Original Research Article

AssessingStructural Performance of Ceramic Wasteas Partial Replacement of Coarse Aggregate on Properties of Concrete

ABSTRACT

The need to reduce the increasing demand for crushed granite as coarse aggregate as well as the need to safeguard the environment from degradation has given rise to various researches on alternative materials that can serve the same purpose while minimizing environment hazard. This study assessedthe suitability of waste ceramic tiles as coarse aggregate in concrete and to ascertain its strength against normal crushed granite. Crushed waste ceramic tiles from ceramic manufacturing industries and construction sites were mixed with crushed granite stones as partial replacement for concrete. A mix ratio of 1: 1.11: 2.72 (cement: sand: stones) for nominal C30 concrete was produced with (0, 10, 20, 30, 40, 50 and 100) percent volume ceramic waste aggregate replacement for crushed granite at a constant water-cement ratio of 0.5. Concrete cubes of size 150mm x 150mm x 150mm were produced and tested for 7 days and 28 days compressive strength, density and water absorption. The results revealed the viability of waste ceramic tiles as partial replacement for crushed granite in concrete production, but the partial replacement should not exceed 20% as recommended maximum for structural concrete. Thismode of recycling ceramic waste could positively sustain the environment.

***Keywords**: Ceramic waste, partial replacement, crushed granite, concrete, compressive strength*

1. INTRODUCTION

Coarse aggregate as used in concretes, occupies the greatest volume of the concrete, and is generally thought of as inert 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 and influences the properties of both fresh and hardened concrete. The composition, shape, texture, size and properties of the aggregate all contribute to the strength, durability and workability of concrete. Changes in gradation, maximum size, unit weight, and water absorption can all alter the character and performance of concrete mix.

Generally, coarse aggregates are classified into heavyweight aggregate, normal aggregate and lightweight aggregate and each 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, the dimensions 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. Lightweight concretes are those with weight ranging from 1800 kg/m^3 to 2200 kg/m^3. Lightweight aggregates find application 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).

In Ghana, the construction of new infrastructure and rebuilding of deteriorated roads, highways, bridges, seaports, and private and public buildings require huge quantities of crushed rock aggregates. This puts a lot of pressure on the environment as the rocks are obtained solely from natural sources. The scarcity of crushed rock aggregate has effect on concrete cost; this prompted some researchers in coming out with alternative materials that could be used either as a substitute or as partial replacement. One material that could be used as replacement for the crushed rocks from the quarry sites is waste ceramic aggregate. There is extensive availability of waste ceramic tiles found at almost all construction sites in the country. 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 gooduse. Ceramic waste aggregates are hard, having considerable value of specific gravity, rough surface on one side and smooth on other side, and 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 and 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 the positive cost implications in the use of ceramic waste aggregate as coarse aggregates, they are lighter in weight when compared with the normal broken stones from the quarry sites andwill impact positively on the soil on which the building is founded. Additionally, the environment which would otherwise be destroyed is protected from degradation. This research therefore, focuses on assessing suitability and sustainability of producing concrete of adequate strength with waste ceramic as partially replaced coarse aggregate for crushed granite stones and determining the best coarse aggregate mix ratio to achieve this strength.

2. EXPERIMENTAL METHODS

2.1 Materials and procedure

The materials for the study included pit sandobtained from Greater Accra Region of Ghana, crushed granite from quarry, ordinary Portland cement (GHACEM) grade 32,3R,potable water and waste ceramic tilesfrom construction sites and sales points. The crushed granite aggregate was partially replaced by waste ceramic aggregate in different percentages (0, 10, 20, 30, 40, 50 and 100) as coarse aggregate for the experiment to produce various concrete mixes of C30 nominal strength (for a mix ratio of 1: 1.11:2.72) at a constant water - cement ratio of 0.5.

Material tests and slump tests were conducted on the aggregates and fresh concrete to determine their physical properties and workability, respectively. Concrete cubes of size 150mm x 150mm x 150mm were then cast from the various mixes for compressive strength test on the 7thand 28thday. The test results were then compared to standard values given in texts while the specimens were weighed to determine the density of the various mixes.

2.2 Tests onMaterials

Various tests conforming to the 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) were conducted. These tests included Gradation, Organic matter, Moisture Content, Bulk Specific Gravity, Loss Angeles Abrasion t(LAA) and Aggregate Impact Value (AIV) as detailed in the sections that follow.

2.2.1 Sand

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

Fig 1: Sample of sand used for the study

2.2.2 CrushedGranite and CeramicTiles

Crushed granite sampled from Cedar Quarry at Shai Hills in the Greater Accra Region ofGhana was used as the normal coarse aggregate and broken ceramictiles from construction sites in Accra with average size of 20mm. 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 3show samples of the coarse granite and ceramic aggregates used in the study.

Fig 2: Sample of coarse granite aggregate used.

Fig 3: Sample of ceramic waste aggregate used.

2.3 Details of Tests Conducted onMaterials

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 GradationTest

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

2.3.2 Water Content Test onAggregates

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 required water cement ratio) at temperature of 105 $\pm$ 5°C for a period of 24 hours. The Moisture Content as expressed as percentage by dry mass was computed as shown in Equation 1:

Moisture Content (% dry mass) $= \left[\frac{(M2-M3)}{M3-M1}\right] 100$ 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 SpecificGravity 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 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) sieveand free of all foreign particles as indicated for crushed granite and waste ceramic tiles above were used.

2.3.4 Aggregate Impact ValueTest

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. The percentage passing and retained were both weighed to the nearest 0.1g and recorded.

2.3.5 Loss Angeles AbrasionTest

Abrasion test was used to determine the toughness and abrasion characteristics of the aggregate using Los Angeles Abrasion test conforming to AASHTO (2000)todetermine 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. By procedure, the specimens were placed in the abrasion test machine after which steel balls were added. The machine was rotated to a number of 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 theaggregate.

2.4 Batching ofMaterials and Mixing

Batching is the process of determining the quantity of the various constituent materials to be used in a 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.4typically shows the batching of a constituent material.Mixingof 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 SlumpTest

Slump test was conducted to check the workability of the concrete in a conical-shaped mould with base diameter of 200mm and top 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 case. 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 rule to the nearest 5mm. A difference in height not exceeding 10% of the height of the mould was satisfactory. Fig.5 shows the slump test being conducted on fresh concrete.

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

2.6 Placement of Concrete in Moulds

The concrete cubes prepared for compressive strength test 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 curingin 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.Fig. 6 shows samples of cubes beingmoulded.

Fig. 6: Samples of cubes being moulded.

2.7 Water AbsorptionTest

Water absorption of concrete is an important parameter when considering the durability 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 inan 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.

2.8 Compressive StrengthTest

Compressive strength test was conducted to check the strength of the concrete under compression. On the 7thday, 21 cubes from the various mix ratios were removed and crushed in a compressive strength test machine to determine their strengths. Same was done on the 28th day for the remaining 21 test specimens. Fig. 8 shows the test set-up for the concrete compressive strength.

Fig. 8: A cube being crushed in a compression machine.

3. RESULTS AND DISCUSSION

Tests conducted included Grading, Organic matter test, Bulk Specific Gravity, Apparent Specific Gravity, Aggregate Impact value, Loss Angeles Abrasion and Water Content testson the aggregates used for the study. The slump test was conducted on the fresh concrete to check the workability of the various mixes while compressive test was 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

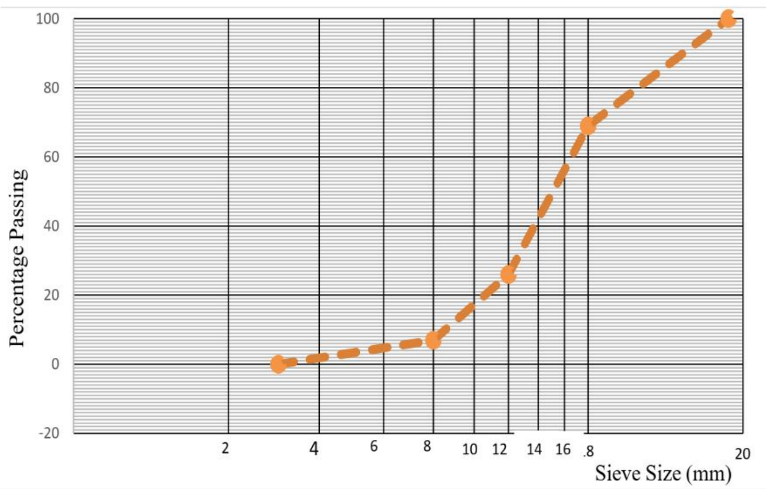

Fig 9: Particle size distribution of crushed granite

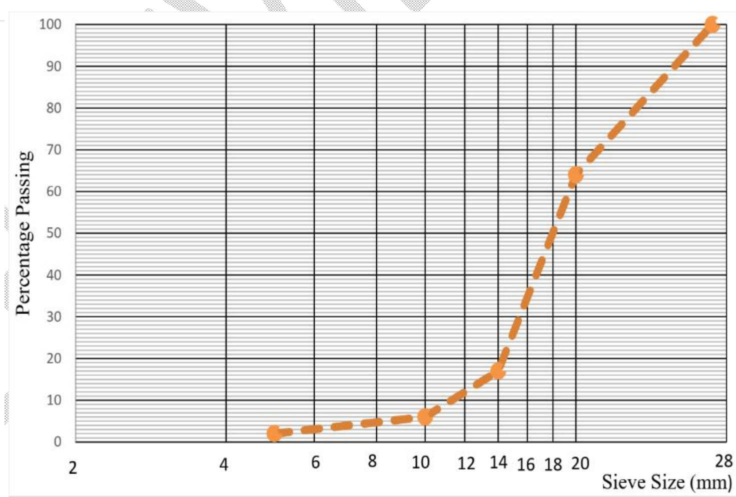

Fig 10: Particle size distribution curve for waste ceramic tile

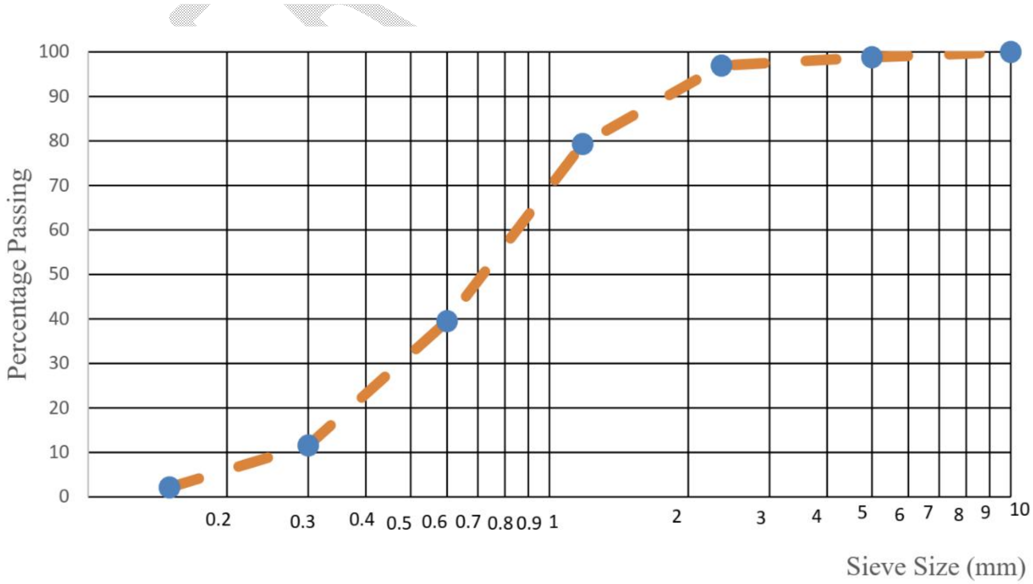

Fig 11: Particle size distribution curve for sand.

From Table 1, the particle size distribution of the crushed granite lay between 7mm and 28mm with the majority having the size of 20mm while ceramic waste aggregate, on the hand lay between 20mm and 4.75mm with majority being 20mm sizes. Lastly the sand had 99% passing through the No. 4 (4.75mm) sieve size but predominantly retained on the No. 200 (75 µm) sieve. Both fine and coarse aggregates were considered to be well graded and therefore suitable for use as part of constituents for theconcrete.

3.2 Physical properties of aggregates

The physical properties are indicated in table 2

3.2.1 Organic Matterof sand

FromTable 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, indicates bulk density of the various aggregates, thus 1420 Kg/m^3, 1323 kg/m^3 and 1355 kg/m^3 for crushed granite, ceramic waste aggregate and sand respectively. From the tabulated values, the crushed granite and the ceramic waste aggregate both fell within the range of normal weight aggregate range of 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 of the concrete produced. The values obtained from the laboratory tests were factored into the calculations for the mix design of the concrete.

3.2.3 Water Content

Water content test was initially conducted on the fine and coarse aggregates to ascertain the quantity of moisture stored in the materials. The values from the tests as indicated in Table 2were 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.

3.2.4 Los AngelesAbrasion of coarse aggregate

The Los Angeles Abrasion test was to determine the resistance of the coarse aggregates used in this study to abrasion or wear. From Table 2, it can be seen that the crushed granite had a lower abrasion value of 22% while the ceramic waste aggregate recorded 28% indicating their levels of resistance to abrasion. However, these figures were below the 35% maximum permissible limit of abrasion value specified by AASHTO (2000) for structural concrete mixes.

3.2.5 Aggregate ImpactValue

Similarly, Aggregate ImpactValue test conducted on 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. However, both wereequally capable of resisting large impact loads.

3.3 Slumpof concrete

The workability of the various concrete mixes by the slump testconducted is illustrated inFig12. 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 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. It was also observed that there was percentage change in slump from 4.55% on specimens with 10% replacement to 30% percentage 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.

3.4 Density of concrete

A similar trend of reduction was seen in the determination of the densities of the concrete product produced in the study for both 7 and 28 day curing.

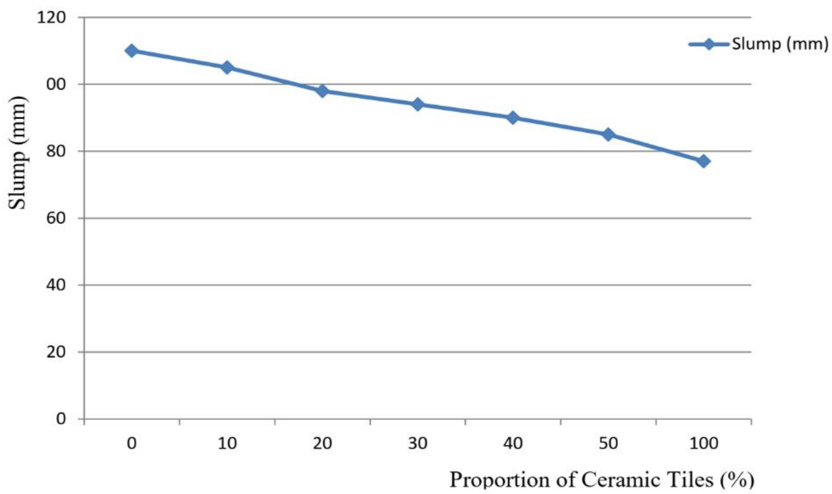

Fig 12: Slump of concrete with varying percentage of ceramic waste

The **density** decrease with increase percentage ceramic waste replacement for granite in the concrete produced. This could be as a result of the weight difference between granite and ceramic aggregates.See fig 13, and for more detail in table 4 at appendices.

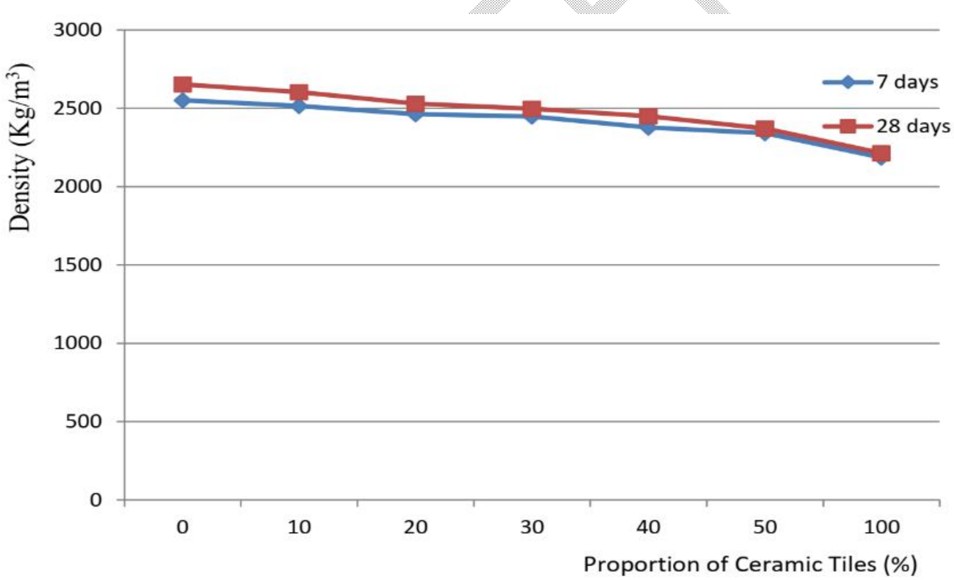

Fig 13: Density of concrete of varying percentage of ceramic waste.

3. 5 WaterAbsorption of concrete

Water absorption was determined by measuring the increase in mass as a percentage of dry mass. Fig 14 presents the results obtained from the water absorption test conducted. It was observed that the percentage water absorption rose gently from 8.75% for the control to 10.75% for 50% ceramic waste replacementof granite specimen. It then rose significantly to 13.03% for the specimens with 100% granite replacement. The increase in water absorption was probably due to relatively porous nature of the unpolished/unglazed side of the ceramic waste as compared to the granite. It is therefore advised that coarse aggregate replacement must not exceed 20% since there was notmuch significant increase in water absorption up to this limit compared to the control.Further details of the water absorption test are presented in Table 5 in the Appendices.

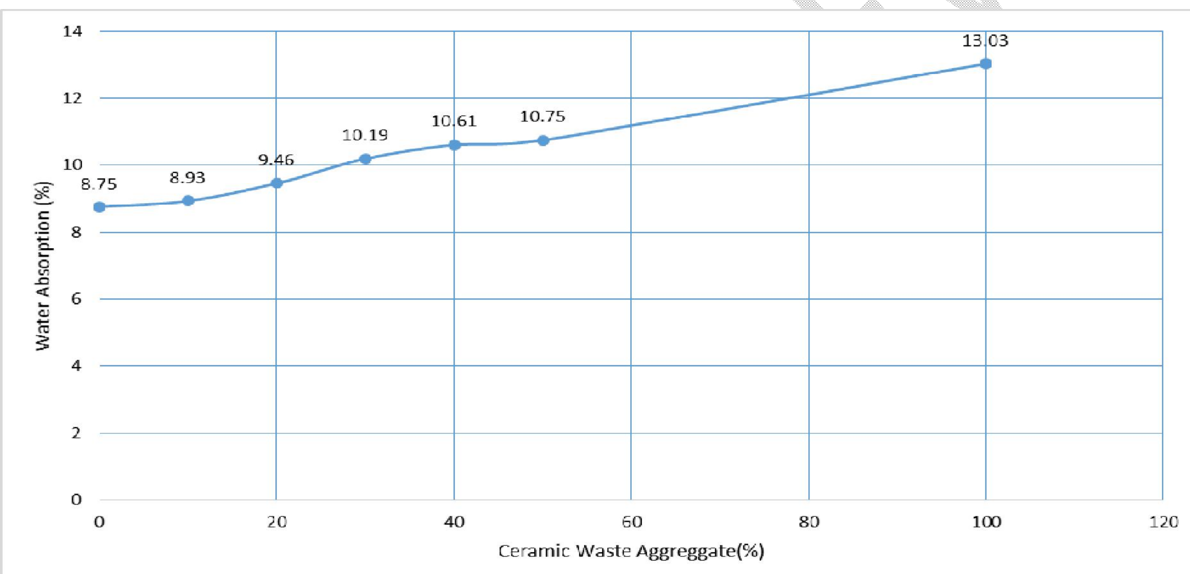

Fig 14: Water absorption of concrete for varying percentages of ceramic tiles.

3.6 CompressiveStrength of concrete

Determination of compressive strength of the partial ceramic waste replacement was key to this study in order to ascertain required percentage content replacement that could be encouraged.Table 3. indicates the detail result of the compression test conducted while Fig. 15 graphically presents the trend of the compressive strength of the various mixes. In general,a decrease was seen in the compressive strength of the concrete as the percentagecontent of ceramic waste aggregate increased for both 7and 28daysold concrete specimens.In the case of 7 daysspecimen, compressive strength reduced from 30.43 N/mm^{2}for the control to 20.11 N/mm^2 for 100% ceramic waste replacement for crushed granite. Similarly. 28days old specimen had strength reducing from 47.68 N/mm^2 for control to 36.31 N/mm^2 for 100% ceramic waste replacement for crushed granite, in line with similar finding by Singh and Singla (2015). From Table 3,in consideration of the percentage reduction in 28th day compressive strength of the various specimens with respect to the control specimen, it is observed that the specimen with 10% replacement had the least percentage reduction of 1.3%, followed by the specimen with 20% replacement. The specimen with 100% replacement had the greatest percentage reduction of 23.85%. It was evident thatthe specimens with 20% replacement and below recorded single digit of percentage reduction while the specimens having above 20% replacement recorded double significantdigits percentage reduction. Therefore thedecrease in the strength when the percentage of ceramic waste in the concrete increases beyond 20% was significant. This could be due to the fact that ceramic waste aggregates might not be as strong enough to resist compressive loads as compared to the crushed granite aggregate and also possibly due to reduced bond between the cement matrix and waste ceramic tile. Nevertheless, the results indicate that ceramic waste aggregates could be used to partially replace crushed granite as coarse aggregate but the quantity must not exceed 20% of the coarse aggregate in the mix for serious heavy duty concrete work,even though 36.31N/mm^{2}concrete containing 100% ceramic waste coarse aggregate may also be suitable for normal structural concrete members. This result is consistent withDaniyal and Ahmad (2015) and Tamanna and Sharma (2018) findingsthat the percentage of ceramic waste aggregate used in concrete must not exceed 20% of the coarse aggregate content but inconsistent withtheoutcome of research published by Kumar et al. (2015) that a maximum of 10% ceramic waste replacement for the main aggregate was ideal.

Table3: Compressive strength of concretemixes.

Item	Percentage of Ceramic Waste Aggregate	CompressiveStrength(N/mm^2) 7thDay	28thDay	28th day Percentage Reduction
1	0	30.43	47.68	-
2	10	29.77	47.06	1.30
3	20	28.23	46.55	2.37
4	30	26.15	42.89	10.07
5	40	25.31	42.47	10.93
6	50	23.84	41.25	13.48
7	100	20.11	36.31	23.85

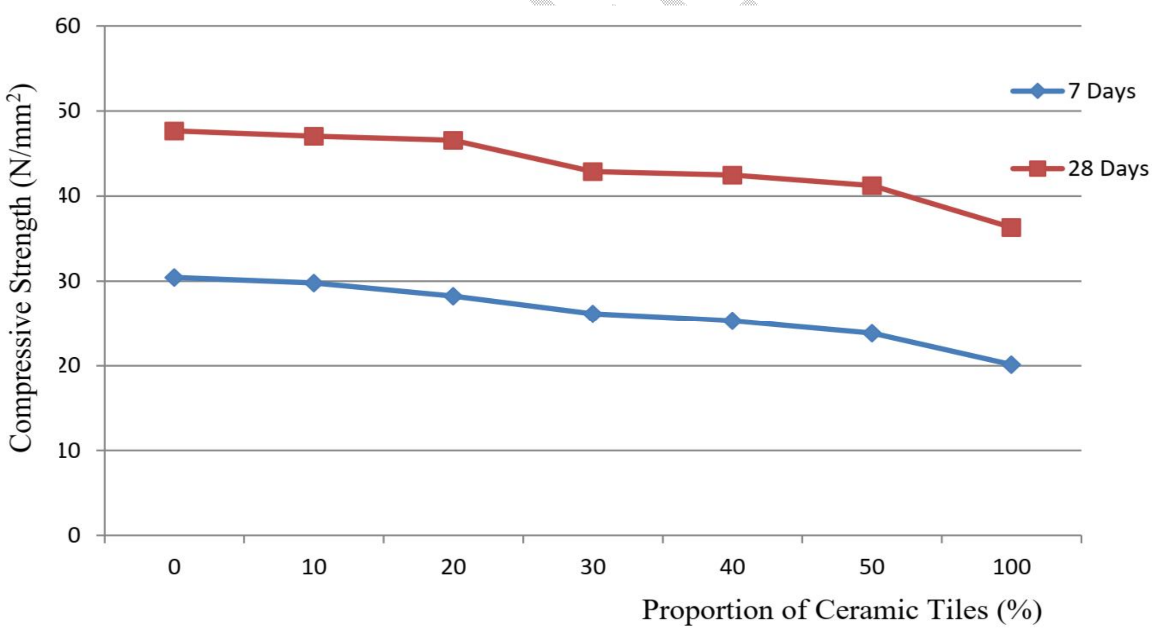

Fig. 15: Compressive strength of concrete for varying proportion of ceramic tiles

4. CONCLUSION

This study aimed to determine the suitability of partially replacing crushed granite aggregate with ceramic waste in structural concrete. After experimental methods employed, it was concluded that:

1. Crushed granite had better resistance to Abrasion and Impact load compared to ceramic waste aggregate. Nonetheless, the Abrasion and Impact values obtained for the both aggregate are below acceptable maximum limit of 35% and 30% respectively for structural concrete.
2. Ceramic wastes from the construction sites and ceramic manufacturing industries could be recycled by breaking them into various coarse aggregate sizes and used in concrete mixes. However, a maximum content of 20% ceramic waste aggregate replacement in a mix is ideal to produce the required strength and durability of structural concrete.

This use of ceramic waste aggregate in concrete would ultimately save the environment and naturalhabitat from degradation while alleviating the burden on the limited quarry sites for crushed granite.

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Appendices

Table 4: 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

Table 5: 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