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THE EFFECT OF CERAMIC WASTE AS COARSE AGGREGATE ON STRENGTH PROPERTIES OF CONCRETE

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ABSTRACT
This paper reports the findings on an experimental investigation of the effect of partial replacement of coarse aggregate with ceramic waste on strength properties of concrete. Compressive strength tests were conducted using 150x150x150mm cube specimens, while tensile strength was investigated using 150x300mm cylinder specimens. Results of tests show that workability, density, compressive and flexural strength of concrete decreased with increase in ceramic waste content. The compressive strength at 90 days curing age for the control sample was 24.67 N/mm². Compressive strength values at 90 days curing age for 25%, 50% and 75% replacement levels were 21.78 N/mm², 19.85 N/mm²and 17.85 N/mm² respectively. The decrease in density and strength was due to ceramic waste being lighter and more porous than normal coarse aggregate. Tensile strength of concrete with ceramic waste decline gradually from 8.39 N/mm² to 6.13 N/mm² for the control and 75% replacement samples respectively. This could be attributed to the water absorption capacity and external porcelain nature of the waste material. A production cost savings of 10.7% for 1:2:4 concrete mix was noted at 75% replacement level. This study concludes that ceramic waste could be used for both structural and non-structural works and recommends that beyond 75% replacement level, ceramic waste material should not be used in concrete structures where strength is the major consideration.

Keywords:- *Ceramic Waste, Aggregate, Compressive strength, Splitting Tensile Strength, Cost Analysis.*

1. INTRODUCTION
Concrete is the world's second most utilized substance after water and it shapes the built environment. it is also recoverable as recycled aggregate. An estimated 33 billion tonnes of concrete are manufactured globally each year. This means that over 1.7 billion truckloads each year, or about 6.4 million truckloads a day, or over 3.8 tonnes per person in the world each year. Twice as much concrete is used in construction around the world than the total of all other building materials, including wood, steel, plastic and aluminum [1]. According to Nigerian Environmental Society (NES), Nigeria generates over 60 million tonnes of waste annually with less than 10% waste management capacity. The need to manage these wastes has become one of the most pressing issues of our time, requiring specific actions aimed at preventing waste generation such as promotion of resource recovery systems (reuse, recycling and waste-to-energy systems) as a means of exploiting the resources contained within waste, which would otherwise be lost, thus reducing environmental impact. According to [2], million tonnes of these waste materials are abundantly available and discarded every year in the world. Recycling of such wastes as a sustainable construction material appears to be a viable solution not only for pollution problems control, but also as an economical option in the design of green buildings.

In Nigeria today, the increasing concern for environmental protection, energy conservation with minimal impact on the economy has been motivating researchers to look for other alternatives for coarse aggregates in concrete industry [3]. In view, different industrial waste materials such as fly ash, blast furnace slag, quarry dust, tile waste, brick, broken glass waste, waste aggregate from demolition of structures, ceramic insulator waste, etc. have been investigated as likely viable substitute material to the conventional materials in concrete.

Mujedu, *et al* [4] investigated the suitability of broken tiles as coarse aggregates in concrete production, and observed that the compressive strength and density are maximum for concrete cubes with 100% crushed granite and minimum when broken tiles content is 100%. It was reported in [4] that replacement of crushed granite with 39% to 57% broken tiles content showed satisfactory result. Kumar, *et al* [5] investigated the effect of waste

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ceramic tiles as partial replacement of coarse and fine aggregate in concrete and concluded that the compressive strength increased for all mixes and the maximum compressive strength was obtained for the mix having 10% of crushed tiles and 20% of tiles powder. They opined that the optimum percentage of coarse aggregate that can be replaced by crushed tiles is 10%. Takakoi, *et al* [6] studied the properties of concretes produced with waste ceramic tile aggregate and observed that the optimal replacement of ceramic tile aggregate for sand falls within 25% to 50% and 10% to 20% replacement levels was the best range for coarse aggregate. Further observation showed an increase in compressive strength and a decrease in unit weight due to the adverse effect of water absorption. Binici [7] used crushed ceramic waste and pumice stone as partial substitute for fine aggregates in the production of mortar and concrete. The results showed that the resultant product had good compressive strength and abrasion resistance, as well as strong resistance to chlorides attack. This provides greater protection for the reinforcement when used in reinforced concrete. Another noteworthy study was that of [8] in which the possibility of incorporating ceramic waste from electrical porcelain into concrete structures was investigated. The study demonstrated the viability of reuse, although the damaging effect of certain by-products which generated an alkali-aggregate reaction made it necessary to use sulphate resisting cement. Also, [9] studied the viability of incorporating coarse aggregate from concrete waste and ceramic block waste in the production of new concrete and concluded that as regards durability, structural concrete can be made using recycled aggregates, but that the 4-32 mm fraction of natural aggregates cannot be totally substituted. Various researchers have worked on partial replacement of coarse aggregate with ceramic waste, but little or no work has been reported on total replacement of aggregate with ceramic waste. This work aims at investigating the effect of replacing coarse aggregate with ceramic waste in production of concrete. The parameters to investigated are the physical properties, workability, compressive strength and tensile strength.

2. MATERIALS AND METHODS

2.1 Materials

To carry out the investigation, the following materials were used: cement, fine aggregates, coarse aggregates, ceramic waste and water. Cement used was Ordinary Portland Cement (Grade 32.5R) produced in accordance with the standards [10, 11].The water used for the experiment was portable tap water, free from any sulphate, ferric, alkaline, oils, vegetation or salt that could affect the properties of concrete in the fresh or hardened state [12]. River sand obtained from Ogun river basin located at Ibafo in Ogun State, Nigeria was used as fine aggregate. The sand was dried and sieved through sieve with the aperture size of 3.35mm but retained on sieves of 63μm and treated in accordance with the standard methods [13]. It was confirmed to be salt-free and free from deleterious substances.

The coarse aggregate used in this study was crushed granite of igneous origin. The size of the aggregate varied between 12.5mm to 19mm.The Ceramic Waste used was obtained from on-going construction sites within the University of Lagos.

The crushing of ceramic wastes was done manually and made into smaller pieces about 5-40mm sizes by hammer blows. The broken small pieces were then fed into vibrator, sieved to get the required 12.5 -19.0mm size. For the purpose of this investigation, a mix ratio of 1:2:4 by weight of cement, sand and coarse aggregate was used, and the water-cement ratio of 0.60 was adopted. The granite in the mix was partially replaced with ceramic waste at an interval of 25% up to 100%. Concrete with 0% CW replacement served as the control.

2.2 Methods

The following pertains to some laboratory procedures carried out in this report

2.2.1 Physical Analysis of Materials

Laboratory tests carried out on the aggregates include particle size distribution, specific gravity, dry and bulk densities, and moisture contents. Water absorption test was performed on both the ceramic waste and granite by keeping the samples immersed in water and removing the excess water on the surface of the samples after 24 hours, and measuring the saturated weight. After that, the samples were kept in the oven by maintaining 100 ±5°C for one day. Oven dry weight of the samples was recorded and the water absorption capacity evaluated.

Plate 1: Crushing and Sieving of Ceramic Waste

2.2.2. Workability Test

The slump test was carried out in accordance with the provisions of [14]. The replacement of coarse aggregate with CW was done at interval of 25% up to 100%. The sample without CW served as the control.

2.2.3 Compressive Strength Test

Compressive strength test was performed in accordance with [15, 16]. For the tests, 150x150x150 mm cube specimens were used. This test was performed to confirm whether the targeted 28-day compressive strengths for both the normal concrete and concrete having ceramic waste were achieved. The cubes were tested for their compressive strength at 7, 14, 28, 45 and 90-day curing ages. The strength characteristics of each cube were determined on 1500 kN Avery Denison Universal Testing Machine at a loading rate of 120 kN/min. Three specimens for each mix were tested at each curing age and the values of the crushing load were averaged and used to evaluate the mean strength for each batch. A total number of 75 cube specimens were produced and tested.

2.2.4 Tensile Strength Test

In order to assess the tensile characteristics of concrete samples produced with coarse aggregate partially replaced with ceramic waste (CW), the splitting tensile strength test was conducted on 150x300mm concrete cylinder specimens in accordance with the provision of [17]. The splitting strengths were determined on 1500 kN Avery Denison Universal Testing machine at a loading rate of 120kN/min until failure. The splitting tensile strength (Ts) was then calculated as follows:

$$T_s = \frac{2P}{\pi l d} \qquad (1)$$

In equation (1), 'Ts' is the splitting tensile strength (N/mm^2), 'P' is the maximum applied load (in Newton) by the testing machine, 'l' is the length of the specimen (mm) and 'd' is the diameter of the specimen (mm).

3. RESULTS AND DISCUSSIONS

3.1. Physical Properties and Sieve Analysis

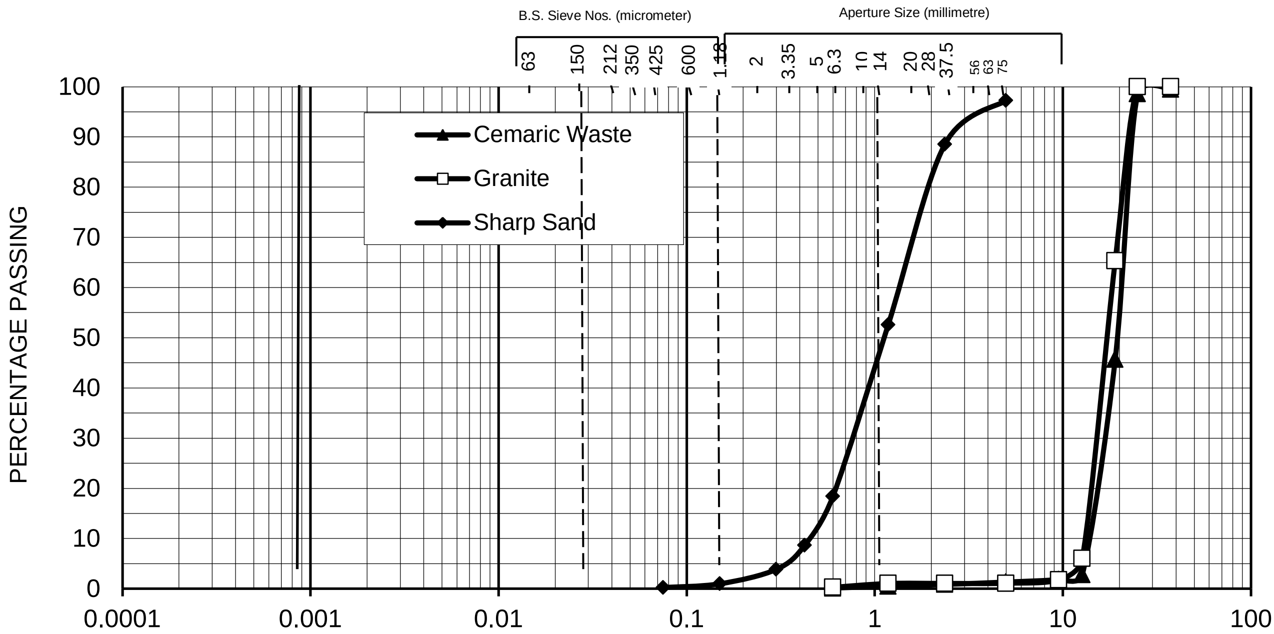
The results of the preliminary investigation on some physical properties of cement, ceramic waste, and aggregates used, are presented in Table 1. The values of bulk density and the specific gravity (properties that reflect the weight features of materials) for Ceramic Waste were lower than that of the granite. A higher water absorption value was observed for ceramic waste because of the surface area, pore structure, and clay content. The aggregate crushing value (ACV) for ceramic waste was found to be lower than that of normal coarse aggregate and this suggests the possibility of reduction in the compressive strength because ceramic waste exhibited lower capacity to resist load. From the results of sieve analysis conducted on the materials, the computed coefficient of uniformity $c_u = \frac{D_{60}}{D_{10}}$ for sand, granite and CW were 2.73, 1.43 and 1.40 respectively. Also, the coefficient of curvature $c_c = \frac{D_{30}\times D_{30}}{D_{60}\times D_{10}}$ for sand, granite and ceramic waste were 0.73, 1.03 and 1.15 respectively.

Grading curves showed that the sand, granite and ceramic waste were gaped graded and suitable for concrete production. The grain size analyses of the materials (fine aggregates, coarse aggregates and ceramic wastes) used is presented in Figure 1.

Plate 2: Avery Denison Universal Testing Machine

Table 1: Physical Properties of Aggregates, Cement and Ceramic Waste

Physical Property	Sand	Granite	Ceramic Waste	Cement
Fines Content (% passing through 600μm sieve)	-	-	-	99.5
Uniformity Coefficient (Cu)	2.73	1.43	1.4	-
Coefficient of Curvature (Cc)	0.73	1.03	1.15	-
Specify Gravity	2.50	2.76	2.16	3.15
Texture	-	Rough on all sides	Rough on all sides except top	-
Shape	-	Angular	Flaky	-
Dry Density (kg/m3)	1248.31	1102.86	947.54	-
Bulk Density ((kg/m3)	1410.59	1468.69	1323.43	1297.79
Moisture Content (%)	0.1391	0.5475	0.2028	-
Aggregate Crushing Value (%)	-	17.39	13.56	-
Water Absorption (%)	-	0.10	0.18	-



CLAY	fine	medium	coarse	fine	Medium	coarse	fine	medium	coarse	COBBLES
	SILT			SAND			GRAVEL			

Figure 1: Particle Size Distribution Curves for Materials

3.2 Effect of Ceramic Waste on Workability

Slump is a measure of concrete's workability or fluidity. Results of the slump test on the ceramic waste concrete are presented in Figure 2.

It was observed that the slump value decreased as ceramic waste content increased. This is an indication that inclusion of ceramic waste (CW) in the mix has effect on the cohesiveness of the mix to the extent of causing shear or collapse slump. This decrease in slump value with increase in CW content can be attributed to higher water absorption capacity and the angular shape of the ceramic waste.

3.3 Effect of Ceramic Waste on Concrete Density

The density of concrete is a measurement of concrete's solidity. Figure 3, illustrates the effect of ceramic waste content on the mass density of the hardened concrete for different curing ages. It was observed that concrete density increased gradually as curing age increased. Also, as the content of ceramic waste increased, the density of concrete decreased. The fact that the ceramic waste (CW) was lighter (Table 1) than the normal coarse aggregate could also have contributed to the lower density as a result of the loose packed inner matrix. The numerical values of all the densities at all replacement levels were in the density range for normal concrete of between 2200–2550kg/m^3 in accordance with [18]. Thus, replacing normal coarse aggregate with ceramic waste will cause a decrease in self-weight of concrete structures.

3.4. Effects of Ceramic Waste on Compressive Strength of Concrete

The compressive strength of concrete cube specimens for different percentages of ceramic waste are shown in Figure 4. It was observed that the compressive strength of ceramic waste concrete was 15.11N/mm^{2}and 17.85N/mm^{2}at 90 days curing age for 100% and 75% replacement levels respectively. Compressive strength decreased with increase in CW content. At 100% replacement level, the strength declined to 39% relative to control sample having its compressive strength as 24.67N/mm^2 at 90 days curing age. The strength value decreased as the percentage replacement increased from control (0%) to 100%. This is an indication that the substitution of normal coarse aggregate with ceramic waste aggregate beyond 25% replacement level is not recommended for use in structural works. The decrease in strength may be due to flaky nature and the smooth surface texture of ceramic waste aggregate; these probably resulted in poor bonding properties of the matrix. The strength values increased progressively as the curing age increased; an indication of the effect of curing age on concrete strength development.

3.5. Effects of Ceramic Waste on Tensile Strength of Concrete Cylinders

The effect of ceramic waste on the tensile strength of concrete is presented in Figure 5. Trends observed are similar to that of compressive strength. As the percentage replacement of granite with ceramic waste increased, tensile strengths of all the specimens decreased. At 100% replacement level, split tensile strength was lower by 26% for 7 days and 35% for 28 days when compared to the conventional aggregate concrete. As the curing age increased from 0 to 28 days, a gradual increase in tensile strength was observed and from 28 days to 90 days of curing, a decline in the values was noted. Tensile strength decrease may again be due to water absorption capacity of ceramic waste and reduced bonding between concrete constituents. This is also an indication that CW aggregate concrete may not be suitable for use in under-water environment.

3.6. Cost Benefit Analysis of Concrete with Ceramic Waste Aggregate

From Table 2, the production costs of 1m³ concrete with ceramic waste replacement at intervals of 25% were comparatively evaluated for 1:2:4 mix. Technically, the ceramic waste material being a waste, has no cost value. However, in preparing the waste material to be reusable, cost incurred in transporting, crushing and sieving to the required particle sizes was ₦2.06 per kg. This cost was used for the cost benefit analysis.

During the experimental work, cost of cement was ₦1650 per bag; that being ₦9900 for 6 bags of cement per m³. The cost incurred on water, fine and coarse aggregates were ₦100, ₦2250 and ₦5820 per m³of concrete respectively. The analysis was based on existing market values of the constituent materials and workmanship in Lagos state, Nigeria. It was observed that the cost savings on granite per m³ of concrete increased from 0 - 57.45% as the percentage replacement of CW is increased from 0-100%, but since 75% replacement can be used for structural works, the savings made was 43.14%.

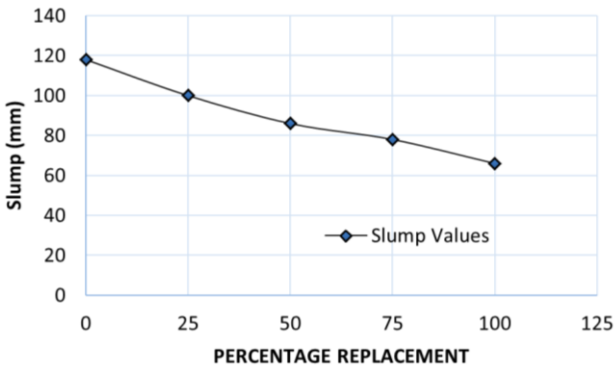


Figure 2: Variation of workability with CW content

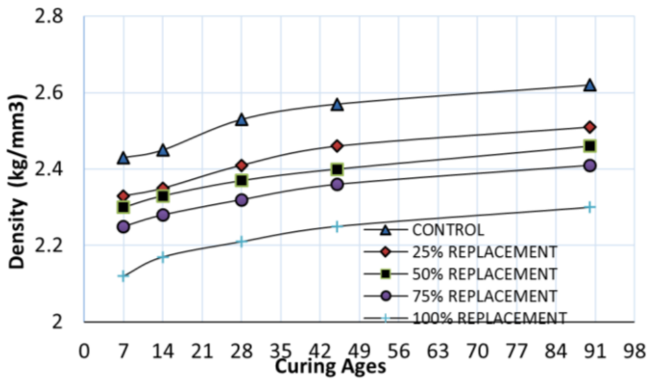


Figure 3: Variation of density with CW content

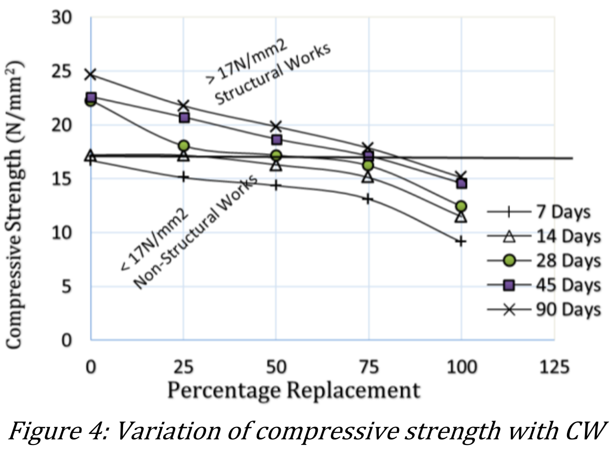


Figure 4: Variation of compressive strength with CW content

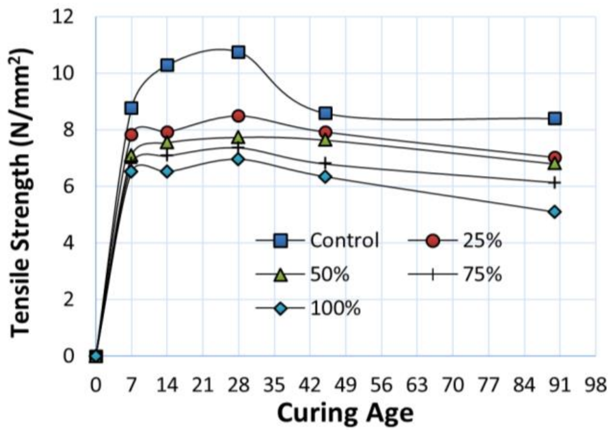


Figure 5: Variation of tensile strength with CW content

Table 2: Cost Analysis between Control Concrete and Ceramic Waste Concrete

S/No	CW Replacement (%)	Grade 25 Concrete w/c = 0.45	Cost Granite (₦)	Cost of Ceramic Waste (CW) (₦)	Cost of 1m³ Concrete (₦)	Cost Savings on Granite (₦)	Percentage Cost Savingson Concrete (%)	Percentage Cost Savings onGranite (%)
1	0		5,820	-	25,600	-	0	0
2	25		4,365	619.1	24,764.1	835.9	3.27	14.36
3	50	1:2:4	2,910	1,238.2	23,928.2	1,671.8	6.53	28.73
4	75		1,455	1,854.0	23,089.0	2,511.0	9.81	43.14
5	100		0	2,476.4	22,256.4	3,343.6	13.06	57.45

Also, the percentage cost savings on concrete was observed to have increased as the ceramic waste content increased. For structural concrete with percentage replacement level of granite with ceramic waste at 75%, the percentage savings in cost of concrete was 9.81%.

4. CONCLUSIONS

From the results of this investigation, the following conclusions are made:

1. The use of ceramic waste in concrete mix resulted in considerable reduction in the workability as replacement level increased.
2. The use of ceramic waste (CW) in concrete resulted in the decrease of its density but was still within the normal concrete range values. If used, this also could result in reduced dead weight of concrete structures.
3. The strength of ceramic waste concrete decreased due to higher flakiness value, weaker bonding of the aggregate with cement paste due to porcelain surface and higher water absorption of the ceramic waste aggregate. Hence, the substitution of coarse aggregate with ceramic waste beyond the 75% replacement level is not recommended for use in structural concrete.
4. The use of ceramic waste in concrete is an effective way to reducing the costs of concrete and keeping the environment clean through efficient management of waste and decrease in the use of normal coarse aggregate in concrete production.

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