Utilization of Waste Ceramic Tiles as Sustainable Coarse Aggregate in Concrete Production

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Abstract- Concrete production is highly resource-intensive and contributes substantially to environmental degradation due to its reliance on natural aggregates and Portland cement. This study investigates the feasibility of using waste ceramic tiles (WCT) as a sustainable replacement for conventional coarse aggregates in concrete production. Concrete specimens of Grade 15 were produced with a 1:2:4 mix ratio and water–cement ratio of 0.6, incorporating WCT at replacement levels of 0–100%. Physical properties of aggregates, including specific gravity, bulk density, and water absorption, were assessed, along with compressive strength and density of concrete at curing ages of 3, 7, and 28 days. Results showed that increasing WCT content reduced both density and compressive strength; however, prolonged curing improved performance. At 100% replacement, concrete achieved a 28-day compressive strength of 15.8 N/mm², meeting the BS 8110-1 (1997) requirement for structural concrete and classifying as lightweight concrete per ASTM C138/C138M. These findings confirm the potential of WCT as a viable, eco-friendly aggregate for selected structural and non-structural applications, contributing to sustainable waste management and resource conservation in construction.

Index Terms- Waste Ceramic Tiles, Sustainable Concrete, Aggregate Replacement, Compressive Strength, Density

I. INTRODUCTION

Concrete is the most widely used construction material worldwide, with global cement production exceeding 4.1 billion metric tons in 2022 (Statista, 2023). Its widespread use is attributed to durability and versatility; however, dependence on cement, sand, and coarse aggregates such as granite has raised concerns about cost escalation, depletion of natural resources, and environmental degradation (Baloch et al., 2020; Alves et al., 2020). Aggregates, which constitute 70–75% of the total concrete volume, are especially critical for strength and durability, yet their continuous extraction contributes to ecological imbalance and resource scarcity. In response, researchers have explored sustainable alternatives by incorporating recycled and waste materials into concrete. Among these, waste ceramic tiles (WCT), a by-product of construction and demolition activities, have attracted attention due to their high durability, hardness, and chemical resistance (Umar & Shuaibu, 2021; Subedi et al., 2020). Prior studies have shown that partial substitution of natural aggregates with ceramic waste, typically in the 20–30% range, yields mechanical properties comparable to conventional mixes while enhancing sustainability (Kannan et al., 2020; Kumar & Baskar, 2021). However, issues such as increased water absorption and variations in density remain unresolved.

Despite growing interest, limited studies have systematically examined the performance of concrete incorporating WCT at higher replacement levels, particularly with respect to both mechanical properties and classification as lightweight or normal concrete. This study therefore investigates the physical and mechanical properties of M15 grade concrete containing WCT at replacement levels from 0–100%. The findings aim to clarify the potential of WCT as a sustainable aggregate, contributing to eco-efficient construction practices and improved waste management.

II. LITERATURE REVIEW

Concrete is the most widely used construction material globally, yet its production contributes significantly to environmental degradation through intensive use of natural resources and high CO_2 emissions from cement manufacturing. Aggregates constitute about 70–75% of the total concrete volume and play a vital role in determining strength, durability, and density (Gupta & Gupta, 2012). The rising demand for aggregates has led to excessive quarrying of natural stone, resulting in resource depletion and ecological imbalance (Baloch et al., 2020). These challenges have encouraged the exploration of alternative materials, including construction and demolition waste, as partial or full substitutes for conventional aggregates.

2.1 Use of Waste Ceramic Tiles in Concrete

Waste ceramic tiles (WCT), generated during manufacturing and demolition, represent a significant portion of construction waste that is often landfilled. Due to their high strength, durability, and chemical resistance, ceramic wastes have been proposed as coarse or fine aggregates in concrete. Subedi et al. (2020) and Bikash et al. (2020) reported that crushed ceramic tiles can be successfully used to replace natural coarse aggregates without exceeding standard limits for aggregate impact and crushing values. Ahmad et al. (2021) found that although WCT incorporation reduces compressive strength at higher replacement levels, values remain within structural requirements, making them suitable for sustainable applications. Similarly, Kannan et al. (2020) demonstrated that partial substitution (20–40%) of aggregates with WCT improved mechanical performance in self-compacting concrete.

2.2 Mechanical and Durability Properties

Research has shown that compressive and tensile strengths decrease gradually with increasing WCT content, though adequate curing can mitigate these reductions. Andrade et al. (2021) observed that fine ceramic waste enhances durability by densifying the cement matrix, while Alves et al. (2020) reported improved resistance to chemical attack and acceptable long-term performance. However, higher water absorption of ceramic aggregates compared with granite has been noted (Parminder & Rakesh, 2015), which may affect workability and mix design.

2.3 Density and Structural Classification

The use of WCT in concrete often leads to reduced density due to its lower specific gravity. Kumar et al. (2022) classified concrete with full ceramic aggregate replacement as lightweight, highlighting potential applications in non-structural elements where reduced dead load is advantageous. Bheel et al. (2021) similarly found that ceramic-based concrete is suitable for partition walls and low-load structures, while maintaining sustainability benefits by diverting waste from landfills.

III. MATERIALS AND METHOD

3.1 Materials

Ceramic waste aggregate, granite aggregates, sharp river sand, cement, and water were the materials used in this study for the production of concrete.

a. Cement: Ordinary Portland Cement (OPC) conforming to Nigerian Industrial Standard (NIS 444-1:2003) was used.
b. Fine Aggregate: Natural river sand free from deleterious materials, passing through a 4.75 mm sieve, conforming to BS EN 12620:2013.
c. Coarse Aggregate: Two types were used:

- Natural granite aggregate (control) with maximum size 20 mm.
- Waste ceramic tile (WCT) aggregate, obtained from demolition and tile manufacturing waste. The tiles were manually crushed, sieved, and graded to conform with BS 812: Part 103.1:1985 requirements for coarse aggregates.

d. Water: Portable tap water meeting BS EN 1008:2002 standards for mixing and curing concrete.
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3.2 Mix Proportions

Concrete of grade M15 was designed using a nominal mix ratio of 1:2:4 (cement, fine aggregate, coarse aggregate) with a constant water–cement ratio of 0.6. Granite was progressively replaced by WCT at levels of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% by weight of coarse aggregate.

A total of 54 cube specimens (150 mm × 150 mm × 150 mm) were cast, with three specimens tested for each mix proportion at curing ages of 7, 14, and 28 days.

3.3 Testing Methods

Physical Properties of Aggregates

- Specific gravity, bulk density, and water absorption were determined in accordance with BS812: Part 2:1995
- Aggregate crushing value (ACV) was measured as per BS 812-110:1990.
- Aggregate impact value (AIV) was determined following BS 812-112:1990.

Fresh and Hardened Concrete Tests:

- Workability was assessed using the slump test (ASTM C143/C143M-20)
- Density was measured following ASTM C138/C138M-17a.
- Compressive strength was determined at 7, 14, and 28 days using a 2000 kN capacity compression testing machine, in accordance with BS EN 12390-3:2019

3.4 Curing of Specimens

After casting, all specimens were demoulded after 24 hours and cured by immersion in clean water until the designated testing ages.

IV. RESULTS AND DISCUSSION

4.1 Physical Properties of Granite and Waste Ceramic Tile (WCT) Aggregates, including Specific Gravity, Bulk Density, Water Absorption, Impact Value, And Crushing Value

a. Particle Size Distribution

From Tables 4.1 and 4.2, the particle size distribution revealed fineness modulus values of 4.7–4.8, which fall within the acceptable range for coarse aggregates. This aligns with Gupta and Gupta (2012), who noted that coarse aggregates typically fall between 5.5–8.0, with combined aggregates ranging from 3.5–6.5.

Table 4.1 Sieve Analysis of Coarse Aggregates (Ceramic Tile)

Sieve Size	Weight retained (kg)	Percentage weight retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
50mm	0	0	0	100
28mm	165	13.75	13.75	86.25
20mm	680	56.67	70.42	29.58
14mm	315	26.25	96.67	3.33
10mm	30	2.5	99.17	0.83
6.3 µm	0	0	99.17	0.83
Pan	10	0.83	100	0
Total			479.18	
Fineness modulus			4.8	

Source: (Experimental work, 2024)

Table 4.2 Sieve Analysis of Granite Aggregate

Sieve Size	Weight retained (kg)	Percentage weight retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
50mm	0	0	0	100
28mm	0	0	0	100
20mm	0.41	34.17	34.17	65.83
14mm	0.42	35	69.17	30.83
10mm	0.33	27.5	96.67	3.33
6.3 µm	0.035	2.91	99.58	0.42
Pan	0.005	0.42	100	0
Total			399.59	
Fineness modulus			4.0	

Source: (Experimental work, 2024)

b. Specific Gravity, Bulk Density, and Absorption Capacity of Aggregate

Table 4.3 shows the specific gravity, bulk density, and water absorption capacity of the aggregates. The specific gravity of waste ceramic tile and granite coarse aggregate were found to be 2.31 and 2.67 respectively. Specific gravity results showed lower values for WCT (2.31) compared with granite (2.67), while water absorption was significantly higher (3.15% for WCT, 0.38% for granite).The bulk density of the waste ceramic tile coarse aggregate was lighter in weight than that of granite aggregate which satisfies the requirements of BS 812-108 (1990), that the range for normal weight aggregates is to be between 1280 and 1920 kg/m^3 (for bulk density). It can be observed that the water absorption capacities of both the waste ceramic tile and granite aggregate in the table show that the ceramic waste tile absorbed more water about 3.15 % than that of granite aggregate with 0.38 %. Similar observations were made by Parminder and Rakesh (2015), who reported that recycled ceramic aggregates exhibit higher porosity and water absorption.

Table 4.3: Specific Gravity, Bulk Density, and Absorption Capacity of Aggregate

Properties	Ceramic Tile	Granite
Specific gravity (SSD	2.31	2.67
Bulk density (kg/m^3)	1249	1539
Water Absorption (%)	3.15	0.38

Source: Experimental work (2024)

c. Aggregate crushing value

Table 4.4 shows the result of the crushing value test of waste ceramic tile and granite aggregates. The values of both waste ceramic tile and granite aggregate that passed through the sieve 3.35mm were 0.35kg and 0.54kg respectively. The percentage of the aggregate crushing value for ceramic tile aggregate was found to be 16.93% while the aggregate crushing value for granite aggregate was 20.70%. Ceramic waste aggregates were found to have a higher ability to resist crushing than granite aggregate. The aggregate crushing value of WCT (16.93%) remained within BS 812 (1990) limits, consistent with Subedi et al. (2020) and Bikash et al. (2020), who confirmed that ceramic aggregates meet structural safety requirements despite reduced toughness

Table 4.4 Ceramic Tile and Granite Crushing Value

S/N	Item	Tile	Granite
a.	Sample weight	2.07	2.60
b.	Weight passing sieve 3.35mm	0.35	0.54
c.	Weight retained on sieve 3.35mm	1.72	2.07
d.	Aggregate crushing value (%)	16.93	20.70
	Aggregate Crushing Value	16.93%	20.70%

Source: Experimental work (2024)

d. Aggregate Impact Value

Table 4.5 presents the results of ceramic waste tile and granite aggregate impact value. The values of the ceramic waste tile and granite aggregate that passed through sieve 3.35mm were 0.06kg and 0.13kg respectively. The percentage of aggregate impact value for ceramic waste tile and granite aggregate was found to be 13.37% and 18.97% respectively. The impact value of both ceramic waste tile and granite aggregates falls within a permissible range (<45%). The aggregate impact value of WCT (13.37%) remained within BS 812 (1990) limits, consistent with Subedi et al. (2020) and Bikash et al. (2020), who confirmed that ceramic aggregates meet structural safety requirements despite reduced toughness.

Table 4.5 Ceramic Tile and Granite Impact Value

S/N	Item	Tile (kg)	Granite (kg)
a.	Sample weight	0.47	0.67
b.	Weight passing sieve 3.35	0.06	0.13
c.	Weight retained on sieve 3.35	0.41	0.54
d.	Aggregate crushing value (%)	13.37	18.97
	Aggregate Crushing Value	13.37	18.97

Source: Experimental work (2024)

4.2 Compressive Strength (N/Mm²) of Concrete Mixes Incorporating Different Levels of Waste Ceramic Tile (WCT) as Coarse Aggregate Replacement, Tested at 7, 14, And 28 Days

The compressive strength of concrete cubes for different percentage replacement of waste ceramic tile aggregate (WCTA) is presented in Figure 1. The result revealed that the compressive strength decreases as the percentage of WCTA increases, and increases with the curing period. At 0% replacement, the compressive strength values of 14.59N/mm^2, 20.4 N/mm^2, and 20.6 N/mm^2 were obtained at 3, 7, and 28 days of curing. Hence, the compressive strength of the control at 28 days was 20.6 N/mm^2 achieving 99% of the design strength of 20.8 N/mm^2 as stipulated in ASTM C39/C39M. At 3, 7, and 28 days of curing, the strength decreases with an increase in WCTA replacement. Moreover, as the replacement rises to 100%, especially at 28 days curing, a compressive strength of 15.8 N/mm^2 was achieved per BS8110-Part I (1997) which mandates the strength of 15N/mm^2 for structural concrete. These findings are consistent with Ahmad et al. (2021), who observed a similar decline in compressive strength at higher ceramic replacement levels but noted values remained structurally viable. Kannan et al. (2020) reported improved strength at partial substitution levels (20–40%), which matches the trend in this study where mixes with 20–40% WCT provided the best balance between strength and sustainability

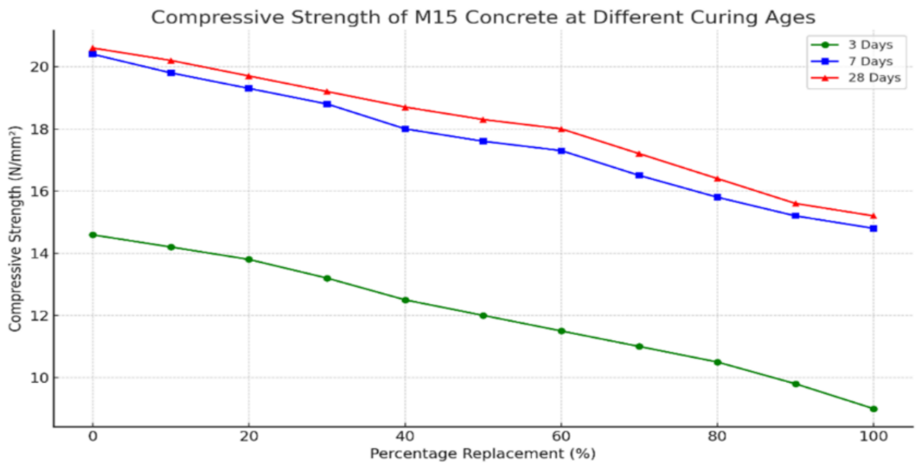

Figure 1. Variation of compressive strength of concrete with different percentages of waste ceramic tile (WCT) replacement at 7, 14, and 28 days of curing (N/mm²).

4.3 Density (Kg/M³) Of Concrete Mixes with Waste Ceramic Tile (WCT) as Coarse Aggregate Replacement after 28 Days of Curing

Figure 2 shows the density of concrete cubes for different percentage replacements of WCTA. The result revealed that the density reduces with an increase in the percentage of WCTA and increases with an increase in curing age. The result also revealed that 0% replacement of WCTA gave density values of 2482kg/m3, 2497kg/m3, and 2542 kg/m^3 at 3, 7, and 28-day curing periods. Hence, the density of control at 28 days was 2542kg/m^3. At 3, 7, and 28 days of curing, the density reduces with an increase in the percentage of WCTA. It was observed that at 0% replacement the concrete has the highest density especially at 28 days where it rises around 2550 kg/m³. However, as replacement rises to 100% the density drops to 2250 kg/m³ indicating how excessive replacement reduces concrete weight and strength. It was noted that at 60% replacement of WCTA, the density of 2400kg/m^3 was obtained. Hence, this density satisfied the value of 2400kg/m^3 for normal concrete as specified by ASTM C138/C138M. Similar reductions in density were reported by Alves et al. (2020), who categorized ceramic-based concrete within the lower range of normal-weight concretes.

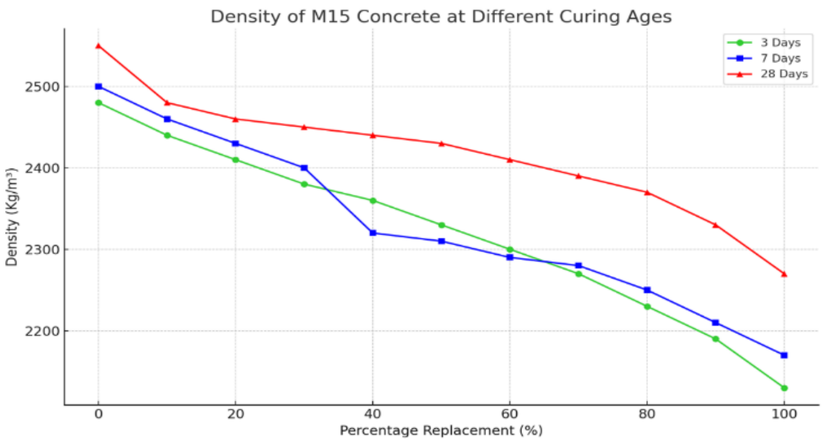

Figure 2. Density of concrete mixes with varying percentages of waste ceramic tile (WCT) replacement at 28 days (kg/m³).

CONCLUSION

This study evaluated the potential of waste ceramic tiles (WCT) as a sustainable coarse aggregate in concrete production. The results demonstrate that WCT possesses lower specific gravity and higher water absorption than natural granite, leading to reductions in density and compressive strength as replacement levels increase. Nevertheless, all mixes met standard requirements, with 100% WCT achieving a 28-day compressive strength of 15.8 N/mm², which complies with BS 8110-1 (1997) for structural applications and classifies as lightweight concrete under ASTM C138/C138M. The findings highlight that while higher WCT content reduces strength, partial replacements (20–40%) can provide an effective balance between mechanical performance and sustainability. Beyond technical feasibility, the use of WCT addresses pressing environmental concerns by diverting ceramic waste from landfills and reducing dependence on non-renewable aggregates. Future research should extend to durability performance, long-term service behavior, cost–benefit analysis, and life-cycle assessment, enabling broader adoption of WCT-based concrete in sustainable construction.

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