A Review on Recycling Ceramic Waste in Construction: Enhancing Durability and Reducing Environmental Impact

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Abstract

The construction industry continually seeks sustainable materials to enhance the durability of structures while minimizing environmental impact. Ceramic waste, a by-product of the ceramics manufacturing process, presents a promising alternative. Traditionally used for applications such as tiles, sanitary ware, and bricks, ceramic materials are valued for their high strength, aesthetic appeal, and thermal insulation properties. The study indicates that ceramic waste enhances the durability of construction materials due to its inherent properties, such as low water absorption and high resistance to abrasion. Additionally, utilizing ceramic waste addresses environmental concerns associated with landfill disposal, which include soil and water contamination, greenhouse gas emissions, and the depletion of landfill space. Incorporating ceramic waste into construction materials not only offers environmental benefits by reducing landfill waste and conserving natural resources but also provides economic advantages through cost-effective waste management and material production. This research explores the incorporation of ceramic waste into construction materials, emphasizing the enhanced durability properties of concrete and mortar mix while highlighting the dual benefits of improved material performance and environmental sustainability, thereby advocating for broader adoption of ceramic waste utilization in the construction industry.

1. Introduction

The construction industry has seen substantial growth worldwide as a result of globalization. This expansion has spurred an increase in infrastructure development and building projects, thereby driving up the demand for concrete [1,2]. Each year, more than 10 billion metric tons of concrete are produced globally, predominantly using Ordinary Portland Cement (OPC). In developing nations such as India, concrete serves as a primary building material, with an annual production of 12 billion tonnes [3]. The production of one tonne of OPC results in the emission of one tonne of CO2. Consequently, OPC manufacturing accounts for 5% -7% of the world's CO2 emissions [4,5]. The construction industry consumes large amounts of natural resources and has notably altered the water systems and natural ecology of urban areas [6]. In the construction sector, sustainability and green manufacturing principles advocate replacing raw materials such as natural aggregates and additional cementing agents with diverse waste products. This strategy reduces construction expenses associated with waste disposal and encourages environmentally friendly building practices [7]. While it may not entirely resolve the problem of aggregate shortages, utilizing secondary materials can provide some relief [8]. Researchers have tackled these challenges by investigating the partial substitution of OPC with supplemental cementitious materials (SCMs) to diminish its consumption. SCMs can effectively decrease the cement content in concrete without necessitating an extra clinkering process, offering a viable environmental strategy. This approach results in a notable reduction in CO2 emissions per ton of binder [9]. Each year, new methods in concrete technology are proposed to make concrete production more cost-effective [10]. Over the past ten years, there has been increasing interest in using various waste materials as aggregates like ceramic waste, in concrete construction due to rising ecological awareness [11,12]. Researchers face mounting pressure to adopt sustainable practices in managing waste, driven by the escalating volume of waste generated and the challenges associated with its disposal. Meanwhile, the concrete industry's extensive reliance on traditional resources such as cement and sand is causing substantial environmental impact in terms of carbon emissions [13,14]. Researchers globally have increasingly adopted diverse waste materials such as fiber-reinforced polymer waste, rubble, glass, coal ash, blast furnace slag, rubber, waste from the granite industry, plastic and ceramic waste in producing concrete and other construction materials. However, these materials carry the risk of triggering various significant environmental concerns **[1,13,15-17]**. Incorporating these waste materials into the construction industry would significantly advance sustainable and cleaner production practices **[18].** Using various supplementary cementitious materials (SCMs) in blended cement production helps create strong and environmentally friendly concrete **[19].** According to a review of studies, industrial wastes have various applications and uses in the construction sector. Materials such as fly ash, red mud, silica fume, and copper slag are replaced in comparable proportions and tested for strength. This approach reduces environmental contamination by converting industrial wastes into valuable by-products **[20]**.

The ceramic industry is categorized into two subgroups based on the products manufactured: red ceramics and white ceramics. The term "ceramics" describes the composition of tiles, which are heat-resistant, non-metallic, and made from inorganic solids derived from compounds of both metallic and non-metallic elements **[4,8]**. Ceramic is a highly favored building material in the construction industry, commonly employed in various applications including floor tiles, cookware, and sanitary ware. Its popularity stems from its exceptional physical properties, such as high compressive strength, durability against wear, fire resistance, and electrical insulation. These qualities make ceramic a superb alternative to natural aggregates in construction **[6].** In the last two decades, extensive research has focused on incorporating waste materials into ceramic matrices **[21-23].** Many researchers have focused on replacing coarse and fine aggregates in construction projects with waste ceramics **[6]**. The impacts of employing ceramic wastes as aggregates and/or pozzolanic admixtures in mortar and concrete, such as blocks, bricks, roof tiles, sanitary ware, or electrical insulators, have been studied by several researchers worldwide **[24]**. Using waste ceramic aggregate (WCA) instead of traditional coarse aggregates improves the consistency of mechanical properties in cast concrete. These enhancements not only benefit environmental preservation but also reduce reliance on natural resources **[11]**. Waste ceramic powder exhibits pozzolanic activity and contains significant amounts of alumina and silica **[9]**. A primary ceramic product utilized in construction is the polished ceramic tile. The production of 1 square meter of polished ceramic tile generates approximately 1.9 kg of waste powder, known as porcelain polishing residue **[25].** Given the properties of these ceramic wastes, using them as a partial replacement for natural aggregates in hot-mix asphalt could provide an additional avenue for their utilization. This approach not only lowers waste management expenses during production but also mitigates environmental effects **[26].** When ceramic waste was used to replace some of the conventional crushed stone and coarse aggregate in concrete, it did not affect the compressive strength significantly. This shows that ceramic waste can effectively serve as coarse aggregate. The properties of ceramic waste coarse aggregate align well with those typically found in aggregates used for concrete production. Concrete made with ceramic waste coarse aggregate performs similarly to regular concrete, indicating no notable differences in properties **[27]**.

(a) (b)

Plate. 1 (a) Fine bone china aggregate "Reprinted from ref. **[28].**" (b) Waste ceramic collected from demolition sites "Reprinted from ref. **[29]**."

2. Ceramic Waste Properties: -

2.1 Physical properties: - Many researchers have experimented with incorporating ceramic waste into concrete alongside other alternative materials. Ceramic waste, due to its particle size distribution closely resembling that of cement, has been utilized as a substitute for both aggregate and cement. Its composition consists of angular and irregular granules, akin in shape to cement particles. Table 1 illustrates the diverse physical attributes of ceramic waste.

Table 1 Physical properties of ceramic

Type of solid waste	Ceramic Aggregate	Ceramic Aggregate	Ceramic Aggregate	Ceramic waste aggregate	Ceramic Waste from Electrical Insulator	Ceramic powder	Ceramic Waste from Electrical Insulator	Ceramic Waste Powder	Ground clay bricks waste	Ceramic waste aggregate	Recycled waste porous ceramic coarse aggregates
Specific gravity	-	-	2.2	2.5	2.45	-	2.3	2.6	2.62	2.45	2.27
Water absorption (%)	0.55	0.55	-	0.18	0.72	-	0.47	-	-	0.72	9.31
Bulk Density	2390	2390	-	1188	1325	2570	-	-	-	1325	-
Loose bulk density	-	-	-	1069	1200	-	-	-	-	1200	-
Impact value (%)	-	-	17	22	21	-	-	-	-	21	-
Crushing value (%)	-	-	27	20	27	-	-	-	-	27	21.4
Maximum size (mm)	-	12.5	12.5	-	20	-	12	-	-	20	-
Fineness modulus	-	6.17	7.854	-	-	-	3.74	-	-	6.88	6.66
Specific surface area	-	-	-	-	-	34.1	-	12.2	5100	(cm2 /g)	-
Total Porosity	0.32	0.32	-	-	-	-	-	-	-	-	-
Ref.	**[30]**	**[31-34]**	**[35]**	**[36]**	**[37]**	**[38]**	**[24]**	**[39]**	**[40]**	**[41]**	**[42]**

2.2 Chemical Composition: - Ceramics are characterized by a higher concentration of silica, alumina, and calcium oxide in their chemical composition. Table 2 details the minor presence of iron, magnesium, and alkali oxides. The presence of alumina and silica in ceramic waste enhances its cementitious properties and pozzolanic reactivity, making it suitable for replacing traditional materials in concrete production.

Table 2 Chemical composition of ceramic

Type of solid waste	Ceramic Waste Powder	Ceramic Tile Waste	Ceramic Waste Powder	Crushed Ceramic	Ceramic Sanitary Waste	Ceramic Polishing Powder	Fine bone china aggregate	Ceramic Waste Powder	Red Paste twice fired ceramic	White Paste twice fired ceramic	Red clay brick waste	Ceramic Powder
SiO_2	69.4	58.6	67.35	88.4	63.45	69.02	28.86	67.51	51.7	59.8	49.9	63.29
Al_2O_3	18.2	14.2	19.79	7.3	13.98	16.04	23.86	16.92	18.2	18.6	16.6	18.29
Fe_2O_3	0.83	6.56	2.52	0.5	5.39	0.73	5.41	0.75	6.1	1.7	6.5	4.32
CaO	1.24	14.7	2.32	0.1	8.18	0.63	24.15	1.33	6.1	5.5	9.7	4.46
MgO	3.53	0.99	2	0.1	-	4.08	2.86	1.82	2.4	3.5	5.5	0.72
K_2O	1.89	1.03	4.13	-	2.43	1.84	1.58	1.31	4.6	2.5	4.4	2.18
Na_2O	3.19	3.56	-	-	0.9	3.15	-	4.8	0.2	1.6	-	0.75
SO_3	-	0.11	-	-	0.1	-	-	-	-	-	3.3	0.1
Cl	0.306	-	-	-	-	-	-	-	-	-	-	0.005
TiO_2	0.617	-	0.92	-	0.77	0.23	-	-	0.8	0.4	-	0.61
ZrO_2	0.266	-	-	-	-	-	-	-	-	-	-	-
P_2O_5	-	-	-	-	-	-	10.99	-	-	-	-	0.16
LOI	-	0.13	-	0.4	-	5.23	-	2.54	-	-	2.4	1.61
Ref.	**[43,44]**	**[45]**	**[46]**	**[27]**	**[47]**	**[25]**	**[48,49,50,51]**	**[52]**	**[53]**	**[53]**	**[54]**	**[55]**

3. **Durability properties of concrete: -** The life duration of concrete is explained by its durability, which is also used to measure the concrete's resistance in the environment. Water absorption, the chloride test, the UPV test, shrinkage, freezing and thawing, sulphur attack, electrical resistivity, and other characteristics are examples of durability attributes.

3.1 **Water absorption: -** Numerous studies are attempting to determine the water absorption of mixtures that use ceramic waste in place of cement, fine aggregate, and coarse aggregate, either partially or completely **[44,49,56]**. **Agarwal et al. [55]** found that the number of cavities in concrete increased along with the amount of ceramic debris present. And permeable concrete resulted from that. **Bartosz et al. [57]** analysis on the impact of recycled ceramic aggregate on concrete revealed that it absorbs four times as much water as basalt and gravel combined. And the economy of producing high-strength concrete reflects that. **Brito et al. [58]** to use ceramic aggregate in place of limestone aggregate. The test findings demonstrated that as ceramic aggregate levels increased, so did the high water absorption. The durability of concrete is affected by its high water absorption. **Elçi [59]** discover that the water absorption of WTA (wall tile aggregate) and FTA (floor tile aggregate) was high. Therefore, concrete with WTA aggregate can be used in temporary or low-load structures, and concrete with FTA aggregate had qualities equal to standard LSA (lime stone aggregate) concrete; FTA aggregate can be utilized as regular aggregate like LSA aggregate. . **Frías et al. [34]** observed that compared to normal concrete, concrete with ceramic aggregate had a higher total water absorption value. The total water absorption of concrete mixes (recycled ceramic concrete) CC-20 and CC-25 has increased by 36% and 46%, respectively. **Ghorpade et al. [36]** it was determined that natural aggregate had a water absorption of 0.10% and ceramic scrap had 0.18%. Although ceramic scrap had a high water absorption value, it was within an acceptable range. Thus, leftover ceramics can be utilized to make concrete.

Gobinath et al. [37] revealed that the increasing trend of water absorption with an increase in the water cement ratio was observed in both the control and the concrete containing ceramic electrical insulator waste coarse aggregate. Furthermore, at varying weight-to-content ratios, the water absorption values for control concrete and concrete containing ceramic electrical insulator trash were 3.1% to 6.52% and 3.74% to 7.21%, respectively. **Günay et al. [60]** found that the concrete with FTWA (floor tile waste aggregate) had a 1.394% good result. Therefore, it was possible to produce concrete using ceramic waste as coarse aggregate. **Jalali and Pacheco-Torgal [53]** showed that, as compared to standard concrete, concrete containing ceramic sand had a greater vacuum water absorption rate. **Keshavarz and Mostofinejad [61]** discovered that, in comparison to a control mix, concrete containing porcelain absorbs more water as the proportion of porcelain increases. Concrete with red ceramic waste had the same effects. **Robles et al. [62]** found that the water absorption of every type of aggregate used in concrete is less than 5%, falling below the EHE-08 limit for both fine and coarse aggregate. **Topçu and Canbaz [63]** claimed that the water absorption values of the concrete samples ranged from 2.06 to 6.86%. Concrete with a CTA (crushed tile aggregate) of 4–16 mm had a 200% rise. **Zareei et al. [29]** revealed that when the amount of RWCA (recycled waste ceramic aggregate) in the concrete increases, the tendency of water absorption by capillarity increases as well. The conventional concrete was found to have the lowest value.

Some researchers also have observed the influence of fine recycled ceramic aggregate on water absorption of concrete/mortar. **Alves et al. [64]** observed that although the fine CBA (crushed red clay ceramic bricks) and SWA (sanitary ware aggregate) concrete absorbed more water than the control concrete, it did so in a comparable manner. More water is absorbed by fine CBA than by NA and SWA. Furthermore, SWA has a sizable WA. **Chaudhary et al. [49]** discovered that the angularity of BCCFA (bone china ceramic fine aggregate) causes voids to form, which results in a modest increase in water absorption. **Etxeberria and Vegas [65]** verify that RA (recycled aggregate)-containing concrete absorbs more water than control concrete. The increase in water absorption capacity was the same for concrete containing 35% and 50% RAs. **Etxeberria and Gonzalez-Corominas [66]** claimed that the water-absorbing capacity of control concrete and concrete with fine ceramic aggregate (FCA) was equal. **Heidari and Tavakoli [38]** revealed that the value of all the concrete mixes containing pulverized ceramic waste was lower than that of ordinary concrete. The trends for the mixes showed a rising tendency after 20% replacement and a decreasing trend up to that point. In addition to being lower than phase A, water absorption is reduced when nano-SiO_2 is added to the concrete mix at a rate of 0.5% to 1%. **Nayana and Rakesh [67]** determined the mortar mix's water absorption after a 28-day curing period using ceramic waste in the amounts of 0%, 15%, 30%, and 50% in place of fine aggregate. In comparison to the control mixture, it was discovered that the 15% replacement group's percentage of water absorption dropped by 1.17%. The main cause of a decrease in water absorption is a reduction in pores.

Some researchers also have observed the influence of ceramic waste powder on water absorption of concrete/mortar. **Huseien et al. [39]** illustrates how the addition of ceramic waste powder at increased amounts of 0, 50, and 80% to GBFS (ground blast furnace slag) affects SCAAC (self-compacted alkali-activated concrete). Additionally, there was an increase in water absorption of 6.8%, 10.1%, and 14.1%, respectively. **Jalali and Pacheco-Torgal [53]** found that all other combinations had lower vacuum water absorption and that concrete with ceramic brick had 5% more than ordinary. **Jerônimo et al. [40]** concluded that the porosity and water absorption index of the concrete mix decreased when 0, 20, 30, and 40% of the waste ground clay bricks were added.

Based on the research findings, it can be concluded that as the amount of ceramic waste material used as aggregate or cement replacement increases, water absorption also increases (Figure 1). Additionally, Pre-treated ceramic waste can lower the overall water demand of the mix, aiding in better workability.

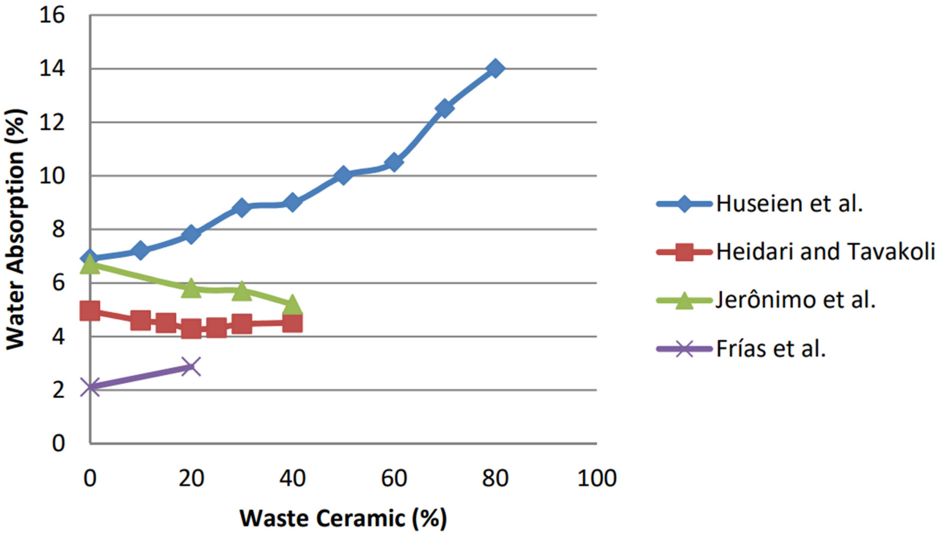


Fig. 1 Water absorption of concrete with ceramic waste **[34,38,39,40]**

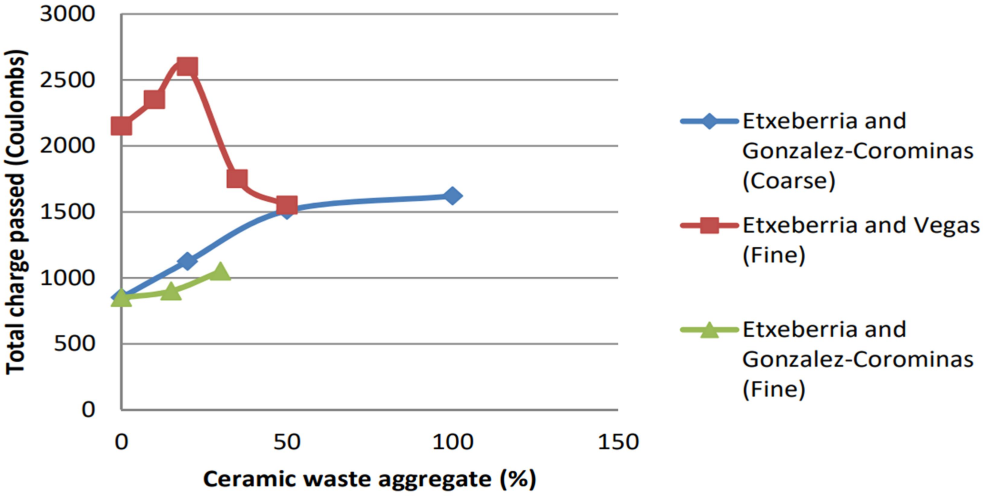
3.2 Chloride test: - The purpose of the chloride test is to determine the concrete's resistance to chlorine and to assess its durability. Rapid chloride permeability tests (RCPT), ion penetration tests, anti-chloride penetration tests, diffusion tests, resistance tests, and attack tests are only a few of the methods used to carry it out.

Gobinath et al. [37] claimed that when the w/c ratio decreased, the (Rapid chloride permeability tests) RCPT charge of concrete containing ceramic electrical insulator waste coarse aggregate decreased. Water absorption predominates in concrete with relatively dry pores, whereas diffusion predominates in concrete with saturated pores. **Polanco et al. [56]** concluded that the chloride ion penetration of concrete mixes (ceramic coarse aggregate) CC-20 and CC-25 is slightly higher than that of the control mix. The increase in chloride penetration for CC-20 and CC-25 was 4% and 8%, respectively.

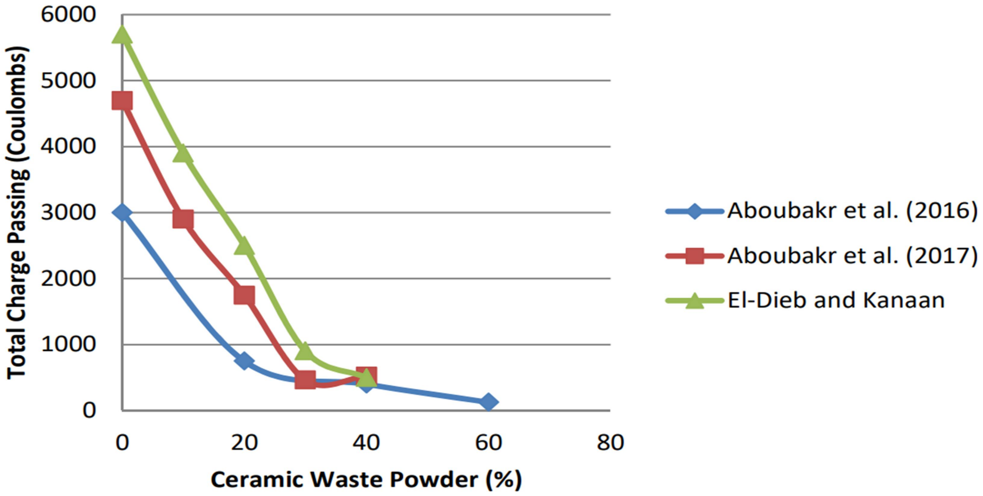
Some researchers also have observed the influence of fine recycled ceramic aggregate on chloride test concrete/mortar. **Alves et al. [64]** found that when the amount of CBA in the concrete increased, the chloride ion migration tendency decreased in the fine CBA (crushed red clay ceramic bricks) concrete. Additionally, when the amount of SWA (sanitary ware aggregate) in the concrete increased, the tendency of chloride ion movement increased as well. The result of this increased movement of chloride ions was a porous microstructure. **Chaudhary et al. [28]** determined that the depth of chloride penetration in concrete decreased as the proportion of fine bone china aggregate increased. At 180 days of chloride exposure, the chloride penetration depths of series A, B, and C control concrete are 37 mm, 100 mm, and 100 mm, respectively. Additionally, the chloride penetration depths for series A, B, and C with 100% FBA (fine bone china aggregate) were 14 mm, 19 mm, and 39 mm, respectively. It is evident that FBA is more resistant to the penetration of chlorides. **Etxeberria and Vegas [65]** it was found that the high density cements paste in the concrete containing 35% and 50% fine ceramic (recycled aggregate) RAs provided greater resistance against the entry of chloride ions than the control concrete. In comparison to the control mix, concrete containing 20% fine ceramic RAs exhibited the strongest resistance to chloride ion penetration after six months and a year of curing. When comparing the electric charge passing through the concrete at 28 days to 1 year of age, the control concrete showed a 45% increase in chloride resistance, while the concrete containing 20% fine ceramic RAs showed the largest reduction due to proper internal curing and a little pozzolanic effect. **Etxeberria and Gonzalez-Corominas [66]** demonstrated that when (fine ceramic aggregate) FCA content increased, resistance to chloride ion penetration reduced at the age of 28 days. Additionally, control concrete had the highest level of resistance to chloride and was categorized as having a decreased risk of corrosion. Concrete containing FCA exhibited the strongest resistance to chloride penetration after 180 days. Additionally, the control concrete saw a 35% drop in the total charge passed in 28 to 180 days. The mixes RC-15-FCA and RC-30-FCA had respective percentages of 52% and 70%, and the percentages for RC-20-CMA, RC-50-CMA, and RC-100-CMA were 47%, 35%, and 40%. The corrosion risk was decreased in Mix RC-100-CMA.

Some researchers also have observed the influence of ceramic waste powder on chloride test of concrete/mortar. **Aboubakr et al. [43]** it was shown that when the proportion of (ceramic waste powder) CWP in all concrete combinations grew, the concrete's resistance to chloride decreased. After 28 days, the resistance to chloride ion penetration of concrete containing 100 kg of CWP and concrete containing 300 kg of slag was nearly equal. According to ASTM C1202, CWP-containing concrete fell into the "very low" range. According to ASTM C1202, concrete with CWP ranging from 0 to 300 kg at 90 days of age demonstrated chloride resistance that ranged from "low" to "negligible." **Aboubakr et al. [44]** highlighted how the amount of (ceramic waste powder) CWP in all concrete mixtures causes the chloride resistance of the concrete to diminish. After 28 days, the (Rapid chloride permeability tests) RCPT revealed that the concrete mixes (high performance concrete) HPC-10, HPC-20, HPC-30, and HPC-40 had decreased by 38%, 63%, 90%, and 89%, respectively, in comparison to the control mix. **El-Dieb and Kanaan [68]** found that after 28 days, the amount of chloride ion penetration in concrete decreases when (ceramic waste powder) CWP is added up to 40% in place of cement. At the age of 28 days, concrete mixtures with 30% and 40% replacement exhibit extremely low values for chloride ion penetration. This is because CWP was present and its tiny particles gave concrete a dense mixture in addition to having a stronger pozzolanic activity. **Jalali and Pacheco-Torgal [53]** Phase A and B of the study examined the effects of replacing 20% of the cement with (waste ceramic powder) WCP and 100% of the sand and (coarse aggregate) CA with ceramic sand and ceramic CA on the diffusion of chloride ions in concrete. Sanitary ware combination produced the same diffusion findings as the control concrete in phase A, and chloride ion diffusion decreased with WC in comparison to the control mix. In phase B, chloride diffusion was better in concrete mixtures including ceramic sand and ceramic CA than in the control concrete. They found that the pozzolanic reaction between WCP and calcium hydroxide, which produced secondary C–S–H, gave concrete a denser microstructure when using WCP. **Xie et al. [69]** since the electric flux of conventional concrete had increased by 58.99%, it was inferred that ceramic concrete (CC-2) was less resistant to chloride ion penetration than ordinary concrete. CC-2 E was shown to have strong anti-chloride permeability. Additionally, the electric flux of CC-2 was larger than that of regular concrete, as seen by the comparison of the two curves; as a result, the permeability of chloride ions in concrete containing ceramic powder was decreased.

Based on the research findings, it can be concluded that using ceramic waste material as aggregate replacement up to 20% increases resistance to chloride ion penetration (Figure 2). However, using ceramic waste powder as a cement replacement reduces resistance to chloride ion penetration. Additionally, using mineral admixtures can positively influence chloride resistance.



(a)



(b)

Fig. 2 Total charge passing in concrete with (a) waste ceramic aggregate (b) ceramic waste powder **[44,45,65,66,68]**

3.3 Ultrasonic Pulse Velocity (UPV) test: - The test is non-destructive. Without causing any structural damage, it is used to assess strength, quality, homogeneity, and durability. Moreover, look for pores and fractures in mortar and concrete. We examine the impact of ceramic waste on mortar and concrete in this study. **Canbaz [47]** discovered that as the amount of ceramic sanitary ware aggregate in the concrete increased, the UPV values showed a downward trend. Canbaz also found that the UPV values of concrete with a 0–100% replacement of ceramic sanitary ware aggregate ranged from 4.12–3.93 km/s. **Elçi [59]** revealed that due of its high porosity, concrete containing floor and wall tile aggregate had lower values than regular concrete using limestone aggregate. According to TS EN 14579, 2006, the UPV values of the limestone concrete with WT (wall tile), FT (floor tile), and LSC (lime stone concrete) were, respectively, 3220, 4030, and 4950 m/s after 28 days of curing. **Zareei et al. [29]** UPV value of the concrete with RWCA (recycled waste ceramic aggregate) was found to have slightly increased. 40% RWCA concrete displayed the highest UPV value. Furthermore, the residual concrete mixtures containing 20%, 40%, and 60% RWCA show 0.8%, 0.9%, and 0.86%.

Some researchers also have observed the influence of fine recycled ceramic aggregate on UPV test of concrete/mortar. **Emiroğlu et al. [70]** revealed that when the amount of ceramic powder in the concrete increased, the UPV values trended downward. 0%, 5%, 10%, 15%, and 20% concrete The UPV values of ceramic powder are 4.98, 4.90, 4.89, 4.86, and 4.81 km/s. Since every value was over 4.5 km/s, the range was deemed excellent. **Etxeberria and Gonzalez-Corominas [66]** analysed and found that the trend for both control and concrete mixtures was declining. At 28 days of curing, the UPV values of control concrete and the concrete mixes RC-15-FCA (fine ceramic aggregate), RC-30-FCA, RC-20-CMA (coarse mixed aggregate), RC-50-CMA, and RC-100-CMA are 5438, 5293, 5205, 5116, 4754, and 4417 m/s. With the exception of 100 CMA, all values were above 4500 m/s, indicating a good value range.

Based on the research findings, it can be concluded that as the amount of ceramic waste material used as aggregate increases, the value of UPV decreases (Figure 3). Similarly, when ceramic waste powder is used as a cement replacement, the value of UPV also decreases.

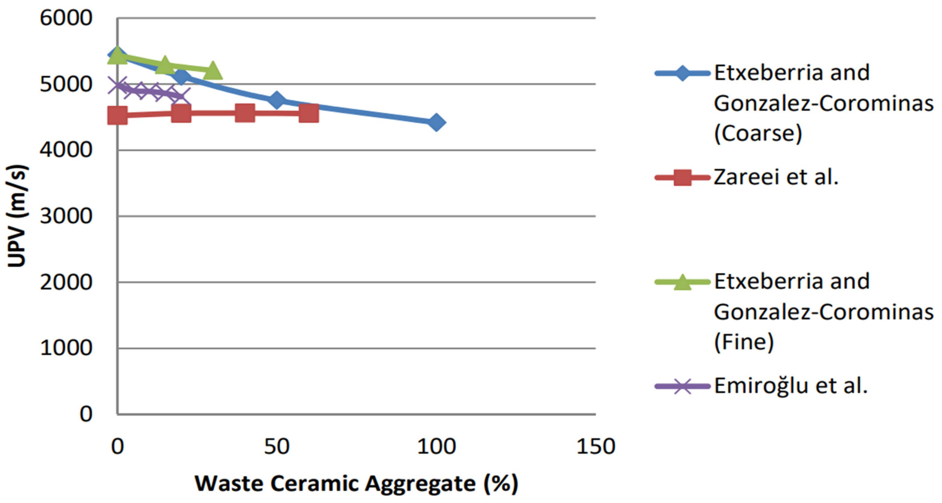


Fig. 3 Ultrasonic pulse velocity of concrete with waste ceramic aggregate **[29,66,70]**

3.4 Electrical resistivity: - Concrete's electrical resistivity is a measure of how likely it is to corrode. We examine the impact of ceramic waste on mortar and concrete in this study. **Polanco et al. [56]** found that, in comparison to the control mix, concrete mixes (ceramic coarse aggregate) CC-20 and CC-25 had 17% and 31% higher resistivity. Additionally, the electrical resistance of these concrete mixtures increases with the number of curing days. **Zareei et al. [29]** revealed that concrete exhibiting a minute reduction in electrical resistance was made possible by partially replacing natural aggregate with (recycled waste ceramic aggregate) RWCA. After 28 days, it was found that the control mix had 7.5% more electrical resistivity than the concrete with 60% RWCA. Concrete with 60% RWCA had the lowest electrical resistivity.

Some researchers also have observed the influence of ceramic waste powder on UPV test of concrete/mortar. **Aboubakr et al. [44]** investigated the concrete containing (ceramic waste powder) CWP and found that the electrical resistivity increased somewhat as the amount of

CWP increased. At 28 days, the electrical resistivity of the concrete mixes (high performance concrete) HPC-10, HPC-20, HPC-30, and HPC-40 increased by 12%, 272%, 389%, and 516%, while at 90 days, it increased by 77%, 297%, 402%, and 665%. **El-Dieb and Kanaan [68]** in this investigation, electrical resistivity was examined at 28 and 90 days after curing, and the incorporation of (ceramic waste powder) CWP up to 40% replacement was noted. Concrete with replacement percentages of 20%, 30%, and 40% exhibited resistivity values greater than 10 kΩ.cm. And a denser microstructure could be the reason of this increase.

Based on the research findings mentioned above, it can be concluded that as the amount of ceramic waste material used as aggregate increases up to a certain limit, electrical resistivity also increases up to that limit; beyond which, it shows a decreasing trend (Figure 4). Additionally, electrical resistivity increases with curing time.

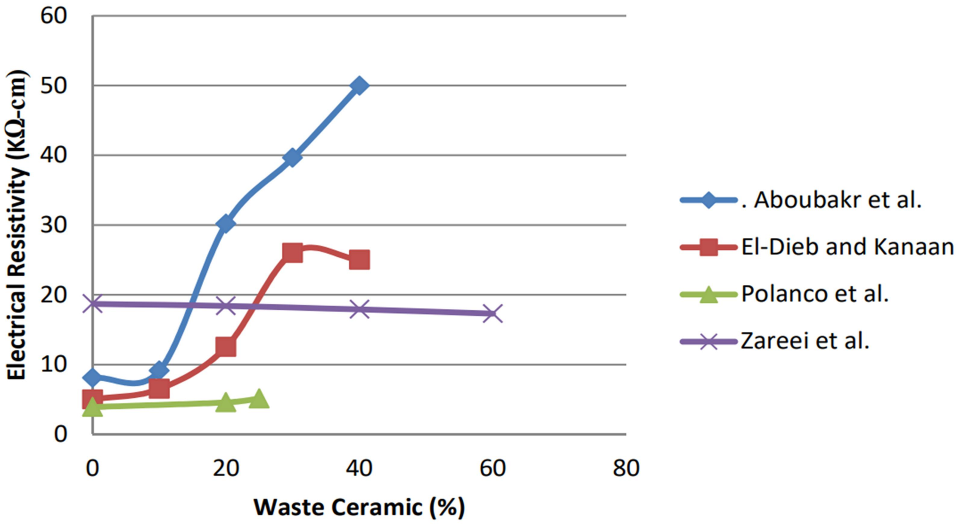


Fig. 4 Electrical resistivity of concrete with ceramic waste **[29,56,44,68]**

3.5 Drying shrinkage test: - The feature of hardened concrete known as "drying shrinkage" is the volumetric change brought on by the concrete's loss of water. We examine the impact of ceramic waste on mortar and concrete in this study. **Elçi [59]** found that concrete with floor tile and wall tile had shrinkage values of 1.37 and 2.42, respectively. And that was due to the high water absorption ratio. **Huseien et al. [71]** observed that control concrete have lower shrinkage value than self-compacting concrete containing ceramic waste.

Some researchers also have observed the influence of fine recycled ceramic aggregate on drying shrinkage test of concrete/mortar. **Alves et al. [64]** observed that concrete containing fine SWA (sanitary ware aggregate) and CBA (crushed red clay ceramic bricks) both showed an increasing tendency of dry shrinkage as the amounts of CBA and SWA increased. Comparing concrete with CBA, the degree of SWA was substantially lower. Concrete containing 20%, 50%, and 100% fine CBA exhibited 35%, 52%, and 101% greater shrinkage strain after 91 days of curing. Additionally, 10%, 12%, and 17% were displayed by concrete with 20%, 50%, and 100% fine SWA. Some researchers also have observed the influence of ceramic waste powder on drying shrinkage test of concrete/mortar. **El-Dieb and Kanaan [68]** studied the effect of increasing the replacement quantity of (ceramic waste powder) CWP in all mixtures on drying shrinkage strain values, which showed a decrease. Using CWP with replacement levels greater than 20% decreased the drying shrinkage strain for 25 MPa mixes between 29% and 60% as compared to the control mixture. When the replacement levels of CWP exceeded 20%, the 50 MPa mixtures exhibited a reduction in drying shrinkage strain values ranging from 28% to 53%. In contrast, the drying shrinkage strain for the 75 MPa combinations was reduced by 25% to 27%.

Therefore, based on the research findings mentioned above, it can be said that when the amount of ceramic waste material used as aggregate increases, drying shrinkage also increases.

3.6 Freezing and thawing test: - One of the most important durability characteristics of concrete is its capacity to withstand temperature drops and the freezing of pore water. **Frías et al. [33]** found that all concrete mixes exhibited the same level of resistance after 56 freeze-thaw cycles, and that the scaling of mass losses was less than that of (reference concrete) RC (2.1% for 20% and 3.68% for 25%). **Topçu and Canbaz [63]** shown that adding coarse tile aggregate to concrete decreased its ability to withstand freezing and thawing. They found that when the amount of coarse tile aggregate in the concrete was raised from 0% to 100%, the weight loss following the freeze-thaw test increased from 0.4% to 1.4%. They ascribed the decrease in the ability of ceramic aggregate concrete to withstand freeze-thaw conditions to the coarse tile aggregate's weak chemical binding and low hardness.

Some researchers also have observed the influence of fine recycled ceramic aggregate on freezing-thawing test of concrete/mortar. **Chaudhary et al. [28]** the results of the investigation showed that after 50 cycles of freeze-thaw, the (reference concrete) RC had the largest mass loss and compressive strength. However, concrete specimens containing (bone china ceramic fine aggregate) BCCFA at 20%, 40%, 60%, 80% and 100% produced better freeze-thaw counteraction than other samples because the bond between the aggregate and mortar paste can withstand changes in internal stress.

Therefore, based on the research findings mentioned above, it can be said that when the amount of ceramic waste material used as aggregate increases, mass loss reduces due to freezing and thawing cycles. Additionally, a favourable impact on freezing and thawing can be attained by the pre-treatment of waste and the application of mineral admixtures.

3.7 Sulphate Attack: - Sulphate attack is a common and significant form of chemical deterioration that affects the durability and longevity of concrete structures. It occurs when concrete is exposed to sulphate ions present in soil, groundwater, or seawater. These sulphates react with the hydrated compounds in the cement paste. These expansive reactions induce internal stresses, causing cracking, spalling, and loss of strength and cohesion in the concrete. **Chaudhary et al. [51]** demonstrated that after 28 days of sulphate assault, the percentage of compressive strength rises in all concrete mixtures. An increase in compressive strength was maintained after 28 days of concrete mixtures, CS100 until 90 days of exposure to H_2SO_4. **Nayana and Rakesh [67]** examined mortar mixtures containing 0% micro-silica and 0% ceramic waste, 0% micro-silica and 15% ceramic waste, 5% micro-silica and 15% ceramic waste, and 10% micro-silica and 15% ceramic waste, demonstrated resistance to sulphate at the 1st, 2nd, 3rd, 4th, 8th, 13th, and 15th weeks after samples were immersed in Sulphuric acid solution. Furthermore, at the fifteenth week of immersion, a sample containing 15% ceramic waste and 0% micro-silica demonstrated a reduced resistance to sulphate attack—4.53% as opposed to 5.28% for the control mix.

Therefore, based on the research findings mentioned above, it can be said that when the amount of ceramic waste material used increases, compressive strength increases up to a certain limit when immersion in sulphuric acid solution.

4. Summary and Conclusions: -

Today, sustainability is a crucial factor that must be integrated into construction activities to ensure the longevity of the construction industry. This study specifically examines the impact of incorporating or substituting ceramic waste in concrete, focusing on an analysis of its durability characteristics. The durability of concrete with ceramic waste was influenced by several key factors. The porous nature of ceramic waste contributed to increased permeability, which can affect the concrete's resistance to freeze-thaw cycles and chemical attacks. The presence of soft particles in the ceramic waste could lead to weaker zones within the concrete matrix, potentially reducing its overall durability. Additionally, the high water absorption capabilities of ceramic waste powder and aggregate altered the water-cement ratio, potentially affecting the concrete's long-term resistance to environmental and mechanical stressors. By understanding these durability factors, this study provides insights into the suitability of ceramic waste as a sustainable material in concrete production, highlighting both its benefits and challenge

Based on the results of the literature review, the following conclusion can be made:

- Using ceramic waste as coarse aggregate in concrete increases water absorption. But water absorption value was up to 10% which is under acceptable limit.
- From the above findings, concrete with ceramic waste powder as cement replacement exhibits better resistance to chloride ion penetration as compared to control mix, since it works as filling material and due to pozzolanic activity of ceramic waste.
- Concrete with incorporating ceramic waste as cement and aggregate replacement generally exhibits lower ultrasonic pulse velocity (UPV) values compared to conventional concrete, as observed in this review.
- Based on the findings, replacing coarse aggregate with ceramic coarse aggregate in concrete increases the concrete's electrical resistivity with curing days. Adding ceramic waste powder (CWP) to concrete also raises its electrical resistance.
- Concrete producing with ceramic waste as aggregate replacement exhibits increasing dry shrinkage values. And on the other hand concrete producing with ceramic waste powder as cement replacement showed reduction in shrinkage values after more than 20% replacement.
- On behalf of observations, it was finding out that concrete with ceramic waste as coarse aggregate showed decrease in resistance to freezing and thawing, due to weaker chemical bonding and lower hardness. Conversely, concrete with fine ceramic aggregate enhances concrete's performance in freezing and thawing.
- Concrete with ceramic waste as a replacement for fine aggregate showed increase in resistance to sulphate attack. However, using ceramic waste up to 15% replacement level results in lower resistance to sulphate attack compared to the control mix.

The growing demand for durable infrastructure has highlighted the need for sustainable concrete solutions. The utilization of ceramic waste contributes to the conservation of non-renewable resources, promoting a viable and sustainable environment. Ceramic waste powder exhibits excellent pozzolanic reactivity, making it an effective substitute for cement in construction applications. Furthermore, incorporating ceramic waste in concrete offers significant benefits for both the environment and society.

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