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Exploration of Non-Biodegradable Materials in Concrete Production for University Building in Nigeria

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Abstract
Construction industry presents an attractive market for the use of non-biodegradable materials, because one of the principal components of construction is concrete, due to its high compressive strength. Incorporating waste glass as coarse aggregate in structural concrete has the potential to not only produce environmental benefits in the reduction of landfill, but to also reduce costs for university building in Nigeria. This paper described the influence of coarse glass on the fresh, hardened properties of concrete and compare to the control (0%) and the Scanning Electron Microscope (SEM) with Energy-Dispersive Spectroscopy (EDS). Coarse aggregate (gavel) was partial replacement with coarse glass aggregates at 5%, 10%, 15% and 20%. Tests are conducted in compliance with British Standard (BS). Mix ratio 1:2.5:3.5 (cement: fine aggregate: coarse aggregate) was used with 0.50 water/cement ratio to produce grade 25 concrete at 28 days. Results showed that slump decreases with increase in coarse glass. 10% partial replacement has good compression of 31.18 N/mm^{2}after 28 days and SEM analysis showed he portion of cracking and bonding effect which denoted the existence of Calcium Silicate Hydrates (C-S-H gel) and Calcium Hydroxide (CH). Therefore, glasscrete showed potential for becoming an additional sustainable solution for waste recycling.

Keywords: Waste, Mechanical, Slump, Glasscrete, Non-biodegradable materials.

Introduction

Most of the aggregates used are naturally occurring aggregates, such as crush rock, gravel and sand which are usually chemically interactive or inert when bonded together with cement. On the other hand, modern technological society is generating substantially high amounts of solid wastes, both in municipal and industrial sectors, posing an engineering challenge for their effective and efficient disposal. Hence, giving rise to partial or full replacement of fine aggregates by other compatible materials like sintered fly ash, crushed rock dust, quarry dust, glass powder, recycled concrete dust, and others are being researched from past two decades, in view of conserving the ecological balance (Olasehinde, 2024). Concrete is durable construction materials which is widely used in construction works. Most countries around the world already devise ways of recycling wastes products to replace and conserve natural resources used in producing concrete. The use of waste glass will not only help in conserving natural resources, it will also help in replacing construction materials made from non-renewable resources (Yussuf, 2015).

Concrete is mostly and continuously used for construction worldwide in which cement and aggregates are the most vital constituents. Further, these aggregates have been customarily treated as inert filler in concrete but in fact, aggregates not truly inert but its physical, thermal, and sometimes chemical properties influence the concrete. Due to tremendous demand of concrete as a construction material from the society, it is necessary to preserve the natural coarse aggregates by using alternative materials like recycled or waste materials. The management strategy for waste glass is recycling, which leads to minimizing environmental impact as well as conservating of natural resources (Chandran, 2017).

The use of siliceous aggregates such as glass in concrete involves a reaction of the concrete on the aggregate (alkali silica reaction). An expansive gel is formed on the interface aggregate-paste and involves an embrittlement of material by creation of microscopic cracks. As glass is mainly made up of silica, so it can be crushed into fine powder and can react with the portlandite (pozzolanic reaction) and form new Calcium Silicate Hydrate (C-S-H), which improves resistance of the concrete (Serifou, Boffoue, Jolissaint, Kouadio & Emeruwa, 2019). When the size of glass aggregate between 0.038 and 1.18 mm are used, the Alkali-silica Reaction (ASR) will not occur. The use of crushed glass as gravels would thus induce an alkali-silica reaction in the concrete (Serifou *et al.,* 2019).

According to Kara & Aleksandra (2012), concrete as a primary building construction material is the most consumed man-made material in the world. In 2007, the world concrete consumption was 11 billion tons or approximately 11.7 ton for each living human being. One of the most important parts of concrete is cement as hydraulic binder and production of cement itself is an energy-intensive and highly polluting process which contributes about 5% - 8% to global CO_2 emissions and accounts for 3% of total (5% of industrial) energy consumption worldwide. Production of each ton of cement results one ton of carbon dioxide (CO_2) into the atmosphere. The aggregates constitute approximately 80% of concrete volume.

The global concrete industry consumes about 10 billion tons of sand and rocks and taking into account today's industry development this number is even higher. Concrete is a necessary material in the human being's life, because of its superior characteristics like strength and durability. The interest of the construction community in using waste or recycled materials in concrete is increasing because of the prominence placed on sustainable construction (Venkatesh & Kumar, 2015).

Concretes which have been incorporated with coarse glass aggregates have in general been found to exhibit low compressive as compared to the normal concretes using conventional aggregates.

Coarse glass has been used as the replacement of the coarse aggregates and the crumb rubber which is almost a powdered form of rubber has been used as the replacement of fine aggregates. But the results by far have been found to be not so satisfactory but still appreciable. Some properties of concrete other than compressive strength get enhanced by the addition of rubber. Rubberized concretes possess ductile characteristics better than the normal conventional concretes. This property of rubberized concrete is useful in the construction of overlaying fatigued or cracked pavements. It can also be used as a durable crack resistant asphalt surface in new construction. More than 6 million of glass get dumped to landfills per year (Olasehinde, 2024).

Waste glass is a silent threat to the environment, and their disposal is a serious issue. To sort out this issue, many efforts were made to reuse the waste glass, but no significant results were achieved. Since waste glass is biodegradable and is present in large quantities, disposal of waste glass in open environment is considered to be a big problem in Nigeria. Out of the total waste glass that is generated, the majority of waste glass are not reused and recycled as it requires massive manpower and large processing cost (Olasehinde, 2017). Cost of crushed rock particles is rapidly increasing because of inadequate raw materials and rise of transport cost due to hike in fuel price and of other inputs. Further, mining of granite causes severe environmental damage by disintegration of rock strata causes landslide and earthquake. This emerging problem obliges contemporary material usage to balance the ecology (Tajamal *et al*, 2016). Therefore the present situation demands identification of substitute materials for the gravel for making concrete. To overcome such problems an experimental study was carried out to replace the coarse aggregate by recycled glass for concrete production.

The assessment conducted in this paper hence highlights the performance of concrete containing crushed glass. Section Two show the materials and methods of the study. The acquired results is presented in Section Three with a discussion of the results also provided in the same section. Section Four concluded the study with some recommendations.

Materials and Method

The materials for this research are ordinary portland cement, water, glass and coarse aggregate. An ordinary Portland cement with brand name Dangote cement was used. It conformed to BS EN 196-6. Fine aggregate which is clean, naturally sharp and free from any visible organic impurity and well graded of 100% passing through 4.75mm standard sieve size conforming to BS 410 was be used. The sand was be collected from Ahmadu Bello University Zaria Dam. Coarse aggregate which is clean, naturally sharp and free from any visible organic impurity and well graded of 100% passing through 19mm standard sieve size conforming to BS 410 was be used. The coarse aggregate was sourced from quarry site Hanwa Fly over Zaria, Kaduna State. The waste glass was be collected from various locations in Ahmadu Bello University, Zaria, Samaru main campus. Beneficiation process of the waste glass involved sorting, soaking, washing, drying and crushing using the dual purpose waste glass processing machine (DPWGPM-2017) at the Department of Glass and Silicate Technology Ahmadu Bello University Zaria. Water that is fit for drinking, free from colour and odour which could affect the strength of the concrete was sourced from the Department of Building, Faculty of Environmental Design, Ahmadu Bello University, aria public was used for mixing the aggregates and for curing the samples in the water tank.

The laboratory tests and analyses was conducted in the department of Building, Faculty of Environmental Design, and the department of Chemical Engineering, Faculty of Engineering, both in Ahmadu Bello University Zaria, Kaduna State, Nigeria. Department of Environment (DoE) method of concrete design was used to design a concrete of grade 25 at 28 days of curing in water. Batching of mix ratio 1:2.5:3.5 (cement: fine aggregate: coarse aggregate) was used. This is the modified mix proportion. The modification was done at the laboratory when casting the trial mix so as to be able to achieve the required level of workability while maintaining the same water-cement ratio as designed. The coarse aggregate was replaced with waste glass by 5%, 10%, 15% and 20% while 0% was control. 0.50 water-cement ratio is used based on what was designed using the DoE method of concrete mix design.

Table 3.1: Mix Proportion per Cube Specimen (100 x 100 x 100) mm of Concrete.

Glass Aggregate (%)	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
0	7.14	14.285	25	7.0
5	7.14	14.285	23.75	7.0
10	7.14	14.285	22.5	7.0
15	7.14	14.285	21.25	7.0
20	7.14	14.285	20.0	7.0

X-ray Fluorescence (XRF) machine with a brand name Xenemetrix was used in carrying out the XRF analysis on the recycled glass in the department of chemical engineering, Ahmadu Bello University, aria to determine the chemical composition of both materials.

Bulk density also known as the unit weight is the mass per unit volume of a material. A procedure was carried out in accordance with BS 812 part 2: 1995 for the bulk density of recycled glass. The bulk density of the aggregates was computed using:

$$\text{Bulk Density} = \frac{\text{weight of sample}}{\text{volume of cylinder}} - - - - - - - - - - - - - - - - - \textbf{Equation 3.1}$$

This is the ratio of the density of a substance to the density of a given reference material. This procedure was carried out according to BS 1377:2(1990) with the recycled glass. The specific gravity of the aggregates was computed using:

$$\text{Specific Gravity (SSD)} = \frac{\text{B}}{\text{P} + \text{B} + \text{Ps}} - - - - - - - - - - - - - - - - - \textbf{Equation 3.2}$$

The method and the procedure of producing the concrete was carried out in accordance with the provision stipulated in BS 12390-2:2000. This is the process of combining the materials together in order to achieve a homogenous mix. It was done mechanically. This is the process of moving freshly mixed concrete from the point of mixing to the point of placing it. A wheel barrow was used for this process. This is the process of placing the mixed fresh concrete into the mould. Before concrete was placed into the 50mm x 50mm x 50mm moulds, the moulds was oiled so as to enable ease of stripping.After the mixed concrete was poured into the steel mould, 2 layers with each layer receiving 10 seconds on model JB/T8292-1995 220V capacity made in China Concrete Vibrating Table (CVT) machine in order to expel air and void. The layer was levelled trimmed with the aid of a hand trowel. The cubes were allowed to dry at room temperature for 24 hours. After 24 hours, the cubes were removed from the moulds and immersed in water (curing tank) for 7, 14 and 28 days.

The slump test was performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It was also be used as an indicator of an improperly or properly mixed batch. This was carried out according to BS 12350- 2:2009. The compressive strength test was carried out so as to be able to know the maximum failure load which a sample can bear its fracture, divided by its cross-sectional area**.** This was carried out in the department of building, faculty of environmental design, ABU Zaria. The procedure was conducted according to BS 12390-3:2009. For the Scanning Electron Microscopy (SEM-EDS), this is a type of microscope that produces images of a sample by scanning the surface with a focused beam of electrons on the glass concrete. The electrons interact with atoms in the glass concrete sample, producing various signals that contain information about the surface topography and composition of the sample.

Result and Discussion

Physicochemical analysis tests for the materials used in the experiment as well as the test results for both the fresh and hardened concretes are presented.

Table 4.1: Bulk Density

Sample	**Bulk Density**
Coarse aggregate (gravel)	1852
Fine aggregate (sand)	1498
Waste Glass	1754

Table 4.1 presents the results for bulk density of materials: coarse aggregate, fine aggregate and waste glass are 1852 Kg/m^3, 1498 Kg/m^3 and 1754 Kg/m^3 respectively. Heavy weight manufactured or natural, bulk density are higher than 1498 kg/m^3, most commonly used in lightweight concrete, many must be screened to get the desired size distribution, and some must be crushed.

Table 4.2: Specific Gravity

Sample	**Specific Gravity**
Coarse aggregate (gravel)	2.40
Fine aggregate (sand)	2.65
Glass	2.72

Table 4.2 presents the results for specific capacity of the aggregates. The specific gravity value obtained for the coarse aggregate (gravel), fine aggregate (sand) and glass were 2.40, 2.65 and 2.72 respectively which shows that the glass contains high specific gravity than coarse aggregate (gravel) and fine aggregate (sand).

Table 4.3: Chemical Composition of Coarse Glass

Element (cps/mA)	Concentration	Peak
Fe_2O_3	0.26667 %	995
SiO_2	38.857 %	2908
Al_2O_3	1.627 %	25
MgO	1.72 %	2
CaO	7.1941 %	10691

The chemical composition of the coarse glass used for the research is presented in Table 4.3. The result shows that the XRF machine used for the chemical analysis was able to detect the major oxides (i.e. SiO_2, CaO, Al_2O_3 and MgO) with percentage value of 38.857 %, 7.1941 %, 1.627 % and 1.72 % (summing up almost 48.00 %) respectively. With the values of the major components exceeding 45 % as per requirement, coarse glass therefore satisfy the chemical requirement of ASTM C618-05 as a pozzolan material.

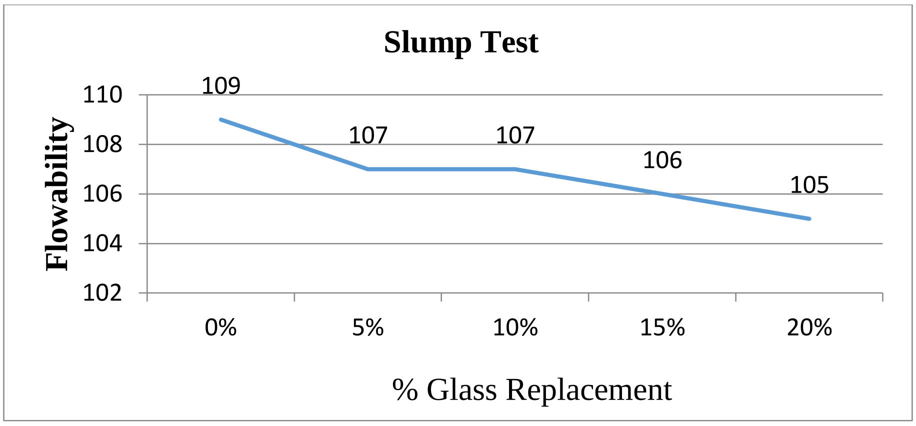

Figure 4.1: Flow ability graph versus percentage of partial replacement of glass.

Figure 4.1 shows the flow ability test results of concrete made with 0%, 5%, 10%, 15% and 20% partial replacement of glass. The water/binder ratio was kept constant in all the concrete mixes, in order to determine the effect of waste glass on the flow ability of the concrete. Water demand reduced in the concrete from 5% to 20% as glass replacement percentage increased. The decrease in water demand is most likely due to the nature of the particles reducing the water absorption of the mix.

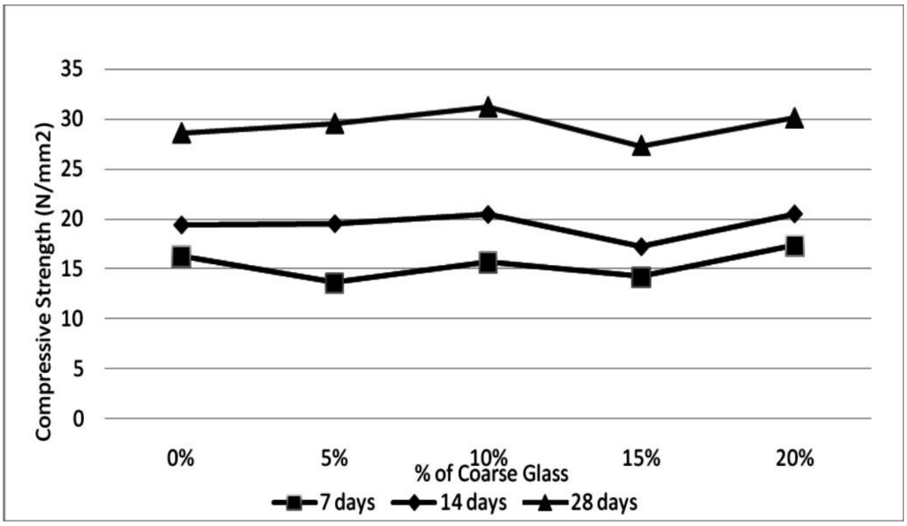

Figure 4.2: Compressive Strength of Specimen.

Figure 4.2 shows the compressive strength development in the glass concrete specimen. This reveals that the strength development of all the specimens containing glass is increasing with increase in curing age. The figure also reveals that increasing glass percentage increase the strength progressively as seen by the 10% showing the greatest in strength. However, the highest strength increments were at 10% cement replacement at 7, 14 and 28 days of curing. Cement paste with 10% replacement show strengths at 28 days curing that are comparable to the control (0%) strengths. Therefore, 10% replacement is considered the optimum percentage replacement in this research. However, similar finding was reported by Olasehinde (2024), who found that the compressive strength increased with the incorporation of glass at different curing days. The difference could be caused by the glass particles covering the anhydrous cement particles at early ages and therefore increasing the rate of cement hydration which may be due to the increase in OPC content.

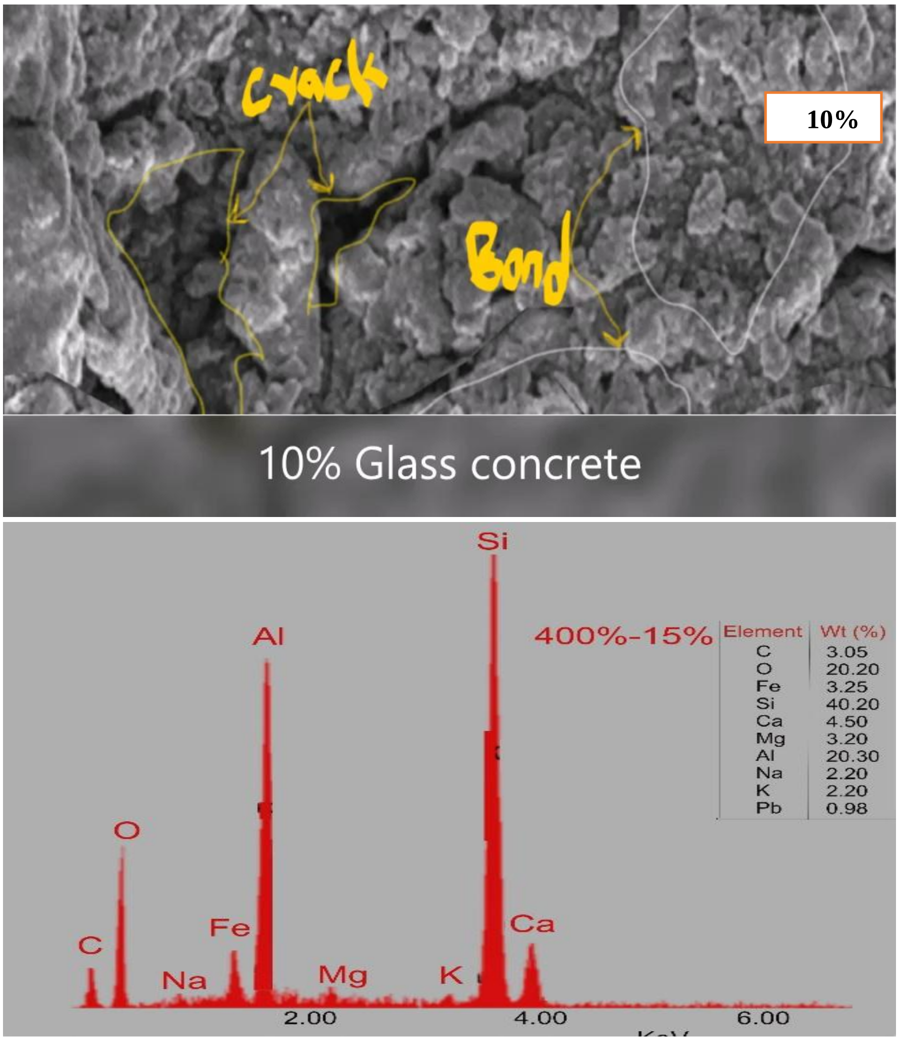

Figure 4: Scanning Electronic Microscopy (SEM with EDS) of 10% Glass Replacement.

Figure 4 shows the Scanning Electron Microscope (SEM-EDS) images were used to explore the microstructure of the corresponding 10% partial replacement, which gave the highest result for compressive strength test. SEM images of the specimen with glass replacement at the age of 28 days were investigated by means of SEM methods. The morphology analysis shows the portion of cracking and bonding effect which denotes the existence of Calcium Silicate Hydrates (C-S-H gel) and Calcium Hydroxide (CH) in all the sample at 28 days. It was observed that the presence of more C-S-H gel in the 10% specimen is due to pozzolanic reaction that took place. The EDS shows that Si has 40.20%, Al has 20.30%, O has 20.20%, Ca has 4.50%, Fe has 3.25% and Mg has 3.30%. This shows that the elemental composition are also found in the XRF result.

Conclusion and Recommendation

The paper examines the properties of coarse glass aggregates mixed in concrete where coarse aggregate are replaced by processed glass. The flow ability of all the specimens showed that water the demanded reduced in the concrete from 5% to 20% as glass replacement percentage increased. Compressive strength of the concrete with partial replacement of glass increased as the percentage replacement increases up to 10%. These findings indicated that it is advisable to use coarse glass aggregates in concrete mixes for high strength and load bearing applications. However, coarse glass aggregate can be used in other applications for non-load bearing components such as road paving, flooring, terrace and other construction activities. Using coarse glass aggregates in such applications can help to prevent pollution and overcome the problem of storing waste glass. Therefore, glasscrete have proved to be potential in concrete production for university building in Nigeria.

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