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SUITABILITY OF CERAMIC WASTE TILES AS FINE AND COARSE AGGREGATES IN CONCRETE PRODUCTION

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Abstract The paper assessed the suitability of ceramic waste tile (CWT – aggregates) as 100% replacement of both fine and coarse aggregates in concrete production for sustainable purposes. The dearth of literature on the combined hundred percent usage of CWT as both fine and coarse aggregate motivates this research, because previous studies focused on the use of CWT as either fine, coarse aggregates or less than or equal to fifty percent combined replacement of conventional aggregates with CWT. The ceramic waste tiles (CWT) were sourced and obtained from Kaduna State and its environs and then transported in bags to Ahmadu Bello University Zaria Concrete laboratory for the preliminary tests. The ceramic waste tiles were soaked for 24 hours in water, washed with clean fabrics and then oven dried for 24 hours before broken down manually into ceramic waste tile – fine Aggregates (CWT – FA) < 2mm in size and ceramic waste tile – coarse aggregates (CWT – CA) ≥ 18mm in size using a hammer and a hard surface. Particle size distribution, specific gravity, bulk density, water absorption capacity, crushing and impact value tests were carried out on the produced CWT - aggregates. Results show that the produced CWT – FA and CWT – CA aggregates have bulk densities of 1449kg/m^3 and 1274kg/m^3 with specific gravities of 2.63 and 2.28 respectively. Furthermore, the CWT – CA aggregates had a water absorption capacity of 2.3%, an average crushing and impact value of 18.11% and 12.22% respectively. The study also reveals that the CWT – CA aggregates were more resistant to crushing and impact than the control Granite GRT – CA aggregates in the range of 14% – 28%. Based on the preliminary study on the CWT Aggregates it is recommended that ceramic waste tiles can be usefully transformed into crushed fine and coarse aggregates and be wholly use to replace conventional aggregates in concrete production.

Key Words: Ceramic, Construction, Material, Recycling, Tiles, Wastes

Introduction

Aggregates are gravels, crushed stones and other materials usually mixed with cement and water to make concrete (Kabir 2016). Maxwell (2016) opine that aggregates are materials which are mixed with cement to form concrete and are classified as either fine or coarse aggregates. Similarly, Garba (2014) argues that aggregates are fillers in concrete which play very active roles in the overall durability of the concrete. Therefore, aggregate is the term used to generally define natural sand, crushed gravel or other materials (Soji, 2018). Fine aggregates are aggregates which passes through 4.75mm sieve but are retained on British Standard (BS) sieve of size 0.075mm while coarse aggregates are the particles that are retained on BS sieve size of 4.75 (Kabir 2016 and Soji 2018). Aggregates were originally viewed as been inert and dispersed throughout the cement paste in concrete mainly for economic reasons as fill material (Maxwell, 2016). However, Neville and Brooks (2010) view aggregate as a building material connected into a cohesive whole by means of the cement paste. Also Kabir (2016) further observes that the importance of aggregate in concrete as about 60 to 75 percent of the total volume of concrete mass is occupied by aggregate.

Aggregates usually affect the strength, shrinkage, creep, thermal resistance and overall cost of concrete thereby providing the basis for determining a good aggregate (Sekar *et al* 2011 and Guerra *et al* 2009). Also, Mashitah *et al* (2008) and Binnici (2007) explained that grading of the aggregate affects the quantity of mixing water, compatibility and denseness of concrete as such a poorly graded aggregate will produce porous concrete that is not durable. Additionally, Kabir (2016), Mashitah *et al* (2008) and Binnici (2007) reported that angular, irregular, elongated and flaky aggregates produce concrete mix of lower workability than rounded and smooth ones. Studies have shown that smooth gravel leads to cracking at lower stresses than irregular or angular crush rock indicating that mechanical bond is influenced by the surface properties and to a certain degree by the shape of the coarse aggregate (Khatib, 2005; Koyuncu *et al* 2004; Lopez *et al* 2007; Neville and Brooks 2010).

Ceramics is a general term that refers to manufactured ceramic products which include wall tiles, floor tiles, sanitary ware, household ceramics and technical ceramics etc (Zongjin, 2011; Ay and Unal 2000). Duggal (2008) is of the view that ceramics are usually brittle, hard and are in the form of amorphous (non-crystalline) or glassy solid usually with mixed ionic and covalent bond which can be made in single crystal forms (Brito *et al* 2005; Binici, 2007 and Senthamarai and Devadas, 2005) however their more common structure is glassy (Brito *et al* 2005). Because of the covalent ionic bond, the electrons are not free which makes the ceramics, thermal and electrical insulators (Binici, 2007; Gomes and De Brito 2009). At low temperatures, ceramics behave elastically (Soji, 2018). However, under proper conditions of stress and temperature they deform by viscous flow (Kabir, 2016; Koyuncu *et al* 2004; Mashitah *et al* 2008).

Koyuncu *et al* (2004); Soji (2018) and Kabir (2016) define tiles as thin rectangular slab baked clay and other materials used in over lapping rows by covering roofs, floors and other surfaces. In agreement with Neville and Brooks (2010), Khatib (2005); Senthamarai and Devadas (2005) also opined that tiles are thin square or rectangular objects made up of hard wearing material such as stone, metal, baked clay, ceramic or glass which can be used to cover either floors, walls, roofs or other objects such as table tops. Similarly, Maxwell (2016) opined that ceramics are inorganic non solid materials which are primarily held together in ionic and covalent bonds usually used for the beautification of either floors, walls or roofs tops. The raw materials for the production of tiles are usually quartz and feldspar which serve as a source of silica and alumina to give the tiles the desired strength as well as good clay which serve as binder (Kabir, 2016; Koyuncu *et al* 2004; and Mashitah *et al* 2008).

Waste is an unavoidable by-product of most human activity (Pacheco and Jalali, 2010). Recently, the rising standards of living and economic development of human activities have led to increases in the quantity and complexity of generated waste (Kabir, 2016). Ay and Unal (2000) highlights that in general, developed countries generate much higher quantities of waste per capita compared to the developing countries. However, in certain circumstances the management of even small quantities of waste is of serious challenge as disposal systems of many countries are grossly inadequate, such incremental growth will pose very serious challenges therefore, the need to properly disposed this waste cannot be overemphasized (Tavakoli *et al* 2013 and Maxwell 2016).

Ceramic waste tiles as one of such wastes is piling up daily and there is urgent need for ceramic industries to look for ways to adequately disposed them without causing harm to the environment (Kabir, 2016). Studies have shown that an estimated value of about 30% of the daily production of tiles goes to waste (Senthamarai and Devadas, 2005). Meanwhile, natural aggregates reserve such as crushed stone is fast depleting (Senthamarai and Devadas, 2005). Therefore, there is urgent need to develop concrete with non-conventional aggregates for environmental sustainability as well as economic reasons as such transforming ceramic waste tiles into useful aggregates for use in concrete will serve as a means to address this problem.

Binnici (2007) reports that there is increase utilization of ceramic waste coarse aggregate in concrete because of the advantages the ceramic waste tiles have over other cementitious materials. The work further revealed that concrete made with ceramic waste powder had increased durability performance because of its pozzolanic properties however the work only focused on using ceramic waste tile as replacement of fine aggregates (sand) while maintaining natural stones as the coarse aggregates. Furthermore, Reddy and Reddy (2007) are of the view that ceramic scrap can be partially used to substitute the usual coarse aggregates up to 10% and 20% without affecting the structural integrity of the concrete. It is observed that the work used only replaced the stones with ceramic waste tile and used sand as the fine aggregates in the concrete production. In agreement with the findings above, Tavakoli *et al* (2013) observe that there was increase in compressive strength properties of concrete made with tiles in the range of 30 – 40% without having any adverse effect on the structural performance of the produced concrete. Similarly, Soji (2018) posits that concrete made with 100% crushed tiles as coarse aggregates had lower density but high compressive strength, tensile strength and flexural strength of 4%, 24% and 15% respectively however sand was still used as the fine aggregate. Table 1 provides a summary of works by different scholars on the use of ceramic waste tiles in concrete production.

Table 1: Efforts by Scholars on the use of ceramic waste tile as aggregates in concrete production

S/No	Scholars with dates of publication	How the ceramic waste tiles was used in the study		
		FA Singly	CA singly	Combination FA and CA
1.	Binnici (2007)	√	x	x
2.	Reddy and Reddy (2007)	x	√	x
3.	Guerra *et al* (2009)	x	√	x
4.	Sekar *et al* (2011)	x	√	x
5.	Soji (2018)	x	√	x
6.	Higashiyama *et al* (2012)	√	x	x
7.	Sivakumar and Subbarayan (2021)	x	x	√

Key: FA – Fine aggregates; CA – Coarse aggregates

From the results of the various findings on Table 1 above it is clear that several researches had been carried out on the possibility of using ceramic waste tiles as either fine or coarse aggregate in concrete production however these researches focuses on using the ceramic waste tiles as either coarse aggregates as clearly observed by Guerra *et al* (2009; Soji (2018); Sekar *et al* (2011) and Reddy and Reddy (2007) or as fine aggregates separately as observed by Binnici (2007) and Higashiyama *et al* (2012), although Sivakumar and Subbarayan (2021) made an attempt to look at the possibility of using the ceramic waste tiles together as both fine and coarse aggregates at a varying percentage levels of 0% to 50% of either fine or coarse aggregates together but the study was limited to 50% replacement only.

This study therefore seeks to bridge the gap in the dearth of literature by assessing the physical properties of the ceramic waste tiles to see if the ceramic waste tiles can be use as both fine and coarse aggregates simultaneously for possible 100% replacement of both the natural aggregates used in concrete production. This will help in solving the problems associated with ceramic tile waste disposal, serve as economical source of raw materials for the construction industry as well as address the issue of environmental degradation caused by continued depletion of natural resources by the activities of man.

Materials and Methods

Materials

The materials used in this study are Ceramic Waste Tile (CWT), the Ceramic Waste Tile CWT – FA aggregates, Ceramic Waste Tile CWT – CA aggregates, GRT - CA aggregates and the Sharp Sand – FA aggregates. Sharp sand (Sand – FA) were used as control specimen while crushed ceramic waste tile fine aggregates (CWT – FA) were used as the sample fine aggregates. Granite coarse aggregate (GRT – CA) were the control specimen while the crushed ceramic waste tile (CWT – CA aggregates) were used as the sampled coarse aggregates. The Ceramic Waste Tiles (CWT) were sourced from Kaduna State and its environs, the ceramic waste tiles were transported to the Department of Building, Ahmadu Bello University Zaria concrete laboratory for the preliminary physical tests. Approximately 2kg of a representative sample of the various aggregate passing through 20mm and retained on 5mm test sieve was taken and the sample was carefully washed with water to remove dust on the surface of the grains. The tiles were then soaked in water for 24 hours at a temperature of 22 ± 5^0C. The specimens were then removed from water, shaken off and rolled in large absorbent cloth until all the visible films of water was removed. Large particles were wipe individually the samples were then dried in a drying oven at a constant temperature of range 105^0C – 110^0C thereafter the samples were cooled to room temperature of range 20^0C – 27^0C. The ceramic waste tile aggregates were then produced in the laboratory by manually crushing the ceramic waste tiles using a hammer and a hard surface. The maximum size of the ceramic waste tile aggregate CWT - FA produced was less than 2mm while CWT – CA tiles were greater than or equal to 18mm CWT – CA. The broken CWT – Aggregates were sieved using the BS Sieve size 2.36mm and 4.75mm for the CWT – FA and CWT – CA respectively. The Preliminary tests were carried out in accordance with the appropriate standard in order to assess the suitability of the materials used the experiment. These tests include:

Particle Size Distribution: The sieves were arranged in decreasing aperture of sizes with the pan at the bottom and the lid on top in order to form a sieving column. 1000g of each of the aggregate samples were weighed and poured into the sieving column and shaken manually. The sieves were then removed starting with the largest aperture sizes, and the sieve shaken manually ensuring no material is lost. The retained material on the sieve was then weighed and the weight recorded. The same procedure was carried out for all sieves in the column and their corresponding weights recorded. Also, the screened material that remained in the pan was weighed and its weight recorded. The particle size test was done in accordance to BS 812-103 (1990).

Specific Gravity Test: This is the ratio of the weight of the aggregate dried in an oven at a temperature of 100^0C – 110^0C for 24 hours to the weight of the water occupying a volume equal to that of the solid including the impermeable pores. The latter weight was determined using a vessel (pycnometer) which can be accurately filled with water to a specific volume. The apparent specific gravity of the aggregate depends on the specific gravity of the minerals of which the aggregate is composed of, the amount of voids, grading, shape, texture and moisture content.

The Specific gravity was then analysed using the relationship: $S_{SD} = W_{SD} \div (W_{SD}-W_W)$

Bulk Density: The bulk density of the aggregates determined based on saturated dry surface. The empty box was cleaned, weighed and marked as W. The box was then filled with aggregate in three different layers with each layer tamped 25 times with tamping rod to ensure compaction. The top of the container was well level, the container and the aggregates were then weighed and named W_1. The test was carried out in accordance with the specification of BS 812-108 (1990). The Bulk density (SSD) was then computed using the relation $W_1 - W \div V$ and results recorded.

Water Absorption Capacity: Two portions of 1000g of the aggregate samples were weighed. One portion was placed in an oven at a constant temperature of $105^0 \pm 5^0$C, and left for 24 hours in the oven. The second portion was put in steel container with the addition of water until the samples were completely submerged under water this was also left for 24 hours. After 24 hours both the sample in the oven and the soaked aggregate sample were weighed after the soaked aggregates has completely drained. The soaked aggregates were then spread on a piece of paper under a blowing fan until the aggregates attained a completely dried surface. The water absorption capacity of the aggregates was computed using the relationship:

$$\text{Water absorption} = \frac{\text{Air weight} - \text{oven dry weight}}{\text{Oven dry weight}} \times 100$$

Aggregate Impact Value Test: The aggregate samples were dried in an oven at a temperature of 105^0C for 4 hours and then allowed to cool. The cylindrical cup was then filled with the aggregate sample in three layers and each layer been tamped 25 times with a standard rammer. The weight of the filled cup was the recorded as W_1. A set of 14kg hammer were then dropped on the test sample at intervals of not less than 1 second from a height of 350 ± 5mm. The fraction of the samples passing through the 2.36mm sieve as a result of the impacts were then weigh. The ratios of the weight of fines formed to the total weight of the aggregate sample was then expressed in percentage. This test was done in accordance to BS812 – 112 (1990).

Aggregate Crushing Value Test: The aggregates were sieved through 14mm and 10mm sieves and materials retained on 10mm sieve adopted for test. The materials retained were placed in the cylindrical measure and the weight recorded as Wt_1. The aggregates were then dried in an oven at a temperature of 105^0C for 4 hours and allow to cool. The test samples were placed in three layers in the cylinder with each layer was subjected to 25 strokes with the tamping rod. The surface of the aggregate was then leveled and the plunger inserted and ensured it rested horizontally on the surface of the aggregates. The apparatus with the test sample and plunger were then placed in position between the plates of the testing machine and loaded at a uniform rate to the required load. After loading, the crushed material was removed from the cylinder and sieved through 2.36mm sieve. The fraction passing the 2.36mm sieve was then weighed and recorded as Wt_2.

The Aggregate crushing value was computed using the relation, $ACV= Wt_1 / Wt_2 \times 100\%$ and in accordance to the specification of BS 812-110 (1990).

Results and Discussion

Particle Size Distribution

Tables 2, Table 3 and Figure 1 present the results of the sieve analysis for the natural sand fine aggregate; Sand (FA) and ceramic waste tile (CWT – FA) respectively. The fineness modulus obtained were 3.70 and 3.52 for the Sand (FA) and CWT (FA) respectively.

Table 2: Sieve Analysis of Fine Aggregates (Sand - FA)

BS Sieve size	Weight retained (kg)	Total weight retained (kg)	Cumulative percentage retained (%)	Weight passing (%)	Percentage passing (%)
4.75mm	155	155	7.75	1845	92.3
2.36mm	500	655	27.75	1345	67.3
1.18mm	455	1110	50.50	890	44.5
600µm	400	1510	90.50	490	24.5
300µm	365	1876	93.75	125	6.23
150µm	120	1995	99.75	5	0.25
Pan	5	-	-	0	0
Total			370		
Fineness modulus			3.70		

Source: Field work (2021)

Table 3: Sieve Analysis of Fine Aggregates (CWT – FA)

BS Sieve size	Weight retained (kg)	Total weight retained (kg)	Cumulative percentage retained (%)	Weight passing (%)	Percentage passing (%)
4.75mm	180	180	9.99	1820	91
2.36mm	600	780	34.00	1220	61
1.18mm	290	1070	43.50	930	46.5
600µm	500	1570	73.50	430	21.5
300µm	250	1820	91.00	180	9.00
150µm	178	1998	99.90	2	0.1
Pan	2	-	-	0	0
Total			352		
Fineness modulus			3.52		

Source: Field work (2021)

Table 4, Table 5 and Figure 2 shows the result of the sieve analysis of coarse aggregates (Granite and ceramic waste tile respectively). The fineness modulus of the granite aggregates GRT - CA was found as 5.88 while that of CWT – CA was 5.79.

Table 4: Sieve Analysis of Coarse Aggregates (GRT – CA)

BS Sieve size	Weight retained (kg)	Total weight retained (kg)	Cumulative percentage retained (%)	Weight passing (%)	Percentage passing (%)
20mm	15	15	1	1485	99
10mm	801	816	54.4	684	45.6
4.75mm	214	1030	68.7	470	31.3
2.36mm	195	1225	81.7	275	18.3
1.18mm	125	1350	90	150	10
600µm	69	1419	94.6	81	5.4
300µm	50	1469	97.93	31	2.1
150µm	25	1494	99.76	6	0.4
Pan	6	-	-	0	0
Total			588		
Fineness modulus			5.88		

Source: Field work (2021)

Table 5: Sieve Analysis of Coarse Aggregates (CWT – CA)

BS Sieve size	Weight retained (kg)	Total weight retained (kg)	Cumulative percentage retained (%)	Weight passing (%)	Percentage passing (%)
20mm	26	26	1.73	1474	98.3
10mm	815	841	56.07	659	44
4.75mm	173	1014	67.60	486	32.4
2.36mm	166	1180	78.66	320	21.3
1.18mm	121	1301	86.73	199	13.2
600µm	79	1380	92.00	120	8
300µm	80	1460	97.33	40	3
150µm	30	1490	99.33	10	0.6
Pan	10	-	-	0	0
Total			579		
Fineness modulus			5.79		

Source: Field work (2021)

Particle Size of Fine Aggregates: Results in Table 2, Table 3 and Figure 2 shows the particle size (gradation) results for the Natural Sand – FA and the Ceramic Tile Waste Aggregates (CWT – FA Aggregates). Results revealed that 67.3% of Natural Sand – FA passed through the BS 2.36mm sieve while 61% of the CWT – FA passed through the BS 2.36mm as shown in Figure 1. This indicates that the Natural Sand – FA has high percentage passing and lower percentage retained on the sieve than the CWT – FA aggregates

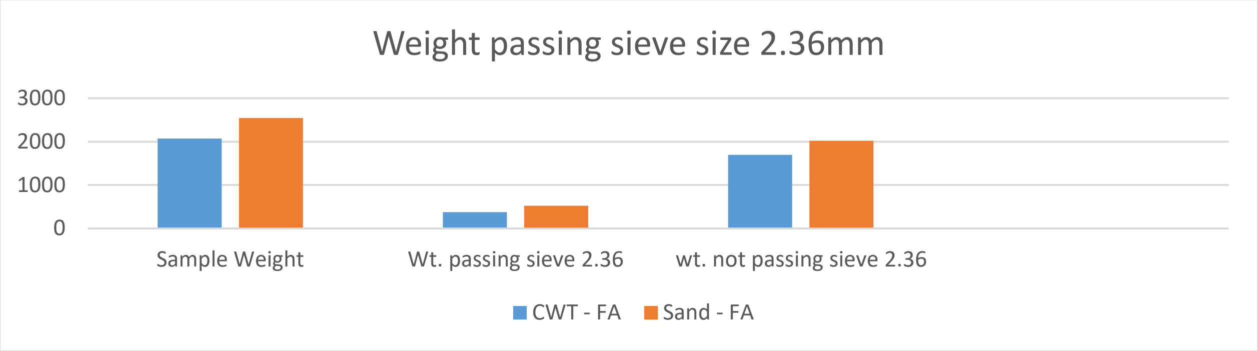

Figure 1: Weight of Aggregates passing sieve size 2.36mm

Findings of the study shows the fineness modulus value of Ceramic Waste Tile aggregates (CWT – FA) as 3.72 and that of the fine sand aggregates (Sand – FA) as 3.85 this values falls within the range of 2 – 3.5 (+ or - 0.2) as posits by works of (Neville and Brooks 2010; Gupta and Gupta, 2012). The results further showed that the percentage of the CWT – FA passing sieve 600 micron was 21.5% which fall within the range of 15 – 34 (Neville and Brooks 2010; Gupta and Gupta, 2012). Also, the percentage of the Sand – FA passing sieve 600 micron was 24.5% which also falls within the range of 15 – 34. Therefore, both fine aggregates fall within (Zone I) as suggested by Neville and Brooks (2010) and reported by Sekar *et al* (2011); Medina *et al* (2009) and Maxwell (2016) in related works.

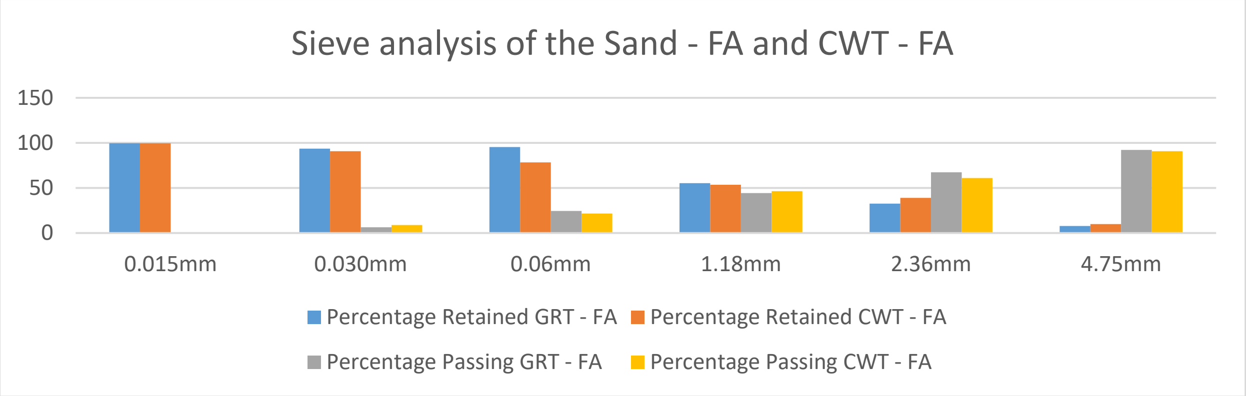

Figure 2: Relationship between the percentage retained and percentage passing of sampled GRT and CWT Fine Aggregates

Particle Size of the Coarse Aggregates: Results in Table 4, Table 5 and Figure 3 shows the particle size (gradation) results for the coarse aggregates: Granite Aggregate (GRT – CA) and the Ceramic Tile Waste Aggregates (CWT – Aggregates). Findings reveals that 99% and 97.3% of the GRT – CA and CWT – CA were retained on the BS Sieve 20mm respectively. The fineness modulus of the GRT – CA aggregates was found as 5.88 while that of CWT – CA was 5.79. This is in agreement with the specification of Gupta and Gupta (2012) the fineness modulus of coarse aggregates should vary between from 5.5 to 8.0.

The result further shows that the fineness modulus value of the CWT aggregates used in this research is within the range of ± 0.09% of the GRT – CA conventional aggregates. It can be argued further that since 1% CWT – CA and less than 2.7% GRT - CA pass through the BS Sieve size 4.75mm then the CWT – CA aggregates can be usefully used as coarse aggregates as reported in similar works by (Ay and Unal, 2000; Brito *et al* 2005 and Binici, 2007). However, Soji (2018), Maxwell (2016) and Kabir (2016) reported a less than 0.5% passage for man-made aggregates however base on the preliminary studies and results obtained both the CWT – FA and CWT – CA can be conclude as promising aggregates in concrete production as found in similar researches by Brito *et al* (2005) and Binici (2007).

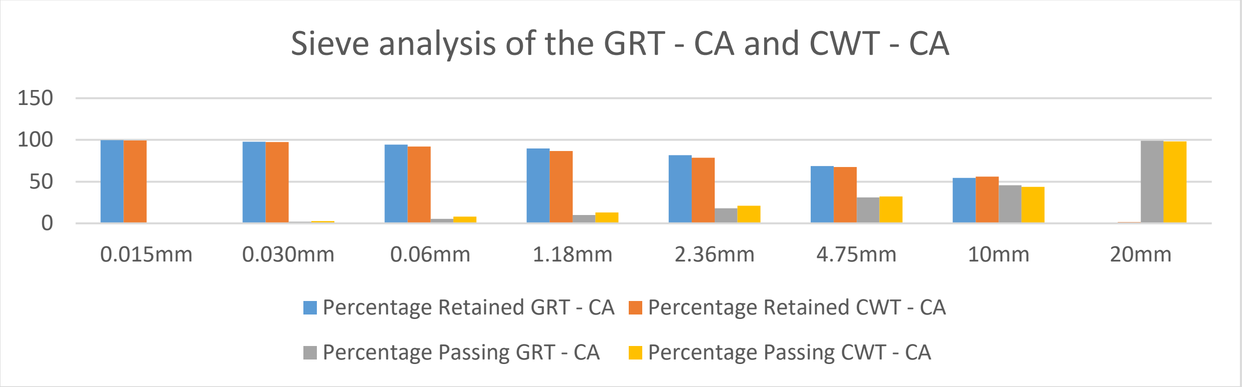

Figure 3: Relationship between the percentage retained and percentage passing of sampled GRT and CWT coarse aggregates

Specific Gravity, Bulk Density and Absorption Capacity of Aggregate: Table 6 shows the specific gravity, bulk density and water absorption capacity of the aggregates. These test were carried out in accordance with the provisions of BS812 – 108 (1990). The specific gravity of ceramic waste tile (CWT – CA) and granite (GRT – CA) coarse aggregate were found to be 2.28 and 2.64 while the specific gravity of the fine aggregate ceramic tile CWT – FA and conventional fine aggregate (Sand – FA) was 2.63 and 2.44 respectively. The Water absorption capacity of the CWT – CA was found as 2.83% while the GRT – CA aggregates had a water absorption capacity of 0.79%.

Table 6: Specific Gravity, Bulk Density and Absorption Capacity of Aggregates

Properties	CWT - CA	GRT - CA	CWT - FA	Sand – FA
Specific gravity (SSD)	2.63	2.64	2.61	2.63
Bulk density kg/m^3	1474	1539	1449	1500
Weight of Wet Sample (W_1)	1470	1525		
Weight of Dry Sample (W_2)	1435	1513		
Absorption capacity (%)	2.83	0.79		

Source: Field work (2021)

Specific Gravity, Bulk Density and Absorption Capacity of Aggregates: The bulk density of both the ceramic tile fine (CWT – FA) and coarse aggregates (CWT – CA) shown in Table 6 were lighter in weight than that of granite GRT – CA and river sand – FA aggregate however they satisfy the requirements of BS 812-108 (1990) that states the range for normal weight aggregates to be between 1280 and 1920 kg/m^3 (for bulk density) (Koyuncu *et al* 2004; Senthemarai and Devadas (2005) and Tavakoli *et al* (2013).

The specific gravity and the bulk density of both the CWT – FA and CWT – CA were within the recommended ranges and in agreement with work reported by Garba (2014), Higashiyama *et al* (2012), Correia *et al* (2006) and Gomes and De Brito (2009).

Table 6 further shows the water absorption capacities of both the CWT - CA and GRT – CA. It was observed that the ceramic waste tile absorbed more water (more than 3 times in percentage) than the granite aggregate with 0.79%. This was found to be in agreement with the findings of Correia *et al* (2006), Lopez *et al* (2007), Khatib (2005) and Guerra *et al* (2009) that report a similar trend of behavior in related works.

Aggregate crushing value: Table 7 shows the result of crushing value test of ceramic waste tile (CWT – CA) and granite (GRT – CA) aggregates. The aggregate crushing value test was carried out in accordance to the provisions of BS812 – 110 (1990). The values of the CWT – CA and GRT - CA that passed through sieve 2.36mm were 375 and 525kg respectively

Table 7: Average Crushing Value of Aggregates

Item	CWT – CA (kg)	GRT – CA (kg)
1. Sample Weight	2070	2545
2. Weight passing sieve 2.36mm	375	525
3. Weight retain on sieve 2.36mm	1697	2020
4. Aggregate crushing value (%)	18.11	21
Aggregate Crushing Value	18.11%	21%

Source: Field work (2021)

Aggregate Impact Value: Table 8 presents the impact value results of CWT – CA and GRT - CA. The weight of the aggregate passing through the 2.36mm sieve was found as 435kg and 530kg for the ceramic waste and granite aggregate respectively as shown in Figure 1.

Table 8: Average Impact Value of Aggregates

Item	CWT – CA (kg)	GRT – CA (kg)
1. Sample Weight	490	620
2. Weight passing sieve 2.36mm	55	90
3. Weight retain on sieve 2.36mm	435	530
4. Aggregate crushing value (%)	11.22	15
Aggregate Impact Value	11.22%	15%

Source: Field work (2021)

Aggregate Crushing and Impact Value of Aggregates: Table 7 and Figure 4 shows the Average aggregate crushing value of the CWT – CA and GRT – CA respectively. The percentage of the aggregate crushing value for CWT - CA was 18.11% while the aggregate crushing value for GRT - CA was 21% (Figure 4). Results obtained shows that the CWT – CA aggregates have conformed to the specifications of BS812 – 110 (1990) which state that the ratio of the fraction passing should not be more than 45% as reported by Gupta and Gupta (2012) and supported by related works of Garba 2014; Khatib (2005); Maxwell (2016) and Pacheco and Jalali (2010). From the findings results have shown that the ceramic waste aggregate CWT - CA have higher ability to resist crushing than the granite aggregate GRT - CA.

Table 8 shows the aggregate impact value results of the CWT – CA and GRT – CA. The average percentage of aggregates impact value of the ceramic waste tile aggregate CWT – CA and GRT - CA were 15% and 11.22% respectively. This indicates that the CWT – CA is more resistant to impact than the GRT – CA this is in support with the findings of Maxwell (2012) which also is in agreement with the findings of (Garba 2014 and Khatib 2005) that reported a similar trend of behavior when using ceramic tiles as either fine or coarse aggregate in concrete making. Also, the results obtained have shown that the CWT – CA aggregates conforms with the specification of BS812 – 112 (1990).

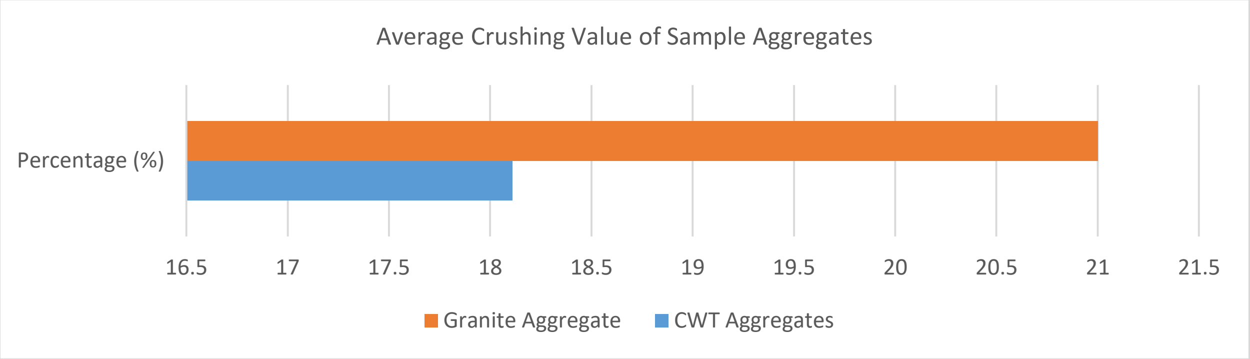

Figure 4: Average Crushing Value of Sampled Aggregates

Conclusion and Recommendation

Inadequate information on 100% use of CWT – aggregates as both fine and coarse aggregates simultaneously to replace natural aggregates motivates this research. The aim was to evaluate if the CWT – aggregates can be use as fine and coarse aggregates in concrete production. The bulk density, particle size distribution, specific gravity and water absorption were studied. Findings shows that the CWT – aggregates can be classed as normal weight aggregates because their bulk densities, specific gravity, rate of water absorption, crushing and impact value all falls within the recommended range of standards which include British Standard 812-112 (1990), British Standard 812-110 (1990), British Standard 812-103 (1990), British Standard 812-101 (1990) and British Standard 812-108 (1990) which specified the methods for determination of aggregate impact value (AIV), methods for determination of aggregate crushing value (ACV), methods for determination of particle size distribution, guide to sampling and testing aggregates and methods for determination of bulk density, optimum moisture content, voids and bulking respectively for materials to be adopted for use as aggregates in concrete production.

The results show that the produced CWT – FA and CWT – CA aggregates have bulk densities of 1449kg/m^3 and 1274kg/m^3 with specific gravities of 2.63 and 2.28 respectively. Furthermore, the CWT – CA aggregates had a water absorption capacity of 2.3%, an average crushing and impact value of 18.11% and 12.22% respectively. The study also reveals that the CWT – CA aggregates were more resistant to crushing and impact than the control Granite GRT – CA aggregates in the range of 14% – 28%. The study therefore recommends that the ceramic waste tile can be usefully transformed into crushed fine and coarse aggregates to wholly (100%) replace both sand and gravel concurrently in concrete production.

Conclusively, this research has bridged the gap existing due to inadequate literature supporting combined hundred percent replacement of conventional aggregates. Additionally, the research has provided experimental prove to guide key construction stakeholders which may include Engineers and Builders with knowledge on using ceramic waste tiles to wholly (100%) replace conventional aggregates in concrete production while ensuring environmental sustainability.

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