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FLEXURAL BEHAVIOR OF CONCRETE BEAMS CONTAINING CERAMIC WASTE AS REPLACEMENT OF COARSE AGGREGATE

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Abstract: The paper presents results of the investigation conducted to evaluate the flexural performance of unreinforced and reinforced concrete beams with ceramic waste as replacement of coarse aggregate. A total of forty-five (45) non-reinforced beams (150x150x750mm) and ten (10) reinforced beams (150x250x2150mm) were used to investigate the flexural behavior of the specimens. The flexural parameters investigated are crack formation and pattern, failure mode, ultimate load, theoretical and experimental ultimate moments, and deflection. From the results of the investigation, the increase in ceramic waste content led to substantial decrease in the failure load which produced higher experimental moments when compared to theoretical moments. Generally, sudden failure mode was observed for all unreinforced specimens with cracks formed about the mid-span of the specimens. Diagonal cracks were observed in the reinforced beam test specimens and failure mode was diagonal tension failure with cracks propagating from the tension face towards the compression face. The investigation further showed an optimum (maximum) allowable deflection value of 5.09mm at 25% replacement level. It is concluded that ceramic waste usage as aggregate in concrete is sustainable for low-cost housing projects.
Keywords: ceramic waste, flexural strength, deflection, failure load, crack pattern

1. INTRODUCTION

There is a high increase in the generation of waste worldwide. Ceramic waste is generated from ceramic industry, construction and demolition activities. Construction and demolition (C&D) wastes contribute the highest percentage of wastes (75%) worldwide with ceramic materials contributing 54% of the wastes [1]. The continued dumping and /or the inadequate management of wastes from the various manufacturing and construction industries have had a remarkable impact on the receiving environment; leading to water, soil, air and noise pollution amongst other complications, and adding to existing ecological problems. At the same time, these practices exemplify an economic cost [2].

In recent times, researchers [3,4,5,6,7] have found that some wastes – Construction and demolition, agricultural and industrial, etc., could be used as partial replacement of coarse aggregate to produce concrete of adequate strength, with little or minimal treatment. Some of these materials that have been found suitable as supplementary coarse materials in the production of concrete include: cow bone, coconut shell, periwinkle shell, granulated blast furnace slag, recycled glass, construction and demolition waste, etc. Significant efforts have been expended by researchers on these materials to investigate their structural performance with emphasis on compressive strengths, splitting tensile strength, and modulus of rupture [8, 9, and 2].

The present study concerns itself with the potential usage of ceramic waste aggregate (CWA) as partial or complete replacement of normal coarse aggregate in the production of concrete, with emphasis on its flexural behaviour. According to [8], it is reported that annual global generation of ceramic waste (CW) is about 30% of all ceramics produced across the globe. It is further stated that they are difficult to dispose and recycle; thus creating environmental problems. The aim of this work, which is to assess the suitability of ceramic waste aggregate (CWA) as partial or complete replacement of granite in the production of concrete, looks at the flexural response of unreinforced and reinforced concrete beams containing the waste as aggregate up to 100% of normal coarse aggregate replacement in steps of 25%.

With the exception of the works done by [7] on periwinkle shells, and[10] on palm kernel shell, most researchers have not considered it worthy to investigate the flexural characteristics of concrete containing ceramic wastes as partial replacement of granite within the context of reinforced beams, The flexural issues investigated in this study using unreinforced and reinforced concrete beams having ceramic waste as partial replacement of normal coarse aggregate are: failure pattern, load-deflection characteristics, stiffness, and ultimate moments.

2. EXPERIMENTAL PROCEDURES

Materials

The cement was Ordinary Portland cement (Grade 32.5R) produced in accordance to [11] and [12]. Ceramic Waste used was obtained from on-going construction sites within the University of Lagos, Nigeria. The crushing of ceramic wastes was done manually and made into smaller pieces of about 5-40mm sizes by a hammer. These small pieces were then fed into stacked vibrator sieves to get the required 12.5 -19mm size. The coarse aggregate used in this research study was crushed granite of igneous origin. The sizes of the aggregate varied between 12.5mm to 19mm. As fine aggregates, river sand was obtained from Ogun River Basin located at Ibafo in Ogun State, Nigeria. The sand was dried and sieved through sieve with the aperture size of 3.35mm but retained on sieves of 63μm treated in accordance with BS 882 (1992) [13]. It was confirmed to be salt-free and free from deleterious substances. The water used for the experiment was portable tap water, free from any sulphates, ferric, alkaline, oils, vegetation or salt that could affect the properties of the materials or concrete in the fresh or hardened state [14]. A mix ratio of 1:2:4 by weight of cement, sand and granite/CWA was used, and the water-cement ratio of 0.60 was adopted. The granite in the mix was partially replaced with ceramic waste at an interval of 25% up to 100%. The concrete with 0% CW replacement served as the control.

Figure 1- Crushing and Sieving of Ceramic Waste

Flexural Strength Test

The concrete beam specimens were designed in accordance with [15]. The loading arrangement is as shown in Figure 2. The flexural strength test was carried out on forty-five (45) beams (150×150×750mm) without reinforcement under two points loading at the curing ages of 7, 14 and 28 days for each percentage replacement. The beams (150×250×2160mm) were reinforced with a minimum area of reinforcement (0.13% bh, b = breadth of beam, and h = depth of beam) in accordance with [15]. The reinforcement for the beams consisted of two 16mmdiameter hot-rolled, deformed bars with yield and ultimate stresses of 534.43N/mm^2 and 785.63N/mm^2 respectively. For shear reinforcement, 10mmdiameter hot-rolled, deformed bars with yield and ultimate stresses of 478.10N/mm^2 and 710.81N/mm^2 respectively were used. The cover was 20mm while the spacing for shear reinforcement was 150mm to satisfy the requirement of [15], limiting the spacing for shear reinforcement to a value less than 0.75 of the effective depth (0.75 x 202 = 151.5 mm).

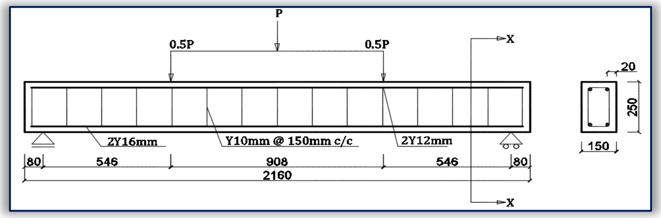

Figure 2- Detailing of Concrete Beam and Loading Arrangement

The replacement of granite with ceramic waste in the beams was varied from 0 to 100% at 25% increment (based on preliminary findings). Beams without ceramic waste served as control. Beam specimens were produced and tested under the third point loading (Figure 3) in accordance with [16]. A dial gauge was placed under the beam at the mid-span to measure the deflection at regular interval of loading. The load at which the first visible crack occurred was noted and recorded; so was the load at which failure occurred. The tests were terminated when a little increase in load led to a very large deflection. A total number of 10 beams were cast and tested at 28-day curing age.

Figure 3- Laboratory Testing

3. RESULTS AND DISCUSSION

Results of preliminary tests on concrete constituent

The initial moisture content of the concrete constituents was determined by oven-drying before usage. The aggregates (sand, granite and ceramic waste aggregate) were found to contain 0.54%, 0.14% and 0.20% moisture content repectively. The ceramic waste was observed to have a higher value of water absorption of 0.18% when compared to 0.10% of granite because of the surface area, pore structure, and clay content.

In this investigation, the bulk density (Kg/m^3) for sand, granite and ceramic waste aggregate were 1410.59, 1468.69 and 1323.43 respectively while the specific gravity were 2.50, 2.76 and 2.16 respectively. The aggregate Crushing Value for ceramic waste (13.56%) was found to be lower than that of the coarse aggregate (17.39%). This may be attributed to the void ratio or void content of the materials and material shape. The granites are generally of irregular shapes. This could result in large void ratio than the ceramic waste that are largely flat shaped and could be more densely packed; hence lower void content.

Effect of ceramic waste on flexural strength of unreinforced beams

» Load Carrying Capacity of the Unreinforced Ceramic Waste Concrete Beams

The table 1 below shows the results of the flexural strength tests on unreinforced beams (150x150x750mm). Three beams were produced from each percentage replacement of ceramic waste, making a total of 15 beams tested using three point loading test machine to determine their flexural strengths.

Table 1- Average flexural strength of ceramic waste concrete beam

S/N	DESCRIPTION	Average Flexural Strength (N/mm^2) 7 Days	14 Days	28 Days
1	Control Samples	2.52	2.69	2.96
2	25% Replacement	2.93	3.02	3.16
3	50% Replacement	3.01	3.09	3.34
4	75% Replacement	3.15	3.27	3.67
5	100% Replacement	2.76	3.05	3.15

From figure 4, it was observed that for all replacement levels, flexural strength increased with curing age. This increase can be attributed to the presence of adequate amount of moisture in the concrete mixes for continuous hydration and development of strength, volume stability and scaling resistance. At all curing ages, flexural strength increased with percentage increase of ceramic waste up to 75% beyond which there was decrease in flexural strength values. The reason for the reduction may be due to the surface texture of the ceramic waste aggregate.

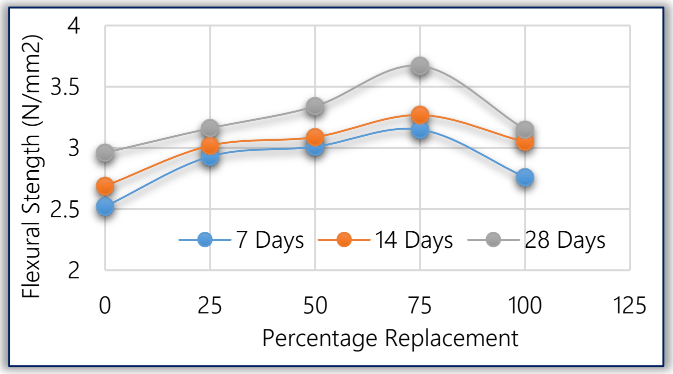

Figure 4- Variation of Flexural Strength for 7, 14 & 28 Day Curing Ages

» Failure mode and crack pattern

From the tests conducted on the beams (150x150x750mm), the crack and failure patterns were similar for all mixes as shown in figure 5. The failure of the beams was seen to occur at almost the Centre of the beams, 380mm from either side of the beams, No cracks were observed prior to the failure of the beams. The failure was sudden without initial crack(s) preceding the ultimate failure of the beams. The sudden failure of the beams can also be attributed to the exclusion of steel reinforcement which contributes immensely to the flexural strength of concrete beams.

Figure 5-Failure Mode of Concrete Beam

Effect of ceramic waste on crack and failure mode of reinforced concrete beams

» Crack formation and pattern

The cracks appeared at the support and propagated diagonally about two-thirds of the depth of the beams from the tension face (bottom), extending towards the compression zone of the beams (top) as sketched in figure 6. Thereafter, the propagation was gradual until failure occurred. The cracks occurred along the line of loading on either sides of the beam; indicating the points of the maximum flexural moment(s). The visible evidence of this type of failure is in the form of diagonal cracks from the support and towards the direction of the point of load application. The cracks widened until failure. Another failure displayed at the tension zone was in form of many cracks inclined in the direction of the applied load, which resulted in the crushing of the concrete specimens at the upper face.

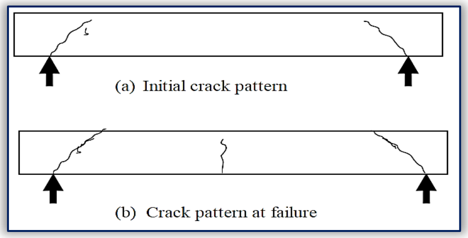

Figure 6- Crack Development of Beams

From table 2, the angle of inclination of the cracks to the horizontal varied between 35.6° - 49° as the percentage replacement of normal aggregate with CWA is increased from 0% to 100% at 25% interval (Table 2); the average being 42.3°. According to [15], it is assumed that the diagonal crack is generated at an angle of 45° to the tension reinforcement (I.e. to the horizontal) for normal concrete. The poor bonding nature of the ceramic waste may have led to the greater angle of crack to the horizontal as ceramic waste content increased.

Table 2- Angle of inclination of the cracks to the horizontal in reinforced beams

Percentage Replacement Ceramic Waste (%)	Angle (degree) of Crack from Horizontal	Deviation from 45°	Percentage Deviation (%)
0	35.60 $\pm$ 0.40	-9.40	-20.88
25	38.80 $\pm$ 0.77	-6.20	-13.78
50	41.90 $\pm$ 0.34	-3.10	-6.89
75	45.30 $\pm$ 0.67	+0.30	+0.67
100	49.00 $\pm$ 0.22	+4.00	+8.89

From the above values of angle of inclination in Table 2, the numerical variation is less than 10%because the ceramic waste aggregate has an angular shape.

» Failure mode

The failure mode for all the specimens, irrespective of the content of the ceramic waste was in the form of inclined cracks that developed at the edge of the supports, extending in the direction of the loading points as the applied load is increased. As displayed in figure 6, according to [17], the failure mode is described as diagonal tension failure.

» Effect of ceramic waste on failure load and failure moment of reinforced concrete beam

The theoretical bending moment was calculated for each of the beam specimens from equation (1), derived by assuming the idealization of rectangular stress block and using an average stress of $0.67f_{cu}$ (N/mm^2) over 0.9 times of the neutral axis depth in line with [15]:

$$M_u = 0.156 f_{cu} b d^2 \tag{1}$$

where: f_{cu}= compressive strength of cube test specimen for each granite replacement level with ceramic waste (N/mm^2); b = width of beam specimen (mm); d = effective depth (mm)

The experimental bending moment (M_{EXP}) was calculated by using the equation for the structural form that is compatible with the third point loading configuration. The bending moment equation is:

$$M = 0.25PL \tag{2}$$

where: M = maximum bending moment; P = Service Load (kN), L = span of beam specimen (m)

The failure load, the theoretical ultimate moment (M_{THE}) and the experimental ultimate moment (M_{EXP}) computed from equations (1) and (2) are shown in Table 3. It is noted, however, that in computing M_{EXP}, the service load was obtained by dividing the load at the first visible crack by 1.6. This presupposes that flexural failure by the load has already occurred at the first visible crack, and this load was thus used to calculate the experimental ultimate moment. From the Table, the following observations are made.

Table 3- Comparison between experimental and theoretical bending moments

Percentage replacement of Ceramic Waste (%)	Load at first crack (kN)	Percentage reduction in load at first crack (%)	Failure load (kN)	Percentage reduction in failure load (%)	% Cracking load in relation to failure load	Service load {Load at 1st crack/1.6} (kN)	Theoretical design moment (M_{THE}) $0.156f_{cu}bd^2$ (kN.m).	Experimental ultimate moment (M_{EXP}) 0.25PL (kN.m),	M_{EXP} M_{THE}
0	80.00	-	147.50	-	54.24	50.00	22.58	27.00	1.20
25	75.00	6.25	120.50	18.31	62.24	46.88	18.29	25.32	1.38
50	65.00	18.75	115.00	22.03	56.52	40.63	17.40	21.94	1.26
75	60.00	25.00	107.50	27.12	55.81	40.00	16.42	21.60	1.32
100	55.00	31.25	105.00	28.81	52.38	34.38	12.59	18.57	1.48

» Effect of ceramic waste on failure load

It is observed from Table 3 that the failure load decreased with increasing ceramic waste content. The load at which the first crack occurred follows the same trend. This can be attributed to a reduction in density of the concrete with the increase in flaky aggregates and the smooth surface texture of ceramic wastes which could have resulted in poor bonding properties of the concrete matrix. At 25% replacement level, the percentage reduction of 6.25% was observed, and this kept increasing to 31.25% reduction at 100% replacement level for the load at first crack. A greater percentage reduction of 18.31% was observed at 25% replacement level of granite with ceramic waste at failure load. This increased to 28.81% at 100% replacement level of the ceramic waste.

» Effect of ceramic waste on ultimate moment

The effect of ceramic waste on the flexural strength is also presented in Table 3. The bending moments at failure (both theoretical and experimental) decreased with increasing ceramic waste content, probably as a result of reduced density and aggregate crushing value (ACV), with a consequent reduction in compressive strength. The bending moments are calculated on the assumption that failure occurred at the onset of the first visible crack. The values of the experimental bending moments are consistently higher than those of the theoretical bending moments calculated using equation (2).

» Comparison between cracking and failure

From table 3, the cracking load decreased with increasing ceramic waste content. This can be attributed to a decrease in density and compressive strength of the concrete. The failure load also follows the same trend, confirming the poor bonding properties of ceramic waste aggregates.

Effect of ceramic waste on load-deflection characteristics of reinforced concrete beam

The deflection values were obtained at different locations with dial gauges, positioned as indicated in figure 7.

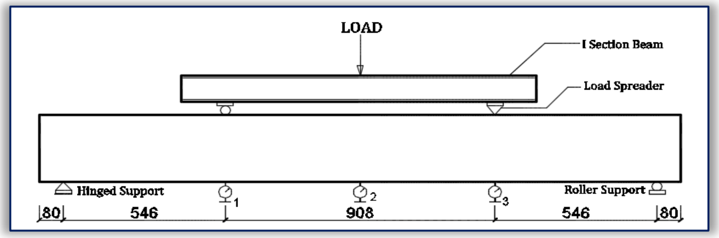

Figure 7-The Loading Arrangement (1, 2, & 3-Dial Gauges)

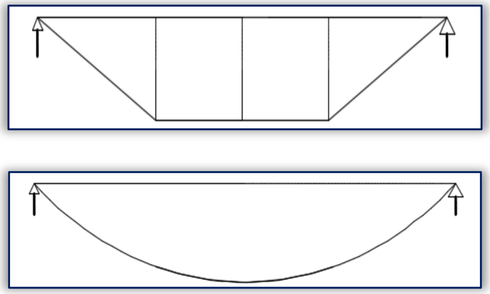

Figure 8-The Bending Moments of a Two Points Loaded Concrete Beam; a) Theoretical Bending Moment; b) Practical Bending Moment

The longitudinal deflection pattern is established from observation of dial gauges at points 1, 2 and 3. Theoretically, in the analysis of a simply supported beam under two symmetrically placed point loads. In plotting the shearing force and bending moment for the applied load on the beams, the bending moment values are calculated by assuming a section just before and after the section under consideration. In which just before, the applied load is assumed to be neglected while after indicated that the applied load is acting on the section. Figure 8a shows the bending moment diagram for two points loaded beam in trapezoidal form. Experimentally, the applied load is not just acting only on at that point, but some stresses are created by the applied load which cause the bending moment diagram to give a non-linear form as shown in figure 8b. For every load applied, it is observed that control concrete gives the least deflection value before failure (abrupt failure) indicating that the first crack load depends on the tensile strength of concrete.

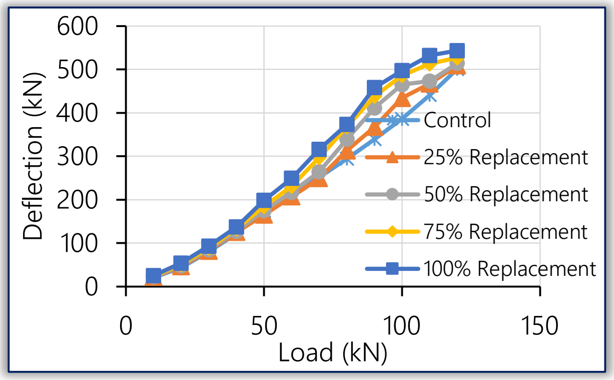

Figure 9(a) - Load deflection for all granite replacements with ceramic waste

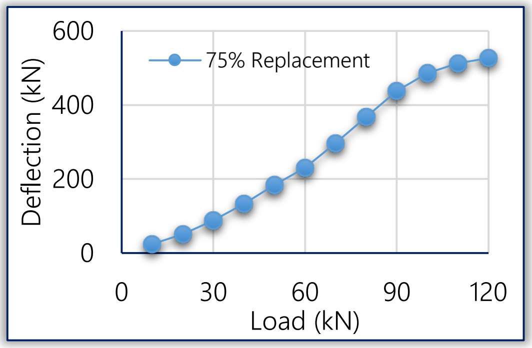

Figure 9(b) - Load deflection for 75% replacement of granite with ceramic waste

From figure 9(a), it can be observed that the deflection increased with the percentage increase in ceramic wastes. The reason for the reduction may be due to the surface texture of the ceramic waste aggregate which led to poor bonding properties of the matrix [18]. Also, the deflection increased as the applied load is increased. Using the 75% replacement (Figure 9b) as representative, the curves are characterized by three different segments connected by three important events that took place during the process of loading until failure. These regions are:

a) Un-cracked sections (Region AB) - All the specimen in the first region corresponds to the un-cracked section. Before the first visible crack appears, the applied load is considered to be directly proportional to the deflection in this region. As shown in figure 9b for 75% replacement, the region terminates at the load at which the first visible crack was noted. A more or less linear pattern was observed in this interval. This indicated that the actual moment is less than the cracking moment and the tensile stress is below rupture.
b) Cracked Sections (Region BC) - This region represents the load at first crack to the load at

Table 4-Load-deflection of ceramic waste (steel Reinforced) concrete beams

Load (kN)	Deflection (0.01mm) 0% CW	25% CW	50% CW	75% CW	100% CW
10	20.5	22	23	24	25
20	43.5	46	48	51	54
30	80	82	85	88	93
40	122	125	127	133	137
50	174	165	175	184	198
60	212	207	217	231	249
70	252	249	264	297	316
80	294	313	339	368	373
90	339	367	411	438	458
100	386	434	465	486	497
110	441	467	473	513	532
120	501	509	514	527	543

failure. The results show relatively large deflection from the increasing applied load until complete failure. The load deflection pattern is considered to be non-linear, indicating that the cracks developed on the tension face of the beam and spread quickly to the neutral axis.

c) Failure Sections (Region CD) - In this region, ultimate stress occurs, and any little increase in load resulted in a significant deflection as shown in figure 9b.

From table 4, according to [15], maximum allowable deflection is given as $\delta = \frac{L}{250}$ for a simply supported beam; that is, 8.64mm. In this experiment, to ensure that this maximum allowable deflection is not exceeded, the maximum load allowable should not be more than 130KN. It is observed that the optimum load and percentage replacement combination to achieve the allowable deflection value (5.09mm) for ceramic waste concrete beam is 120kNat 25% replacement from table 3. This loading can be sustained in residential low-cost housing projects.

4. CONCLUSIONS

From the results of this investigation, the following conclusions can be made:

1. The flexural strength of the beams increases as the ceramic waste content increased up to 75% replacement and a notable decline was observed at 100% replacement.
2. The failure mode for the long reinforced concrete beams was in the form of inclined cracks (diagonal tension failure) irrespective of ceramic waste content, but the failure of the non-reinforced short beams was sudden due to the absence of reinforcing bars.
3. Lesser failure load was attained with an increase in ceramic waste contents in the concrete matrix. The experimental moments was observed higher than the theoretical moments.
4. At a given loading, the deflection increases as the ceramic waste content areincreased from 25% to 100% replacement level due to higher flakiness value, improper (weaker) bonding of the aggregate with cement paste produced by the porcelain surface, and higher water absorption capacity of the ceramic waste aggregate.

The optimum (maximum) allowable deflection value is 5.09mm at 25% replacement. The use of ceramic waste in concrete is sustainable for low-cost housing projects.

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