Sustainable Utilization of Ceramic Tile Waste for Improving Concrete Strength - An Experimental Approach

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Abstract

Due to construction industry's growing need for materials such as aggregate and cement, there has been an increase in the level of concern over the depletion of resources and environment preservation. The construction and demolition (C&D) create a considerable amount of waste highlights the need of recycling and waste reduction. Because ceramics are so long-lasting, their waste offers a chance for recycling. Crushed and sorted ceramic tiles that had been discarded were used in this examination to replicate grading curve of natural aggregates. A series of tests were carried out on the ceramic tiles to evaluate the fresh properties of concrete by slump test and hardened state at 7 days, 28 days and 90 days. Ceramic tile (CT) waste incorporated to concrete by partially replacing of coarse aggregates (CA) by 10% (CT10), 20% (CT20), 30% (CT30), 40% (CT40) and 50% (CT50). The CT30 mix performed comparably to the control in terms of compressive strength, while offering moderate tensile and flexural resistance. However, mixes containing 40% or more CT exhibited significant declines in all strength parameters and workability due to the irregular shape, brittleness, and high absorption of ceramic aggregates. Durability assessments were conducted through water absorption testing, which directly correlates with matrix porosity and long-term serviceability.

Keywords: Construction and demolition (C&D), Waste ceramic tiles, Sustainability, compressive strength (CS), Flexural strength, Waste management.

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1. Introduction

Due to its enormous demand for natural resources, especially aggregate and cement, the construction sector has raised concerns about resource depletion and environmental protection [1-2]. Ceramic materials make up a large part of global C&D waste. Ceramic waste durable for concrete since it lasts and doesn't degrade [4].Previous research has studied employing CT waste as a partial cement or natural aggregate substitute, but India has not generally utilized these findings [5-6] This research adds scraps/discarded ceramic tiles to concrete for economic and environmental benefits while boosting compressive strength or maintaining traditional concrete mix levels. Flexural strength is measured for reference and optimal concrete compositions. Reference concrete utilized natural coarse aggregate, whereas optimal concrete compositions incorporated waste in concrete [7-8]. Construction has emphasized sustainable waste use, particularly waste ceramic tiles. Studies have shown that waste ceramic tiles enhance concrete properties and solve environmental concerns [9-10] In some cases, concrete made from leftover waste outperforms regular cement concrete, reducing natural resource depletion and carbon dioxide emissions [11-12]. The concrete using ceramic sanitary ware aggregate has mechanical qualities similar to those with regular aggregates, suggesting that recycled ceramic aggregate might be a sustainable concrete waste management option [13]. In another study, recycled concrete with a high ceramic content was used to make precast concrete elements with comparable mechanical, micro structural, and durability properties [14]. Concrete may be used to value building and demolition detritus using leftover ceramic particles. Waste material composition, manufacturing procedure, and intended use might affect the performance of concrete formed from waste ceramic tiles [15]. Crushing, grading, and adding leftover ceramic tiles affect concrete performance. Optimizing engineering processes utilizing standardized methods yields consistent and dependable results [16]. Long-term use of discarded abandoned ceramic tiles in concrete may improve concrete characteristics and alleviate environmental issues [17]. More research and testing are needed to determine the pros and cons of employing discarded ceramic tiles in concrete and standardize techniques. Greener production ensures long-term resource use [18]. Durable and versatile ceramic tiles are ideal for concrete. Porcelain and quarry (sandstone) tiles are ceramic, lighter, stronger, more durable, and less polluting than coarse aggregate [19]. Ceramic tiles may replace up to 100% of coarse aggregate in concrete, depending on the desired properties. Advantages include reduced weight, strength, durability, and environmental impact [20]. Cost, use, and strength are problems. Ceramic tiles work well on walls, floors, roofs, and walkways. Ceramic tiles may outperform concrete, but they must be tested to ensure they meet standards before widespread use [21]. The project examines using leftover ceramic tiles in concrete to decrease aggregate and cement depletion, increase structural integrity without sacrificing strength, and promote sustainable design for optimized composition [22-24]. Optimizations are necessary in engineering solutions for attaining sustainable design [25-27].

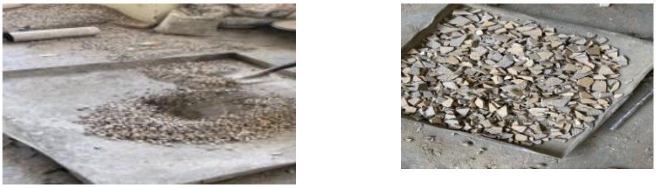
Methodology

The discarded ceramic tiles subjected to crushing and sorting procedures to match the grading curve of natural aggregates as specified by IS 383-1970. In preparing the numerous mixes with varying quantities of aggregate composed of discarded ceramic tile were used. Workability, compressive strength (CS), flexural strength (FS)and split tensile strength (SPT)was all assessed by a series of tests that were carried out. The replacement level of ceramic tile with coarse aggregates range from 10% to 50% and one concrete sample with any replacement is taken for the reference. **Table 1** shows the results of natural coarse aggregates and ceramic tile waste. **Figure 1** shows image of CA and CT waste taken for the experimental work.

Table 1: Material results

Test Name	**Observed Value (Ceramic tile)**	**Observed Value (Coarse Aggregates)**	**IS Code**
Specific Gravity	2.48	2.7	IS 2386 (P-3)
Water Absorption (%)	2.1%	0.8%	IS 2386 (P-3)
Crushing Value (%)	25%	21.4%	IS 2386 (P-4)
Impact Value (%)	22%	18.7%	IS 2386 (P-4)

The workability determined using slump test and the mechanical properties determined with three types of tests namely CS test, SPT, and FS test at 7D, 28D and 90D. **Table 2** shows the nomenclature and proportioning of the mix design.



(a) Coarse aggregates (CA) (b) Ceramic tile aggregate (CT)

Figure 1: Material sample.

Table 2: Proportions of ceramic tiles in Concrete.

S.No.	Mix	Ceramic tiles (%)	Coarse Aggregates	Cement	Fine Aggregates
1	CT0	0	100	100	100
2	CT10	10	90	100	100
3	CT20	20	80	100	100
4	CT30	30	70	100	100
5	CT40	40	60	100	100
6	CT50	50	50	100	100

2. Results and Discussions

3.1 Slump test

The Figure 2 and Table 3 displays the variation in **slump values** over time for M40 grade concrete mixes incorporating **ceramic tile waste (CT)**. The mixes are denoted as CT0, CT10, CT20, CT30, CT40, and CT50. Slump is a direct indicator of concrete **workability**, and the data were recorded at 0, 20, 40, 60, and 90 minutes. At **0 minutes**, CT0 (control mix without ceramic waste) shows the highest initial slump (~107 mm), indicating superior workability in the absence of ceramic aggregates. The initial slump values progressively decline. CT50, with the highest replacement, exhibits the lowest initial slump (~70 mm), confirming that increasing ceramic content reduces workability. This reduction is attributed to the angular, rough-textured, and absorbent nature of crushed ceramic tile particles, which increases internal friction and water demand within the mix. Over time, all mixes show a declining trend in slump, typical due to ongoing hydration and evaporation. However, the rate of slump loss is more pronounced in higher CT mixes. Notably, CT50 displays a steep drop, reaching as low as ~25 mm at 90 minutes, reflecting poor workability retention. On the other hand, CT0 and CT10 maintain relatively better slump over time, stabilizing around 75–80 mm, indicating acceptable workability for practical use.

Table 1: Slump values of CT mixes

Time (minutes)	**CT0**	**CT10**	**CT20**	**CT30**	**CT40**	**CT50**
0	105	100	95	90	80	70
20	100	92	87	84	70	62
40	90	87	78	76	68	54
60	80	74	69	66	57	43
80	77	69	61	52	41	22

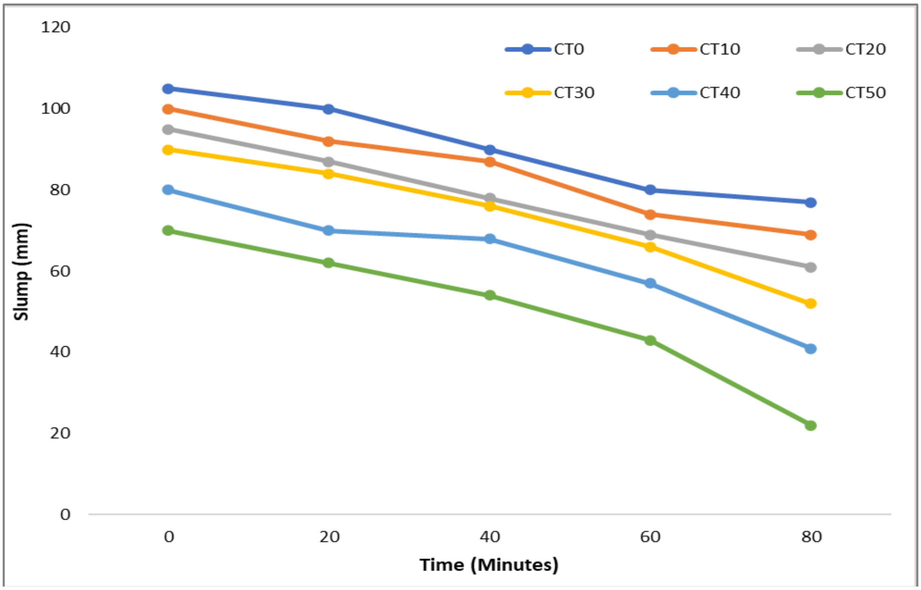


Figure 2: Workability of CT mixes

2.2 Compressive Strength Results (CS)

The study revealed that strength gradually increases at 7 from CT0 to CT30 and CT30 found to be mix with optimum value. The strength enhancement can be due to better interlocking between the ingredients of the concrete. Also, it has been also found that from CT40 onwards strength started declining. The decline in the strength due to the increased porosity, poor bond and uneven aggregates and the results revealed in Table 4 and Figure 3. The most effective 28-day compressive strength (CS) is produced by 30% coarse waste ceramic tile aggregate when matched with reference concrete. Comparative to reference concrete, compressive strength declines after 30% of coarse waste ceramic tile aggregate. It indicates that waste chipped tile when utilized as a coarse aggregate may increases concrete compressive strength without reducing strength. Tile samples are comparable in strength. Chipped waste aggregate may decrease sample strength as ceramic tile amounts rise. Tile aggregates, particularly larger ones increase the percentage of chipped aggregate in concrete and decrease strength. Another possibility is that aggregates' flat surfaces prevent concrete-aggregate contact.

Table 4:CS Results

Mixes	CS (7D)	CS (28D)	CS (90D)
CT0	27	46	49
CT10	27.2	46.3	48
CT20	27.6	46.6	49
CT30	28	47	49.3
CT40	24	35	36
CT50	23	33	34

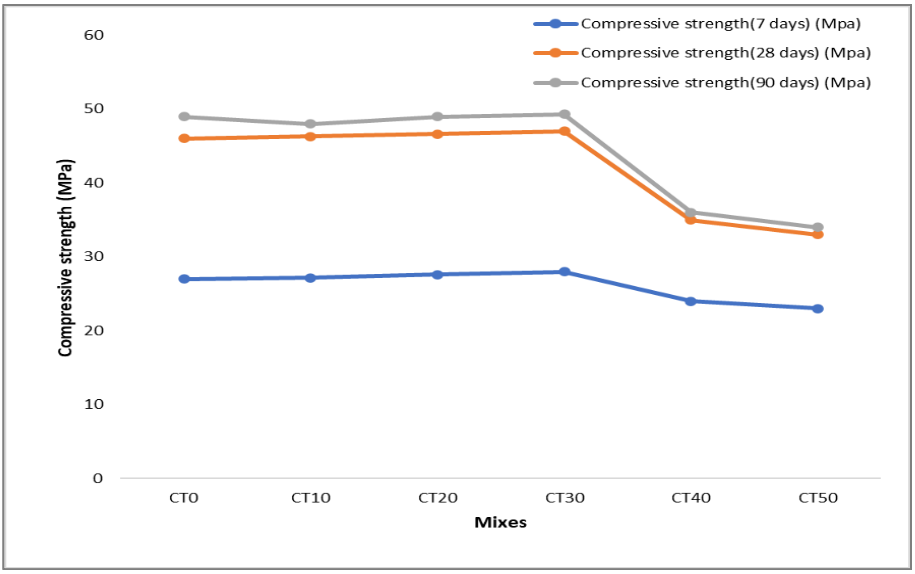


Figure 3: Compressive strength of CT mixes

2.3 Split Tensile Strength Results (SPT)

It measures concrete's strength by placing cylindrical specimen horizontally and applying force radially to its surface, causing a vertical fracture along its diameter. Tensile-stressed concrete frequently forms micro cracks first, then macro cracks. Increased load promotes critical fracture propagation at macro crack leading edges, causing concrete collapse. No standard technique exists for determining the behavior of fractured cement composites, however there are several approaches to determine concrete's tensile strength. The study concluded that CT30 shows the optimum split tensile strength of 4 MPa.

Table 5: SPT Results

Mixes	SPT (7 days)	SPT (28D)	SPT (90D)
CT0	2.3	3.68	3.84
CT10	2.32	3.7	3.8
CT20	2.35	3.72	3.9
CT30	2.6	3.75	4
CT40	2	2.4	3
CT50	1.96	2.1	2.4

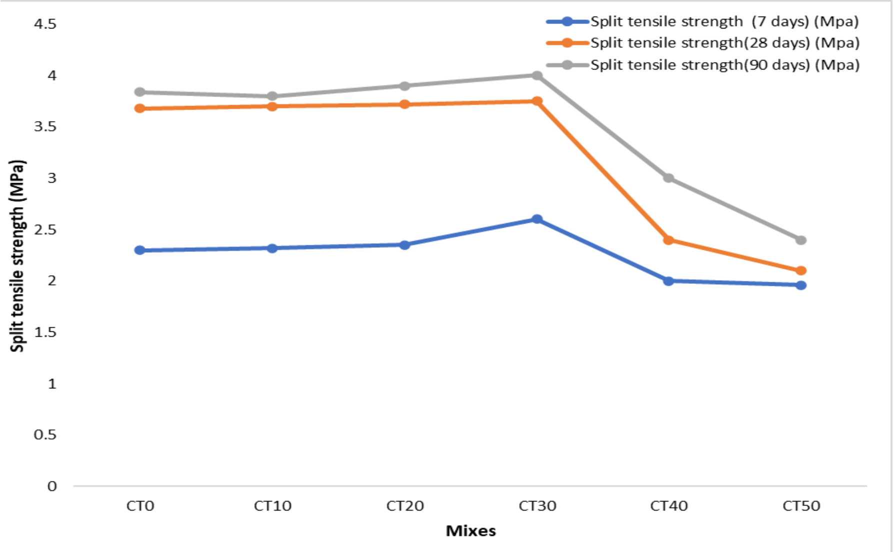


Figure 4: Concrete split tensile strength with ceramic tile aggregate.

2.4 Flexural Strength Test (FS)

The flexural test evaluates beam bending force under two-point stress. Flexural modulus measures a material's stiffness when flexed. Reference Concrete (CT0) and Ceramic Waste Concrete (CT30) with 30% waste ceramic tile aggregate were tested. The experiment showed that the FS of ceramic waste concrete rose when ceramic waste replaced natural coarse aggregate. Ceramic tiles' pozzolanic property and water absorption ability may diminish the w/c ratio, causing this rise. By 90 days, long-term flexural strength gain is evident in all mixes, but the highest value remains at CT30. While CT0 to CT30 maintain relatively high strength, a substantial drop is again seen in CT40 and CT50, affirming the negative impact of excessive ceramic tile waste on the structural integrity of the concrete.

Table 6: Split tensile Strength of CT mixes

Mixes	FS (7D)	FS (28D)	FS (90D)
CT0	2.4	3.73	3.92
CT10	2.42	3.75	3.88
CT20	2.45	3.77	3.98
CT30	2.7	3.8	4.08
CT40	2.1	2.45	3.08
CT50	2.06	2.15	2.48

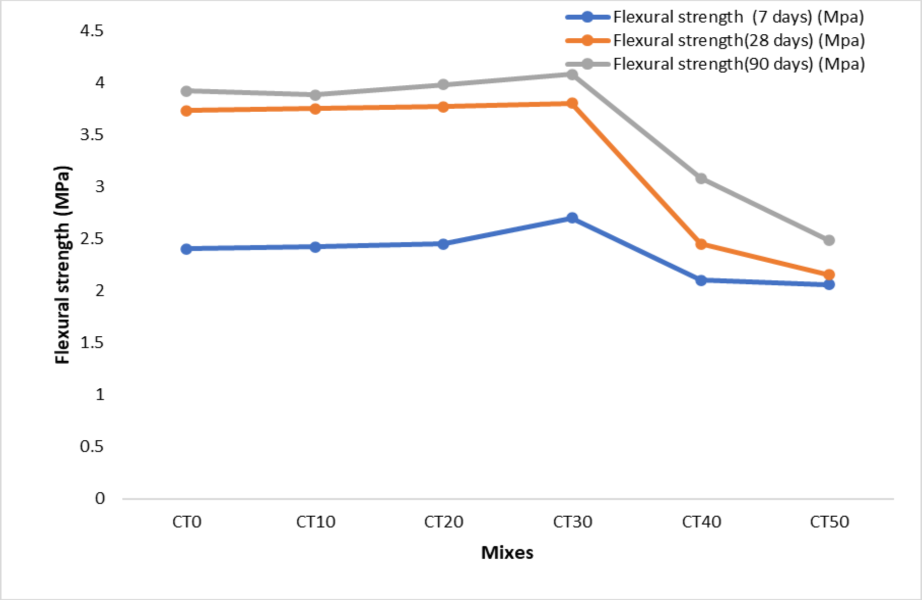


Figure 5: Graphical presentation of flexural strength with tile aggregate.

2.5 Water Absorption test (WA)

The Figure 6 and Table 7 shows the WA values of CT0, CT10, CT20, CT30, CT40 and CT50 and trend revealed that with rise in the CT waste by weight, the WA also increases with respect to the reference mix CT0.The control mix (CT0), which contains no ceramic aggregate, exhibited a baseline water absorption of approximately 4%, indicating a relatively dense microstructure with minimal pore connectivity. A slight decline was observed in the CT10 mix, suggesting that low levels of ceramic substitution may contribute to marginal densification or improved aggregate interlocking. However, beyond the 10% threshold, water absorption increased progressively. The CT20 and CT30 mixes reached absorption values near 4.8%, indicating the onset of structural discontinuity due to the introduction of angular, brittle ceramic particles that lack the natural binding affinity of conventional aggregates

Table 7: Water absorption of CT mixes

Mixes	Water absorption (%)
CT0	4
CT10	3.9
CT20	4.7
CT30	4.7
CT40	6
CT50	6

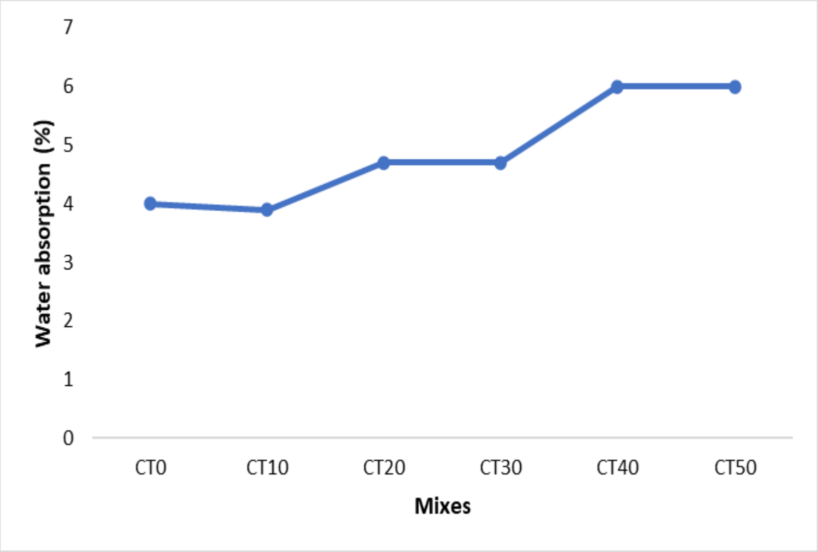


Figure 6: Water absorption test results of CT mixes

3. Discussion

This study found that 30% waste ceramic tile aggregate can improve concrete properties. The research suggests that waste ceramic tile aggregate should be around 30% to ensure excellent compressive, split tensile and flexural strength without affecting structural integrity. The study also highlighted the importance of waste ceramic tile choices in concrete combinations. The findings suggest that using waste/leftover ceramic tiles in concrete is sustainable, cost-effective, and promotes waste reduction, resource conservation, and property enhancement. However, maximizing these benefits requires further research and execution. The following are the pertinent results and discussions of findings:

1. The increasing use of CT aggregate brought about a decline in the fresh con-

crete's workability. This reduction might be ascribed to the angular design of the tiles as well as the water absorption properties of the materials.

2. The addition of discarded ceramic tile aggregate led to an improve in the material's CS. In comparison to the CT0 concrete mix, the ideal combination, which included 30%(CT30) waste ceramic tile aggregate.
3. It was shown that the best percentage range for using discarded ceramic tile aggregate in concrete is between 10 and 30 percent. Both the compressive and flexural strengths increased without affecting the material's overall structural integrity while staying within this range.
4. Sustainability and Economic Benefits: Utilising waste/damaged ceramic tiles as a replacement for natural coarse aggregates has the potential to deliver a number of benefits to both the environment and the reduction of waste. These advantages are a direct result of the use of natural resources that is required for the production of natural coarse aggregates. This method is in line with the fundamentals of sustainable design and has the potential to result in significant financial benefits.

4. Conclusions

- According to the findings of the research, recycling unwanted ceramic tiles and incorporation may have encouraging both the environment and the economy. It brings to light the significance of waste management, environmentally responsible design practices, and the potential for this technology to make mechanical advancements. According to the findings of the research, increasing the amount of waste ceramic tile aggregate that was added to concrete by 30%. **Slump Loss** increased with increase in CT due to irregular shape and higher absorption characteristics of ceramic aggregates.
- Ceramic tile wastes up to 30% (CT30) yielded comparable performance to the control mix (MS0CT0), but further increase led to significant strength reduction.
- **Compressive Strength** of CT30 remained satisfactory and close to conventional concrete, showing the feasibility of using ceramic waste up to 30% without major compromise.
- **Split Tensile and Flexural Strengths** for CT30 were moderate but improved over mixes with higher CT replacement levels (CT40, CT50).
- The future implications of this approach are significant since it recycles unused ceramic tiles, which are a material that is robust and resistant to corrosion. As a result, the construction sector may minimize the amount of trash produced and conserve resources. It adheres to the principles of sustainable design and demonstrates how the building and construction industry may manage trash in a responsible manner. In addition, the use of abandoned ceramic tiles in concrete may produce significant income, save expenses associated with waste management and manufacturing, and provide financial incentives to industry players.

However, the study highlights the need for more research and application in the real world in order to fully harness the environmental and economic advantages of this environmentally friendly building method.

Future Scope

In our current work, we have integrated coarse ceramic tiles with coarse aggregate. The use of ceramic tile, other materials such as micro silica, fly ash or other types of waste like e-waste might be considered for implementation [28]. Subsequently, an examination could be conducted to evaluate the influence of the modified composition of concrete. Taguchi optimization can be utilized to optimize the proportion of waste ceramic tile in concrete, enhancing its economic and environmental benefits [29] . The manipulation of the add mixes ratio now used and the potential substitution of aggregate with these admixtures are being considered as means to assess the resultant strength levels. The workability of tiles may vary based on their unique collection of properties, resulting in different levels of workability for each kind of tile used.

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