[1.]Oluwaseun Adedapo ADETAYO, [2.]Collins Ayomide OPASINA

VARIATION IN STRENGTH PROPERTIES OF CONCRETE USING WASTE GLASS AS PARTIAL REPLACEMENT FOR DIFFERENT COARSE AGGREGATES GRADING

[1-2.] Department of Civil Engineering, Federal University, Oye-Ekiti, NIGERIA

Abstract: This study examined the variation in the strength properties of concrete using waste glass aggregate (WGA) as partial replacement for different coarse aggregates grading. Aggregates sizes of 20mm and 25mm were partially replaced with WGA at 10%, 20% and 30%. Physical properties such as specific gravity, bulk density, and workability of fresh concrete and the compressive strength and tensile strength of hardened concrete of grade M25 were tested after 7, 14, 28, 56 and 90 days curing. Results of the physical properties revealed that WGA exhibited lower specific gravity of 2.70, bulk density of 1364kg/m^3, as compared to granite of specific gravity of 2.74, bulk density 1660kg/m^3. At 28days the compressive strength results of 20mm and 25 mm aggregate sizes of the control mix concrete were 35.05N/mm^2 and 34.02N/mm^2 respectively, while that of 30% of 20mm and 25mm WGA partial replacement were 39.02N/mm^2 and 32.83N/mm^2 respectively. The tensile strength for all the ages reached optimum value at 10% partial replacement WGA for both 20mm and 25mm aggregate sizes. The results of the strength properties showed that the concrete grade M25 adopted was suitable for WGA partial replacement as the compressive strength results for all ages did not fall below 25N/mm^2.
Keywords: waste glass aggregate, partial replacement, workability, strength properties

INTRODUCTION

Concrete is a composite inert material comprising of binder (cement), mineral filler (body) or aggregate and water. It is the name given to a mixture of particles of stone bound together with cement. Because the major constituent of concrete is of particles of broken stones usually gravel, and sand, which is termed the aggregate usually occupying 60-70% of the total volume of concrete. Cement acts as "glue" that binds the concrete ingredients together and is very important for the strength of the composite. The great demand of concrete is due to its structural strength and stability and also its favourable properties as a structural material, among which are its high compressive strength and its property as a fire-resistant element to a considerable extent.

Glass on the other hand is a hard, usually transparent substance formed by melting and cooling without crystallizing. [1], reported that the quantities of waste glass have been on the rise in recent years due to an increase in industrialization and the rapid improvement in the standard of living. The relative abundance of glass makes it available for production of concrete, this will consequently lead to low cost of production thereby making concrete structures (buildings) relatively cheap. Unfortunately, the majority of waste glass is not being recycled but rather abandoned, and is therefore, the cause of certain serious problems such as the waste of natural resources and environmental pollution. This recycled waste glass material has been studied in concrete masonry blocks, and tests on concrete with glass aggregate, including workability, permeability, and shear strength, have been performed to determine the suitability of the material in construction.

Literature survey indicates that the use of waste glass as aggregates in concrete was first reported over 50 years ago. [2], investigated and stated that the increasing awareness of glass recycling speeds up inspections on the use of waste glass with different forms in various fields. One of its significant contributions are to the construction field where the waste glass was reused for value-added concrete production. [3] discussed the various steps that need to be taken by recyclers in the use of glass which are to collect the glass, separate it from the other materials, clean it and crush it to obtain the appropriate grading to meet the specifications for specific applications as aggregate in concrete, either in commodity products, with the only objective being to utilize as much glass as possible, or in value-added products that make full use of the physical and aesthetic properties of colour-sorted crushed glass. [4], stated in their study that the use of waste glass or glass cullet (GC) as concrete aggregate is becoming more widespread each day because of the increase in resource efficiency. In the research of [5], waste glass and stone fragments from stone slab processing are recycled as raw materials for making artificial stone slabs using vibratory compaction in a vacuum environment.

Waste glass powder (40%) and fine granite aggregates (60%) are mixed with unsaturated polymer resins (8%) as binder. Under compaction pressure of 14.7 MPa, vibration frequency of 33.3 Hz and vacuum condition at 50 mm Hg, artificial stone slabs with high compressive strength of 148.8 MPa, water absorption below 0.02%, density of 2.445, and flexural strength of 51.1 MPa are obtained after 2 min compaction.

The artificial stone slabs fabricated in the study proved to be superior to natural construction slabs in terms of strength and water absorption. [6], stated that the demand for recycled glass has considerably decreased in recent years, particularly for mixed glass. Glass is cheaper to store than to recycle, as conditioners require expenses for the recycling process. In order to provide a sustainable solution to glass storage, a potential and incentive way would be to reuse this type of glass in concretes.

Depending on the size of the glass particles used in concrete, two antagonistic behaviours can be observed: alkali–silica reaction (ASR), which involves negative effects, and pozolanic reaction, improving the properties of concrete. Their work dealt with the use of fine particles of glass and glass aggregates in mortars, either separately or combined. [7], investigated the properties of concretes containing waste glass as fine aggregate. The strength properties and the alkali silica reaction expansion were analyzed in terms of waste glass content. An overall quantity of 80 kg of crushed waste glass was partially replacing sand at 10%, 15%, and 20% within a 900 kg of concrete mixes. The results proved 80% pozolanic strength activity given by waste glass after 28 days.

The flexural strength and compressive strength of specimens with 20% waste glass content were 10.99% and 4.23%, respectively, higher than the ordinary control specimen results at 28 days.

The mortar bar tests showed that the fine crushed waste glass helped reduce expansion of concrete by 66% as compared with the ordinary control mix. [8], investigated the effects of recycled glass cullet on fresh and hardened properties of self-compacting concrete.

Recycled glass was used to replace river sand (in proportions of 10%, 20% and 30%), and 10 mm granite (5%, 10% and 15%) in making the self-compacting concrete mixes. The experimental results showed that the slump flow, blocking ratio, air content of the recycled glass self-compacting concrete mixes increased with increasing recycled glass content. The results revealed that the compressive strength, tensile splitting strength and static modulus of elasticity of the recycled glass self-compacting concrete mixes were decreased with an increase in recycled glass aggregate content. [9], established that using waste glass gathered from coloured soda bottles as partial replacement for coarse aggregate (with proportion up to 60%) did not have a significant effect upon the workability of the concrete and only slight reduction was reported in its strength.

MATERIALS AND METHODS

— Materials

The waste glass materials used for the study were gathered from dumpsites and restaurants in Ikole-Ekiti. These materials were primarily wine bottles, soft drink bottles and alcoholic drink bottles as shown in Figure 1.

Figure 1. Waste glass collected before breaking

The waste glass materials were crushed manually using a metallic rammer and a metallic basin and were later separated into sizes of different grades using manual hand method as shown in Figure 2.

The selection of cement used involved the exact knowledge of the connection between cement and performance required and, in particular, between kind of cement and either strength or durability or both the properties of concrete [10].

Figure 2. Waste glass after being broken and separated

Type II Ordinary Portland cements, which can provide sufficient levels of strength and durability, and the most common cements used by concrete users was used with brand name Elephant. Its chemical composition was determined using X-ray florescence technique. Natural sand is the fine aggregate chiefly used in concrete mix. Sand may be obtained from sea, river, lake, etc, but when used in a concrete mix, it should be properly washed and tested to ascertain that it is free from clay, silt, and such organic matters. Fine aggregate used was river sand while crushed granite of maximum nominal particle size of 20 mm was used as coarse aggregate. The grading for the aggregates was done according to [11]. The uniformity coefficient (Cu) for the sand and granite were 5.4 and 5 respectively while their coefficients of curvature (Cc) were 1.36 and 1.0 respectively. Potable water was used in producing the concrete mixture.

— Mix Proportion

A mix ratio of 1:1:2 by weight (cement: fine aggregate: coarse aggregate) was adopted to achieve a concrete cube strength of $25N/mm^2$ and cylindrical strength of $25N/mm^2$. While the water – cement ratio of 0.5 was used. Waste Glass at 0%, 10% 20% and 30% replacement level were partially replaced coarse aggregate.

— Test Procedures

The mineral content of the digested sample were analyzed using Atomic Absorption Spectrophotometer (Buck Scientific 210 VGP), flame photometer (FP 902 PG) and their oxides were calculated using a conversion table. The production of concrete for this test was conducted at the Civil Engineering workshop at Federal University Oye-Ekiti according [12]. All of the materials were measured to scale as calculated using a weighing balance and then mixed thoroughly to avoid segregation. A mix ratio of 1:1:2 by weight (cement: fine aggregate: coarse aggregate) was adopted to achieve a concrete cube strength of $25N/mm^2$, the water – cement ratio of 0.5 was used. Waste Glass at 0%, 10% 20% and 30% replacement level would replace coarse aggregate grading. Mixing of the concrete was carried out manually with a shovel.

The workability test was carried out using a metal mould in the shape of a conical frustum known as a slump cone which is opened at both ends and has an attached handle. The tool typically has an internal diameter of 100mm at the top and 200mm at the bottom with a height of 300mm, as shown in Figure 3.

Figure 3. Concrete workability test using slump cone

Figure 4: Concrete moulds for Compressive Strength and Tensile Strength tests

The cone was filled with fresh concrete in three stages. Each time, each layer was tamped 25 times with a 600 mm long bullet-nosed metal rod measuring 16mm in diameter At the end of the third stage, the concrete was struck off flush with the top of the cone. The cone was carefully lifted vertically upwards with twisting motion so as not to disturb the concrete cone.

The upturned slump cone was placed on the base to act as a reference, and the difference in level between its top and the top of the concrete was measured and recorded to the nearest 5 mm to give the slump of the concrete. When the cone was removed, the slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways.

The mixed concrete was transferred into the moulds of 150 mm x 150 mm x 150 mm for compressive test and 300 mm x 150 mm cylindrical pipes for tensile test (Figure 4)

RESULTS AND DISCUSSION

— Chemical Analysis

The result of the chemical analysis summarized from the procedures above are given in Table 1.

Table 1: Chemical composition of constituent elements

S/N	Chemical Composition	Portland Cement	Waste Glass	Granite	Sand
1	Na_2O	0.51	9.609	5.194	0.356
2	CaO	62.60	21	7.114	0.223
3	K_2O	0.29	2.176	8.208	1.091
4	MgO	1.74	0.719	0.609	2.271
5	$AlO2_3$	5.09	3.017	9.670	12.104
6	OnM_3	0.007	0.072	0.275	0.03
7	Fe_2O_3	3.20	0.746	4.817	0.497
8	SiO_2	20.34	94.23	75.830	81.484
9	SO_3	2.19	0.012	3.701	2.130
10	LOI	0	0.023	2.096	0.697

— Physical Properties

The value of bulk density of granite, sand and WGA aggregate were 1660 kg/m^3, 1786 kg/m^3 and 1364 kg/m^3 respectively. Bulk density shows how densely the aggregate is packed when filled in a standard manner.

The bulk density depends on the particle size distribution and shape of the particles. Table 2 shows the results of the specific gravity, moisture content and bulk density of the aggregate samples.

It should be noted that the higher the bulk density the lower the void content to be filled by sand and cement. Since sand aggregate had maximum bulk it alludes that it has minimum voids and it's the right aggregate sample for making economical mix. WGA had the lowest bulk density and the result shows that it had about less weight compared to both the fine and coarse aggregate making it a light weight aggregate.

Table 2: Physical Properties of aggregate

Properties	WGA	Granite	Sand
Specific gravity	2.70	2.75	2.64
Moisture content	0.60	0.01	1.14
Bulk density	1364	1660	1786

— Slump Test

The variation of result of the workability of the fresh concrete mix at 20mm and 25mm WGA partial replacement is shown in Figure 5.

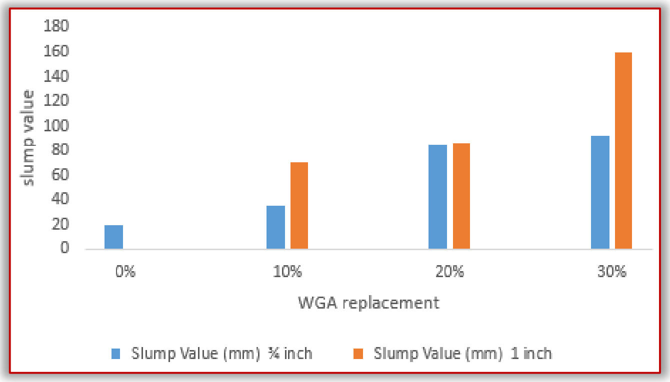

Figure 5. Workability of 20mm and 25mm WGA replacement

— Compressive Strength

The change in the compressive strength for concrete with different proportion of WGA at different percentages (0%, 10%, 20%, and 30%) for the 20mm granite replacement is shown in Figure 6, the compressive strength was found to decrease at 10% WGA glass replacement and then increased progressively as the percentage of the glass increases from 20% to 30%.

The maximum strength of the concrete cube was found at 30% replacement at 90 days which gave a compressive strength of 45.70 N/mm^2, while the lowest strength of the concrete cubes was found to be 27.98 N/mm^2 at 10% replacement of WGA at 14 days.

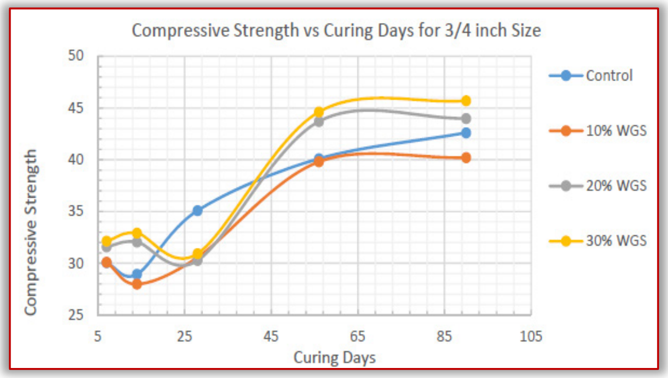

Figure 6. Compressive strength of concrete at 20mm WGA replacement at different proportion

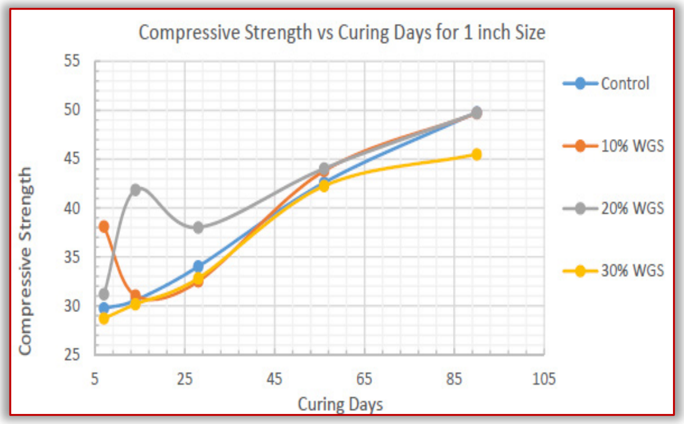

Figure 7. Compressive strength of concrete at 25mm WGA replacement at different proportion

The compressive strength for concrete with different proportion of WGA at different percentages (0%, 10%, 20%, 30%) for the 25mm granite replacement, the compressive strength was found to increase progressively at replacement from 0% to 20% and then continue to decrease at 30% replacement. For all ages except for 7days and 28 days which does not increase progressively from 0% to 20%, before it later decreased at 30 % like the other ages, as shown in Figure 7.

The maximum strength of the concrete cube was found at 0% replacement at 90 days which gave a compressive strength of 49.80 N/mm^2 while the lowest strength of the concrete cubes was found to be 28.71 N/mm^2 at 30% replacement of WGA at 7 days.

— Tensile Test

The tensile strength for all the ages reached it maximum at 10% and gradually began to fall as the percentages of the WGA increases except for the 90days result which strength decreases as the WGA increases from 0% to 30 %, as shown in Figure 8.

The maximum strength was 3.26 N/mm^2 at 10% WGA, 56 days curing age while the minimum tensile strength was 1.98 N/mm^2 at 30% WGA 90 days curing age.

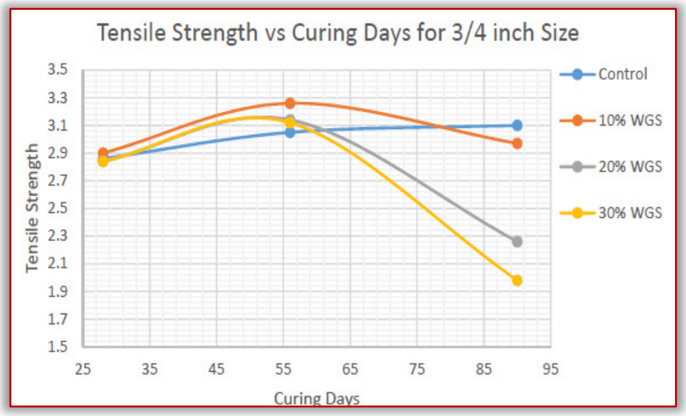

Figure 8. Tensile strength of concrete at 20mm WGA replacement at different proportion

The tensile strength for the 25mm WGA replacement for all the ages reached it maximum strength at 10% and gradually began to fall as the percentages of the WGA increases except for the 28 days result whose tensile strength decreases as the WGA increases in a nonlinear manner from 0% to 30%, as shown in Figure 9.

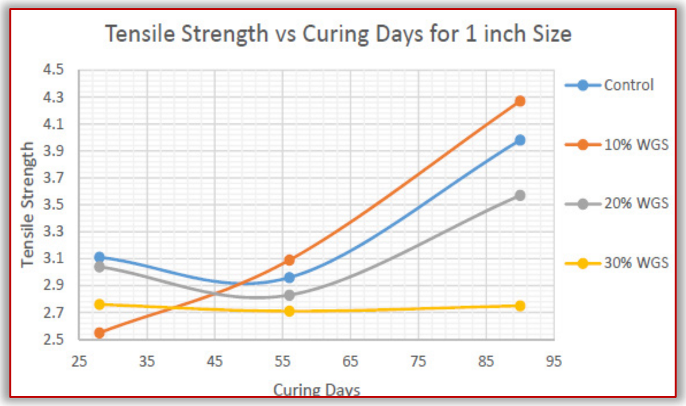

Figure 9: Tensile strength of concrete at 25mm WGA replacement at different proportion

At 10% WGA, 90 days curing age the 25mm WGA replacement was found to be 4.27N/mm^2 and the minimum tensile strength was found to be 2.55N/mm^2 also at 10% WGA, 28 days curing age.

CONCLUSIONS

Based on the findings of this study, the following conclusions were drawn;

- The physical and strength properties of the WGA are satisfactory, based on [13]. Physical properties such as specific gravity and bulk density values are found to be lower than corresponding values for the coarse aggregates, (granite). Waste glass aggregates WGA possess a low moisture content which affect the workability of the concrete at the mixing stage with subsequent effect on the hydration of the cement.
- The workability in the concrete mix with the 25mm WGA partial replacement was found to be greater than that of the 20mm WGA partial replacement because the 25mm WGA provides a greater void in the concrete mix, allowing for more air and water in the concrete mix which in turn resulted to the concrete mix of 25mm being more workable than the 20mm WGA.

Based on the physical properties of waste aggregate, WGA is a potential replacement for granite in regard with its different grading.

- The compressive strength of concrete with both 20mm and 25mm WGA increases as the curing age of the concrete increases progressively from 7 days up to 90 days.
- For the 20mm WGA replacement, the compressive strength at 10% was found to be lesser than that of the control mix (i.e. 0%) and the strength started increasing as the WGA increases progressively from 20% to30% increment and the maximum compressive strength was at 30% for the 20mm WGA.
- For the 25mm WGA replacement, the compressive strength of concrete at 10% was found to be lesser than that of the control mix, the maximum strength was at 20% of 25mm WGA replacement.
- Result showed that the tensile strength for all the ages reached it maximum strength at 10% and gradually began to fall as the percentages of the WGA increases for both 20mm and 25mm WGA replacement except for the 28 days and 90 days results whose tensile strength decreases as the WGA increases in a nonlinear manner from 0% to 30%.
- The densities of concrete with different proportion of WGA for the 20mm and 25mm coarse aggregate replacement ranges from densities of 2240 and 2400kg/m^3 and are classified as a Normal weight concrete and this helps in the optimization of concrete density to improve structural efficiency (the strength to density ratio), reduce transportation costs, and also enhance the hydration of high cementations concrete mixtures with low water-binder ratios.
- The M25 mix design used for this work was found suitable for the WGA partial replacement as the resulting compressive strengths for all the ages did not fall below 25N/mm^2 which was the minimum compressive strength of concrete of ratio 1:1:2.
- WGA is suitable in Civil Engineering construction with design mix M 25 up to 30% replacement without compromising the strength of the concrete

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