Effect of Recycled Porcelain-Ceramic Aggregates on Concrete: a Review

Mohsin Ali Bhutto and Mehran Sudheer

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Effect of Recycled Porcelain-Ceramic Aggregates on Concrete: A Review

Mohsin Ali Bhutto[a*], Mehran Sudheer[b]

[a]*BS Student, Department of Civil Engineering, Capital University of Science & Technology, Islamabad, Pakistan.*

[b]*Lecturer, Department of Civil Engineering, Capital University of Science & Technology, Islamabad, Pakistan.*

[*] Corresponding author: Mohsin Ali Bhutto, Email: mohsinalibhutto0786@gmail.com

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A B S T R A C T

Due to recent increasing industrialization and urbanization, Effective management of waste is one of the most problematic issues constantly faced by today's world. By reducing the degradation of natural resources brought on by the extraction of natural aggregates, ceramic waste from construction sites presents a sustainable and efficient endeavor for environmental problems. A profusion of research has been attempted to analyze the suitability of ceramic wastes from various sources as a possible alternative to natural aggregates in concrete. This paper provides an organized and contemporary review of ceramic aggregate concrete physical and mechanical properties. Based on conducted review research it can be said that ceramic aggregate concrete has identical physical and mechanical attributes to conventional concrete. It has been highlighted that ceramic aggregates can be used to create medium and high-strength concrete in place of natural aggregate. This also revealed that the compressive strength, permeability properties, bond strength, etc. of the concrete utilizing ceramic aggregate exceeded the necessary standards, confirming the feasibility of using ceramic waste as a successful alternative to natural aggregates in structural concrete. However, there is a need to explore the mechanical properties of ceramic waste concrete structural members to comment on its sustainability for structural applications.

K E Y W O R D S: Ceramic Waste Aggregate, Ceramic Aggregate Concrete, Physical Properties, Mechanical Properties, Durability, Review.

1. Introduction

The use of earthenware materials such as tiles, clean fixtures, and other waste products has evolved in modern construction techniques [1]. Additionally, research is being done to improve the strength and longevity of concrete. Materials made from renewable resources have been developed in response to worries about resource depletion and global pollution. To reduce the building industry's environmental impacts and conserve natural resources, eco-friendly materials are currently the subject of extensive research. Similar problems with capacity and the environment arise from disposing of demolition concrete waste in landfills. Finding appropriate substitutes to make concrete is therefore urgently needed [1].

Ceramic is a trendy furnishing material right now. But when ceramic approaches the end of its useful life, it no longer has any value and is just wasted. Ceramic wastes also come from subpar production and poor workmanship, along with outmoded furniture products. Every day, growing amounts of ceramic waste are produced, and the ceramic industries are now under pressure to find a practical way to dispose of it. If these materials are not properly disposed of, they will have a severe effect on the environment. Construction businesses are under pressure to find a suitable method of disposing of these pollutants [2].

The remaining modern items utilized in substantial production, particularly as unrefined components, are one the most proficient approaches to using these inorganic squanders as total possesses a huge volume portion for concrete, around 80%-85% of a regular substantial blend, it has a major sway on the concrete's compressive strength as well as other assets. Ceramic aggregates have a mildly low development coefficient and are resistant to scraped patches and intensity. Additionally, ceramic items are highly durable, strong, and resistant to wear, heat, and fire. Therefore, using these contemporary wastes in place of aggregates in concrete could be a workable solution for the waste evacuation process [2].

Various scientists possess effective endeavours to build a lying starting point for prospective works, examining the physical characteristics of ceramic aggregate [3], [4], [5] and mechanical properties of ceramic aggregate concrete [6], [7], [8], [9]. To optimize the usage of ceramic wastes in structural concrete, the investigation of ceramic aggregate concrete will be planned in a way that will be simultaneously productive for present researchers and valuable till the next ones. This paper reviews ceramic waste's suitability to be used as aggregate and its effectiveness as coarse and fine aggregates in concrete. In addition, various ceramic aggregate properties are also examined and contrasted with those of natural aggregates. A literature review on the mechanical characteristics of concrete made with ceramic aggregates is also provided.

2. Characteristics of Porcelain Ceramic Aggregates

Porcelain ceramics are very dense, have low porosity, and have high strength. Due to its attractiveness, heat resistance, and strength, the most recent ceramic product is made from clay, feldspar, granite, and silica under intense pressure and heat for use as flooring and facade material in buildings. High-temperature baking transforms porcelain ceramics into vitreous materials with very little porosity and very little water absorption, which are frequently referred to as "manufactured stone." Due to their extreme strength, they are typically dumped and released into the environment as waste as shown in Fig. 1, because they can't be easily recycled back into the production process [10].The characteristics of the ceramic aggregates that constitute ceramic aggregate concrete greatly influence its attributes (physical, mechanical, and durability). The chemical composition of porcelain ceramic tile aggregates is shown in Table 1.

Table 1. Porcelain Ceramic's Chemical Breakdown [11]

Chemicals	Breakdown %
Lime (CaO)	1.70%
Silica (SiO2)	68.60%
Alumina (Al2O3)	24.5%
Magnesium oxide (MgO)	2.50%
Iron tri-oxide (Fe2O3)	0.80%
Sulphur tri-oxide	0.12%
Loss of ignition	1.78%

Fig. 1. Waste Porcelain Ceramics

3. Influence of Porcelain-Ceramic Aggregate on the Physical Properties of Concrete

The properties of the various ceramic aggregates that constitute ceramic aggregate concrete heavily influence its physical, mechanical, and durability properties.

Table 2. Properties of Ceramic Waste Aggregates

References	Ceramic aggregate source	Ceramic aggregate type	Bulk density/ density (kg/m3)	Water Absorption %
[12]	Sanitary ware	Fine (Max)	2210(Loose)	6.1
[13]	Sanitary ceramic waste	Fine(0-4mm)	2360(Loose)	1.5
[14]	Ceramic tile	Coarse (Max 20mm)	1325(Compact)	4.5
[15]	Wall tile, floor tile	Coarse (Max 4.75mm)	1060(Loose)	6.3
[16]	Ceramic tile waste	Coarse (Max 31.5mm)	-	11.5

3.1 Specific Gravity

Any material's specific gravity is determined by comparing its density to that of water [17]. The ranges for specific gravities of coarse and fine ceramic aggregate are 2.20-2.50 and 2.26-2.58, respectively [18]. [19] demonstrated the maximum specific gravity of (2.580) in the finest ceramic aggregate, while [20] recorded an intrinsic value of (2.50) for coarse ceramic aggregate. (Awoyera et al. 2017) claimed the lowest specific gravity for doable ceramic aggregate to be 2.26, According to (Sekhar et al. 2011), coarse ceramic aggregate has the lowest specific gravity, 2.20. Ceramic aggregates often have a lower specific gravity than natural aggregates.

3.2 Density/ Bulk Density/ Particle Density

The density variation of ceramic aggregates is illustrated in Table 1 from distinct sources and types. As shown in Table 2, researchers noted that the bulk densities of ceramic aggregate, both coarse and fine were (1010 – 2969) kg/m3 and (966 – 2401) kg/m3. The majority of the study found that ceramic fine and coarse aggregates had lower bulk densities than equivalent natural fine and coarse aggregates. Additionally, it was found that ceramic aggregates' particle densities were lower than those of natural aggregates, it has been demonstrated that ceramic aggregates manufactured from absorbent ceramics frequently have a greater bulk density value (>2000 kg/m3). Whereas aggregates made from electrical insulators and insulator bush have a bulk density that fluctuates between 1069 and 1325 kg/m3, another factor is that these aggregates are made from insulator bush. The bulk densities of recycled brick aggregate and ceramic tile ranged from 966 to 2050 kg/m3 and 1060 to 2401 kg/m3, respectively.

3.3 Water Absorption and Moisture Content

Ceramic aggregates take up water in a diverse range of ways, as demonstrated by Table 2, depending on their kind and source [3]. According to the findings of various studies, ceramic aggregates are better at absorbing water than natural aggregates. Ceramic aggregates' high porosity is the cause of their high-water absorption capacity. the level of moisture in ceramic aggregates from differently sourced, as the workability, and consistency of concise are influenced by the aggregates' water absorption. To effectively build a concrete mix, it is therefore vital to determine the amount of water absorption that ceramic particles must have [2].

(a) (b)

Fig. 2. (A) Ceramic Aggregate's flaky shape; (B) Ceramic Aggregate's (right) angular and uneven shape in comparison to natural Aggregate (left)

3.4 Porosity

The three aggregate characteristics of porosity, water absorption, and specific weight are strongly related to one another. (K. McNeil, 2013) As a result of their greater porosity, aggregates absorb more water and have a lower specific weight (Elçi, 2016). Researchers noticed higher porosity in ceramic aggregates when contrasted with normal aggregates. The porous form of sanitary ceramic aggregate particles is depicted in Fig. 3 with irregularly shaped and sized pores. According to (C. Medina M. S., 2012), sanitary ceramics have a porosity of 0.32 (% volume), whereas rocks have a porosity of 0.23 (% volume). Since of their high porosity, ceramic aggregates can retain water in their pores, bringing about inner restoration and subsequently further developing concrete hydration of cement. [21]High porosity ceramic aggregates result in a reduction in the transparent thickness of reused ceramic cement and, as a result, a reduction in the structure's self-weight, which is advantageous for creating long-range structures (F. Liu, 2015).

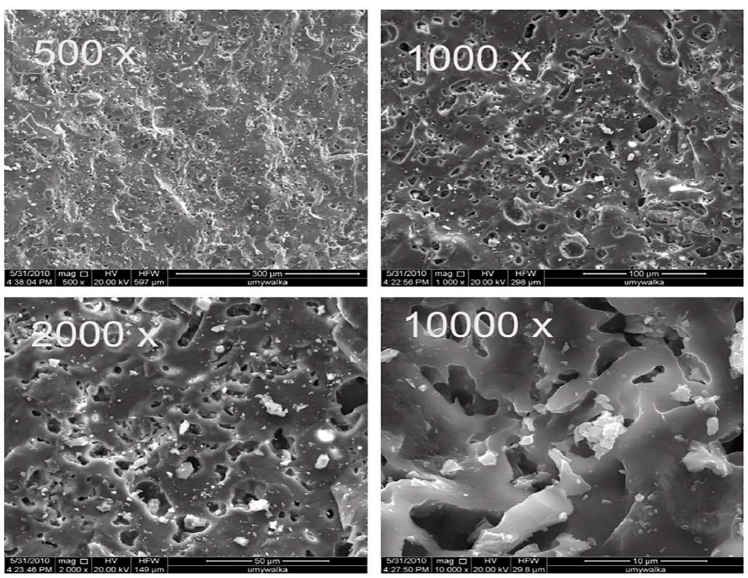

Fig. 3. Under a scanning electron microscope, a sanitary ceramic aggregate particle's porous structure may be viewed ((A. Halicka P. O., 2013)

4. Influence of Porcelain Ceramic Aggregates on Mechanical Properties of Concrete

4.1 Compressive Strength

The significant attribute for compressive strength of structural concrete has been carefully examined in studies including ceramic waste aggregate. Various amounts of ceramic coarse and fine aggregate, various hardening times, and different testing circumstances have all been investigated by researchers to produce different classes of strength

[23].

According to (Medina et al. 19), the amount of coarse aggregate made of sanitary ceramics added to the concrete mix enhanced the concrete's compressive strength. The average 4-week compressive strength of concrete with a percentage of the coarse sanitary aggregate of 0, 15, 20, and 25% was found to be 35.87, 37.24, 38.53, and 39.83 MPa, and some of the compressive strengths are discussed in the graph as shown in Fig. 4. The authors argue that sanitary ceramic coarse aggregate's irregular shape as shown in Fig. 2 offers a greater specific surface than natural aggregate, increasing the concrete's mechanical strength and influencing a strong bond between the cement paste and ceramic aggregate.

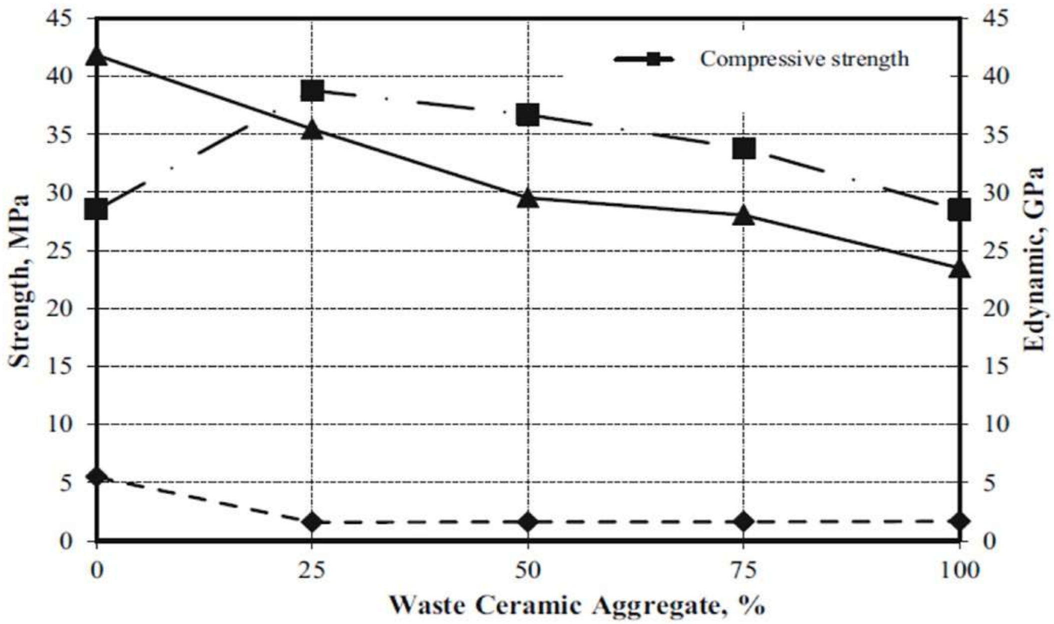

Fig. 4. Concrete's compressive and flexural strengths as well as its dynamic modulus of elasticity [22].

4.2 Splitting Tensile Strength

The concrete's splitting tensile strength dictates the pattern of progressive cracking that arises under tensile stress, together through a way to infer the amount of load that causes the crack in the material (C. Fapohunda, 2017). Using ceramic aggregate in concrete has a less significant impact on the splitting tensile strength than using ordinary concrete.

Similar to what was seen for compressive strength, (Awoyera et al. 2017) found that the volume of fine and coarse tile aggregate inclusion augmented the splitting tensile strength of concrete. They stated that the addition of ceramic aggregates altered the mixture's pore structure, resulting in an increase in capillary pores and a decrease in the porous structure[23].

According to (Medina et al. 2012), concrete with (15–25%) coarse sanitary ware aggregates had a (12–25%) higher splitting tensile strength than reference concrete. They contend that the higher specific surface area and irregular shape of ceramic aggregates result in a stronger bond between the aggregate and slurry, which in turn contributes to the high strength of ceramic aggregate concrete.

4.3 Flexural Strength

Flexural strength is a gauge of a material's resistance to distortion under bending stresses (N. Saikia, 2012). It indicates the maximum stress in materials under collapse loading (N. Saikia, 2012).

In comparison to ordinary concrete, Concrete produced with ceramic tiles as coarse aggregate seems to have a 32.2% enhanced flexural strength, according to Daniyal and Ahmad. Additionally, Subramani and Suresh discovered that aggregate concrete had higher flexural strength (5.64-6.95 MPa) in comparison to control concrete (5.2 MPa). According to studies by (Y. Tabak M.K, 2012) and (Sekhar et al 2011), 100% coarse tile aggregate concrete has a stronger flexural strength than conventional concrete of all ages. The discussion above illustrates the fact that ceramic waste can be a more effective replacement for natural aggregate and has particular advantages to the control mix.

5. Conclusion and Recommendations

To evaluate whether the ceramic waste is a potential aggregate for concrete, the currently available literature was reviewed. The results of these experimental results reveal that ceramic waste might be an effective replacement for natural aggregates in concrete. The following conclusions are reached in light of the literature reviews:

1. Depending on their source, ceramic aggregates may possess a smooth surface texture, be porous, lumpy, angular, flat, or flaky in shape, and typically reddish or white in colour.
2. Ceramic aggregates' specific gravities in fine and coarse particles, which are typically lower than those of natural aggregates, are 2.26 and 2.58 and 2.20 and 2.50, respectively. The volume weights of ceramic aggregates, whether they be fine or coarse, are typically (1010) and (2969 kg/m3) and (966 - 2401 kg/m3). Furthermore, the ceramic aggregate particles' density ranges from 1032 to 2640 kg/m3. Ceramic aggregate is extremely absorbent because it has a higher porosity than natural aggregate. As assessed by the source, water absorption by ceramic aggregates differs widely and typically ranges from 0.18% to 18.91%.
3. Because of the comparatively higher permeability of ceramic aggregates than natural aggregates, the absorbency, and permeability of concrete are enhanced by the inclusion of all varieties of ceramic aggregates.
4. The proportion of aggregate used raises the compressive strength, split tensile strength, and flexural strength of ceramic aggregate concrete.

Given the current knowledge of ceramic aggregate concrete, additional research is needed in various areas before ceramic waste aggregate may be used effectively in the manufacturing of concrete. The flexure and shear performance of concrete members constructed with ceramic particles should be thoroughly investigated. Additionally, it is possible to investigate the deflection properties of Ceramic Aggregate concrete beams and slabs. And is possible to study the performance of reinforced prestressed concrete members made from ceramic waste under static and fatigue loads. Further research will be needed to examine the long-term mechanical and durability characteristics of ceramic aggregate concrete.

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