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Recycling of Waste Glass Cullet into High Quality Construction Bricks

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ABSTRACT: The use of glass cullet as aggregate material for concrete building bricks was investigated. A standard concrete batch (batch A), was formulated from cement, sand and ¼ inch granite aggregate in the ratio of 1:2:4. 25% of the granite aggregates were replaced by glass cullets of the same particle size range in Batch B and 50% of granite aggregate were replaced by glass cullets of the same particle size range in batch C. Batch D contains 75% of glass cullets in place of granite aggregates and batches E and F contain no granite aggregates at all, as they were replaced fully with glass cullets. Batch E contained the same ¼ inch glass cullets, while batch F contained 2 Parts (1/4 inch) and 2 Parts (1/8 inch) glass cullets in place of 4 parts of granite aggregates. Test pieces measuring 6cm x 6 cm x 6cm were cast from each batch and allowed to cure for 28 days. A water to cement ratio of 1:2 was used in all the batches. The cured concrete samples were tested for their cold compressive strength, apparent porosity, water absorption and bulk density. Batch A had a compressive strength of 35892.4 KN/m^2, batch B had a compressive strength of 48148.12KN/m^2, batch C had a compressive strength of 40908.4KN/m^2, batch D had a compressive strength of 23333.2KN/m^2, batch E had a compressive strength of 26110.8KN/m^2 and batch F had a compressive strength of 22222.4KN/m^2. Partial replacement of granite aggregates with cullets, in the range of 25-50%, improved the compressive strength of the concrete remarkably, possibly due to the reduction of the total porosity of the aggregate particles by the glass component. Further increase in the amount of cullets produced a declining result in strength, possibly because of the smooth texture of the cullets in comparison with the rougher texture of granite aggregate. All the concrete batches containing glass cullets have a remarkably higher compressive strength in comparison to sancrete bricks with a compressive strength value of about 4600Kn/m^2 reported in literature. These results suggest that concrete bricks made from such compositions containing cullets could be successfully employed in some load bearing walls, thereby reducing total amount of steel reinforcement. These results hold promising potentials in construction of low cost housing units, especially in developing countries, where high cost of granite quarrying makes the material quite expensive.

KEYWORDS: glass, cullets, granite, concrete , sandcrete, compressive strength.

I. INTRODUCTION

A building brick is a molded unit of ceramic material used in the construction of masonry walls, pavements, pillars and foundations. Brick is significant for the construction industry since the olden days, and it has several types such as burnt clay bricks, concrete bricks, fly ash clay bricks, sand-lime bricks, and engineering bricks. Bricks are very essential materials in the construction industry and it helps to build walls, foundations and road pavements. The selection of a particular type of brick would depend on the construction requirement, (Raju et al 2020).

In its earlier history, the construction industry relied typically on burnt red earth bricks for most of the construction of masonry walls. Environmental concerns over indiscriminant digging of earth for brick making has led to greater reliance on bricks made from mixtures of cement and sand. This type of bricks are often technically referred to as sandcrete bricks.

Sandcrete bricks are the main building materials for non- load bearing walls in West Africa and their compressive strengths are typically around 4.6N/mm^2. Introduction of aggregates improves the compressive strength to levels comparable to concrete which is about 40N/mm^2, Alain et al (2002). However, the addition of more solid materials makes the mix much less fluid, making it difficult to cast into blocks.

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Occasionally designs would require the use of bricks with higher strength to weight ratio for load bearing applications, for example in low cost buildings, where the use of reinforcement steel bars are minimal, Joglekar et al (2017). The compressive strength, water absorption and bulk density of the bricks becomes critical parameters in such situations, Iftikhar et al (2020). The strength, workability and durability of concrete mix for bricks production would depend on the water/cement ratio, as well as the physical and mineralogical properties of the aggregates, including shape, texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight, Mehta, et al (1993).
The amount of cement paste used in concrete is a critical economic factor since cement is the most expensive ingredient, (Mindess et al 1981). Besides the cost of cement paste, cost of aggregates is another significant consideration in the overall cost of a concrete mixture. According to Kosmatka et al (1994), though aggregates are considered to be inert filler material in concrete, the different properties of the aggregate have a large impact on the strength, durability, workability and economy of concrete.

Ola (2022), reported the cost of granite aggregate in most parts of Nigeria to be about N10000 per ton. According to Eze et al (2003), glass waste forms up to 4.5 percent of the solid waste generated in most urban areas in Nigeria. In 2003, Onitsha, an urban city in Nigeria with a population of about 740,000 and an area of 49,000 km2, generated about 370706 tons of solid waste, which translates to about 17,000 tons of waste glass, (Nwachukwu 2010).

The chemical composition of granite rock in most Nigerian locations was determined by Obiefuna et al (2018) to consist mainly of crystalline silica (above 70%), alumina (14%), K2O (5.4%), Fe2O3(2.7%) and CaO (2.6%). Karazi et al (2017) states that commercial soda-lime-silicate glass typically has the following composition: SiO_2 (73 %); Na_2O (15 %); CaO (7 %); MgO (4 %); Al_2O_3 (1 %), although actual composition could vary marginally, depending on the manufacturer.

Although glass is amorphous, a short range order yet exists in the silica tetrahedral, in so far as each silicon atom is bonded to four oxygen atoms and the bond strength in the tetrahedral is similar to the bond strength in crystalline silica, Zachariasen (1932). This fact suggests that glass cullet could provide reasonable strength as an alternative aggregate material in concrete. The lower comparative costs compared to crushed granite make them especially attractive in the development of low cost housing.

II. DESCRIPTION OF STUDY AREA

Preparation of glass culets, including crushing and sieving were done at the ceramic workshop of Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria. Mold preparation, batching of samples, casting of test pieces and curing, were also done at the ceramic workshop. Cold compressive strength of the test pieces were tested at the civil engineering laboratory, while other physical tests including apparent porosity, bulk density and water absorption tests were carried out at the physical testing laboratory of the ceramic and glass technology department.

III. MATERIALS AND METHODOLOGY

Broken pieces of colourless glass were gathered from a waste disposal site in Afikpo north local government area of Ebonyi state. The glass pieces were crushed using a jaw crusher and sieved on a mesh 3 sieve (6.7mm) and the oversized particles discarded. The sieved mass was then passed through a mesh 4 sieve and the fraction that did not pass through were collected. This particle size, i.e 4mm – 6.7 mm was similar to the particle size of granite used in the control sample. Wooden molds were prepared measuring 6cm x 6 cm x 6cm.

Various batches of concrete were formulated from the cullets and granite aggregates using a ratio of one part of cement to two parts of sand to 4 parts of aggregate. A water to cement ratio of 1:2 was used in all the batches. Table 1 below shows the composition of the various batches.

The moulds were lubricated with used oil for easy demolding of the test pieces. The prepared concrete were then cast in the prepared molds and allowed to set. After two days, the test pieced were demolded and allowed to cure for a total of twenty eight days from the day of casting.

After curing for 28 days, the test pieces were tested for their mechanical behavior using the cold compressive strength test. Each test specimen measured 6cm x 6cm x 6cm. The specimen was griped between the two flat plates of the compressive strength test machine. A compressive force was then applied on the specimen through the hydraulic system. The force was steadily increased until failure of the specimen occurred. The maximum load reached at failure was recorded as L_f.

The cold compressive strength was then calculated as,

$CCS = \frac{Maximum\ load\ at\ failure\ (N)}{Area\ of\ breaking\ face\ (mm^2)}$ ……Equation 1, Osonwa et al (2018). The average of three tests was used for each batch.

The apparent Porosity, bulk density and water absorption of the samples were determined using the soaking method as described by Gadzama et al (2016). Each sample was first weighed in air and the weight recorded as M_1. The sample was then soaked, fully immersed in water for 24 hours. The sample was then removed from the water and the excess water was wiped off using a dry cloth. The sample was then weighed again and the weight recorded as M_2.

The sample was then immersed fully in water and weighed again, and the weight was recorded as M_3. Apparent porosity of the sample was then calculated as,
$Apparent\ porosity\ (\%) = \frac{M_2 - M_1}{M_2 - M_3}\ x\ 100$ ……Equation 2

Table 1. Composition of the various batches of test pieces.

Batch	No. of parts of Cement	No. of Parts of Sand	No. of Parts of Granite Aggregate (1/4 inch)	No. of Parts of Glass Cullets (1/4 inch)
A (Control Sample)	1	2	4	0
B	1	2	3	1
C	1	2	2	2
D	1	2	1	3
E	1	2	0	4
F	1	2	0	2 Parts (1/4 inch) + 2 Parts (1/8 inch)

Bulk density of the sample was calculated as,
$Bulk\ density = \frac{M_1}{M_2 - M_3}$………..Equation 3
Water absorption of the sample was calculated as,
$Water\ absorption = \frac{M_2 - M_1}{M_1}$ x 100………Equation 4, (Gadzama et al 2016).

IV. RESULTS AND DISCUSSION

From the results presented in table 4.1, it can be seen that partial replacement of granite aggregates with glass cullet produced a remarkable improvement in the compressive strength of the concrete test pieces. Batches B and C which contained 25% and 50% replacements produced the best strength results compared to the control sample which contain no glass cullet.

Table 4.1 Results of Physical and Mechanical tests of the Batches.

Sample No.	Cold Compressive strength (KN/m^2)	Apparent Porosity (%)	Water absorption (%)	Bulk Density
A	35892.4	7.18	5	1.44
B	48148.12	6.7	4.9	1.38
C	40908.4	7.2	6.4	1.52
D	23333.2	13.45	12.8	1.08
E	26110.8	13.9	8.20	1.45
F	22222.4	15.13	12.9	1.26

The reduction of the total porosity of the aggregate particles by the glass component appear to have played a role in the strength improvement as suggested by Lo et al (2004). Further increase in the amount of cullets produced a declining result in strength, possibly because of the smooth texture of the cullets in comparison with the rougher texture of granite aggregate. Mindess et al (1981) reported that rougher aggregate surface generates a stronger bond between the cement paste and the aggregate, creating a higher strength.

It is worth observing that though batches E and F that contain full replacement of granite aggregates by glass cullet have lower strengths than batches A, B and C, the strengths of batches E and F are still significantly greater than that of pure sandcrete quoted in literature, i.e 4600KN/m^2. The values of apparent porosity, water absorption and bulk density of the samples are consistent with the general idea that increased pore presence reduces strength and density in any material.

V. CONCLUSION AND RECOMMENDATION

From the results of this research work, it can be seen that glass cullet can be successfully utilized as a partial or full replacement for granite aggregates in concrete formulations. The best strength development is achieved at between 25 to 50 % replacement of granite by cullets. The results of this research work hold promising potentials in construction of low cost housing units, especially in developing countries, where high cost of granite quarrying makes the material quite expensive.

The findings from this work also suggest that concrete bricks made from such compositions containing cullets could be successfully employed in some load bearing walls, thereby reducing total amount of steel reinforcement. Such compositions might also find use in low weight concrete applications, such as parapets and concrete facials.

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