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E. I. Ogunjiofor
Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

R. Onuh
Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

K. C. Ojukwu
Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Correspondence:
E. I. Ogunjiofor
Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Compressive Strength Development of Concrete Produced with Partial Replacement of Fine Aggregate with Crushed Glass

E. I. Ogunjiofor, R. Onuh, K. C. Ojukwu

Abstract
This study investigates the compressive strength and properties of concrete produced from the partial replacement of fine aggregate with crushed waste glass thereby providing a reusable approach to waste glass bottles in concrete production. This experiment was focused on finding the best mix ratio with crushed glass replacing 5%, 10%, 15% and 20% of fine aggregate with the most desirable properties that would be effective in concrete works. Sieve analysis, bulk density, slump test and compressive strength test were carried out on the materials, fresh and hardened concrete. The results indicated that the average compressive strength for 7 days ranged from 14.15-15.49Nm, the 14 days ranged from 14.32-15.56Nm, the 21days values were between 15.06-16.00Nm, the 28days average compressive strength ranged from 20.00-20.60Nm, all with 0.50w/c ratio. It was discovered that adding waste glass to the mixture increased the compressive strength up until the ideal amount of replacement.

Keywords: Compressive strength, waste Glass, Concrete, fine aggregate, recycling.

1.1 Introduction

The utilization of waste glass as an aggregate in concrete has been endeavoured as of late in engineering and environmental research, this was a result of the environmental and recycling problems associated with the waste glass (Malik, et al, 2013). A strict decision, given the potential to reduce the cost of glass reuse, recycling and substantial creation, is to use such glass as a development material (Ismail and Al-Hashmi, 2009). The approach and variation between glass concrete and conventional concrete are common in design mechanisms. The major observable challenge is the glass aggregate's binding capability with cement paste. With glass compared to regular aggregate, the interlocking shear strength between the aggregate and the concrete adhesive seems to be lower (Masaki, 1995).

Conventionally sand is the major fine aggregate in use, it is characterized by the fineness that enables it to go in between the coarse aggregates. The excess usage of sand is posing a challenge in some areas where they are sourced ranging from erosion, challenges of a landfill, availability of land for agricultural crop challenge etc calls for concern (Viera et al., 2006) (Torres et al, 2017). Recent research has focused on evaluating the qualities of large stirs that incorporate waste glass as a midway substitution up to 20% by volume of sand (AL-Rubaie 2007). The results show that considerable blends with less than 20% replacement in waste glass are roughly equivalent to standard concrete and weigh less (Parthiban and Thirugnanasambandam, 2018).

The effects of using locally accessible scrap windows glass as fine aggregate on the mechanical characteristics of cement were investigated in this exploratory review studied by (Guatham et al, 2012). The compressive strength, elasticity, modulus of rupture, and extension of the cement and mortar examples were tested for various ages and glass extents ranging from 0% to 40% by weight of sand (Adaway and Wang, 2015) (Gautam, S. P. and Srivastava, V. (2012).

Concrete is one of the important and broadly utilized construction materials as most buildings are now made of reinforced concrete members (Gagg, 2014). The desire to lower the cost of concrete via alternative cheaper and comparative advantageous materials is one of the goals of modern engineering (Ogunjiofor, 2020). The viability of being able to utilize the available resources to provide a structure that would satisfy the required need at the lowest cost possible and the structure will still not fail at the maximum loading condition. This research is necessary since Building supplies have become more expensive recently as a result of inflation. Concrete, which is a combination of sand (fine aggregate), stones (coarse aggregate) binder (cement), and freshwater, is one of the main components of the majority of structures. The availability and cost of fine aggregate are affected by a few issues since it is made from natural crushed stone particles that have been processed through a 3/8-inch sieve rather than manufactured in a factory (Ilangovana et al, 2008).

In the past, the natural aggregate was the only type of material used to build concrete; but, as technology advances, various materials that can serve as substitutes for these aggregates are currently being researched. University of Al-Qadisyia researchers investigated the use of waste window glass as fine aggregate in a 2009 study. He replaced the fine aggregate with percentages of 10%, 20%, 30%, and 40%, and the results show that waste windows glass aggregate can be a sufficient replacement for normal fine aggregate at replacement levels up to 20% with properties similar to the provided control samples (Haider et al., 2009).

This study aimed to investigate the chance and proportion of waste glass as fine aggregate in concrete and to determine the optimum level at which crushed glass can be replaced partially as fine aggregate and also the properties of the glass-sand concrete.

Glass is one of the materials that is found in almost every section of human artificial materials, ranging from homes, appliances, laboratories, drinks etc. it is made up of sand, soda ash and limestone. It is usually one of the best means of storage and hardly reacts chemically with its content. The current way of life is farfetched without glass for its adaptable applications. Glass was found quite a while back in Mesopotamia and has been created for different applications from that point forward (Shi and Zheng, 2007). Glass is supplied in a variety of structures depending on the type of synthetic material used as well as lead glass (neon tubing, different TV pipes, electronic parts, and optical thick stone), borosilicate glass (compound devices, pharmaceuticals, and tungsten fixing), and aluminosilicate glass (ignition cylinders, fibreglass, and resistor substrates) (Jani and Hogland, 2014).

One of its disadvantages is that it takes over 400 years to decay (Scholze, 1991) and constitutes a large source of waste materials. Geotechnical investigations to date suggest that the use of recycled glass as a roadway sub-base could be cost-effective, and thus preclude the need for expensive sorting.

Glass is a material that can be recycled several times without losing quality and is completely recyclable (Sobolev et al., 2007). Due to variations in recycling rates between other nations, the waste glass began to be recycled in the 1970s, and since then, waste glass has been collected for recycling all over the world. Due to the low value of recycled glass, the mixing of various coloured glasses at the source, and the difficulty of eliminating diverse pollutants including soil, metals, paper, and compound buildups from the waste glass stream, recycling waste glass can occasionally be challenging (Afshinnia and Rangaraju, 2016). Hong Kong landfills collected daily an estimated 300 tons of used glass. The percentage of recovery was only 10% due to the low commercial value of waste glass and the absence of a glass manufacturing industry in Hong Kong. (Lu et al., 2017).

Only 29% of the 72,800 tons of waste glass that was produced in Singapore in 2011 was recycled. The reuse rate fell to 20% in 2016. According to the National Environmental Agency, 57,600 tons of the 72,300 tons of waste glass that were delivered that year were thrown away (2017). Just 26% of the 11.5 million tons of waste glass produced in the United States in 2013 was salvaged for reuse, according to the Environmental Protection Agency. Even though the amount of recycled glass climbed from 0.75 million tons in 1980 to several million tons in 2013, around 74% of waste glass—primarily lime glass from soft drink bottles—was discarded in landfills.

This research investigated the compressive strength development of concrete produced with partial usage of fine aggregate with crushed glass. Glass is one of the substances that does not biodegrade easily. Normal separation requires significant investment over time. Glass waste that cannot be recycled is taken to a landfill, which harms the environment (Sobolev et al, 2007). Involving it in the construction sector is a productive strategy to prevent glass waste from ending up in landfills and constituting an environmental nuisance. With varying degrees of success, a few specialists have concentrated on employing recycled waste glass in concrete as either one or the other aggregate (both coarse and fine aggregate). Most of these tests are restricted to research facility testing, and only a small number of them have concentrated on employing recycled glass in actual field applications (Bhat and Rao, 2014).

2. Materials and Method

2.1. Materials

- Waste Crushed glass: The researchers used crushed waste glass that was gathered from the scrap and waste bins. After collection, all undesirable items, such as labels, were removed before being crushed into the necessary sizes.
- Cement: Grade 43 Dangote Portland cement was used in the research.
- Fine Aggregate: Fine aggregate was regular river sand. The 9.50mm sieve was used to screen the sand since the sand that passed through it was used as fine aggregate.
- Coarse Aggregate: The common coarse aggregate was sieved via a 25mm sieve, and the material that passed through was collected as coarse aggregate.

2.2 Particle Size Distribution of the Aggregates

The aggregates were of evenly distributed sizes to ensure that quality concrete was produced. The waste glass bottles were properly crushed using a combination of a compaction machine and manual compactor machine to ensure that the glass particles were within the range of fine aggregate distribution as seen in Figure 1. For uniformity of the aggregate, sieve analysis was carried out on the fine aggregate and crushed glasses, they were put in sieves of different sizes and placed on the sieve shaker. The results of the fine and crushed glass sieve test were presented in Figure 5.

Fig. 1: Recycled waste glass as fine aggregate.

2.3. Batching, Mixing and Slump Test

The batching was done by weight with a mix ratio of 1:2:4 was used. The mixing method used for the production of the concrete was manual. The cement and fine aggregates were mixed properly on a plane surface until the mixture was homogeneous. Then the coarse aggregate was added to the mix and was turned properly until the mixture was homogeneous. Water was added until the concrete became homogeneous and of the desired consistency. A slump test was carried out on the fresh concrete to ascertain the workability of the concrete at different percentages. A sample of the slump cone test for 20% replacement was shown in Figure 2. The fine aggregate was batched by weight, and the crushed glass replaced 5%, 10%, 15% and 20% of the measured fine aggregate.

Fig. 2: Slump test for 20% replacement.

2.4. Placing and Compaction

We cleaned and applied oil to the mould (150x150x150), and poured the concrete in the moulds in layers, using steel rods, a poker vibrator was used to eliminate voids from the fresh concrete mix. After which the top level of the mould was levelled as seen in Figure 3.

Fig. 3: Vibrated fresh concrete in the mould

2.5. Curing and Testing

The curing was done by immersing the demoulded concrete cubes as seen in Figure 4 into the curing tank in the civil engineering laboratory after 24 hours of the cast and the specimens were cured for 7 days, 14 days, 21 days and 28 days respectively. The water used for the curing was free from impurities and chemical components to avoid interfering with the strength development of the concrete. The cured samples were removed from the curing tank, cleaned and allowed to air dry before placing them on the compressive test machine. The compressive strength test was done using the universal compressive testing machine, the cubes were placed in between the upper and bottom plate and the machine was set for the compressive test, gradually the cubes were loaded until the failure point and readings were recorded for all the cube crushing. I ensure that cubes were placed between the upper and bottom plates. The testing was carried out according to BS 8500-1 and BS 8500-2 (2002) specification

Fig. 4: Demoulded concrete ready for curing.

3 Result

3.1 Particle Size Distribution

The particle size distribution for fine and crushed glass aggregates was illustrated in Figure 5, it was shown that the sizes were properly distributed as required.

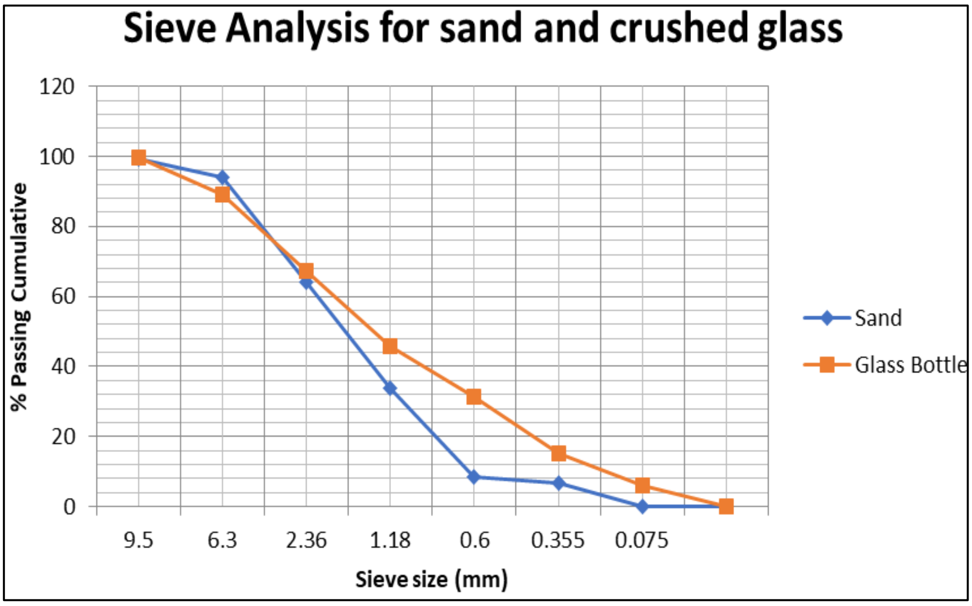

Fig. 5: Particle size distribution of sand and Glass particles.

Bulk Density

The results in table 1 were gotten from the bulk density test carried out on river sand and crushed glass.

Table 1: Sand and Glass Bulk Density.

Samples	Sand			Glass		
Mass (kg)	5.35	5.34	6534	5.94	5.92	5.92
Volume of bottle in(m^3)	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042
Bulk density in(kg/m^3)	1511.90	1509.52	1509.52	1652.38	1647.62	1650.00
Average bulk density	1510.31			1650.00		

Bulk density of the fine aggregate showed that the volume that the graded crushed glasses will occupy in the concrete production is in sequence with the BS Specifications. That the degree of filling voids when combined with other fine and coarse aggregates is above average. The average bulk density of crushed glass as seen in table 3 can be seen to be higher than the average bulk density of river sand. The High bulk density signifies that the crushed glass is characterized with low porosity and high compaction attributes.

3.2

3.3 Compressive Strength Test

Table 2 presented the compressive strength of the crushed cubes for different percentages of replacements.

Table 2: Compressive Strength Test Results of 7, 14, 21 and 28 days.

DAYS	0%	5%	10%	15%	20%
7DAYS	14.15Nm	14.19Nm	14.60Nm	15.04Nm	15.49Nm
14DAYS	14.32Nm	14.77Nm	14.96Nm	15.12Nm	15.56Nm
21DAYS	15.06Nm	15.23Nm	15.40Nm	15.64Nm	16.00Nm

28DAYS	20.00Nm	20.10Nm	20.40Nm	20.45Nm	20.60Nm

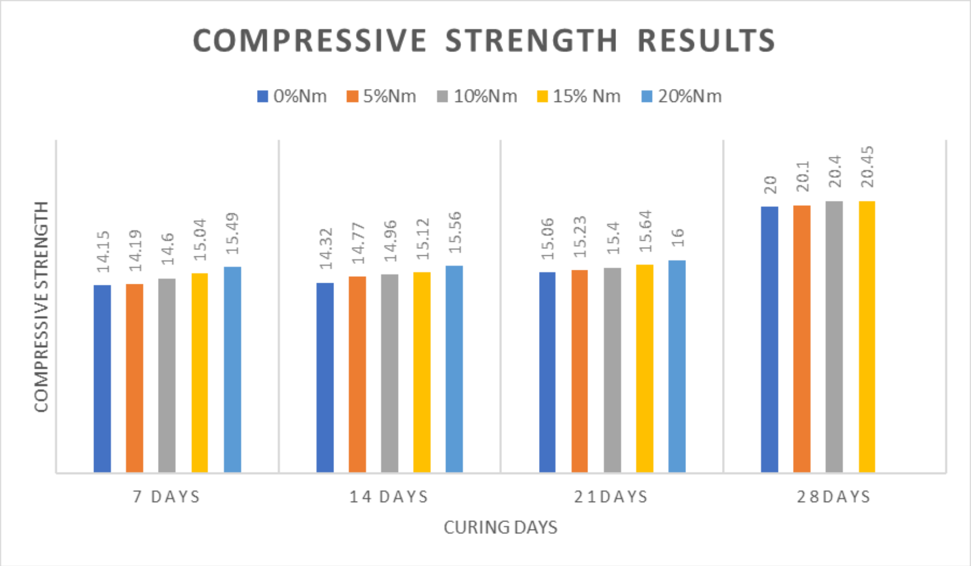

Fig. 6: Compressive strength results for different percentage substitutions.

The result of the average compressive strength for 7 days ranged from 14.15-15.49Nm, the 14 days ranged from 14.32-15.56Nm, the 21days values were between 15.06-16.00Nm, the 28days average compressive strength ranged from20.00-20.60Nm, all with 0.50w/c ratio, A Figure of compressive strength test was prepared to show and also for a better understanding of the variation amid the compressive strength of concrete and at the same water cement ratio when compressed at different days after curing. Figure 6 shows that concrete strength increased with time, the results obtained are acceptable for an M20 grade of concrete which has a minimum compressive strength of 13.5Nm for 7 days,14.32Nm at 14 days,15.06Nm at 21days and 20.00Nm at 28days.with a 0.50w/c ratio produced concrete, there was a progressive increment in compressive strength.

4. Conclusion

This laboratory investigation defined the characteristics of using waste crushed glass as a partial replacement for fine aggregate in concrete production. The sieve analysis result showed that crushed glasses are properly graded. The average bulk density was within the value of the control (fine aggregate). The mixing was found not to be different in characteristics with usually consistent behaviour. The slump test showed that the workability and consistency of the concrete up to 20% replacement is still in line with the BS specifications. The research is in line with the practices or policies that do not adversely impact the environment, this would have a dual positive impact on the environment by reducing the need for raw materials and avoiding extra landfill garbage. The optimal amount of fine glass aggregate to replace sand was found to be 20%.

The findings show that meaningful success can be achieved in recycling waste glass in concrete other than the landfill method which constitutes an environmental nuisance.

It was discovered that adding waste glass to the mixture increased the compressive strength up until the ideal amount of replacement. This is explained by the fact that the angular shape of the glass particles promotes stronger bonding with the cement mixture.

The waste glass was discovered to have a detrimental effect on the development of compressive strength in amounts greater than 30% (Haider et al., 2009). It is hypothesized that when used in greater amounts, the angularity of the glass aggregate reduces the amount of cement paste that is readily available and causes microscopic voids to form in the concrete matrix.

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