

Assessing Engineering Properties of Concrete Produced with Broken Earthenware as a Partial Replacement of Coarse Aggregate

Samuel Amoako

Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development

Peter Paa Kofi Yalley

Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development

Elijah Kusi

ekusi@aamusted.edu.gh

Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development

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Abstract

This study investigated the engineering properties of concrete produced with broken earthenware as a partial replacement for coarse aggregate. Crushed granite was partially replaced at 0%, 10%, 20%, 30%, and 40% with broken earthenware aggregates to produce concrete. Concrete specimens were prepared and tested at 7, 14, 21, and 28 days of curing for density, compressive strength, tensile strength, water absorption, and magnesium sulfate attack. The study found that at 10% replacement, the concrete specimen recorded a compressive strength of 26.39 N/mm² at the 28-day curing age, 2.7% lower than the control specimen. Similarly, the tensile strength at 10% was 3.8% lower than that of the control specimens. The density for the 10% replacement was 2432.00 kg/m³, 2.2% lower than the control, while the water absorption for the 10% was 2.52%, 3.2% higher than the control. The study concluded that concrete made with broken earthenware aggregates meets acceptable standards per BS EN 12390:2019 and BS 1881 – 122:2011. It recommends a 10% replacement for standard concrete works and a 40% replacement for environments with high magnesium sulfate exposure. The study shows that using broken earthenware aggregates to replace traditional aggregates reduces construction costs and minimizes environmental impacts by reusing low-cost ceramic waste. This approach enhances both cost efficiency and environmental sustainability in the construction industry.

1.0 Introduction

The consumption of natural resources is rapid, which poses a serious challenge for the construction industry on the one hand and increases construction costs significantly on the other (Bommisetty et al., 2019). Interestingly, concrete ranks second in terms of consumption after water, with an approximate yearly rate of about 6 billion cubic meters (Amankwah et al., 2015). Concrete is the most widely used building material. The extensive usage of concrete raises overall housing costs and causes environmental issues due to the extraction of aggregates (Amankwah et al., 2015; Botchway & Masoperh, 2019). About 75–80% of the volume of concrete is made up of aggregates (Sankh et al., 2014). The excessive quarrying, mining, and winning of aggregates for concrete production leads to the depletion of natural resources. This directly results in detrimental effects on the ecological environment, including pollution and the degradation of ecosystems and landscapes (Voordijk et al., 2014).

The severity of this issue is especially high in developing nations like Ghana, which led to the search for suitable and practical alternatives to the traditional components of concrete that might be employed either as an additive or as a partial replacement to preserve current natural resources as much as possible and ensure their availability to coming generations (Daniel & Sangeetha, 2021). Vijayan et al. (2020) postulated that utilizing waste is one of the finest ways to decrease this problem. Solid wastes, such as tiles, blocks, steel, and wood, make up the structural debris collected from demolished buildings. The removal of earthenware waste following building demolition results in the pottery interacting negatively with groundwater and sand in a landfill (Islam & Shahjalal, 2021). One of the biggest issues facing our day is the necessity to deal with this trash, which necessitates specific actions intended to prevent waste (Mundra et al., 2020).

Utilizing the waste of earthenware gives a variety of benefits to building construction in addition to protecting the environment (Abbas & Abd, 2021). Most buildings employ vital construction materials, some of which are ceramic items used for earthenware. Ceramics used for earthenware have decorative uses, but they also produce garbage that, among other things, pollutes the environment severely (Najm & Ahmad, 2022). Studies on the manufacture of ceramics as well as earthenware have revealed that over 30% of the raw materials end up as waste for building construction (Medina et al., 2012; Zimbili et al., 2014), and they are currently not being used to their full potential. Ghana's ceramic industry is thriving, with numerous medium to large companies and hundreds of small-scale ceramic and pottery enterprises spread throughout the country (Asante-Kyei, 2019). According to Dharan and Mohan (2016), a portion of ceramic production, amounting to approximately 2%, is discarded as scrap, contributing to industrial waste. Ghanaian ceramic producers are not exempt from generating such waste, which is often discharged into the environment. This underscores the need to explore potential uses for this waste to mitigate its environmental impact and promote sustainability. Similarly, Gautam et al., 2022, also established that about 70% of all materials used to make concrete are aggregates. Due to the strong demand for aggregates from both rural and urban groups, the price is rising. Thus, the study sought to investigate the mechanical, physical, and durability properties of concrete produced from granite and broken earthenware bowls as coarse aggregate.

2.0 Materials and Methods

This section of the paper outlines the raw materials used in the experimental study and their properties. It also details the procedures for mixing, moulding, and curing the concrete specimens. Additionally, it explains the test methods employed and the approach taken to analyse the obtained data.

2.1 Materials

The materials that were used for the study include cement (GHACEM Super Strong 42.5R), pit sand (fine aggregate), crushed granite stones (coarse aggregate), broken earthenware bowls (coarse aggregate), and water.

Cement

Ordinary Portland Cement (GHACEM Super Strong 42.5R Grade) per BS EN 197-1, 2011 was used.

Aggregates: Fine and coarse aggregates conforming to BS EN 12620:2019 were used as shown in Fig. 1.

Earthenware aggregate: Waste from earthenware industries was collected and segregated. Earthenware aggregate conforming to BS EN 12620:2019 was used as shown in Fig. 1.

Water: Water from the Ghana Water Company Limited, adhering to the standards set by BS EN 1008:2002.

2.2 Methods

2.2.1 Preparation of Specimens

Batching

Batching of materials by weight was done.

Mixing: Based on trial mix target strength of 25N/mm^2 and ratio of 1:2:4 with a water-to-cement ratio of 0.55, mixing of concrete was done in accordance with BS EN 12620:2019.

Casting of the concrete mix was done with steel cubes and cylinders as shown in Fig. 2(a). 100mm x 100mm x 100mm for cubes and 100mm diameter x 200mm height for cylinders were moulded in accordance with BS EN 12390-2.

The earthenware aggregate was replaced at percentages of 10%, 20%, 30%, and 40%, with 0% replacement for the control specimens.

2.2.1 Testing of Specimens

The concrete specimens were tested for density, compressive strength, split tensile strength, water absorption, and magnesium sulphate attack after 7, 14, 21, and 28-days curing periods. The results obtained from conducting these tests were plotted into tables and charts using Microsoft Excel. A one-way ANOVA was performed to identify statistically significant differences between variables, using the Pairwise Multiple Comparison procedure to determine where the differences occurred.

Density: The specimens' densities were determined in accordance with BS EN 12390-7:2019. Five replicates were selected and weighed, and the densities calculated for each variable, and their averages were presented using a table. Density was calculated using the formula; $D = \frac{M}{V} (\text{kg/m}^3)$

Compressive Strength

The compressive strength test was conducted using a computerized Universal Testing Machine (UTM) of a maximum capacity of 1000KN per BS EN 12390-3 (2019).

Split Tensile Strength

The split tensile strength was done per BS EN 12390-6 (2009) standard as seen in Fig. 3(b).

Water Absorption: The water absorption test was conducted on the cubes after the 28-day curing period, following BS EN 1881 – 122: 2011. Each cube was oven-dried for 24 hours at a temperature of 110°C and weighed for the oven-dry weight (W_1), after which it was immersed in water for thirty minutes (30min) and finally weighed for the saturated surface dry weight (W_2). The weight result recorded was then used to determine the amount of water absorbed by each cube, see Fig. 3(c). The percentage of water absorption is given by $\frac{W_2 - W_1}{W_1} \times 100$

Magnesium Sulphate Attack (MgSO_4)

The chemical/magnesium sulphate attack test was done following BS EN 206-1:2000 and tested for compression using BS EN 12390-3 (2019) standard. The specimens for the test (cubes) were cured in a magnesium sulfate solution for 28 days and then tested for compressive strength.

3.0 Results and Discussions

3.1 Density

The test results showed that the average densities of the concrete specimens increased as curing progressed. However, the density decreased as the percentage of earthenware aggregate increased. The control specimen consistently recorded the highest densities, particularly on the 28th day of curing. The average densities of the specimens recorded ranged between 2486.67 and 2276.67 Kg/m^3 on the 28th day of curing, as shown in Table 1. While the control gave the maximum density values of 2486.67 Kg/m^3 , C10% replacement of the broken earthenware aggregate demonstrated the highest density values of 2432.00 Kg/m^3 , compared to C20%, C30%, and C40%, which had values of 2362.67 Kg/m^3 , 2354.33 Kg/m^3 , and 2276.67 Kg/m^3 , respectively.

The reduction in density obtained could be attributed to the strength of the earthenware aggregate, which has a lower density than granite stone, which was replaced; an increase in its percentage replacement reduced density. This is possible because hydrated products from cement and water tend to fill pores openly occupied by material and air. This pattern is noticeable at all coarse aggregate replacement percentages and aligns with how concrete behaves as it steadily strengthens and stabilizes over time during the curing process. There is a discernible drop in the density of the concrete specimens as the replacement percentage of shattered pottery rises, particularly at higher replacement percentages. For instance, during all curing times, the density values are continuously lower at 40% substitution than they are at 0% substitution. There are some differences in density values within each category, even if there are general patterns in density changes with curing time and substitution percentage. Factors including curing conditions, aggregate properties, and mixing techniques may impact these discrepancies (Yahya et al., 2020).

In contrast to other alternative materials, research has shown that waste from coconut shells and palm kernel shells as aggregate is considered lightweight aggregates with densities within ranges of (1600 and 1900) kg/m^3 (Radha et al., 2020; Ranjith, 2023), whereas earthenware aggregates show densities of concrete as normal weight concrete. This gives the earthenware material an advantage over these materials used to replace traditional aggregate in concrete. This study's finding is consistent with Rasool et al. (2020), stating that, independent of the percentage of broken pottery substitution, longer cure times generally result in higher density values for all concrete. Biney et al. (2022) also observed a steady decline with increasing percentage of broken pottery substitution. This implies that the inclusion of broken pottery in the concrete mixture results in a less dense and compacted concrete mixture, which

might have an impact on the concrete's strength and longevity. The densities obtained were found to meet the (1842 to 2483 kg/m³) range per ASTM C138/C138M Standard, hence affirming that concrete formulated with broken earthenware bowl aggregates is suitable for structural works.

Table 1
Density Density (Kg/m³)

Curing days	Specimens				
	C _{0%}	C _{10%}	C _{20%}	C _{30%}	C _{40%}
7	2398.33	2340.33	2335.67	2319.67	2215.00
14	2412.33	2395.33	2345.33	2331.00	2250.33
21	2418.67	2416.33	2353.33	2341.33	2255.33
28	2486.67	2432.00	2362.67	2354.33	2276.67

3.2 Compressive Strength

The compressive strength results obtained for this study are displayed in Table 2. The study revealed that at a constant interval of 10 earthenware content, the compressive strength increased with an increase in curing age. Additionally, at a constant curing age, the compressive strength of the concrete specimens decreased as the percentage replacement of the earthenware aggregates increased in the concrete mix. While the control gave the maximum compressive strength, C_{10%} replacement of the broken earthenware aggregate demonstrated the highest compressive strength among the earthenware concretes. As shown in Table 2, the results recorded strength values of 27.13 N/mm², 26.39 N/mm², 26.28 N/mm², 25.93 N/mm², and 24.76 N/mm², on 28-day curing for C_{0%}, C_{10%}, C_{20%}, C_{30%}, and C_{40%}, respectively. The strength of the control is about 2.7% higher than the C_{10%} replacement (Table 2). The study revealed that earthenware wastes as aggregates demonstrated results comparable to natural coarse aggregates (NCA), unlike recycled coarse aggregates (RCA), which showed a reduction in the mechanical properties of concrete within ranges of 20% to 45% per research by Gomes et al. (2014), Martins (2013), and González et al. (2017). The study is consistent with the findings of (Ali & Alam, 2019; Sivakumar et al., 2021 & Abdullah et al., 2022). They observed a decline in the compressive strength of the concrete specimens as the amount of broken earthenware substitution rose.

The findings also somewhat resonate with a study by Mishra and Pathak (2017). They studied the application of Earthenware Aggregates (EA) and Eggshell Powder (ESP) as substitute materials in the creation of a particular concrete. A grade M25 concrete mix was created by substituting ESP (5 to 30 percent by weight) for cement and EA (5 to 30 percent by weight) for sand. Tests were conducted with several mixed combinations, and it was found that as replacement percentages increased, the average compressive strength fell. The research discovered that at 28 days, 15% replacement of both ESP and EA can attain the required compressive strength. Dixit & Nagar (2020) also investigated Earthenware Aggregates (EA) and Egg Shell Powder (ESP) as potential replacements for traditional components in M-

20 grade concrete. The research indicates that the compressive strength of concrete rises as the age of maturity progresses. The analysis revealed that an increase in the percentage of ESP + EA correlates with an increase in the compressive strength of concrete, provided that the combined percentage of EA (30%) and ESP (5%) does not exceed 35%. The ESP action as pozzolana might be the cause of the increase in the compressive strength. The observed compressive strength is 18.52 N/mm² after 7 days and 23.8 N/mm² after 28 days. A slight decrement was observed following this proportion.

Subathra et al. (2020) also found that longer curing times consistently increased compressive strength across all percentages of broken pottery substitution. This is to be expected because the curing process gives concrete strength and stability over time. The findings show that concrete specimens cured for 28 days typically have higher compressive strengths than specimens treated for shorter periods. Factors including curing conditions, aggregate properties, and mixing techniques may impact these discrepancies (Abdullah et al., 2022). The findings of the compressive strength test showed that using broken earthenware in place of coarse aggregate in concrete can significantly affect the mixture's compressive strength. Lower compressive strength is typically the result of higher replacement percentages, which may compromise the structural integrity and load-bearing capacity of the concrete. Irrespective of the compressive strength obtained for the various replacements, all the specimens recorded values that were within the targeted compressive strength value of 25N/mm² except for C_{40%}, yet fell within the acceptable standard. Per ASTM C90-22: Standard Specification, the minimum compressive strength for load-bearing concrete masonry units is 13.8 MPa. Based on this standard and the results obtained from the compressive strength test, it is evident that concrete made with broken earthenware bowl aggregates as a partial replacement for conventional aggregates is suitable for load-bearing concrete.

Table 2
Compressive Strength Average Compressive Strength
(N/mm²)

Curing days	Specimens				
	C _{0%}	C _{10%}	C _{20%}	C _{30%}	C _{40%}
7	20.93	20.57	19.51	18.91	17.95
14	22.94	22.55	22.24	21.72	21.32
21	24.69	24.36	23.85	23.27	23.00
28	27.13	26.39	26.28	25.93	24.76

3.2.1 Analysis of Variance (ANOVA) of Compressive Strength

An Analysis of Variance (ANOVA) was conducted at a significance level of 5% to explore potential notable disparities in the compressive strength of specimens, as delineated in Table 4. From the analysis, it was revealed that, at a 5% significance level, the variations in the mean values among the treatment groups are not significant enough to rule out the possibility that the difference is attributed to random sampling variability. The test performed obtained a $P < 0.050$ indicating that there was a statistically significant difference in the compressive strength of the specimens. However, the multiple comparison analysis as shown in Table 5 indicated that there is a significant difference between the 0% vs. 40%, 10% vs. 40%, 20% vs. 40%, 0% vs. 30%, and 30% vs. 40%, implying that an increase in the percentage of the broken earthenware bowl aggregate in the concrete slightly influenced the compressive strength of the specimen ($P = 0.001$).

Table 3
Descriptive Statistics and One-Way RM ANOVA

Descriptive statistics					
Treatment Name	N	Missing	Mean	Std Dev	SEM
0%	5	0	27.127	0.0188	0.00842
10%	5	0	26.392	0.144	0.0645
20%	5	0	26.283	0.466	0.209
30%	5	0	25.927	0.413	0.185
40%	5	0	24.763	0.798	0.357

Table 4
One-way-RM ANOVA for compressive strength

The difference between the compressive strength for 28 days					
One Way RM ANOVA					
Source of Variation	DF	SS	MS	F	P
Between Subjects	4	0.493	0.123		
Between Treatments	4	14.95	3.738	16.211	< 0.001
Residual	16	3.689	0.231		
Total	24	19.131	0.797		

Table 5
Pairwise comparisons between P-values for compressive strength

Pairwise comparisons between P-values for compressive strength 28 days				
Comparison	Diff of Means	T	P	P < 0.050
0% vs. 40%	2.364	7.783	< 0.001	Yes
10% vs. 40%	1.629	5.364	< 0.001	Yes
20% vs. 40%	1.52	5.005	0.001	Yes
0% vs. 30%	1.199	3.949	0.008	Yes
30% vs. 40%	1.164	3.834	0.009	Yes
0% vs. 20%	0.844	2.778	0.065	No
0% vs. 10%	0.735	2.419	0.107	No
10% vs. 30%	0.465	1.53	0.376	No
20% vs. 30%	0.356	1.171	0.451	No
10% vs. 20%	0.109	0.359	0.724	No

3.3 Split Tensile Strength

Table 6 presents the split tensile strength test results that were obtained. The test results on the split tensile strength showed the same trend as the compressive strength of the concrete specimens. The study revealed that longer curing days resulted in higher tensile strength values. Furthermore, as the percentage substitution of broken earthenware bowls in the concrete mix increased, the tensile strength of the concrete specimens decreased. This was due to the probable lower strength of the earthenware aggregate compared to conventional granite stone. The tensile strength recorded for the 28th day was 2.769 N/mm², 2.663 N/mm², 2.569 N/mm², 2.550 N/mm², and 2.487 N/mm², for C_{0%}, C_{10%}, C_{20%}, C_{30%} and C_{40%} respectively. Like the compressive strength, the control specimen also recorded the highest tensile strength compared to the specimens with broken earthenware aggregate; however, the difference in value is insignificant between the control and C_{10%}, and will not affect the strength of concrete.

Kosmatka et al. (2002) stated that, generally for conventional concretes, the tensile splitting strength is about 8% to 12% of the compressive strength, IS 456–2000, section 6.2.2, (10–15%) of the compressive strength. The split tensile strength of concrete specimens was found to be between 8 to 15% of the compressive strength, hence suitable for load-bearing masonry units.

The findings of this study somewhat resonate with the study by Dixit & Nagar (2020), who applied Earthenware Aggregates (EA) and Egg Shell Powder (ESP) as potential replacements for traditional components in M-20 grade concrete and discovered that as maturity grew, so did the concrete's tensile strength. The split tensile strength tended to increase up to 30%, after then, a decline in the strength of the concrete was seen. Bommisetty et al. (2019) also observed that all percentages of broken pottery

substitution showed a continuous pattern of increased split tensile strength with longer curing durations, like the compressive strength data. This is to be expected because the curing process gives concrete strength and stability over time (Daniel & Sangeetha, 2021). When compared to specimens cured for shorter periods, concrete cured for 28 days often displays higher split tensile strength. The findings indicate a general decline in split tensile strength with increasing substitution percentages of broken earthenware, which is especially noticeable at higher substitution percentages. For instance, for all curing times, the split tensile strength values are consistently lower at 40% substitution than they are at 0% substitution.

A progressive loss in strength was observed as the proportion of substitution increased when split tensile strength measurements for varying percentages of broken pottery substitution at each curing interval are compared. This suggests that the split tensile strength of the concrete was lowered when broken pottery was added to the mixture, which may have an impact on the concrete's resistance to cracking and deformation under tensile loads. Like the compressive strength findings, split tensile strength values varied within each category and could be impacted by curing conditions, aggregate properties, and mixing techniques (Bheel et al., 2019). The results of the split tensile strength test point to the possibility that adding broken earthenware in place of coarse aggregate in concrete may significantly affect the material's tensile strength as well as its resistance to deformation and cracking under tensile loads. Lower split tensile strength is typically the result of higher substitution percentages, underscoring the significance of considering how such substitutions may affect the mechanical characteristics and structural performance of the concrete (Noaman et al., 2021). To completely comprehend the practical significance of these discoveries in concrete applications in the real world, more investigation and testing would be required.

Table 6
Split Tensile Strength Average Split Tensile Strength
(N/mm²)

Curing days	Specimens				
	C _{0%}	C _{10%}	C _{20%}	C _{30%}	C _{40%}
7	2.076	2.035	2.022	1.913	1.753
14	2.275	2.227	2.208	2.095	2.082
21	2.471	2.466	2.336	2.319	2.296
28	2.769	2.663	2.569	2.550	2.487

3.3.1 Analysis of Variance (ANOVA) of Split Tensile Strength

At a significance level of 5%, an Analysis of Variance (ANOVA) was conducted to examine potential notable disparities in the split tensile strength of concrete. The analysis was to determine which of the

factors considered had a significant effect on the split tensile strength of the concrete. The test performed obtained a $P < 0.050$, Table 8 indicating that there is a statistically significant difference in the tensile strength of the specimens. On another hand, the multiple comparison analysis conducted as shown in Table 9 also indicated that there is a significant difference between 0% vs. 40%, 0% vs. 30%, 0% vs. 20%, and 10% vs. 40% replacement, implying that incorporating broken earthenware bowls as a partial aggregate replacement does influence the tensile strength of the specimen ($P = 0.001$).

Table 7
Descriptive statistics and One-Way-ANOVA RM of Split Tensile Strength

Descriptive statistics					
Treatment Name	N	Missing	Mean	Std Dev	SEM
0%	5	0	2.767	0.00837	0.00374
10%	5	0	2.66	0.0453	0.0202
20%	5	0	2.573	0.105	0.0471
30%	5	0	2.547	0.0999	0.0447
40%	5	0	2.49	0.14	0.0626

Table 8
One-way ANOVA for split tensile strength

The difference between the split tensile strength for 28 days					
One-Way-RM ANOVA					
Source of Variation	DF	SS	MS	F	P
Between Subjects	4	0.0881	0.022		
Between Treatments	4	0.235	0.0586	11.3	< 0.001
Residual	16	0.083	0.00519		
Total	24	0.406	0.0169		

Table 9
Pairwise comparisons between P-values for split tensile strength

Pairwise comparisons between P-values for split tensile strength 28 days				
Comparison	Diff of Means	T	P	P < 0.050
0% vs. 40%	0.277	6.081	< 0.001	Yes
0% vs. 30%	0.22	4.838	0.002	Yes
0% vs. 20%	0.194	4.259	0.005	Yes
10% vs. 40%	0.17	3.732	0.013	Yes
10% vs. 30%	0.113	2.489	0.137	No
0% vs. 10%	0.107	2.349	0.15	No
10% vs. 20%	0.087	1.91	0.266	No
20% vs. 40%	0.083	1.822	0.239	No
30% vs. 40%	0.0566	1.242	0.41	No
20% vs. 30%	0.0264	0.58	0.57	No

3.4 Water Absorption

From Table 10 below, the water absorption levels recorded for the specimens were 2.44%, 2.52%, 3.01%, 3.06%, and 3.19% for the various percentages of replacement $C_{0\%}$, $C_{10\%}$, $C_{20\%}$, $C_{30\%}$, and $C_{40\%}$ respectively. The results showed that among the specimens with earthenware aggregate, 10% replacement recorded the lowest water absorption rate compared to $C_{20\%}$, $C_{30\%}$, and $C_{40\%}$. This implies that the $C_{10\%}$ had low porosity and permeability and hence absorbed less water. However, the control displayed the lowest water absorption level over the $C_{10\%}$. The results further revealed that broken earthenware aggregates have lower water absorption rates compared to other alternative aggregates, such as palm kernel shell (PKS) and coconut shells, which ranged from 4.6% to 6.43% according to Ealias et al. (2014). This lower water absorption in earthenware aggregates may be attributed to the burning process during their production, which enhances their resistance to water. The finding of this study is consistent with the study by Bommisetty et al. (2019). They observed that a progressive increase in water absorption is seen as the substitution percentage of broken pottery increased. Concrete's ability to absorb water is an important characteristic since it shows the material's porosity and permeability, which can affect how resilient and long-lasting it is against outside elements like moisture and chemicals (Pacheco-Torgal & Jalali, 2010). The findings showed that there was a discernible increase in water absorption as the fraction of broken earthenware substitutes rose. For example, at 0% substitution, the water absorption was comparatively lower than specimens with substitutions ranging from 10% to 40% for shattered pottery. Given the variations in porosity and texture

between earthenware and conventional coarse aggregate materials, it may be inferred that the inclusion of broken earthenware in the concrete mix led to increased water absorption.

Increased water absorption values signify increased permeability and porosity in the concrete samples. More gaps or spaces inside the concrete matrix indicate increased porosity, which might provide easier water penetration. Increased permeability suggests that water can pass through the concrete more easily, which could eventually cause problems including chemical erosion, moisture intrusion, and deterioration (Bheel et al., 2019). The results highlight how crucial it is to consider how replacing broken pottery may affect the longevity of concrete. Broken pottery may have benefits, such as reduced waste and resource consumption, but it is important to consider how it may affect important characteristics, such as water absorption (Kaish et al., 2021). Elevated water absorption readings indicate a possible reduction in robustness and longevity, especially in conditions where there is a high risk of moisture or chemical exposure. The results of the water absorption test showed how the replacement of broken earthenware affects the porosity and permeability of concrete, highlighting the necessity of carefully weighing material substitutions to guarantee the desired durability and performance characteristics in concrete applications. The water absorption test results fell within the acceptable range and standard. As indicated by Wilson & Tennis (2021), a water absorption value within the range of 4–6% is deemed optimal, and anything below 5% is considered indicative of high-quality concrete, as outlined by Tracz & Śliwiński (2012). Hence, concrete specimens made from broken earthenware bowl aggregates are deemed suitable for structural concrete works.

Table 10
Water absorption Average water absorption (%)

Curing days	Specimens				
	C _{0%}	C _{10%}	C _{20%}	C _{30%}	C _{40%}
28	2.44	2.52	3.01	3.06	3.19

3.5 Magnesium Sulphate Attack

The study found that the strength of the concrete specimens decreased due to exposure to magnesium sulphate (MgSO₄). The percentage losses in the compressive strength of the specimens after the chemical attack as shown in Table 11 were 2.5%, 1.6%, 1.2%, 0.9%, and 0.3% for the replacement of C_{0%}, C_{10%}, C_{20%}, C_{30%}, and C_{40%} respectively. By comparison, C_{0%} replacement produced the optimum results over the C_{10%} in all instances, however, it was discovered that C_{10%} replacement has stronger resistance to magnesium sulphate (MgSO₄) attack than C_{0%}. Interestingly, the C_{40%} replacement, which initially produced the lowest results, showed optimum performance after exposure to magnesium sulphate (MgSO₄) attack. This study resonates with a study by (Kirankumar et al., 2017). Their study partially replaced natural aggregates with ceramic powder waste from ceramic insulators and exposed to 1%, 3%, and 5% magnesium sulphate (MgSO₄) and hydrochloric acid (HCl) during the curing period. They found that the influence of MgSO₄ led to compressive strength loss and weight loss in the concrete specimens.

The results indicated that with up to 10% ceramic partial replacement, the concrete was resistant to sulphate attack at concentrations of 1% and 2%, but this resistance decreased at 3%.

4.0 Conclusion

- The study found that the concrete specimens with the various percentage replacements ($C_{10\%}$, $C_{20\%}$, $C_{30\%}$, and $C_{40\%}$) of broken earthenware aggregates demonstrated densities and water absorption levels that are within acceptable range by standard, and therefore deemed suitable for load-bearing concrete masonry works.
- The study observed that density has a positive relationship with compressive and tensile strength. It was found that the compressive and split tensile strength values of concrete specimens with the various percentage replacements ($C_{10\%}$, $C_{20\%}$, $C_{30\%}$, and $C_{40\%}$) of broken earthenware aggregates were found to fall within the range acceptable for standard concrete.
- The study found that the concrete exposure to magnesium sulphate solution affected the strength of the concrete. The investigation discovered that, although all the concrete specimens exhibited loss of strength with the various percentage replacements ($C_{10\%}$, $C_{20\%}$, $C_{30\%}$, and $C_{40\%}$) of broken earthenware bowl aggregates, $C_{40\%}$ demonstrated a stronger resistance to attack which was attributed to the material's ability to resist magnesium sulphate attack.

The study therefore, concludes that the incorporation of broken earthenware bowls aggregate as a partial replacement for crushed granite positively influenced the properties (such as density, compressive and tensile strengths, water absorption, and $MgSO_4$ attack of the concrete with $C_{10\%}$, replacement recommended for construction application. The results of this investigation indicate that replacing traditional aggregates with broken earthenware aggregates can significantly reduce construction costs, as earthenware waste is a low-cost material. Additionally, reusing ceramic waste helps mitigate the environmental impacts associated with the extraction, processing, and transportation of natural aggregates. This sustainable approach promotes cost efficiency and environmental conservation in construction practices. promotes sustainable construction practices, reducing the amount of waste sent to landfills and conserving natural resources.

Declarations

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Data will be made available upon request.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions:

☒ Each author declares substantial contributions through the following:

Conceptualization: ***Samuel Amoako, Peter Paa Kofi Yalley, Elijah Kusi***

Methodology: ***Samuel Amoako,***

Review of literature: ***Samuel Amoako, Elijah Kusi,***

Data collection: Samuel Amoako,

Validation: ***Peter Paa Kofi Yalley,***

Data analysis and visualisation: ***Peter Paa Kofi Yalley***

Data curation: ***Samuel Amoako, Peter Paa Kofi Yalley, Elijah Kusi***

Writing—original draft preparation: ***Samuel Amoako, Peter Paa Kofi Yalley, Elijah Kusi***

Writing—review and editing: ***Samuel Amoako, Peter Paa Kofi Yalley, Elijah Kusi***

Ethics Approval and Consent to Participate

This study did not involve human participants, human biological materials, or animals. Therefore, ethical approval and informed consent to participate were not required. The research was conducted in accordance with accepted scientific and ethical standards for laboratory-based materials research.

Consent for Publication

Not applicable. This manuscript does not contain any individual person's data, images, or other information requiring consent for publication.

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Figures

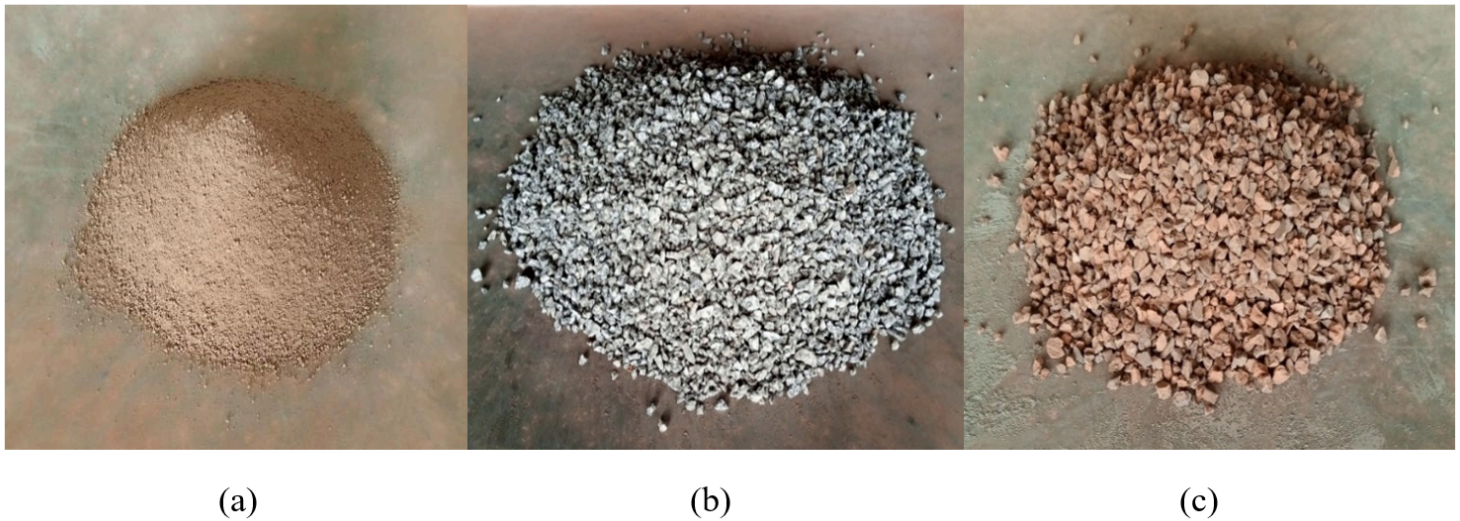


Figure 1

Pictures of fine and coarse aggregates (a) fine aggregate (b) Granite aggregate
(c) Earthenware aggregate



(a)



(b)



(c)

Figure 2

Preparation of specimens (a) Moulding of specimens (b) Curing by immersion (c) Curing with magnesium sulphate solution (MgSO_4 attack).



(a)



(b)



(c)

Figure 3

Testing of specimens (a), Compressive strength, (b) Split tensile strength, and (c) Water absorption test.