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Performance of Ceramic Tiles Waste as a Partial Replacement of Brick Aggregate on Mechanical and Durability Properties of Concrete

Sumit Basak, Md. Rashedul Haque, Abul Kalam Azad, Md. Muntasir Rahman*

Department of Civil Engineering, Faculty of Engineering, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur-5200, Bangladesh

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ABSTRACT

The availability of natural aggregates such as stone chips is a particularly challenging issue nowadays. Ceramic materials are increasingly being used in new projects such as tiles, sanitary fittings, electrical insulators, and so on, due to ceramic's fragile properties, which often break during production, shipping, and installation. So, ceramic waste is one of these materials that are probably cost-efficient to use as a substitution (0%, 25%, 50%, and 75%) for brick chips. This research examined the mechanical strength properties of ceramic tile waste (CTW) concrete, including its compressive strength and splitting tensile strength, and utilized a water absorption test to assess its durability and performance. This research used a mix ratio of 1:1.5:3 with a constant water-cement ratio (w/c) of 0.45, and a water-reducing superplasticizer named Conplast SP337 was used. For the mechanical and durability tests, a total of seventy-two (72) concrete cylinders of 100 mm × 200 mm were cast, cured, and tested at 7, and 28 days. Mechanical strength results revealed a significant increase of around 16.71% for 50% CTW concrete mixtures at the place of brick aggregates, and the water absorption performance improved with the incorporation of CTW in concrete mixes.

Keywords: Ceramic Tiles Waste, Brick Chips, Superplasticizer, Mechanical Properties, Durability Properties.

1 Introduction

Concrete has been broadly recognized as a renowned construction material, basically because of its availability, affordability, performance, and comfort of working [1]. Concrete is a universally used construction material in all forms of structures. It is predicted that approximately 25,000 million tons of concrete will be produced annually. This equates to around 3.8 tons per person yearly [2]. For that reason, the natural resources of aggregates are depleting worldwide in the present day. Hence, it's possible that using substitute materials in place of natural aggregates will be necessary [3]. One of the most dangerous problems in the globe has been removing waste and reusing it. In several studies, researchers employed different waste materials as a substitution for natural aggregates in varying amounts and examined concrete's mechanical and durability aspects. Therefore, there is a growing concern for defending the atmosphere and a need to reserve natural resources, such as aggregate, by using complementary materials that are redundant as waste. Construction and demolition (C&D) wastes represent nearly 75% of all waste produced globally. Additionally, around 54% of the waste generated from construction as well as demolition is made up of waste from ceramic products [4], [5]. Ceramic items (tiles, electrical insulators, sanitary fittings, etc.) are increasingly being used in building and structural construction, owing to the fragile properties of ceramic, which often break during production, shipping, and installment. Ceramic waste, such as floor tiles, wall tiles, sanitary wares, as well as household ceramics, is probably cost-efficient to use as a substitution for natural aggregates [6]. Based on the global production data, China is the largest ceramic tile producer, producing 46.6% of the overall production, while India comes in third with 6.2% of the worldwide production [7], [8]. Over 12 billion m^2 of different kinds of ceramic tiles were produced worldwide in 2012. About thirty percent of the output in the ceramics sector is squandered [9], [10]. Ceramic aggregate has a low thermal expansion coefficient and is heat and abrasion-resistant. Additionally, ceramic items are very strong, long-lasting, and resistant to heat, fire, and wear. As such, using these industrial wastes in concrete in place of aggregates may prove to be a practical way to eliminate waste [11]-[14]. Many researchers have successfully attempted to build a basis for their future work by examining the mechanical properties of ceramic aggregate concrete [15]-[18] and the qualities of ceramic aggregate [19], [20]. The study on ceramic aggregate concrete needs to be compiled in an orderly manner to facilitate the use of ceramic wastes in structural concrete. This will help future researchers and potential builders by offering essential knowledge.

In Bangladesh, most of the construction works such as buildings, bridges, and highways are being constructed using a significant amount of local brick aggregates. The application of ceramic waste will lower the utilization of brick chips in concrete production. It will help control hazardous gases such as CO_2, CO, SO_2, NO_2, and others emitted from brickfields [21]. Utilizing ceramic waste tiles as a substitution for brick aggregate in concrete construction can have several potential implications, including environmental sustainability and cost-effectiveness. The objective of this research is to determine the safe proportion of ceramic waste aggregate (CWA) usage to improve the concrete without compromising its properties and to compare the mechanical properties such as compressive strength and splitting tensile strength between conventional brick aggregate concrete and CWA concrete. Besides these durability properties such as water absorption capacity will also be investigated in this research. Therefore, employing these

*Corresponding Author Email Address: rashed.civil@hstu.ac.bd

wastes in concrete manufacturing might be an efficient way to protect the environment while also increasing the quality of concrete.

2 Materials and Methodology

2.1 Materials

2.1.1 Cement

For this research, ordinary Portland cement (Premier cement) was utilized. It conforms to the Bangladesh Standard BDS EN 197-1:2003 CEM-I 42.5 N and 52.5 N.

2.1.2 Aggregates

Sand. River sand was used as fine aggregate in concrete. The origin of this sand was the Panchagarh district, which was collected from Dosmile in the Dinajpur district.

Brick chips. It's a coarse aggregate composed of broken bricks. Brick gravel, brick khoa, and brick ballast are its various names. For this research work, 19 mm downgrade brick chips were generally utilized as coarse aggregate. Sieve analysis was conducted for both sand, brick chips, and ceramic aggregate by ASTM standards.

Ceramic waste aggregate. This research used ceramic floor porcelain tiles as a Partial replacement for brick chips. Ceramic tile waste has been collected from Parbatipur, Dinajpur. The collected tiles were broken manually into standard aggregate sizes (19 mm downgrade). Fig. 1 shows the materials utilized in this research work.

(a) Cement

(b) Brick chips

(c) Sand

(d) Ceramic tile waste

(d) Ceramic tile aggregate

Fig. 1 Various types of materials used in this research work

2.1.3 Admixture

The main purpose of using admixture was to produce high-workability concrete without losing strength and high-quality concrete with improved durability. Conplast SP337 was used as a superplasticizer for the better workability of concrete, and a reduced water/cement ratio increased density.

2.1.4 Concreting ingredients

Concreting ingredients such as aggregate, cement, admixture, and water were collected locally and tested in various properties in the laboratory according to ASTM standards. Table 1 depicts the properties of aggregates.

Table 1 Properties of Aggregate

Property	**Fine Aggregate (Sand)**	**Coarse Aggregate (Brick chips)**	**Ceramic Tile Aggregate**	**ASTM Standards**
Fineness Modulus	3.16	6.16	6.96	ASTM C136 [22]
Maximum Aggregate Size (mm)	-	19	19	-
Unit Weight (kg/m^3)	1704	1130	1399	ASTM C29 [23]
Voids (%)	35.43	55.12	41.21	
Specific Gravity	2.65	1.80	2.39	ASTM C127 [24]
Water Absorption (%)	1.01	16.04	1.26	ASTM C128 [25]

2.2 Mix Proportions

A total of four mixes were prepared including the control mix containing brick chips. For conducting this research work, a mixed proportion of 1:1.5:3 was adopted, and a fixed w/c ratio of 0.45 for all mixes including the control mix was taken. A super-plasticizer admixture of 1% of the cementitious materials was used in all mixes to produce high-workability concrete without losing strength. The mixing proportions of concrete are summarized in Table 2.

Table 2 Mixing proportions of concrete

Mix Name	% of Broken Ceramic Tile Replacement	w/c Ratio	Cement (kg/m^3)	Water (kg/m^3)	Fine Aggregate (kg/m^3)	Brick Chips (kg/m^3)	CWT (kg/m^3)
CWA-0	0%	0.45	403	181.35	715.68	949.2	0
CWA-25	25%					711.9	237.3
CWA-50	50%					474.6	474.6
CWA-75	75%					237.3	711.9

2.3 Workability Test

This test was frequently used on construction sites across the world as an indirect measure of concrete performance. Finally, workability was examined at the end of each concrete mix according to standard ASTM C143 [26]. Fig. 2 shows the workability test of brick and CWA concrete.

Fig. 2 Workability test of brick and CWA concrete

2.4 Preparation of Concrete Specimen and Testing

A total of 24 nos of cylindrical concrete specimens (100 mm × 200 mm) were prepared and tested for mechanical properties such as compressive strength by ASTM C39 [27], 24 nos of specimens for split tensile strength by ASTM C496 [28], and 24 nos for durability properties such as water absorption tests. The test setup used in this research is shown in Fig. 3.

(a) Compressive strength setup

(b) Splitting tensile strength setup

Fig. 3 Compressive and splitting tensile strength setup

3 Results and Discussion

3.1 Workability

The slump value of conventional brick aggregate concrete was found to be 85 mm. After that, when the replacement was started at that time, the slump value increased. Because ceramic tile waste has a smooth surface, particles reduce friction and flow more easily. By replacing brick chips at a rate of 25%, 50%, and 75% with ceramic waste tiles, the slump value increases by about 41% for 75% of replacement of CWT than the 0% CWT. This increase in slump value is good for workability and ease of placement. Slump value of various mixes is shown in Fig. 4.

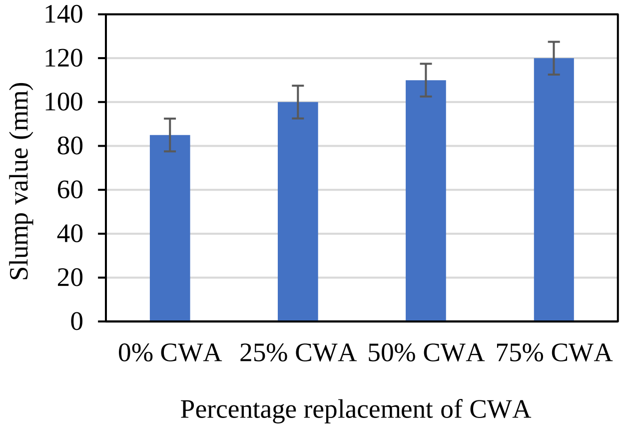

Fig. 4 Comparison of slump value of different concrete mixtures

3.2 Unit weight of Cylindrical Concrete Specimens

The unit weight of a cylindrical concrete specimen is the weight of the specimen per unit volume. In this research, unit weights for different types of mixed proportions were determined for brick and CWA concrete. Fig. 5 shows the comparison of the unit weight of brick and CWA concrete. The percent replacement of ceramic waste aggregate is increased the unit weight might be increased by around 9% for 75% replacement of CWT than 0% of CWT at 28 days because of higher specific gravity and lower presence of voids in ceramic waste aggregate.

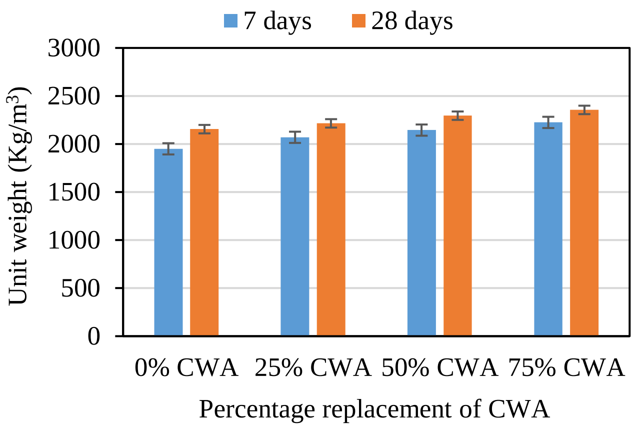

Fig. 5 Comparison of unit weight of brick and CWA concrete

3.3 Mechanical Properties of Concrete Specimens

3.3.1 Compressive Strength

The compressive strength of concrete is significant because it influences the load-bearing capacity and longevity of concrete structures. The compressive strength of the specimen improves with curing periods in both conventional brick aggregate concretes and ceramic waste aggregate concretes, as expected. A different pattern of gaining strength of conventional brick aggregate concrete and CWA concrete can be observed in Fig. 6. At 7 days of curing, the optimum compressive strength of CWA concrete at 50% replacement is 28.95 MPa, which is 15.62% higher than conventional brick aggregate concrete. At 28 days of curing, the maximum compressive strength of CWA concrete at 50% replacement is 31.78 MPa, which is 16.71% higher than conventional concrete. After that 75% replacement, the compressive strength decreases due to the weakness in the concrete mixture, when a high proportion of CWT is used.

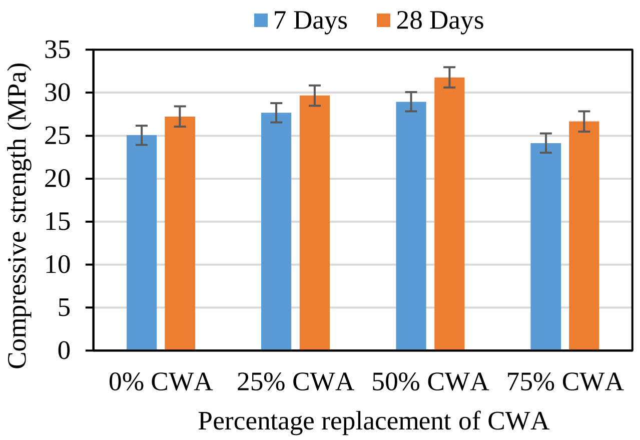

Fig. 6 Comparison of 7 and 28-day compressive strength of brick and CWA concrete

3.3.2 Modulus of Elasticity

The elastic modulus of cylindrical concrete specimens, commonly known as Young's modulus, measures the stiffness or resistance to deformation of the concrete. The modulus of elasticity improved a significant amount by using ceramic waste aggregate in concrete. Fig. 7 shows the variation of the modulus of elasticity at different percentages of replacement of CWA. The modulus of elasticity of concrete for 28 days is more than the 7 days. The optimum modulus of elasticity is obtained at 50% replacement which is 8.07% higher than conventional brick aggregate concrete at 28 days of curing. The modulus of elasticity decreases at 75% replacement due to the differences in properties between CWT and traditional brick chips.

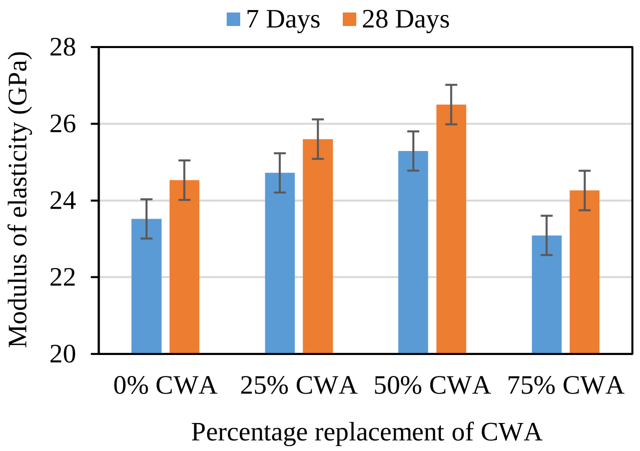

Fig. 7 Modulus of elasticity of brick and CWA concrete at 28 days of curing

3.3.3 Split Tensile Strength

Split tensile strength is a tensile strength measurement of a material, commonly concrete. A compressive load is applied to a cylindrical specimen, causing the cylinder to split along its vertical diameter. In this research, using CWA can significantly improve split tensile strength. Fig. 8 shows the variation of splitting tensile strength after different curing ages. At 50% replacement of CWA, the maximum splitting tensile strength of CWA concrete is 4.04 MPa and 4.45 MPa respectively, at 7 and 28 days of curing, which is 17.78% and 14.10% higher than conventional brick concrete. This improvement is due to the interlocking mechanisms that enhance the overall bonding between the tile and the matrix and decreases after 75% of CWT because of high proportions of CWT.

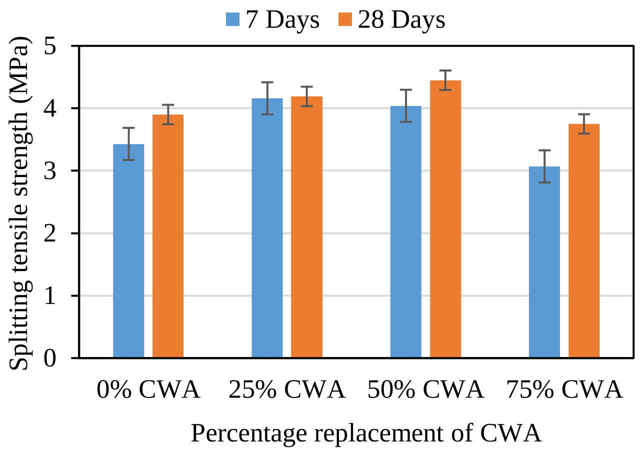

Fig. 8 Comparison of 7 and 28-day split tensile strength of brick and CWA concrete

3.4 Durability Properties of Concrete Specimens

3.4.1 Water Absorption Test

The cylindrical concrete specimen water absorption test is used to assess how much water a concrete sample can absorb. In conventional concrete specimens, the average absorption is 10.70%. But, after the replacement is started, the average absorption decreases by 7.12%, 6.8%, and 6.02%, respectively. Because brick chips have higher water absorption than ceramic tiles waste. If water absorption of the concrete specimen decreases, it indicates that the concrete is less porous and denser. The percentage of water absorption of brick and CWA concrete specimens is shown in Fig. 9.

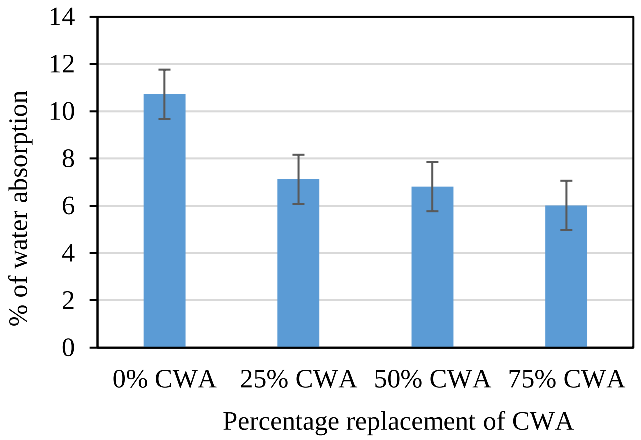

Fig. 9 Comparison average (%) of water absorption of brick to CWA concrete

4 Conclusions

In this research, various percentages of ceramic tile waste (25%, 50%, and 75%) were utilized for producing concrete. The following conclusions were found:

- From the slump value, it can be said that if the amount of CWA is increased, the concrete will be more workable.
- The unit weight of ceramic waste aggregate concrete was high as compared to conventional brick aggregate concrete

specimens due to its higher specific gravity and lower presence of voids.

- For 28 days of curing the maximum compressive strength of CWT concrete is 31.78 MPa which is 16.71% higher than conventional concrete at 50 % substitution.
- The modulus of elasticity is gained at 50% substitution which is 8.07% higher than conventional brick aggregate concrete after 28 days of curing.
- The splitting tensile strength of CWA concrete is almost like the 50% replacement of brick aggregate concrete.
- On the other hand, the water absorption capacity is decreased if the replacement is increased. It indicates that the CWA concrete is less porous and denser.

So, it can be concluded that 50% ceramic waste aggregate substitution in place of brick chips is recommended to produce concrete in terms of mechanical and durability performance.

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