Original Research Article

Assessing Fresh Concrete Performance and Water Absorption Characteristics of Concrete with Partially Replaced Broken Tiles

UNDER PEER REVIEW

ABSTRACT

A number of research seeking alternative materials to augment normal coarse aggregate to reduce overreliance on granite while saving the environment is on the rise. This study assessed the workability, water absorption and density of concrete with waste ceramic tiles as partial replacement for crushed granite coarse aggregate. Crushed waste ceramic tiles from ceramic manufacturing industries and construction sites were blended with crushed granite for concrete production. A mix ratio 1: 1.11: 2.72 (cement: sand: coarse) for nominal C30 concrete was produced with (0, 10, 20, 30, 40, 50 and 100) percent volume ceramic waste replacement for crushed granite at constant water-cement ratio of 0.5 to produce concrete cubes and cured for 7 and 28 days. Tests conducted revealed concrete workability and density decreased with increasing ceramic waste while water absorption increased with increasing ceramic waste but not above acceptable limits. However, use of waste ceramic tiles as partial replacement for crushed granite in concrete is encouraged, but not exceeding 20% maximum for structural concrete. This mode of recycling ceramic waste could positively promote green construction for sustained environment.

***Keywords**: Ceramic waste, partial replacement, crushed granite, concrete, workability, water absorption.*

1. INTRODUCTION

The coarse aggregate in concrete occupies the largest volume, and is generally thought of as passive material within a concrete mix. Aggregates form between 60% and 75% by volume of a typical concrete mix (Maza et al, 2016). Coarse aggregate plays a major role in terms of properties of both fresh and hardened concrete. The composition, shape, texture, size and properties of the aggregate contribute to the workability, density, strength, water absorption and durability of concrete.

Largely, coarse aggregates are classified into heavyweight, normal and lightweight aggregates. The classification is selected based on important considerations that must be made by the Structural Engineer. Heavyweight aggregates provide an effective and economical use of concrete for radiation shielding by giving the necessary protection against X-rays, gamma rays and neutrons, and for weight coating of submerged pipelines. The effectiveness of heavyweight concrete, with density ranging between 4000 kg/m^3 and 8500 kg/m^3, depends on the aggregate type, size, shape and the degree of compaction. The normal aggregates are suitable for most purposes and produce concrete with a density ranging from 2300 kg/m^3 to 2500 kg/m^3 while Lightweight concrete ranges from 1800 kg/m^3 to 2200 kg/m^3. Lightweight aggregates are applicable in a wide variety of concrete products ranging from insulating screeds to reinforced or prestressed concrete although their greatest use has been in the manufacture of precast concrete blocks. Concretes made with lightweight aggregates have good fire resistance properties (Neil and Dhir, 1996).

The need for crushed rock aggregate in Ghana and the world at large to support infrastructural projects such as roads, bridges, seaports and buildings increases daily. This in effect deteriorates the environment as the rocks are natural in nature and also get depleted and scarce, thereby promoting increased concrete cost vis-à-vis the need to protect the environment. The situation leads to increasing research to develop alternative materials that could substitute or partially replace crushed rock. One material capable for such replacement is waste ceramic tile aggregate which is extensively available at almost all construction sites and their sales points in Ghana and several other countries in the world (Njogu, 2022;Singh and Singla, 2013;Daniyal and Ahmed, 2015; Biney, 2020). It is also very common for one to find ceramic wastes from construction sites being dumped as filling material in depressions and open gaps in the fields (Biney, 2020). Tonnes of ceramic wastes are also generated from the ceramic industries in Ghana which are not put into any good use (Biney et al., 2022). More recently, Njogu (2022) partially replaced natural coarse aggregate with ceramic coarse aggregate (0%, 10%, 20% and 30% volume) in concrete to assess its compressive strength and water absorption properties. The author observed that adding ceramic coarse aggregates up to 20% led to a notable increase in the compressive strength of concrete, but drastically decreased at 30% below the control while water absorption increased significantly. Ceramic waste aggregates are hard, have considerable value of specific gravity, rough surface on one side and smooth on other side, and

UNDER PEER REVIEW

are lighter in weight than normal stone aggregates (Singh and Singla, 2015). They are manufactured from a mixture of clay, sand and other natural substances, moulded into the required shapes, and finally fired in kilns at extremely high temperatures between 1000°C and 1250°C (Framinan et al., 2014). Apart from favourable financial effects, using ceramic waste as coarse aggregates will benefit the natural foundation because they are lighter than typically crushed stones from quarry sites. The environment is also shielded from deterioration to prevent what otherwise might happen. This research therefore, focused on assessing suitability and sustainability of producing concrete of adequate workability, density and water absorption resistance with waste ceramic as partially replaced coarse aggregate for crushed granite and determining the best coarse aggregate mix ratio to achieve these properties.

2. EXPERIMENTAL METHODS

2.1 Materials and procedure

Pit sand from the Greater Accra Region of Ghana, granite that had been crushed in a quarry, regular Portland cement (GHACEM) of grade 32,3R, potable water, and leftover ceramic tiles waste from construction sites and retail locations were all used in the study. With the experiment to make various concrete mixes of grade C30 nominal strength (for a mix ratio of 1: 1.11:2.72) at a constant water-cement ratio of 0.5, waste ceramic aggregate was used in place of crushed granite aggregate in varying percentages (0, 10, 20, 30, 40, 50, and 100). In order to ascertain the aggregates' physical characteristics and workability, slump tests and material tests were performed on fresh concrete. Then, on the 7th and 28th days, concrete cubes measuring 150mm x 150mm x 150mm cast from the various mixtures were tested for water absorption and density. The test findings were then compared with reference values from texts.

2.2 Tests on Materials

Several tests were carried out in accordance with British Standard Codes of Practice (BS 812: Part 112, 1990; BS 882, 1992; BS 1881: Part 122, 1983 and BS 812: Part 109, 1990) and the American Society for Testing Materials (ASTM C 150, 2017). Gradation, Organic matter,

UNDER PEER REVIEW

Moisture Content, Bulk Specific Gravity, Loss Angeles Abrasion (LAA), Aggregate Impact Value (AIV), slump and water absorption were among the tests performed, as detailed in the sections that follow.

2.2.1 Sand

The tests conducted on the sand were Gradation, Organic matter content, Moisture content and Bulk Specific Gravity accordance with BS 812, Part 112: 1990. A sample of the test specimen is shown in Fig. 1.

Fig 1: Sample of sand used

Fig 2: Sample of coarse granite aggregate used.

Fig 3: Sample of ceramic waste aggregate used.

UNDER PEER REVIEW

2.2.2 Crushed Granite and Ceramic Tiles

Crushed granite sampled from Cedar Quarry at Shai Hills in the Greater Accra Region of Ghana was used as the normal coarse aggregate and partially replaced with broken ceramic tiles of 20mm maximum size from construction sites in Accra. They were tested to assess their engineering properties such as Gradation, Moisture content, Bulk Specific Gravity, Aggregate Impact Value and Los Angeles Abrasion value, in accordance with standards or specifications in the BS 882 (1992). Figures 2 and 3 show samples of the coarse granite and ceramic aggregates used in the study.

2.3 Details of Tests Conducted on Materials

Testing of the materials (or ingredients) for the concrete was necessary as it had great impact on the outcome of the product.

2.3.1 Gradation Test

Sieve analysis was performed on the fine and coarse aggregates to determine their particle size distribution in accordance with British Standards (BS EN 933-1:1997) and the results were tabulated. The organic matter test was also performed on the fine aggregate using a glass bottle and caustic soda in accordance with BS 1377. (1990).

2.3.2 Water Content Test on Aggregates

Water content test conforming to BS 812: Part 109:1990 was conducted on the aggregates (in order to determine more accurately the quantity of water to be added to the mix to achieve the required water- cement ratio) at temperature of 105 ± 5^{o}C for a period of 24 hours. The Moisture Content as expressed in percentage by dry mass was computed using Equation 1as follows:

Moisture Content (% dry mass) $= \left[\frac{(M2-M3)}{M3-M1}\right] \mathbf{100}$ Eq. 1

where:

M_1 = weight of container

M_2 = weight of container and wet material

M_3 = weight of container and dried material.

2.3.3 Bulk Specific Gravity and Water Absorption

The Bulk Specific Gravity of the coarse aggregates being the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water; and the rate of water absorption of the coarse aggregates and hardened concrete were determined in accordance with American Association of State Highway and Transportation Officials (AASHTO, 2000). Coarse aggregates that retained on the No. 4 (4.75 mm) sieve and free from all foreign particles as indicated for crushed granite and waste ceramic tiles

UNDER PEER REVIEW

above were used (Biney et al., 2022).

2.3.4 Aggregate Impact Value Test

The resistance of the aggregates to sudden impact or shock, which may differ from its resistance to gradually applied compressive load were determined as specified in the BS 882 (1992) using the impact machine. A measuring scale and a well-ventilated oven were also integral parts of the apparatus for the test. The cup was fixed firmly in position on the base of the machine with the test specimen placed in it. A total of 25 strokes of the tamping rod were made with adjusted hammer height of 380 ±5 mm after which a total of 15 blows were given to the aggregates at intervals not less than 1sec. The aggregates were then removed and sieved on a 2.36mm sieve size (Biney et al., 2022). The percentage passing and retained were both weighed to the nearest 0.1g and recorded.

2.3.5 Loss Angeles Abrasion Test

Abrasion test was used to determine the toughness and abrasion characteristics of the aggregate using Los Angeles Abrasion test conforming to AASHTO (2000) to determine the quality and suitability of aggregate for the intended construction work. The test setup consisted of a set of sieves, mechanical component comprising a hollow steel cylinder with closed ends, standard steel balls, and the test coarse aggregate. The specimens were placed in the abrasion test machine after which steel balls were added. The machine was rotated to 500 revolutions at a speed of 33 revolutions per minute. The aggregates were then poured into the No. 12 sieve for the percentage passing and retained to be recorded. They were then dried in an oven and the percentage aggregate loss due to abrasion was calculated by finding the difference in weight between the percentage retained and the initial weight of the aggregate (Biney et al., 2022).

UNDER PEER REVIEW

2.4 Batching and Mixing of Materials

Batching was done to determine the quantity of the various constituent materials to be used in the concrete mix. Materials were batched in a ratio of 1:1.11:2.72 for cement, fine aggregate and coarse aggregates respectively by weight for all concrete mixes. Fig. 4 typically shows the batching of a constituent material. Mixing of the concrete was then done in a concrete mixer in order to attain a high degree of consistency of concrete mixes.

Fig 4: Batching process of the constituent materials.

2.5 Workability of Fresh Concrete

The slump test was conducted to check the workability of the concrete in a conical-shaped mould with a base diameter of 200mm and top diameter of 100mm having a length of 300mm. Concrete was carefully placed in the mould and compacted with a tamping rod in three layers up to 25 strokes in each layer The top of the concrete was levelled after which the mould was removed carefully and slowly in the vertical direction between 5sec and 10sec. The slump was then measured with a steel rule to the nearest 5mm. A difference in height not exceeding 10% of the height of the mould was satisfactory (Biney et al., 2022). Fig.5 shows the slump test being conducted on fresh concrete.

UNDER PEER REVIEW

Fig. 5: Slump test being conducted on fresh concrete.

2.6 Placement of Concrete in Moulds

Concrete cubes were prepared for density and water absorption tests using cubical moulds of dimensions 150mm x 150mm x 150mm. The concrete was placed in three layers of 50mm each and compacted with a tamping rod for 25 strokes per layer. The top of concrete was smoothened and allowed to harden for 24 hours before curing in water for 7 and 28 days. In all, a total of 42 samples of C30 concrete cubes were cast for all the various percentages of ceramic waste aggregate replacements (0, 10, 20, 30, 40, 50, and 100) six for each (Biney et al., 2022). Fig. 6 shows samples of cubes being moulded.

Fig. 6: Samples of cubes being moulded.

2.7 Density of Hardened Concrete

The density which is mass per unit volume and usually expressed in kg/m^3 plays significant role in determining the dead weight of a concrete structure. On the 7th and 28th days of curing, the

UNDER PEER REVIEW

cube specimens were removed, wiped and measured to determine their actual dimensions and volumes. The cubes were weighed by means of a weighing balance of 3 kg capacity, capable of weighing to 1 gram accuracy, to determine the mass of each of the concrete mixes for all percentages of ceramic tile replacement. The densities of the concrete specimens were computed with reference to BS EN 12390-7:2000 and plotted for analysis.

2.8 Water Absorption Test

Water absorption of hardened concrete is an important parameter when considering the durability and environmental conditions of concrete structures. For this study, the BS 1881-122: 2011 served as a guide in conducting water absorption test. Concrete cube specimens were dried in an oven at 110ºC controlled temperature for 72 hours, and then allowed to cool for 24 hours in an airtight container. The weights of specimens were then recorded and immersed in water for 30 hours after which they were removed, wiped with cloth and weighed (Fig. 7). The percentage of the weight of water absorbed to the dry weight of the sample was calculated as the water absorption for each specimen.

Fig. 7: Weighing and oven-drying of cube specimens.

3. RESULTS AND DISCUSSION

The key reason for the study was to determine the workability, density and water absorption properties of concrete in which coarse aggregate was partially replaced by

UNDER PEER REVIEW

waste ceramic tile. Tests such as Grading, Organic matter test, Bulk Specific Gravity, Apparent Specific Gravity, Moisture Content, Aggregate Impact value and Loss Angeles Abrasion were conducted on the materials while slump test was conducted on the fresh concrete to check the workability of the various mixes; and water absorption conducted on the hardened concrete. The results obtained from the above-mentioned laboratory tests are presented in the sections that follow:

3.1 Gradation of aggregates

Sieve analysis was conducted on all aggregates used for the research to determine their particle size distribution. Table 1 shows the results of the grading test on the crushed granite, ceramic waste aggregate and sand with their corresponding graphs in Figures 1, 2 and 3 showing particle size distribution curves of the crushed granite, ceramic waste aggregate and sand respectively.

Table 1: Grading of fine and coarse aggregates.

SAMPLE	**PERCENTAGE OF WEIGHT PASSING SIEVE**												
Sieve size	75	50	37.5	20	14	10	5	2.36	1.18	600	300	150	Pan
	mm	mm	Mm	mm	mm	mm	Mm	mm	Mm	µm	µm	µm	
Crushed granite	100	100	100	54.5	16.6	0.9	0	0	0	0	0	0	0
Ceramic Waste Aggregate	100	100	100	64	17	6	2	0	0	0	0	0	0
Sand	100	100	100	100	100	100	98.8	96.9	79.3	39.5	11.5	2.1	0.8

UNDER PEER REVIEW

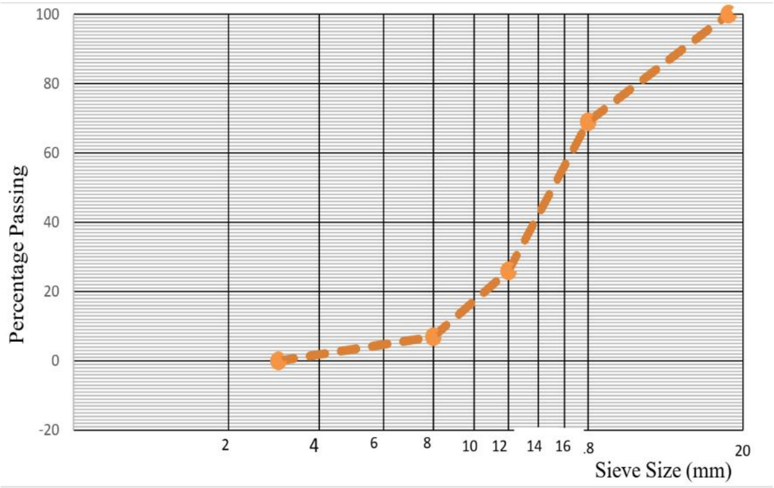

Fig 8: Particle size distribution of crushed granite

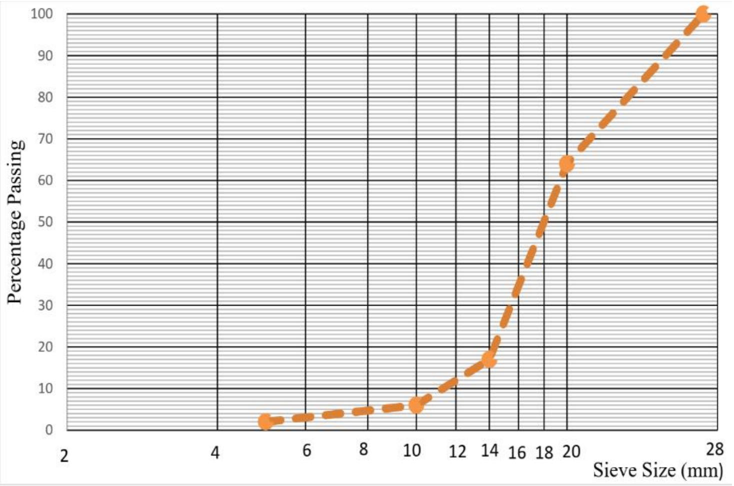

Fig 9: Particle size distribution curve for waste ceramic tile

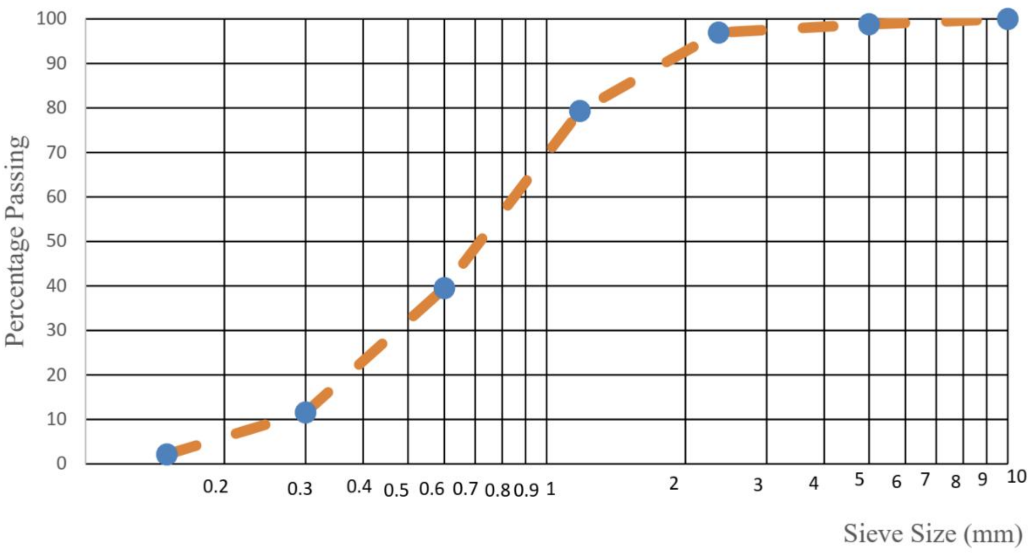

Fig 10: Particle size distribution curve for sand.

The particle size distribution of the crushed granite lay between 7mm and 20mm with the majority having the size of 20mm (Fig. 8) while ceramic waste aggregate, on the hand lay between 28mm and 4.75mm with majority being 20mm size (Fig. 9). Lastly the sand had 99% passing through the No. 4 (4.75mm) sieve size but predominantly retained on the No. 200 (75 µm) sieve (Fig, 10). Both fine and coarse aggregates were considered to be well graded and therefore suitable for use as part of constituents for the concrete (Biney et al., 2022).

3.2 Physical properties of aggregates

The physical properties of the aggregates are indicated in Table 2

3.2.1 Organic Matter of sand

From Table 2, it is clear that the sand did not contain organic matter. This made it suitable for use as fine aggregate for the concrete.

Table 2: Physical properties of aggregates

Material	**Organic content**	**Bulk density (kg/m^3)**	**Water content (%)**	**Los Angeles abrasion (%)**	**Impact value (%)**
Crushed granite	-	1420	0.6	22	16
Waste ceramic tiles	-	1323	0.09	28	23
Sand	Nil	1355	1.2	-	-

3.2.2 Bulk Density

Table 2 presents the bulk density of the various aggregates, namely, 1420 Kg/m^3, 1323 kg/m^3 and 1355 kg/m^3 for crushed granite, ceramic waste and sand respectively. Both crushed granite and the ceramic waste aggregates as well as sand fell within the normal weight range of aggregate, being 1120 kg/m^3 and 1680 kg/m^3 (Neil and Dhir, 1996) even though the ceramic waste aggregate was found to be comparatively lighter, indicating the quality and weight of the concrete produced.

3.2.3 Water Content

Water content test was initially conducted on the fine and coarse aggregates to ascertain the

UNDER PEER REVIEW

quantity of moisture stored in the materials. The values from the tests as indicated in Table 2 were 0.6%, 0.09% and 1.2% for crushed granite, ceramic waste aggregate and sand respectively. The ceramic waste aggregate had the least moisture content while the sand recorded the highest. This might be due to the fact that the glazy/polished surfaces of the ceramic tiles did not allow easy penetration of water. These moisture content values were particularly necessary as they were considered in determining the quantity of water required for the concrete mix to achieve adequate water- cement ratio.

3.2.4 Los Angeles Abrasion and Impact Value of coarse aggregates

The Los Angeles Abrasion test was used to determine the abrasion or wear resistance of the coarse aggregates used in this study. According to Table 2, crushed granite had a lower abrasion value of 22%, while ceramic waste aggregate had a higher abrasion value of 28%, indicating their levels of abrasion resistance. These figures, however, were significantly lower than the 35% maximum permissible abrasion value specified by AASHTO (2000) for structural concrete mixes. This shows they met the required quality needed for the concrete used in this study.

Similarly, **Aggregate Impact Value** of the coarse aggregates as shown in Table 2 specifies 16% for the crushed granite and 23% for the ceramic waste aggregate. These values do not exceed the 30% maximum permissible limit of Impact Value as specified in BS 812, Part 112 (1990) for structural concrete mixes. It was deduced from these values that the crushed granite had a better resistance to impact load and abrasion than the ceramic waste aggregate. Nevertheless, both were equally capable of resisting large impact loads.

3.3 Workability of Fresh Concrete

The workability of the various concrete mixes by the slump test conducted is illustrated in Fig

UNDER PEER REVIEW

11 and Table 1 at appendices. From the graph it can be seen that the control mix of 0% ceramic waste aggregate replacement of granite had the highest slump of 110mm while the mix with 100% ceramic waste replacement of granite recorded the least value of 77mm. It can be seen that there was a general trend of reduction in the slump as the percentage of ceramic waste aggregate replacement for granite increased in the mix. This is consistent to earlier research outcome by Nhari et al., (2022) Aly et al., (2019) and Bhogilal & Jayantilal (2018), that mechanical properties such as slump value were reduced with an increase in crushed ceramic tile in self-compacting concrete. This was probably due to increase in specific surface area as a result of the increase in the quantity of ceramic waste aggregate, thus requiring more water to lubricate the material surfaces and make the concrete workable (Biney et al., 2022). On the contrary, the increasing ceramic waste did not go with corresponding rapid water absorption by the ceramic waste due to its glazed surface, making the concrete too wet and loosened. It was also observed that there was percentage change in slump from 4.55% on specimens with 10% replacement to 30% change on the specimens with 100% replacement. It could therefore be mentioned that the slump is inversely proportional to the quantity of ceramic waste aggregate replacement for granite in the concrete (Biney et al., 2022). The graph shows a linear mathematical relationship between the concrete slump and percentage replacement of ceramic tiles waste of the form:

$S = S_c = kT$ Eq. 2

where S = slump of concrete mix; S_c = control mix slump; T = percentage of ceramic tiles waste; k = slope of line.

For this particular case of concrete mix proportions of (cement: sand: coarse aggregate) 1: 1.11: 2.72 and water-cement ratio of 0.5, the linear relationship is:

$S = 110 – 0.5T$ Eq. 3

UNDER PEER REVIEW

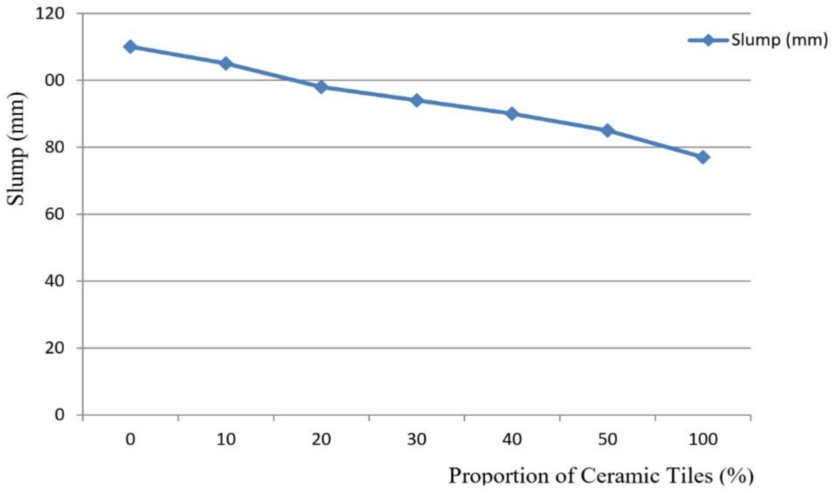

Fig 11: Slump of concrete with varying percentage of ceramic waste

3.4 Density of Hardened Concrete

A similar trend of reduction was seen in the determination of the densities of the concrete products produced in the study for both 7 and 28 day curing. The **density** decreased from 2653kg/m^3 for the control after 28 days with increased percentage ceramic waste replacement for crushed granite in the concrete produced although in a slightly reduced rate of change as shown in Figure 12. This could be as a result of the weight difference between granite and ceramic waste aggregates. However, it can be seen that all the mixes have more than 2000 kg/m^3 for both 7 days and 28 days curing periods, and therefore could be classified as light to normal weight concrete for structural works; an implication for large variety of precast concrete products. According to Neil and Dhir (1996) normal weight concrete ranges from 2300 – 2500 kg/m^3 while light weight ranges from 1800 – 2200 kg/m^3. Full details of the density of concrete mixes are presented in Table 2 in the Appendices. From the graph of Fig. 12, a linear mathematical relationship deduced of form:

$$D = D_c - k T \qquad \text{Eq. 4}$$

where D = density of concrete mix; D_c = density of control mix; T = percentage replacement of waste ceramic tiles; k = slope of line.

UNDER PEER REVIEW

In the particular case of this concrete mix design of (cement: sand: coarse aggregate) 1: 1.11: 2.72 and water-cement ratio of 0.5, and after 28 days, the linear relationship yields:

$D = 2653 - 5.64T$ Eq. 5

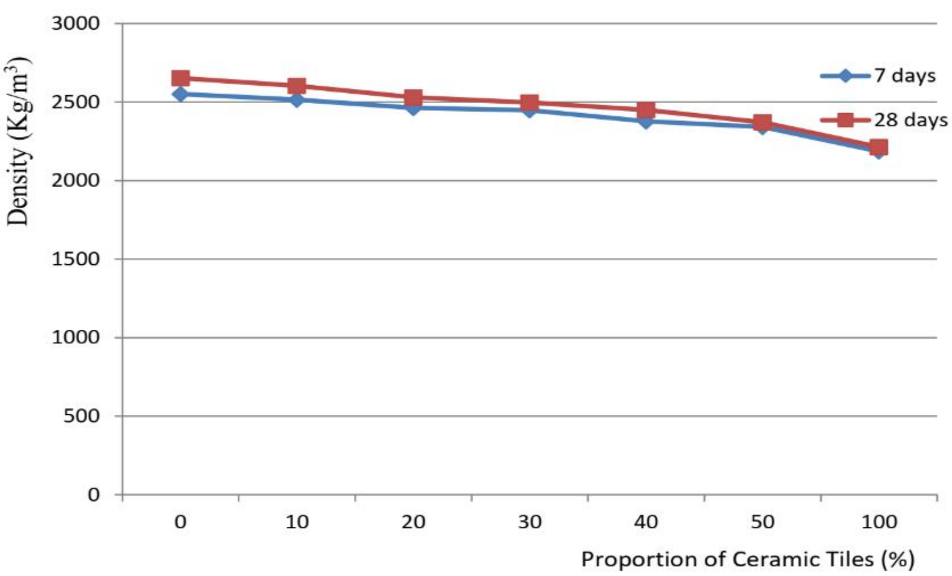

Fig 12: Density of concrete of varying percentage of ceramic waste.

3. 5 Water Absorption of Hardened Concrete

Water absorption of concrete was determined by measuring the increase in mass as a percentage of dry mass. From Fig 13, it can be observed that the percentage water absorption rose gently from 8.75% for the control to 10.75% for 50% ceramic waste replacement for granite specimen. It then rose significantly to 13.03% for the specimens with 100% granite replacement (The full details of the water absorption test are presented in Table 3 in the Appendices). Below 50% ceramic tile replacement, the increase in water absorption in the concrete was 2% relative to the control concrete mix. This is found to be within the acceptable maximum limit of 3% as specified by the British code for maritime construction (BS 6347:2021). The increase in water absorption could probably be attributed to relatively porous nature of the unpolished/unglazed side of the ceramic waste when kept in moist condition for a long period as compared to the

UNDER PEER REVIEW

granite. This increased water absorption was also realised by Njogu (2022) about hardened concrete containing varied percentage of ceramic waste. On the other hand, Ajamul et al. (2018) found similar increase in water absorption in hardened concrete up to 30% ceramic waste replacement for normal coarse aggregate but saw downward trend beyond 30%. Consequentially, Ikponmwosa1 and Ehikhuenmen, (2017) concluded that 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. Thus the strength of the concrete would be undermined if its water absorption is excessive

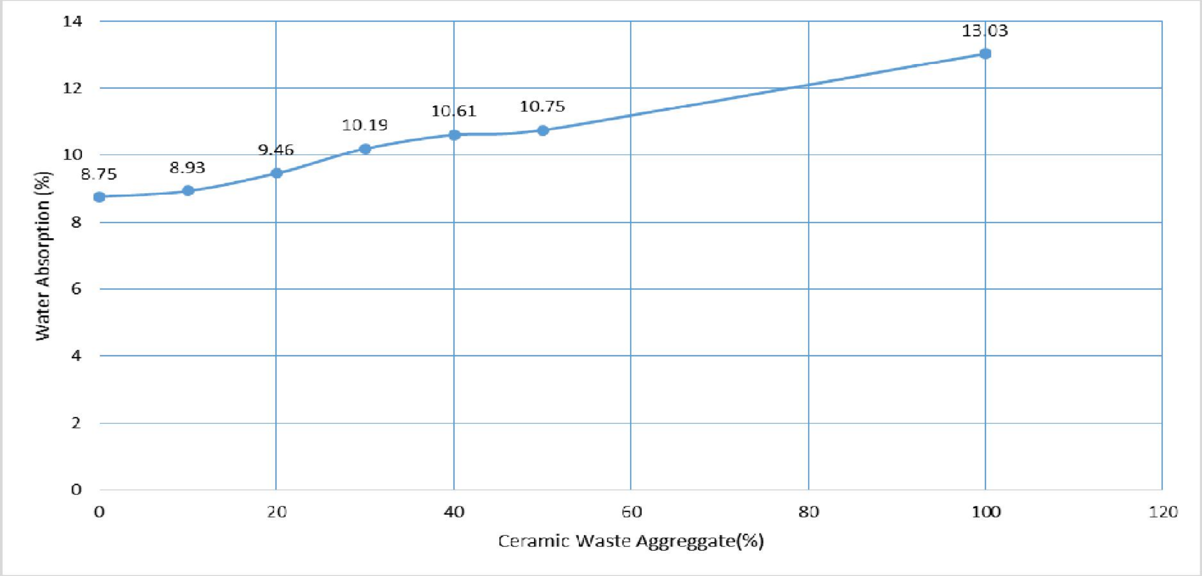

Fig 13: Water absorption of concrete for varying percentages of ceramic tiles.

The clear evidence that steady increase in percentage water absorption is seen indicates environmental and loading as well as durability limitations on the concrete product containing varied amount of ceramic waste aggregate. It may therefore not be advisable to encourage such concrete product for water retaining structures or in areas where there is constant moisture or high-water table in the ground. Consequently, in order to attain the necessary required durability, it is advised that coarse aggregate replacement with ceramic waste aggregate must not exceed 20% since there was not much significant increase in water absorption up to this limit compared to the control; although Ajamul et al. (2018) recommended that replacement of conventional aggregates with ceramic tile waste in concrete production must be limited to 40%. However, this result is consistent with Daniyal and Ahmad (2015) and Tamanna and Sharma (2018) findings that the percentage of ceramic waste aggregate used in concrete must not exceed 20% of the coarse aggregate content. The trend in the graph of Fig. 13 indicates a linear mathematical relationship of form expressed in equation 6:

$W = W_c + k\,T$ Eq. 6

where W = water absorption of concrete mix (%); W_c = water absorption of control mix (%); T = percentage replacement of waste ceramic tiles; k = slope of line.

With particular reference to the design concrete mix adopted in this study (1: 1.11: 2.72 and water-cement ratio of 0.5), the linear relationship reduces to equation 7 as follows:

$W = 8.75 + 0.04\,T$ Eq. 7

The mathematical forms of relationship between Slump, Density, Water Absorption of concrete mixes and the percentage replacement of waste Ceramic Tiles expressed respectively by Equations 2, 4 and 6 may be valid for all concrete mix proportions, with anticipated differences in only the constants in the equations, namely, control mix values and gradients of the linear relationships.

UNDER PEER REVIEW

4. CONCLUSION

This study aimed to determine workability, density and water absorption characteristics of partially replaced crushed granite aggregate with ceramic waste in structural concrete. After experimental methods employed, it was concluded that:

1. The workability of concrete made with partial ceramic waste replacement for crushed granite decrease with increasing percentage waste ceramic tiles in the mix. It was found that the slump is inversely proportional to the quantity of ceramic waste aggregate replacement for granite in the

concrete

2. The densities of concrete mixes evaluated for all ceramic tile percentage replacements were above 2000 kg/m^3 for both 7days and 28days curing periods, and therefore could be classified as light to normal weight concrete for structural works.

3. Increased percentage of ceramic waste replacement for crushed granite aggregate in concrete resulted in mild increased water absorption of hardened concrete (below acceptable level of 3% according to British maritime standard) but became severe after 50%; an implication for its durability and application limitations.
4. Ceramic wastes could be recycled into various coarse aggregate sizes and used in concrete mixes. Nevertheless, a maximum content of 20% ceramic waste aggregate replacement in a mix is ideal to produce the required workability, density, water of absorption and anticipated durability of structural concrete.

This use of ceramic waste aggregate in concrete would eventually promote green construction and save the environment and natural habitat from dilapidation while alleviating the burden on the limited existing granite.

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UNDER PEER REVIEW

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UNDER PEER REVIEW

Appendices

Table 1: Slump of various concrete mixes.

Batch Number	Ceramic Waste Aggregate (%)	Slump measured (mm)	Percentage reduction in slump with respect to the Control
1 (Control)	0	110	-
2	10	105	4.55
3	20	98	10.90
4	30	94	14.55
5	40	90	18.18
6	50	85	22.73
7	100	77	30

Table 2: Density of concrete measured in 7 days and 28 days.

Batch Number	Ceramic Waste Aggregate (%)	Density of Concrete in 7 days (Kg/m^3)	Percentage Reduction from Control	Density of Concrete in 28 days (Kg/m^3)	Percentage reduction in density with respect to the Control
1 (Control)	0	2551	-	2653	-
2	10	2515	1.43	2604	1.8
3	20	2463	3.45	2531	4.60
4	30	2448	4.04	2498	5.84
5	40	2378	6.78	2450	7.65
6	50	2342	8.19	2371	10.63
7	100	2186	14.31	2215	16.51

UNDER PEER REVIEW

Table 3: Water absorption of concrete mixes.

Item	**Ceramic Waste Aggregate**	**Oven Dry Weight, (A)**	**Saturated Surface Dry weight (B)**	**Difference in Weight (B – A)**	**Percentage Water Absorbed $\left[\frac{(B-A)}{A}\right]100$**	**Percentage increase**
	%	**grams**	**grams**	**grams**	**%**	**%**
1	0	7460.0	8113.0	653.0	8.75	-
2	10	7230.5	7876.0	645.5	8.93	2.06
3	20	7358.5	8054.5	696.0	9.46	8.11
4	30	7015.5	7730.5	715.0	10.19	16.46
5	40	7192.0	7955.0	763.0	10.61	21.23
6	50	7254.0	8033.5	779.5	10.75	22.86
7	100	6260.5	7076.0	815.5	13.03	48.91

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