ilorin. The wet sand and granite after being dried separately for 6 hours at room temperature were sieved through a 4.75 mm and 20 mm sieve size to ensure separation of the sand and granite that are present.

 

Figure 3 Burning process of ash samples at controlled temperature]

2.2 Mixing And Preparation Of Specimens

Before mixing and casting of concrete constituent materials, OPC was partially replaced with brewers dried grain ash-hydrated lime (BDGA-HL) at 0 %, 5 %, 10 %, 15 % and 20 % replacement. The 0 % represents the plain cement, which consists of cement without any additive. British Department of Environmental (DOE) method of mix design for a grade of 20MPa, target strength of 32.5 MPa and a target slump ranging from 30 - 60 mm was adopted. OPC, fine aggregate (sand) and coarse aggregate (granite) were mixed mechanically in a ratio of 1:1.5:3.2 and w/c ratio of 0.61 (obtained using the DOE method). Table 2 presents the mix ratios and water/cement ratio for the various blend of OPC with BDGA-HL additives. Batching of concrete constituents materials was done by weight until a uniform mix was achieved. The cube, cylindrical and beams moulds were oiled to allow for easy removal of the specimens. The fresh concrete was placed in the mould in three layers. For each layer, a tamping rod used to compact the concrete. The Concrete specimens were then left inside the moulds for 24 hours. This was carried out to allow for proper setting of concrete. Afterwards, the concrete was removed from the moulds and cured in water. The cubes were completely submerged in water. On each testing day, the samples were brought out from the tank and allowed to attain a dry surface state before the density, and the strength test was carried out

2.3 Physical Properties Of Crushed And Uncrushed Aggregate

Particle size distribution, specific gravity, water absorption and aggregate impact value test were determined for both fine and coarse aggregate in accordance with BS 812-103 (1985), BS 8122 (1995), BS 812-112 (1990).

2.4 Fresh Properties Test

Workability (Cone) test, consistency, Initial and final setting time test procedure was carried out in accordance with BS 1881-102 (1983) and BS EN 196-3 (1994).

2.5 Hardened (Mechanical) Properties Test

One hundred cubes of size 150×150×150 mm after being cured in water were tested for compressive strength at 7, 14, 28, 56 days in accordance with BS EN 12390-3 (1990) specification. Twenty-five beam of size 100×100×500 mm and cylindrical specimens of size 100×200 mm were cured in water for 28 days. The samples were then removed and tested for flexural and tensile strength in accordance with BS EN 12390-5 (2000) and BS EN 12390-6 (2000) specification. Beams tested for flexural strength were subjected to one point loading and the mode of deflection was noticed at the center of the beam.

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties Of Fine And Coarse Aggregate

From the results obtained, coarse and fine aggregate had a specific gravity of 2.73 and 2.66, which falls with the range of 2.6 - 2.8 mm specified in BS 812-2 (1995) for aggregate to be regarded as normal weight. The fineness modulus of fine aggregate falls within the range of 4.75 - 40 µm specified in ASTM C33 (2008). The water absorption capacity of coarse and fine aggregate was found to be 0.61 and 0.54 % respectively. Coarse aggregate had an aggregate impact value of 19.3 %. The particle size distribution curve for both fine and coarse are shown in Figure 4 and Figure 5

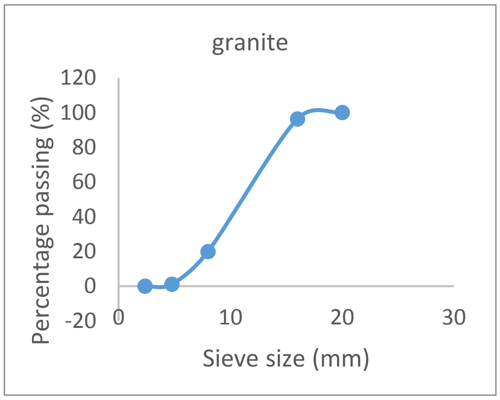

Figure 4 Particle size distribution of Coarse aggregate

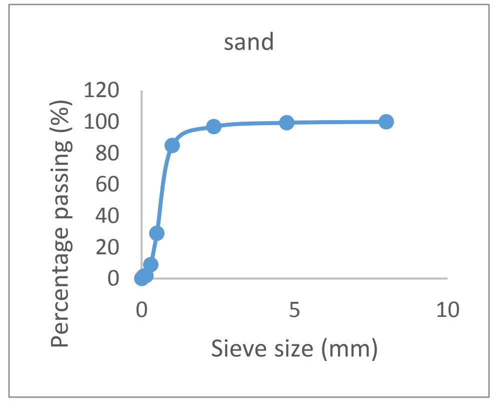

Figure 5 Particle size distribution of fine aggregate

3.2 Fresh Properties

Table 1 presents the results obtained for normal consistency, initial and final setting time of BDGA-HL cement mortar. The percentage of cement replacement level with BDGA-HL content vs standard consistency graph as shown in Figure 6 indicates that the water required to achieve a standard consistency increases linearly with an increase in BDGA-HL content. This is because BDGA-HL has higher water absorption capacity than OPC. Also, the specific gravity of BDGA-HL is higher than that of OPC. Hence, more water is required to achieve a standard consistency.

Figure 7 shows the initial and final setting time of BDGA-HL cement mortar. Observed is a decrease in the initial and final setting time of the mortar with BDGA-HL addition up to 20 % replacement. The initial and final setting time of cement mortar blended with BDGA-HL at 20 % was lower than that of the plain cement mortar by 64.1 %. On the other hand, the final setting time was lower by 47.2 %. The final setting time result falls within the ASTM C-618 (1978) specification for the mortar to be regarded as a cementitious material. The results initial setting time obtained at 5%, 10% and 15% replacement fall within the specification limit while result obtained at 20 % falls outside the limit. Contrarily, Tuleun et al. (2018) reported an increase in both initial and final setting time when BDGA without hydrated lime was blended with cementitious mortar. BDGA contains a high percentages of SiO2 which is dormant during its initial face of cementitious reaction. This therefore means that as the cement is partially replaced with BDGA, the rate of strength gain will reduce and setting time increases. However, this is not the case with the blend cement mortar with BDGA-HL. During its initial face of cementitious reaction, as the cement mortar is partially replaced with BDGA-HL, a certain percentage of SiO2 in BDGA reacts with Calcium Oxide in the presence of moisture to form calcium silicate hydrate (C-S-H). The presence of silicate hydrate results in increase of the rate of strength gain and reduction in setting of the BDGA-HL cement mortar.

Table 1 Normal consistency, initial and final setting time

Blend of Brewers Dried grain Ash and Hydrated Lime in Cement Mortar (BDGA-HL)						
Ash Content (%)	**Weight (g)**	**Water Content (mm)**	**Penetration Depth (mm)**	**Consistency (%)**	**Initial Setting Time (min)**	**Final Setting Time (min)**
5%	-	136	33	34.00	62	175
10%	-	151	33	37.75	55	168
15%	-	155	34	42.75	38	149
20%	-	171	33	40.50	33	132

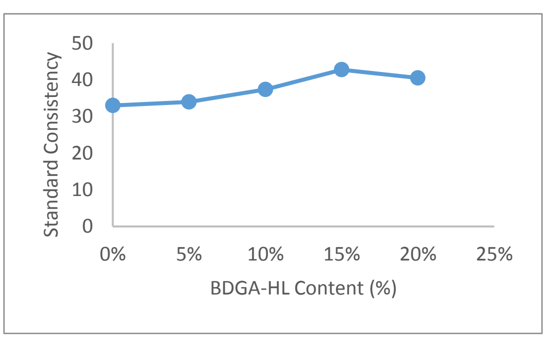

Figure 6 Standard consistency of BDGA-HL mortar

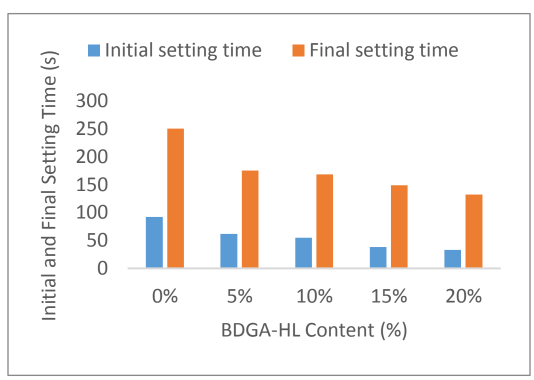

Figure 7 Settings time of BDGA-HL mortar

Results of the workability test is shown in Table 2. To achieve a target slump of 30-60 mm, the water content demand in the concrete mix increased with increase in BDGA-HL content. BDGA-HL has a higher surface area than OPC; hence, more water is required to coat the surface of the sample and allow for workability in the fresh concrete mix. Similar behavioural pattern were recorded by Zeyad, et al. (2017), Tangchirapat, et al. (2009), and Kajaste and Hurme, (2016) for Palm oil fuel ash - cement mortar.

Table 2 Results of the workability test

Blend of Brewers Dried grain Ash with Hydrated Lime (BDGA-HL)								
Ash Content (%)	**Weight of Ash (A) Kg/m³**	**Weight of Cement (C) Kg/m³**	**Weight of Sand (FA) Kg/m³**	**Weight of Granite (CA) Kg/m³**	**Moisture content Kg/m³**	**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	238.50	1:0.05:1.55: 3.46	0.65	48
10	36.90	332.10	544	1212	231.30	1:0.11:1.64:3.65	0.63	44
15	55.35	313.65	544	1212	253.00	1:0.18:1.73:3.86	0.69	49
20	73.80	295.20	544	1212	260.70	1:0.25:1.84:4.11	0.71	55

3.3 Hardened Properties

As presented in Table 3 and shown in Figure 8, the density of BDGA-HL concrete ranges between 2503 - 2687 Kg/m3 for a curing age of 7,14, 28 and 56 days. This falls within the range of 2300 – 2800 Kg/m3 recommended by Neville (2011) for concrete to be regarded as a normal weight concrete.

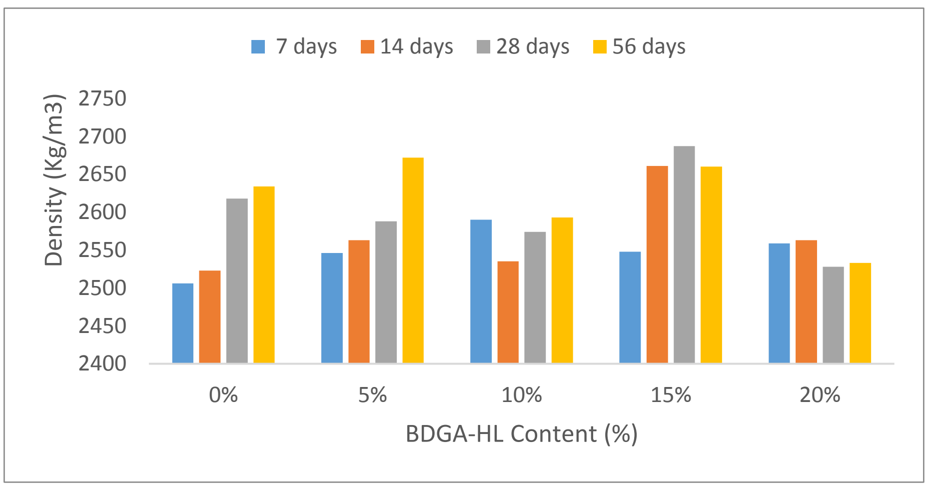

Figure 8 Density of BDGA-HL concrete at the curing days

Figure 9 shows the compressive strength of the different percentages of BDGA-HL in concrete. The results of the compressive strength of BDGA-HL concrete are presented in Table 3. In this study, the replacement of cement with BDGA-HL at 15 % in concrete yields a maximum compressive strength of 32.6 MPa at 28 days curing age. At 20 % cement replacement with BDGA-HL, the compressive strength decreases. The maximum strength results obtained is greater than the strength of plain concrete by 13 %. In fact, the compressive strength improvement of the blended cement concrete is attributed to the pozzolanic reaction of the reactive silica in the BDGA with the Portlandite (Ca(OH)2) formed during the Portland cement hydration process. The secondary Calcium Silicate-Hydrate (C-S-H) formed by this pozzolanic reaction reduces the amount of Calcium Hydroxide (Ca(OH)2) and increases that of C-S-H and hence, reduces the porosity by filling up the large capillaries and refining the pore system. Thus, compressive strength increases over time. The Calcium Hydroxide (Ca(OH)2) in hydrated lime also reacts with Silica in BDGA to form Calcium Silicate Hydrate (C-S-H) leading to an improvement in bond at the interface between the cement paste and aggregate. Interestingly, this further validates the results findings by Praveenkumar et al. (2019), Adesanya and Raheem (2009). According to Tuleun et al. (2018), an optimum strength of BDGA concrete without hydrated lime is achieved at 10% replacement. Islam et al. (2016) and Kanadasan, J. and Razak (2015) reported a reduction in compressive strength when cement was partially replaced with Palm oil fuel ash (POFA) pozzolan. They attributed the decrease in strength of POFA concrete to the lower density and high porosity of the POFA

The results when compared with the results obtained by Tuleun et al. (2018) on the use of Brewers dried grained ash without hydrated in concrete, shows a drop in compressive strength results when BDGA is used with hydrated lime than just BDGA alone. It therefore means that the use of BDGA without hydrated lime will give a better performance in concrete at a later stage than when BDGA is blended with hydrated lime. Nevertheless, the rate of strength development of BDGA-HL concrete at the 7 and 14 days curing age gave higher result values than the results obtained by Tuleun et al. (2018). At the 56 days curing period, the maximum strength is attained at 5 % replacement, with a resultant value of 38.6 MPa. Also observed as presented in Table 3, between the 7th and 14th day curing age, the rate of strength increases rapidly with curing age at 5% and 10% cement replacement with BDGA-HL in concrete; subsequently, from 14 days, 28 days to the 56th day, the rate of strength development decreases, meaning less calcium silicate hydrate is formed in concrete over time.

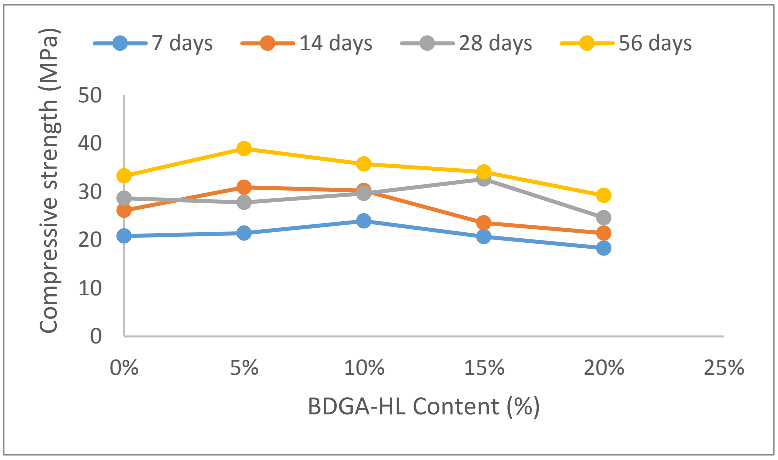

Figure 9 Compressive strength of BDGA-HL concrete at the curing days

Table 3 Results of density and compressive strength

Blend of Brewers Dried grain Ash with Hydrated Lime (BDGA-HL)										
Content (%) ((%)	0		5		10		15		20	
	A	B	A	B	A	B	A	B	A	B
7	2506	20.8	2546	21.4	2590	23.9	2548	20.7	2559	18.3
14	2523	26.1	2563	30.9	2535	30.2	2661	23.5	2563	21.4
28	2618	28.6	2588	27.8	2574	29.6	2687	32.6	2528	24.6
56	2634	33.3	2672	38.9	2593	35.7	2660	34.1	2533	29.2

A = Density (Kg/m3), B = Compressive strength (MPa)

Figure 10 shows the pattern of flexural and split tensile strength development as cement is partially replaced with BDGA-HL samples in concrete, while the results are presented in Table 4. It can be seen that the results of both the flexural and split tensile strength increases with BDGA-HL content up 10 % respectively. And beyond 10%, a drop in strength values is noticed. Result values obtained at 10 % replacement for both the split tensile and flexural strength are higher than that of OPC concrete by 9 % and 5 % respectively.

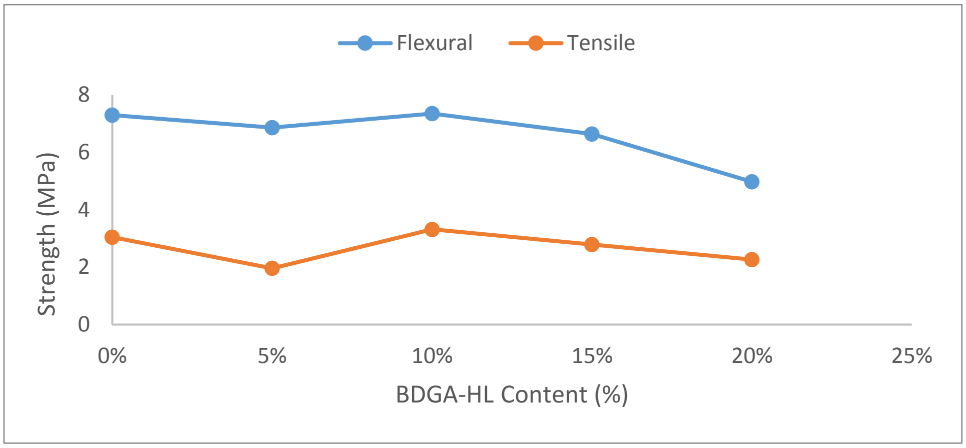

Figure 10 Flexural and split tensile strength of BDGA-HL concrete at 28th day curing

Table 4 Results of flexural and split tensile strength

BDGA - HL Content (%)	0	5	10	15	20
Split tensile strength (MPa)	3.05	1.96	3.32	2.79	2.26
Flexural strength (MPa)	7.304	6.867	7.355	6.641	4.977

Figure 11 presents the flexural load-deflection curve for the blend of brewers dried grain ash with hydrated lime in concrete beams. As shown in Figure 11, the peak load of 9806.5 N was attained at 10 % cement replacement with the ash, with a resultant deflection of 2.114 mm. This deflection obtained was greater than the deflection of plain concrete beam by 12 %. This therefore, means that even though the beam deflects by 12 %, it will be able to withstand an additional load of 9806.5N without failure.

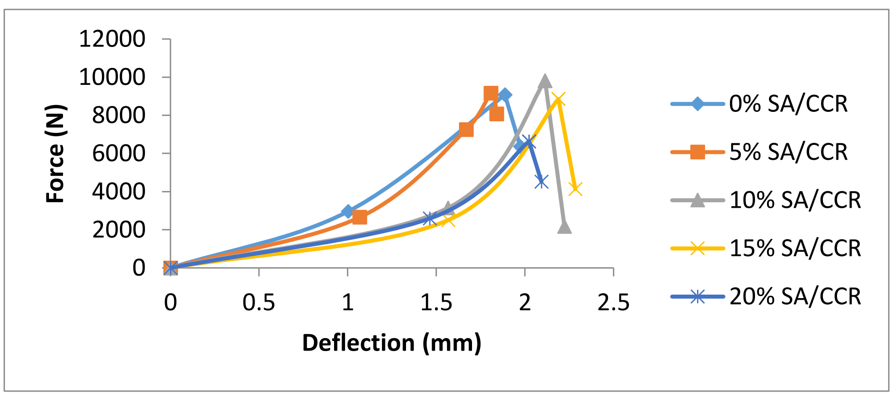

Figure 11 Flexural load, deflection curve of concrete beam specimens

4.0 CONCLUSION

The following conclusions were deduced from the study

i. The initial and final setting time of BDGA-HL mortar decreases as cement is partially replaced with BDGA-HL. The results obtained at 5%, 10%, and 15% replacement falls within the ASTM C618 (1978) permissible limit.

ii. The quantity of water required to achieve a particular target slump and workability in BDGA-HL concrete increases as cement is partially replaced with BDGA-HL content.

iii. The density of BDGA-HL concrete is in the range of 2503 - 2687 Kg/m3, which falls within the range of 2300-2800 Kg/m3 specified in BS standard for normal weight concrete.

iv. A concrete of improved compressive strength is achieved when cement is replaced with BDGA-HL at 10% replacement, and the result obtained is higher than the strength of plain concrete by 19.1%.

v. When subjected to static loading, the deflection of the beam specimen incorporated with BDGA-HL at 10% cement replacement level is greater than the deflection of plain concrete by 12%.

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