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Engineering Properties of Crushed-Fine Glass as Partial Replacement of Fine Aggregate in Concrete

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Abstract
Several challenges are resulting from poor management and utilization of construction wastes globally. Its menace poses a hazard to both human being and the environment. Addressing this menace is the focus of this research using fine waste glass (FWG) from construction waste to partially replace fine aggregate in concrete. Concrete cubes (150mm) were made using a different graded volume of 0, 5, 10, 15, and 20% of FWG. Sixty cubes in total were made and three cubes for each percentage of FWG cured for 7, 14, 21 and 28 days respectively. Engineering properties tests like density, compressive strength and water absorption were carried out. The results revealed that the densities of concrete cubes with 5 -15% FWG replacement were above 2400Kg/m^3 and the compressive strength at 28days for 0%, 5%, 10% ,15% and 20% replacement of fine waste glass were 27.06N/mm^2, 27.25N/mm^2, 25.58N/mm^2, 25.30N/mm^2 and 17.08N/mm^2 respectively. Thus, meeting the requirement for use in normal-weight concrete. In conclusion, replacement of fine aggregate with broken waste glass up to 15% is recommended for normal-weight concrete productions.

Keywords: Broken waste glass, Workability, Compressive Strength, Water absorption.

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1. Introduction
Industrial wastes are elements or materials originating from various human industrial and non-domestic activities that have to be dumped as waste. These industrial waste materials generally include domestic, industrial and medical wastes (Hogland & Stenis, 2000; Batayneh, et al, 2007). In specific, construction wastes are waste arising from construction and destruction activities, restoration, repair, elimination of prevailing structures, and installations (Lau et al, 2008; Gulghane & Khandve, 2015). These construction wastes include but not limited to the following: rubbles, sand, stone, granite, tiles (ceramic, clay, marble), glass, metal (iron, aluminium, copper) wood, rubber, asbestos, paper, paints, cables, pipes, electric parts, and so on (Carneiro, et al 2000). One of the core environmental concerns concerning the landfills in Nigeria is the effective management of such sites (Oluseyi, et al 2014). The management of waste and its attendant challenges have emerged as an important subject in today's ever-growing society (Oyelami, et al, 2013; Bassey et al, 2015). So, as the population levels around the globe are increasing particularly in Nigeria, there is an unprecedented surge in the levels of waste generated (Olukanni & Oresanya, 2018; Elemile, et al, 2019).

One of these construction wastes and non-biodegradable is Glass, and it is not suitable for disposal to landfill. Interestingly, glass can be recycled, but first needs to be sorted by colour. Recycling of glasses is an expensive process, and therefore a simpler way to use waste glass is in the construction industry is increasingly being adopted, such as an aggregate (Johnston, 1974; Adaway & Wang, 2015; Chung, et al., 2017; Lalitha, et al., 2017; Mohajerani, et al, 2017). Over the years, concrete has emerged as a major component in the construction industry due to its adaptability to forms, ease of construction, strength, and durability. Nevertheless, concrete production accounts for approximately 5-8% of worldwide greenhouse gas emissions due to its extreme resourceful and energy-intensive process. (Batayneh, et al., 2007; Drzymała, et al., 2020). Intrinsically, every opportunity to curtail the negative impacts of the concrete industry on the environment is required to be explored (Ling, et al., 2013; Srivastava, et al., 2014). Natural aggregates are becoming limited in quantities and producing crushed aggregate is costly. To this end, there is a ready-made market in the construction industry to use waste glass as an aggregate. The inclusion of recycled glass as an aggregate (coarse or fine) in structural concrete has the potential to not only reduce negative environmental impact and the consumption of existing raw materials, but also construction cost will be reduced (Shayan & Xu, 2004; Lee, *et al*., 2011; Lu, & Poon, 2019)

2. Materials and Methods

Crushed granite of a maximum size of 19mm was used for the study. It was obtained from the quarry located at Abeokuta Ogun State, Nigeria. The broken glass used was sourced from the glass sellers at Abeokuta, Ogun State of Nigeria and was broken down by hammer and sieved through an aperture size of 1.18mm sieve. Sharp sand used, was obtained from Sand sellers in Ilaro. Dangote brand of ordinary Portland cement (OPC) produced at the Dangote cement factory, Ibese Plant, Ogun State of Nigeria is obtained from the market at Ilaro in Ogun State was used in the concrete production with chemical properties shown in Table 1. The cement conforms to BS 12 (2000).

Table 1: Chemical and Physical Properties of Dangote Cement X3- Type of cement to be stated

Material	CaO	SiO_2	Fe_2O_3	Na_2O	Al_2O_3	K_2O	SO_3	MgO	Specific Density	Surface Area (cm^2/g)
CEM I 42.5N	63.14	20.53	2.36	0.21	5.33	0.72	3.39	1.49	3.05	3860

Water obtained from Federal Polytechnic Ilaro, Department of Civil Engineering was used in mixing the materials. Sieve analysis on both coarse and fine aggregates was done following BS 1377-2 (1990). The water used for this research work conformed to the requirements of BS 3148 (1980). The mixing of aggregate and water was done by hand and the composition is presented in Table 2 and the picture of the broken waste glass in Figure 1. Workability of fresh concrete was carried by slump method in accordance to BS 1881-102 (1983) and water absorption BS 813-2 (1995). Compressive strength was carried out following BS 1881- 116 (1983).

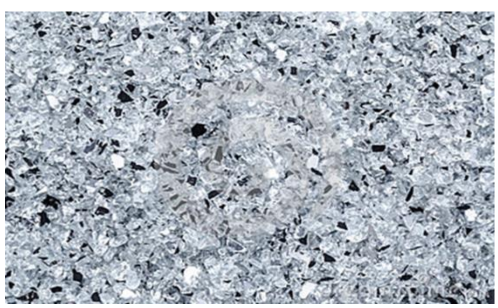

Figure 1: Broken waste glass after hammering.

Table 2: Batch Weight of materials (kg) for each mix with 0.5 water-cement ratio

	Mix I (0%)	Mix II (5%)	Mix III (10%)	Mix IV (15%)	Mix V (20%)
Cement	18.0	18.0	18.0	18.0	19.0
Fine Aggregate	36.0	36.0	36.0	36.0	36.0
Coarse Aggregate	72.0	68.4	64.8	61.2	57.6
BCT	0.0	3.6	7.2	10.8	14.4
Water	9.0	8.75	8.5	8.25	8.0

This study explored five different mixes designed and prepared at 5%, 10%, 15% and 20% replacement of sand with FWG and control set at 0% replacement. The aggregate grading was carried out to properly identify the particle distribution of the fine aggregate. The aggregates were mixed in their dry state and the quantity of water used equals the water absorption.

3. Results and discussions

The result of the particle size distribution for the coarse aggregate is presented in Figure 2. From the curve in Figure 2,

Coefficient of gradation (curvature)

$Cc = (D30)2/D60*D10$

$Cc = 92/13*3$

$= 2.08$ (well-graded)

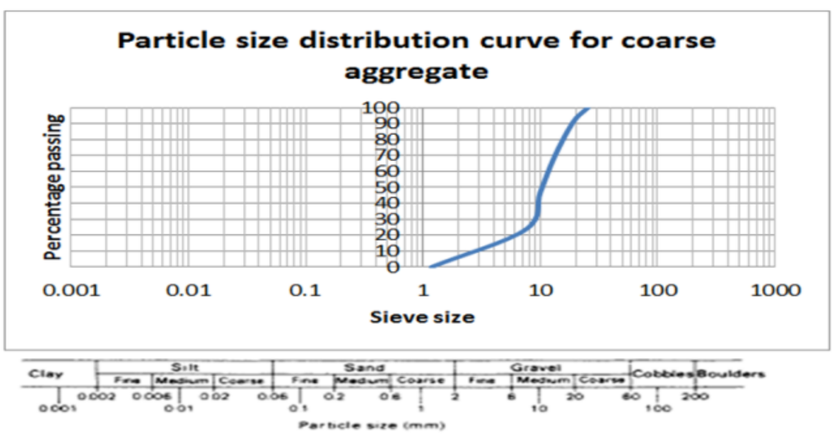

Figure 2: Particle size distribution curve for coarse aggregate (granite).

Coarse aggregate was well-graded according to (BS 1377; 1990) because Cu and Cc lie between 4 & 6 and 1 & 3 respectively.

Figure 3 shows the particle size distribution for both sand and the crushed waste glass. From the curve in Figure 3 for sand,

$Cu = D60/D10=0.40/0.16 = 2.5< 3$ (uniform)

$Cc = D302/D60*D10$

$Cc = 0.202/0.40*0.1=0.63$

$=0.63$ lies 0.5 and 2. (Well graded)

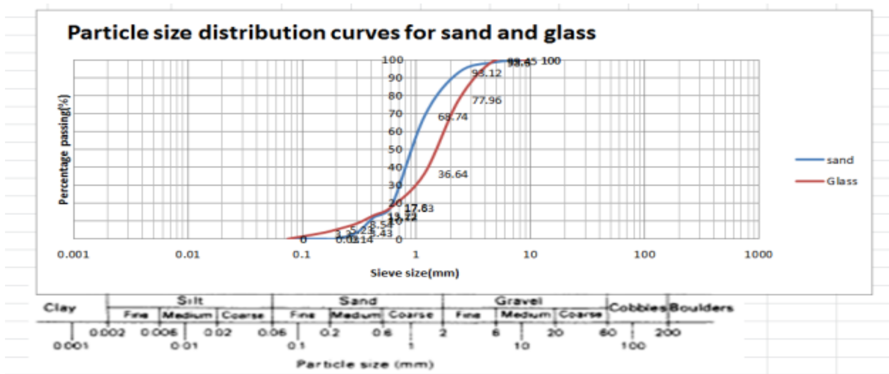

Fig .3: Particle size distribution for fine aggregate and crushed waste glass

From the Figure 3 curve for broken waste glass,

Cu=1.17/0.38=3.08 (uniform)
Cc= (D30)2/D60*D10
Cc = 1.002/1.17*0.38=2.22 (Well graded)

Fine aggregate (sand) and broken waste glasses were uniformly and well-graded according to BS 1377-2 (1990). The surface of the crushed waste glass is different from that of the fine aggregate with the surface of the crushed waste glass appearing smoother. It is further observed that the crushed waste glass contains flat and drawn-out particles which are commonly angular in shape.

3.1 Workability

Figure 4 shows a graphical representation of slump height for concrete containing conventional concrete and concrete containing different percentages of FWG at 1:2:4 with water-cement ratio of 0.5 All the measured slumps were true slumps and it was observed that the slump is 7mm, on reaching 5% replacement, it was 4mm and at 10 % replacement the height of slump was 6mm. The slump was 5mm at 15% replacement and 4mm at 20% replacement of fine aggregate with FWG in concrete.

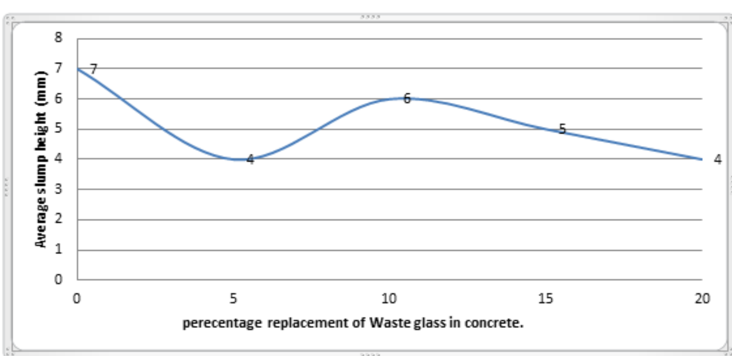

Fig 4: Average slump height against fine glass concrete

The highest Slump was 10% replacement and was the closest to the control mix. All the mixes are a good mix with workable concrete. Because the surface of the crushed waste glass is smooth, it is more impermeable and that account for the slump result.

3.2 Compressive Strength of crushed glass concrete (CGC)

The compressive strength of the concrete made with FWG as a partial replacement for fine aggregate at 28 days tests are presented in Figure 5. It was deduced that at 5% replacement, the compressive strength of 30.25N/mm^2 compared to the control specimen which has a compressive strength of 27.54N/mm^2.

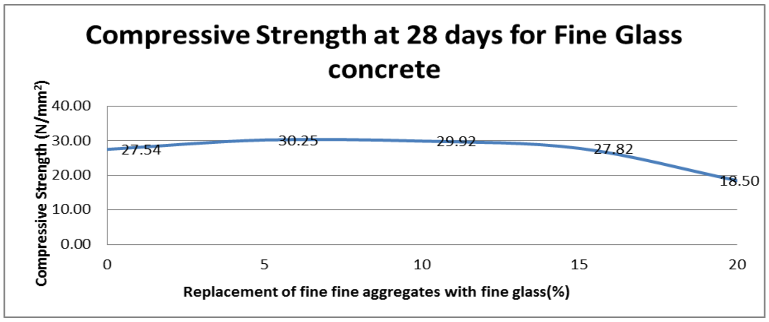

Fig 5: Graph of compressive strength at 28 days against percentage replacement of fine waste glass.

The compressive strength decreases to 29.92N/mm^2 at 10% replacement, and then declined further to 27.82N/mm^2 at 15%, replacement and at 20% replacement, compressive strength reduced rapidly to 18.50N/mm^2. The higher the waste glass content in concrete the lower the compressive strength, which is an indication that the shapes and smoothness of the FWG affect the strength of the concrete, this was also buttressed by Federal Highway Administration (2008).

Figure 6 presents the compressive strength of all the replacement aggregate over the tests period. The Compressive strengths are higher in the % replacement up to 15% replacement than the control with the optimal strength at 5%. The 5% replacement of sand with crushed waste glass give an increase in strength of 35% at 7 days test and 14.4% at 28 days test.

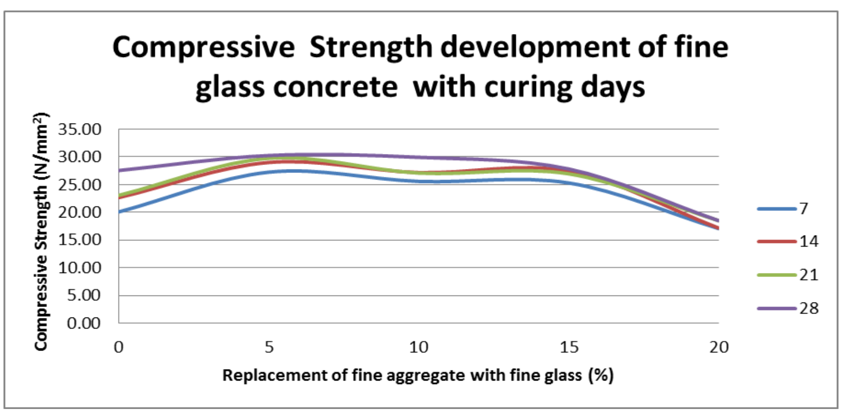

Figure 6: Graph of compressive strength development against curing days of modified concrete.

The 20% replacement of sand with crushed waste glass produced the lowest strength compared to the control specimen. The strength at 7 days was at 15% and gets higher at 28 days with a 35.7% reduction. The volume of the replacement is the cause of this drop in strength.

The results were further analysed using the best fit line for the % replacement with the 28 days compressive strength as depicted in Figure 7. Using Microsoft Excel, it gives a linear line with the equation:

$$y = -0.4102x + 30.908$$

where y is the compressive strength and x is the percentage replacement.

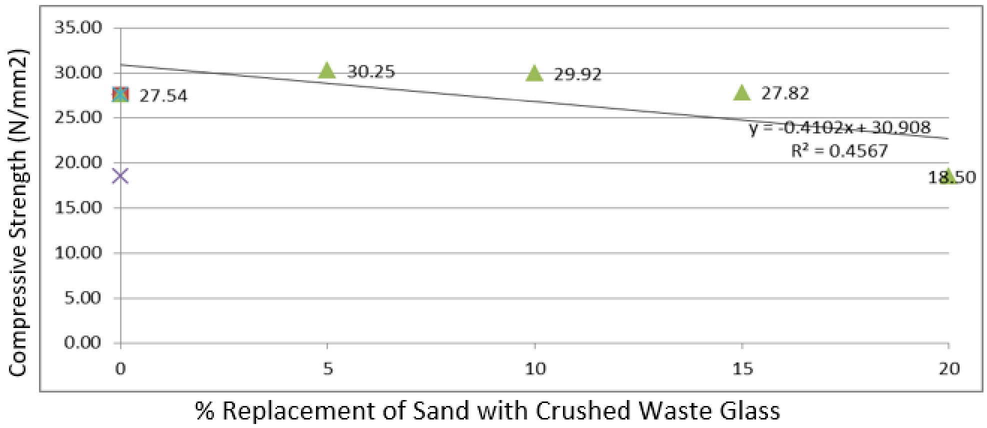

Figure 7: Compressive strength of waste glass concrete and percentage replacement of FWG in concrete.

There is a fair relationship between compressive strength and percentage replacement of waste glass in concrete with

$$R^2 = 0.4567$$

From the above analysis, for instance, to determine the quantity of crushed waste glass in concrete that will produce compressive strength of 25N/mm^2.

$$25 = -0.4102x + 30.908$$
$$x = 14.4\%$$

It means 14.4% of FWG will be required to produce compressive strength of 25N/mm^2.

3.3 Water Absorption

It was observed that 15% FWG concrete has the highest water absorption rate of 3% and 5% FWG has the lowest water absorption rate of 0.66%. It was shown that an increase in broken waste glass led to an increase in the water absorption of concrete.

Table 2: Water Absorption

	Weight (g)		
% Replacement	Before Curing	After Curing	% Water Absorption
5	8027	8080	0.66
10	8080	8186	1.31
15	7993	8240	3.00
20	5403	8140	

4. Conclusions

The research investigated the effect of crushed waste glass on fresh and hardened concrete. The effects of broken waste glass on workability, water absorption and compressive strength of the concrete were investigated.

From the results and analysis of this research, it can be concluded that the incorporation of broken waste glass affects the workability of fresh concrete, that is, an increase in FWG content in the concrete matrix led to a decrease in workability. Reduction in the compressive strength of concrete was observed at higher broken waste glass content. Concrete containing 5%, 10% and 15% FWG at 28 days compressive strength can be used to produce normal weight concrete. Concrete containing 10% broken waste glass has the lowest water absorption rate.

The regression curvey = -0.4102x + 30.908x and $R^2 = 0.4567$, can be used as a first-hand approximation to establish the trend of compressive strength at varying percentage.

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