JCE

JOURNAL OF CIVIL ENGINEERING
ISSN 2086 - 1206 E-ISSN 2579 - 9029

Ceramic Waste as a Viable Alternative to Natural Aggregates in Concrete: Workability and Strength Analysis

Saniul H. Mahi[a*]

Correspondence

[a]Civil Engineering Department, Dhaka International University, Satarkul, Badda, Dhaka 1212, Bangladesh.

Corresponding author email adress: saniulmahice@gmail.com

Submitted : 24 March 2025
Revised : 19 November 2025
Accepted : 24 November 2025

Abstract

Concrete is one of the most frequently employed building materials because to its superior mechanical performance and long-term durability; yet, its pervasive usage adds to resource depletion and considerable environmental impacts, mainly from cement manufacturing and aggregate extraction. To address these problems, this study studies the inclusion of ceramic waste as a sustainable alternative to natural aggregates in concrete. The purpose was to examine the impact of ceramic waste on workability, compressive strength, and split tensile strength. A total of sixteen concrete mixes were made, comprising one control mix and fifteen mixes with different quantities of ceramic waste as fine and coarse aggregate replacements. The mix design followed a ratio of 1:1.67:2.81 with a water-to-cement ratio of 0.50, targeting a 28-day compressive strength of 20 MPa. Workability was examined using the slump test, while compressive and split tensile strengths were recorded at 7 and 28 days in line with ASTM standards. The experimental data show that partial replacement of fine aggregates at 10–20% and coarse aggregates at around 10% gave optimal mechanical performance, with strength values similar to or above those of the control mix. Higher substitution levels resulted in losses in both workability and strength due to increased porosity and poorer bonding within the interfacial transition zone. Beyond technical performance, the study indicates that mixing ceramic waste into concrete minimizes landfill disposal and conserves natural resources, consistent with circular economy concepts. These results emphasize the potential of ceramic waste as a viable and eco-efficient material for sustainable concrete manufacturing.

Keywords

Ceramic waste, Concrete sustainability, Mechanical properties, Compressive strength, Split tensile strength

INTRODUCTION

Concrete functions as a worldwide standard building material because it displays remarkable mechanical properties along with excellent durability and fire-resistant qualities [1], [2], [3], [4], [5]. Each year the global concrete production exceeds 21 gigatons to support current infrastructure advancement initiatives [6] [7]. The accelerating global demand for concrete has generated multiple resource depletion problems and environmental problems linked to natural aggregate scarcity as well as the environmental impact of cement manufacturing operations. Concrete strength and durability rely heavily on cement because this vital component forms the fundamental base of concrete formula. Cement manufacturing increased to 4.3 gigatons during 2020 and experts project a 23% additional increase until 2050 [8, 9]. tách industry contributes to 7% of worldwide CO_2 emissions that release 2.7 gigatons of CO_2 into the atmosphere yearly [10, 11, 12]. The cement manufacturing process releases dangerous pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x) together with fine particulate matter (PM) leading to water and soil acidification while producing ozone depletion effects [13] [14]. The cement sector consumes large energy amounts totaling 3–5 MJ per kilogram of clinker leading to substantial environmental consequences [15] [16] [17].

Research teams pursue sustainable alternatives to conventional cement and aggregates as cement replacement options since they decrease construction industry carbon emissions. The implementation of waste materials within concrete production attracts increasing attention because of its relevance to sustainability goals (SDGs) [18]. The recycling of ceramic waste proves to be a viable option for concrete manufacturing as an aggregate replacement material for both fine and coarse sizing.

Construction projects have expanded rapidly thus CDW has become one of the biggest waste streams worldwide. Among the United States and Europe and other regions municipal waste management systems produce recycling rates reaching 70–90% but developing countries achieve less than 10% CDW recycling [19], [20], [21]. The majority of CDW stems from ceramic waste which arises mainly from construction activities and demolition work together with industrial ceramic production activities [22] [23].

Floor tiles together with wall tiles along with sanitary ware and household ceramics produce ceramic waste according to [24] and [25] and [26]. Ceramic production generates waste amounting to 30% but researchers have documented this figure in [27] [28] [29] [30]. wjgland disposal of such waste in landfills pollutes environmental elements including soil, air and groundwater quality according to studies [31] [32] [33]. The non-biodegradable nature of ceramic products causes extensive environmental damage through improper disposal which results in illegal dumping sites and health risks according to sources [34], [35], [36].

In the context of circular economy ceramic waste material substitution for natural aggregates in concrete reduces both waste in landfills and saves natural resources [37, 38, 39]. The incorporation of ceramic waste in sustainable construction materials helps lower maintenance costs while minimizing raw material usage because it decreases aggregate expenses and prevents the consumption of natural materials [40, 41].

The mechanical properties of concrete containing ceramic waste have been investigated through various research investigations. The research of Pacheco-Torgal and Jalali [41] demonstrated that concrete manufactured with ceramic replacement particles up to 50% of total natural aggregate displayed better strength characteristics. High-performance concrete containing 40% ceramic waste as coarse aggregate showed substantial reductions in autogenous shrinkage according to Subaşı et al. [42].

Ceramic waste usage as concrete material is technically practical because it demonstrates strong compressive strength alongside corrosion resistance and temperature endurance and provides thermal insulation while resisting thermal shocks according to studies [43] [44]. Researchers have widely studied the separate replacement of fine and coarse aggregates with ceramic waste yet they have investigated its simultaneous use as material for both sizes of aggregates within concrete mixtures at a minimal extent.

This research study evaluates the potential application of ceramic waste material as a joint alternative to fine along with coarse aggregates in concrete while investigating its modifications of essential mechanical characteristics. The main objective is identifying the best proportion of ceramic waste replacement which maximizes concrete characteristics with minimal environmental effects. The research examines three major characteristics including workability in addition to compressive strength as well as split tensile strength in concrete consisting of ceramic waste aggregates. These research findings will support sustainable construction because they develop a practical approach to recycle ceramic waste while decreasing aggregate consumption of natural resources. The main objective is to create sustainable concrete compositions which implement circular economy principles for lowering construction industry material usages.

MATERIALS AND METHODOLOGY

A. MATERIALS

1. Cement

A locally sourced regular Portland cement of CEM I 42.5 grade was used in this study. The cement complies with E.S.S. 4756-1/2013 CEM I 42.5N and BS EN 197-1:2011 CEM I 42.5N standards. The cement's fineness was measured at 3390 cm²/g as per ASTM C204, and its specific gravity was found to be 3.15, determined according to ASTM C187. The initial setting time was assumed to be 45 minutes, and the final setting time was 8 hours, based on typical values of similar cement types.

2. Fine and Coarse Aggregates

a. **Fine Aggregate:** Natural river sand was used as fine aggregate. The sand conformed to ASTM C33 specifications, with an assumed maximum particle size of 4.75 mm.
b. **Coarse Aggregate:** Brick chips were used as coarse aggregate, crushed to an **assumed** maximum particle size of 20 mm.
c. **Waste Ceramic Aggregate:** Manually crushed ceramic tile waste was used as both fine and coarse aggregates. The fine fraction passed through a 4.75 mm sieve, while the coarse **fraction** was retained on the 4.75 mm sieve and had a maximum size of 20 mm.

The particle size distribution curves for these aggregates are presented in Figure 1.

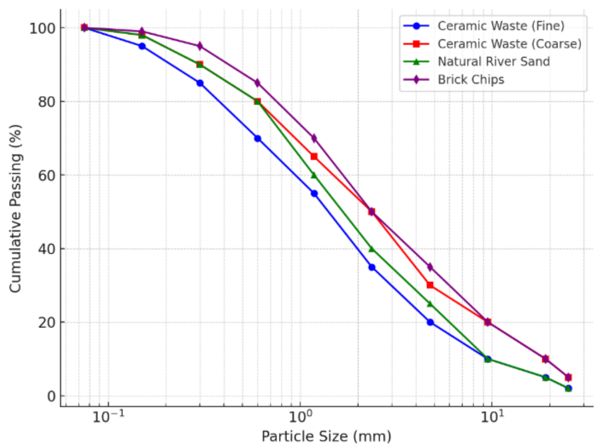

Figure 1 Particle size distribution of aggregate

3. Water

Potable tap water was used for mixing and curing, complying with ASTM C1602 standards.

B. MIX PROPORTION AND DESIGNATION

A total of 16 concrete mixes were prepared, including one control mix (CC) and fifteen mixes with different replacement percentages of ceramic fine and coarse aggregates. The concrete mix ratio was 1:1.67:2.81 (cement: fine aggregate: coarse aggregate) with a water-to-cement ratio (w/c) of 0.50, designed to achieve a target compressive strength of 20 MPa at 28 days. The mix designations are provided in Table 1 and concrete mix ratio in Table 2.


(a) (b) (c)

Figure 2: (a) Aggregates, (b) Compression test setup, (c) failure surface after loading

Table 1 Mix Designation and Replacement Percentages

MIX Designation	% of FA replacement	% of CA replacement	Water/Cement
CC	0	0	0.50
F10	10	0	0.50
F20	20	0	0.50
F30	30	0	0.50
F40	40	0	0.50
F50	50	0	0.50
C10	0	10	0.50
C20	0	20	0.50
C30	0	30	0.50
C40	0	40	0.50
C50	0	50	0.50
F5C5	5	5	0.50
F10C10	10	10	0.50
F15C15	15	15	0.50
F20C20	20	20	0.50
F25C25	25	25	0.50

Table 2 Concrete Mix Ratio

Mix ID	Cement (kg/m³)	Sand (kg/m³)	Brick Chips (kg/m³)	Ceramic Fine (kg/m³)	Ceramic Coarse (kg/m³)	Water (kg/m³)
CC	400.00	666.66	1125.00	0.00	0.00	200.00
F10	400.00	599.99	1125.00	66.67	0.00	200.00
F15	400.00	566.66	1125.00	100.00	0.00	200.00
F20	400.00	533.33	1125.00	133.33	0.00	200.00
F25	400.00	500.00	1125.00	166.66	0.00	200.00
F30	400.00	466.66	1125.00	200.00	0.00	200.00
F40	400.00	400.00	1125.00	266.66	0.00	200.00
F50	400.00	333.33	1125.00	333.33	0.00	200.00
C10	400.00	666.66	1012.50	0.00	112.50	200.00
C15	400.00	666.66	956.25	0.00	168.75	200.00
C20	400.00	666.66	900.00	0.00	225.00	200.00
C25	400.00	666.66	843.75	0.00	281.25	200.00

Mix ID	Cement (kg/m³)	Sand (kg/m³)	Brick Chips (kg/m³)	Ceramic Fine (kg/m³)	Ceramic Coarse (kg/m³)	Water (kg/m³)
C30	400.00	666.66	787.50	0.00	337.50	200.00
C40	400.00	666.66	675.00	0.00	450.00	200.00
C50	400.00	666.66	562.50	0.00	562.50	200.00
F5C5	400.00	633.33	1068.75	33.33	56.25	200.00

C. TESTING PROCEDURES

All tests were conducted following ASTM standards to evaluate the workability, mechanical strength, water absorption, and thermal resistance of concrete.

1. Workability

The slump test was performed as per ASTM C143 to assess the workability of fresh concrete. A target slump of 75-100 mm was considered suitable for this study.

2. Mechanical Properties

a. **Compressive Strength:** Standard cylindrical specimens (150 mm × 300 mm) were cast and tested at 7 and 28 days according to ASTM C39.
b. **Split Tensile Strength:** Cylindrical specimens (150 mm × 300 mm) were cast and tested at 7 and 28 days, following ASTM C496.

3. Curing

All specimens were cured in normal potable water at room temperature for 28 days, in compliance with ASTM C511.

RESULT AND DISCUSSION

A. WORKABILITY

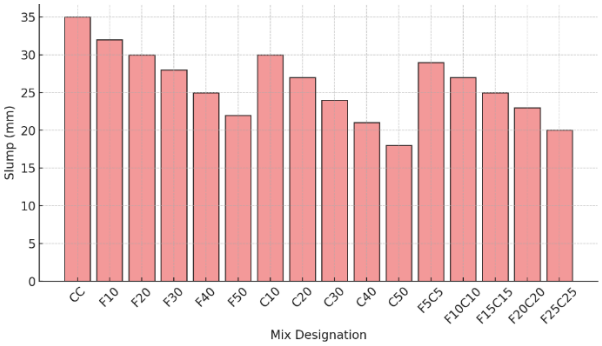

Figure 3 Slump value for different mix designation.

The concrete workability decreases in a steady pattern as the ceramic waste material content increases in different mixes. Figure 3 shows the slump values for different mix designations, illustrating the pattern of decreasing workability with increasing ceramic waste content. Previous research verifies this workability decrease through the explanation of ceramic waste aggregate properties such as high water absorption and rough texture [24], [31], [37].

The control concrete (CC) achieved the highest slump value of 36 millimeters which proved its optimal workability status. The slump values decreased steadily from 35 mm to 24 mm throughout the replacement sequence from 10% to 50% fine aggregate (F10 to F50). The substitution of coarse aggregates with C10 to C50 resulted in a stepwise decrease of measuring points from 30 mm to 20 mm. The combined replacement of fine and coarse aggregate from F5C5 to F25C25 resulted in decreased slump measurements in which F5C5 showed 33 mm and F25C25 showed 22 mm.

Slump values decreased at higher rates when using Fine ceramic aggregate (F-series) substitutions instead of the Coarse ceramic aggregate (C-series) replacements. The workability of F50 decreased to 24 mm but C50 maintained 20 mm. Previous research investigations by [34] and [37] confirm that fine ceramic waste particles generate greater paste internal friction as well as decreased cement paste mobility. The increased porosity in ceramic fines requires more water addition because such a condition boosts total water content which results in diminished slump values [32].

Workability decreased to a greater extent when fine and coarse aggregates were substituted together (F5C5 to F25C25) compared to when they replaced independently. The F25C25 mix combination demonstrated a slump value of 22mm which amounted to a 38.9% reduction from the reference mix. Scientists previously established that when mixing fine and coarse ceramic waste specimens flowability decreases through increased friction between particles [24].

The incorporation of ceramic waste materials caused slump value reductions in every mix composition due to multiple contributing factors. Ceramic waste aggregates absorb much higher amounts of water when compared to natural aggregates. The ceramic particles absorb a larger amount of water from mixtures which results in reduced available water for lubrication thus lowering flowability [31]. The angular texture and rough nature of ceramic waste aggregates reduces concrete mixture movement as it enhances particle to particle friction [24] [43]. The weak cement paste to ceramic waste bond creates unstable interlocks between components that negatively influences mixture workability [32].

Research conducted previously discovered equivalent decreases in slump values occur when ceramic waste serves as a replacement for part of the total aggregate. Ceramic waste substitution at a level of 30% for fine aggregate reduced flowability by 25% similarly to the F30 formulation in this research according to Martínez-Lage et al. [25]. According to Medina et al. [44] the mix with F25C25 experienced similar workability reductions that reached up to 40% similar to their reported findings.

The measurements of concrete workability exhibit concrete workability decrease when natural aggregates are replaced by ceramic waste materials. Research findings support these results which demonstrate workability issues that may be resolved through changes in water-cement ratios and the use of superplasticizers and ceramic waste pre-soaking methods [24], [43].

B. COMPRESSIVE STRENGTH

Building sustainability is achieved through concrete applications which incorporate ceramic tile waste (CTA) instead of natural aggregates. Multiple studies have analyzed the impact of ceramic waste incorporation on concrete mechanical properties toward compressive strength assessment because this vital characteristic defines concrete structural feasibility. The provided table and figures show compressive strength results of concrete with various proportions of ceramic waste used either as fine aggregate or coarse aggregate or both at both seven-day and twenty-eight-day time periods. When using conventional materials for control mix testing the obtained compressive strength values were 12.13 MPa at 7 days and 20.65 MPa at 28 days. Aleatory concrete performance evaluation happens through the use of these reference values to measure the ceramic waste concrete mix results against them.

Addition of ceramic waste to concrete results in decreased strength measurements throughout the 7-day curing period. Enhancing fine ceramic waste samples with F50 led to 8.73 MPa of 7-day strength reduction because ceramic aggregates negatively affect both workability and hydration processes within early stages. The absorption properties of ceramic waste together with its porous structure hinder cement hydration in the first curing stages leading to reduced initial strength development [38]. Design analyses described in other studies revealed that ceramic aggregate water absorption limited complete cement hydration thus reducing material strength during the early stages [24].

The tests for 28-day compressive strength revealed an intricate effect which produced different results from early strength measurements. A reduction in strength was noticeable when the mix included F10 F20 or F30 amounts of ceramic waste relative to the non-administered mix. Data revealed that F30 reached 21.66 MPa as it replaced 30% of its coarse and fine aggregates with ceramic waste while maintaining a low difference from the control mix at 20.65 MPa. When ceramic waste amounts stay within moderate dimensions the compressive strength demonstrates stable characteristics. Strength evaluations of specific mixtures showed positive improvements in their performance when rates were measured at day 28. Using a mixture of F10C10 that incorporated 10% ceramic waste in both coarse and fine aggregates achieved maximum strength growth reaching 22.83 MPa after 28 days which represented a 10.56% improvement above the control mix. Ceramic waste displays its pozzolanic properties in moderate quantities because it forms a chemical reaction with the calcium hydroxide (CH) released from the cement paste. Additional formation of calcium silicate hydrate (C-S-H) through this reaction leads to strengthened concrete material with decreased material porosity [44]. The roughness of ceramic aggregates enhances their bond with the cement matrix which results in improved strength values [14].

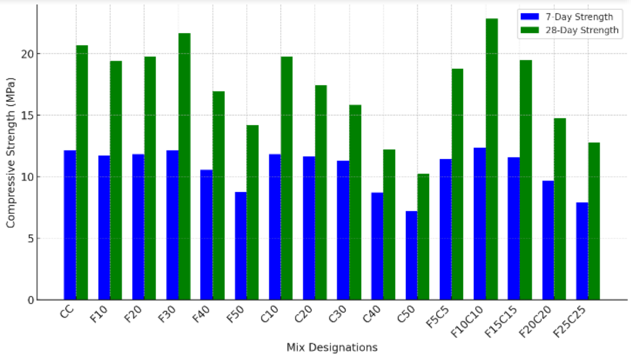

Figure 4 Compressive Strength for Different Mix Designation

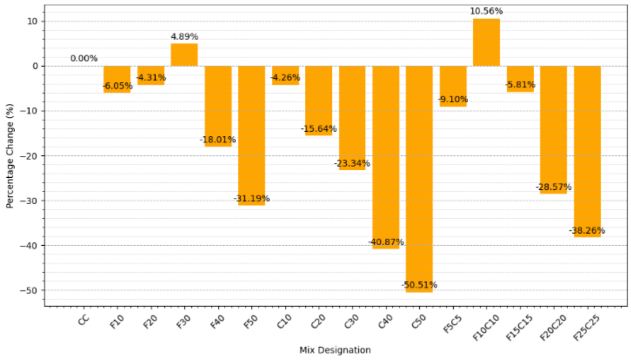

Figure 5 Comparison of Compressive Strength Relative to CC

Figure 4 illustrates the compressive strength of concrete mixes with various ceramic waste replacement levels, highlighting the differences at 7-day and 28-day curing periods. Figure 5 provides a graphical comparison of the compressive strength relative to the control concrete (CC) mix. The compressive strength of concrete suffers noticeable deterioration when the amount of ceramic material surpasses a specific point. When concrete contained higher percentages of ceramic waste such as F50 C50 and F40 it led to large-scale reductions in strength reaching 50.51% in the case of F50. The weak bond between ceramic aggregates and cement matrix material at the interfacial transition zone (ITZ) results in strength reduction. The mechanical properties of concrete decrease because ceramic aggregates have weaker bond strength due to their porosity and angular shape which restricts strong ITZ development [24]. An excess of ceramic waste material produces greater water absorption which results in insufficient hydration water thus weakening the concrete microstructure [38].

The test results demonstrate how setting the optimum ceramic waste substitution levels stands as a vital operational factor. The replacement of concrete material with ceramic waste at levels up to 20% results in either no strength loss or slight increases while any higher replacement leads to substantial strength reduction. Studies show that mixes containing F10C10 demonstrated positive strength improvements which suggests that ceramic waste can enhance concrete longevity when properly applied possibly due to pozzolanic activity and better packing efficiency according to [44]. Any replacement value beyond the optimal usage levels produces negative effects on concrete by degrading hydration strength and reducing bonding efficiency and increasing porosity until the concrete becomes weakened.

There are substantial environmental advantages when ceramic waste serves as a natural aggregate alternative. Ceramic waste composed of main construction materials from building demolition frequently ends up in landfill sites where it causes environmental contamination. By recycling ceramic waste into concrete producers gain two essential environmental benefits which reduce both natural aggregate requirements and concrete production emissions through landfill waste minimization and quarry reduction [12].

C. SPLIT TENSILE STRENGTH

The tests on different concrete mixes through split tensile strength measurement at days 7 and 28 show distinct variations due to changing ceramic waste replacement levels (Figure 6). The data presented in Figure 7 shows the percentage variations of 28-day split tensile strength values against control concrete (CC) to evaluate ceramic waste impact on concrete materials.

Split tensile strength of concrete samples increased by 0.7% and 2.81% at F10 and F20 replacement levels when natural fine aggregate was replaced with ceramic waste (F-series) compared to CC at 28 days (Figure 7). Enhancing the ceramic waste substitution beyond F40 and F50 led to decreasing tensile strength values by 19.3% and 29.82% respectively. A higher density of fine ceramic waste causes increased interfacial bonding while improving tensile strength when used at lower percentages [24]. Higher ceramic particle additions weaken the matrix cohesion and create matrix porosity which decreases tensile properties [44].

The C-series representing C10 to C50 demonstrated identical patterns during the study. The tensile strength experienced reductions with increasing amounts of coarse ceramic aggregate utilization. The C10 mix recorded a 7.02% improvement however C40 and C50 experienced 24.56% and 29.82% respective weakening of strength (Figure 7). Previous studies [27] supported the observed results showing that ceramic coarse aggregates exhibit rough texture and porous nature which leads to decreased bonding with cement paste thus causing strength reduction at higher replacement levels. A weakening of the interfacial transition zone occurs when ceramic coarse aggregates exceed 30% replacement of total aggregate content [32].

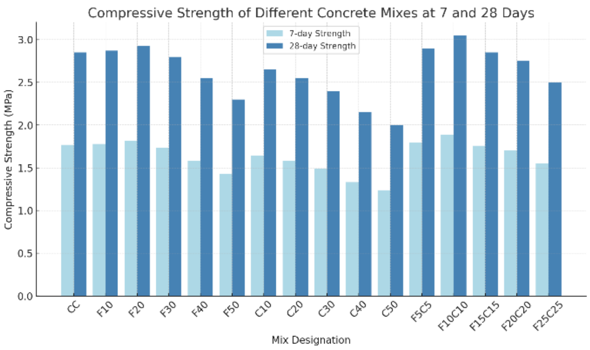

Figure 6 Split tensile strength for different mix designation

The mixes containing both fine and coarse aggregate replacement with ceramic waste in FCCA-series (F5C5 to F25C25) showed noticeable strength gains until 20% replacement (F20C20) followed by strength deterioration. F10C10 achieved the most significant strength gain at 7.02% as against CC yet F25C25 showed the most considerable reduction at 12.28%. Concrete packing density reaches its optimum level when fine and coarse ceramic waste are combined in suitable proportions thus enhancing both compressive and tensile strength results. The load-bearing strength of concrete decreases when the ceramic replacement ratio exceeds 20% because it creates excessive porosity [19].

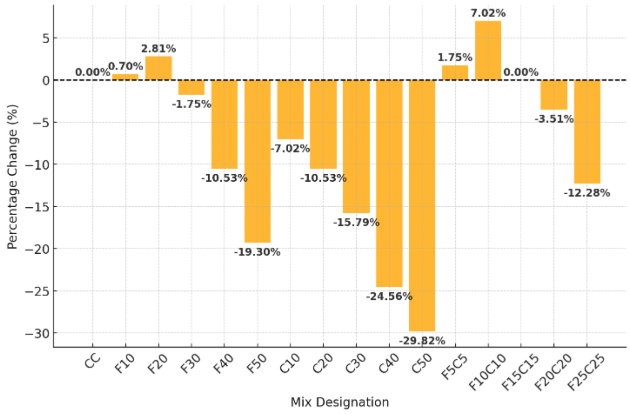

Figure 7 Comparison of Split Tensile Strength Relative to CC

All concrete mixes show a split tensile strength relationship of 7-day to 28-day that follows standard patterns documented in literature [1] when observed through Table 1. The F10C10 mix (3.05 MPa) demonstrated the highest 28-day strength which exceeded the CC (2.85 MPa) value by 7.02 percent. The 28-day strength measurement for C50 reached 2.00 MPa making it the lowest at 29.82% below the CC value. The slow pozzolanic reaction of ceramic waste in concrete mixes leads to reduced early-age strength because it requires prolonged curing for improvement according to [10].

Research findings demonstrate that using ceramic waste as an additive in concrete improves split tensile strength by being suitable to replace fine and coarse aggregates at specific ratios. Analyses demonstrated that utilizing 10% to 20% ceramic waste shows the best performance with fine aggregates under test conditions while 10% replacement with coarse aggregates proved most advantageous yet further increments decreased strength measurements by processes of increased porosity and weak interfacial bonding. Tensile strength increased most effectively when concrete specimens received combined replacement of fine and coarse aggregates at levels between 10% to 20%. Strengthening effects became apparent when substituting less than 30% but any rate above this threshold led to strength deterioration in concrete materials. Previous research supports the findings that show ceramic waste potential as a sustainable concrete ingredient subject to specific replacement levels required for structural purposes [4] [10].

CONCLUSION

This study focused on workability, compressive strength, and split tensile strength to investigate the viability of using ceramic waste as a partial substitute for natural fine and coarse aggregates in concrete. The experimental findings indicated that ceramic waste may be efficiently included up to specified thresholds without negatively impacting the mechanical qualities of concrete. The substitution of fine aggregates by 10–20% and coarse aggregates by around 10% yielded optimal performance, with compressive and tensile strength values equivalent to or slightly surpassing those of the control mix. Surpassing these proportions resulted in significant declines in strength and workability, due to heightened porosity, increased water absorption, and diminished bonding in the interfacial transition zone.

The findings suggest that meticulous regulation of replacement ratios is essential for optimizing performance and sustainability in engineering practice. The usage of ceramic waste should be kept within the established optimal limits to create a balance between mechanical integrity and environmental advantages. Furthermore, owing to the elevated absorption capacity and angular structure of ceramic aggregates, workability must be regulated by pre-soaking methods or the use of chemical admixtures such superplasticizers. Continuous curing is advised to promote strength development at later ages, while suitable modifications to aggregate gradation and moisture correction during batching will further improve mix performance.

Future research should encompass thorough durability evaluations under severe environmental conditions, such as freeze-thaw cycles, sulfate assault, and chloride ingress. Microstructural investigations of the interfacial transition zone are necessary to further clarify the mechanisms driving strength growth in ceramic waste concrete. In addition, investigations on the combined usage of ceramic aggregates with supplemental cementitious materials, as well as comprehensive life-cycle evaluations and pilot-scale field deployments, would give vital insights into the long-term viability and scalability of this sustainable material. These study approaches will together enhance mix design optimization and broaden the utilization of ceramic waste in sustainable construction practices.

REFERENCES

[1] Liu, N., and Chen, B., "Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete," Construction and Building Materials, vol. 68, pp. 227–232, 2014.
[2] S. H. Mahi et al., “Ceramic waste as a sustainable building material: a comprehensive review,” 7th International Conference on Advances in Civil Engineering, CUET, Chattogram, Bangladesh, Dec. 2024, pp. 1769–1776. [Online]. Available: https://icace2024.cuet.ac.bd/
[3] Haido, J.H., Tayeh, B.A., Majeed, S.S., and Karpuzcu, M., "Effect of high temperature on the mechanical properties of basalt fibre self-compacting concrete as an overlay material," Construction and Building Materials, vol. 268, pp. 121725, 2021.
[4] Kodur, V., "Properties of concrete at elevated temperatures," International Scholarly Research Notices, 2014, Article ID 468510.
[5] Kodur, V.K., and Dwaikat, M., "High-temperature properties of concrete for fire resistance modeling of structures," ACI Materials Journal, vol. 105, no. 5, pp. 517–527, 2008.
[6] Klee, M., "The global cement industry," Environmental Science & Technology, vol. 38, pp. 299–306, 2004.
[7] Zhang, Y., Luo, W., Wang, J., Wang, Y., Xu, Y., and Xiao, J., "A review of life cycle assessment of recycled aggregate concrete," Construction and Building Materials, vol. 209, pp. 115–125, 2019.
[8] IEA, "Cement," International Energy Agency, 2021. [Online]. Available: https://www.iea.org/reports/cement.
[9] WBCSD, "Cement technology roadmap plots path to cutting CO_2 emissions 24% by 2050," World Business Council for Sustainable Development, 2018. [Online]. Available: https://www.wbcsd.org/.
[10] Ahmed, M., Bashar, I., Alam, S.T., Wasi, A.I., Jerin, I., Khatun, S., and Rahman, M., "An overview of the Asian cement industry: Environmental impacts, research methodologies, and mitigation measures," Sustainable Production and Consumption, vol. 28, pp. 1018–1039, 2021.
[11] Andrew, R.M., "Global CO_2 emissions from cement production, 1928–2017," Earth System Science Data, vol. 10, no. 4, pp. 2213–2239, 2018.
[12] Mainz, H., "Cement and CO_2 emissions," International Journal of Environmental Science, vol. 20, no. 2, pp. 15–26, 2021.
[13] Isaiah, O.O., Olusegun, O.A., Blessing, A.G., and Samson, A.O., "Environmental and health implications of cement production plant emissions in Nigeria: Ewekoro cement plant as a case study," Chemical Journal, vol. 6, no. 1, pp. 1–8, 2021.
[14] Tanash, A.O., and Muthusamy, K., "Potential of recycled powder from clay brick, sanitary ware, and concrete waste as a cement substitute for concrete: An overview," Construction and Building Materials, vol. 401, p. 132760, 2023.
[15] Bourtsalas, A., Zhang, J., Castaldi, M., Themelis, N., and Karaiskakis, A.N., "Use of non-recycled plastics and paper as alternative fuel in cement production," Journal of Cleaner Production, vol. 181, pp. 8–16, 2018.
[16] Hendriks, C.A., Worrell, E., De Jager, D., Blok, K., and Riemer, P., "Emission reduction of greenhouse gases from the cement industry," Proceedings of the Fourth International Conference on Greenhouse Gas Control Technologies, pp. 939–944, 1998.
[17] Venkatarama Reddy, B.V., and Jagadish, K.S., "Energy efficiency in cement manufacturing: The impact of modern technologies," Energy Journal, vol. 28, pp. 101–114, 2003.
[18] Neshovski, M., "Circular economy in construction: Opportunities and challenges," Journal of Construction Management, vol. 12, pp. 50–56, 2018.
[19] Hoang, N.H., Ishigaki, T., Kubota, R., Yamada, M., and Kawamoto, K., "A review of construction and

demolition waste management in Southeast Asia," Journal of Material Cycles and Waste Management, vol. 22, no. 2, pp. 315–325, 2020.
[20] Nunes, M.J., and Mahler, B., "Waste management in developing countries," Global Environmental Solutions, vol. 10, no. 4, pp. 256–266, 2020.
[21] Villoria Saez, P., and Osmani, M., "Recycling construction and demolition waste in the EU," Environmental Policy Review, vol. 15, pp. 143–155, 2019.
[22] Reig, L., Pitarch, A.M., and Martínez, J., "Construction and demolition waste recycling in Spain," Waste Management Journal, vol. 30, pp. 19–24, 2013.
[23] Zimbili, C., Kumar, N., and Sundararajan, T., "Ceramic waste as construction material," Journal of Construction Engineering, vol. 12, no. 3, pp. 51–63, 2014.
[24] Awoyera, P.O., Akinmusuru, J.O., and Ndambuki, J.M., "Characterization of ceramic waste aggregate concrete," HBRC Journal, vol. 14, no. 3, pp. 282–287, 2018.
[25] Juan, A., Medina, C., Guerra, M.I., Morán, J.M., Aguado, P.J., Sánchez de Rojas, M., and Frías, M., "Re-use of ceramic wastes in construction," Ceramic Materials, W. Wunderlich, Ed., pp. 197–214, 2010.
[26] Monfort, E., et al., "Recycling of ceramic waste in construction," Materials Science Journal, vol. 6, no. 5, pp. 42–49, 2014.
[27] Agrawal, A., Singh, A., and Imam, A., "Utilization of ceramic waste as a sustainable building material," National Conference on Structural Engineering NCRASE–2020, 2020.
[28] Mohit, K., et al., "Ceramic waste recycling: Industrial solutions," Waste Management Journal, vol. 35, no. 9, pp. 512–517, 2021.
[29] Tan, M., et al., "Study of waste ceramic as aggregate in concrete," Environmental Engineering Journal, vol. 24, no. 3, pp. 217–226, 2011.
[30] Umar, M., et al., "Sustainable solutions in concrete with ceramic waste," Sustainable Construction Review, vol. 33, pp. 102–114, 2021.
[31] Aly, S.T., El-Dieb, A.S., and Taha, M.R., "Ceramic waste powder for eco-friendly self-compacting concrete (SCC)," Advances in Civil Engineering Materials, vol. 7, no. 1, pp. 426–446, 2018.
[32] Kanaan, D.M., and El-Dieb, A.S., "Ceramic waste powder as an ingredient to sustainable concrete," Proceedings of Fourth International Conference on Sustainable Construction Materials and Technologies, 1–9, 2016.
[33] Tabak, T., et al., "Pollution effects of ceramic waste," Environmental Science Reports, vol. 19, pp. 231–239, 2012.
[34] Bignozzi, M.C., and Saccani, A., "Ceramic waste as aggregate and supplementary cementing material: A combined action to contrast alkali-silica reaction (ASR)," Cement and Concrete Composites, vol. 34, no. 10, pp. 1141–1148, 2012.
[35] El-Dieb, A.S., Taha, M.R., Kanaan, D., and Aly, S.T., "Ceramic waste powder: From landfill to sustainable concretes," Proceedings of the Institution of Civil Engineers-Construction Materials, vol. 171, no. 3, pp. 109–116, 2018.
[36] Pitarch, A.M., et al., "Recycling ceramic waste for sustainable construction," Environmental Engineering Journal, vol. 28, pp. 144–157, 2021b.
[37] Ray, S., Haque, M., Sakib, M.N., Mita, A.F., Rahman, M.M., and Tanmoy, B.B., "Use of ceramic wastes as aggregates in concrete production: A review," Journal of Building Engineering, vol. 43, p. 102567, 2021.
[38] Singh, N., and Srivastava, S., "Recycling ceramic waste in concrete production," Global Construction Materials Journal, vol. 18, pp. 45–53, 2018.
[39] Suzuki, T., et al., "Circular economy applications in construction," Construction and Building Materials, vol. 21, pp. 134–145, 2009.
[40] Matias, G., Faria, P., and Torres, I., "Lime mortars with heat-treated clays and ceramic waste: A review," Construction and Building Materials, vol. 73, pp. 125–136, 2014.
[41] Pacheco-Torgal, F., and Jalali, S., "Reusing ceramic wastes in concrete," Construction and Building Materials, vol. 24, no. 5, pp. 832–838, 2010.
[42] Subaşı, G., et al., "High-performance concrete incorporating ceramic waste as coarse aggregate," Cement and Concrete Research, vol. 56, pp. 45–50, 2017.
[43] Amin, M., and Mohammed, A., "The effect of ceramic waste aggregates on the properties of concrete," Construction and Building Materials, vol. 230, p. 117063, 2020.
[44] Medina, C., Frías, M., and Sánchez de Rojas, M.I., "Durability of recycled concrete made with recycled ceramic sanitary ware aggregate: Inter-indicator relationships," Construction and Building Materials, vol. 105, pp. 480–486, 2016.