



A Comprehensive Review of Natural and Industrial Waste Recycling in Concrete Production

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Abstract

Concrete is still the most common building material used across the globe, but the extensive production of concrete has put tremendous pressure on natural resources, including river sand and crushed stone. At the same time, the rapid expansion of both construction and manufacturing industries has led to an increased amount of solid waste generated, specifically from ceramic debris and waste glass due to either demolition or industrial processes. Many of these types of waste materials are deposited into landfills, which adds to the degradation of our environment as well as presents challenges in their disposal. In response to this issue, recent research has expanded significantly in terms of utilizing recycled ceramic and glass waste in the development of concrete mixtures, as a means of creating a more sustainable alternative to traditional fine and coarse aggregate. The purpose of this study was to demonstrate the viability of using ceramic waste and crushed glass as a partial replacement for conventional aggregates and how these two types of waste materials affect concrete's mechanical, physical, and durability properties. The goal of using ceramic waste and crushed glass is to reduce the need for extracting natural resources, limit the negative environmental impacts from the accumulation of waste in landfills, and promote sustainable construction practices. The results of this study will provide additional insight into the performance of concrete produced with ceramic waste and glass waste and how these types of materials can help to create a more sustainable construction material.

Keywords: Alternative Aggregates, Environmental Impact, Recycled Ceramic Waste; Resource Conservation, Sustainable Concrete, Waste Glass.

1. Introduction

Rapid urbanization, population growth, and rising living standards in many developed and developing countries have led to a significant increase in the generation of both industrial and construction-related solid wastes [1]. These wastes, especially the ones that come from ceramics of tiles, sanitary ware, and structural components and from glass of bottles, windows, and industrial by-products, are among the most dominant recyclable materials. Despite their high volume and great potential for recycling, a large part of these materials is still thrown into landfills, which intensifies environmental problems and has long-term effects on ecology. Construction and demolition activities are the main contributors to solid waste, which in turn leads to the increase in the amounts of concrete, brick fragments, ceramics, glass, and other non-biodegradable materials that are generated [2, 3]. The more waste disposal is carried out, the more environmental pressures are experienced in terms of land occupation,

pollution, and resource depletion. As a result, many sustainability-oriented initiatives have been implemented for the purpose of promoting the valorization of solid wastes by incorporating them into new construction materials. Reusing ceramics and glass wastes in concrete as partial replacements for fine or coarse aggregates has become one of the most viable and environmentally sound options for the dual problem of wasting and natural resource depletion [4]. The newest studies indicate that ceramic waste has good mechanical strength and low water absorption properties, and therefore, it can be used in the building industry. Also, if glass is finely ground, it can have pozzolanic properties and enhance the long-term performance of the cementitious systems into which it is added. This research explores the feasibility of mixing ceramic and glass waste materials into the concrete examining the effects of these materials on workability, compressive strength, durability, and general performance of the material. The objective of the study is to provide a substantial amount of evidence in favor of



environmentally friendly construction practices by showing how waste materials can be reused without the need of compromising the quality of concrete [5].

2. Olive Waste

Olive oil production generates considerable amounts of organic waste that create serious problems for the environment. The raw waste from olive oil has organic minerals that react chemically when exposed to heat and moisture. As a result, the decomposition of the compounds, especially phenolic acids create strong odorous compounds that may pose a health risk [6]. Because there are currently no effective methods for recycling this material, there has been an increase in the amount of waste produced contributing to greater pollution risk and more difficulties in properly disposing of it. Researchers have looked at the possibility of utilizing olive waste in constructing building materials. Al-Akhras and Abdulwahid stated that the use of Olive Waste Ash (OWA) as a partial substitute for cement in mortar, reduced flexural and compressive strength, and also reduced the curing time and workability of the mortar. On the other hand, the use of OWA as a partial substitute for sand improved some mechanical characteristics of mortar [7]. Eisa, (2014) [8] found that the use of Olive Seed Ash (OSA) as a substitute for cement had a significant impact on the workability of the mortar and reduced the compressive strength by 45%–75%.

Alkheder et al. [9] studied the effects of adding different amounts of the olive waste into the cement paste and reported a small overall decrease in cement pastes' compressive strength at 3, 7, and 28 days after casting. Merino et al. [10] evaluated the use of crushed whole or calcined olive stones as alternatives for lightweight aggregates, and over all mortar mixtures, they reported that the mortars containing olive stones were about 30% less dense than the expanded clay mortars and had approximately 20% greater compressive strengths than the expanded clay mortars.

Other experiments came to the same result. Adwan and Maraqa [11] determined that application of olive waste ash from 10 to 40 percent causes a reduction in the compressive strength of the material. Cheraghizadeh and Akcaoglu [12] reported that the use of olive waste ash increases the volume of the material due to changes and decreases the strength of self-compacting concrete. Abdulkarem et al. [13] established that the replacement of fine aggregates with olive or pumice stones (10–30 percent) led to the improvement of thermal insulation and compressive strength when a superplasticizer was used. Tayeh et al. [14] found that the addition of OWA resulted in the decrease of compressive strength and workability, however, the durability under the harsh condition was improved.

Researchers have conducted several additional studies which support this conclusion, including work by Cheraghizadeh et al. [15], Cabello et al. [16], and Hakeem et al. [17]; they all confirmed that while excessive amounts of olive waste ash may cause a reduction in concrete's compressive strength, optimally combined with other supplementary materials will

improve concrete's durability and reduce the amount of cement required.

3. Pumice Stones

Lightweight pumice is a naturally occurring material that is valued for its many physical/chemical/mechanical benefits. When pumice is combined with Portland Cement, it forms a type of mortar that has good insulating abilities, acoustic qualities, and thermal properties [18]. Research conducted by Parhizkar, et al., [19], found that a lightweight pumice aggregate produced concrete meeting all strength and shrinkage criteria. Sivalinga & Rao [20] demonstrated that replacement of 20% of the coarse aggregates with pumice resulted in enhanced compressive strength of M20 concrete, which was further enhanced when combined with fibers.

There have been several studies on the use of pumice in concrete production and its effects on properties of concrete. Rashiddadash et al [21] found that the addition of pumice resulted in a reduction of weakness due to the presence of porosity. The research by Karataş et al. [22] indicated that the substitution of 10% - 25% of the cement with ground pumice powder not only increased strength, but also decreased the water absorption properties of the concrete.

The studies conducted by Khotbehsara et al. [23] indicated that the use of pumice combined with metakaolin enhanced the microstructure and increased the long-term strength of the specimens. Rashad [24] evaluated pumice as a lightweight aggregate and stated that it reduces the expansion caused by ASR and increases the ability of concrete to resist freeze-thaw cycles and chemical attacks, but may result in decreased early mechanical strength. The research conducted by Idi et al. [25] showed that concrete with 15% pumice as coarse aggregate has a sufficient 28-day strength.

The studies conducted by Naveenkumar et al. [26] and Karthika et al. [27], Jahanzaib et al. [28] and Sathish et al. [29] supported the notion that pumice can be utilized to enhance the durability of concrete and serve as a partial replacement for conventional aggregates and/or cement. Rahman et al. [30] demonstrated that the substitution of 20% of cement with pumice results in a 36% decrease in porosity and a nearly 10% increase in compressive strength at 90 days. Moreover, pumice has shown to be beneficial in increasing resistance to acid attack and therefore can be used in the production of durable and high-performance mortars.

4. Ceramic

Ceramic waste is produced primarily from discarded tiles and sanitary fixtures, and it has been shown to function reasonably well when substituted for either cement or aggregate in the composition of concrete. Several research reports discuss the ability of ceramic waste to absorb water less than concrete and have higher compressive strengths when fired than the typical cement used in the production of concrete, as well as provide an alternate source of aggregates thereby relieving landfill pressure and reducing the requirement for non-renewable sources of natural aggregate. Therefore, there is great potential

for ceramic waste to become an integral part of the creation of sustainable concrete mixes.

The study by Jwaida et al. [31] demonstrated how ceramic waste can also be used as a viable solution to the global problem of landfill accumulation as an alternative to disposal through landfilling. Their review presents several benefits associated with such a practice, i.e., the reduction in the requirement for natural raw materials, decreased energy consumption and less pressure on local landfills. The authors also present additional evidence demonstrating that when utilized in the correct proportions, ceramic waste retains or improves compressive strength and durability of concrete.

Ikotun et al. [32] also indicated ceramic waste as a suitable material to be replaced either in cement or aggregates. The ceramic waste powder which is easily available and can be easily ground has become a popular material in the low-carbon concrete application. The performance of the reviewed studies has been at the minimum level of acceptance at optimized replacement levels which puts ceramic waste powder as a potential environmentally friendly component with negligible tradeoffs in mechanical and durability properties.

Ferrada [33] studied pervious concrete mixes with 10% and 20% cement replacement using glass waste or ceramic waste. He explains that the ceramic waste impairs the compressive strength, especially at the higher levels of the replacement ratio though the strength difference is narrowed at later ages. Also, glass waste causes a drop in the early strength but at 28 days the values are very close to the control mix. In addition, all mixes keep the permeability within the allowable limits which means that the waste materials do not cause functional performance to be compromised.

Kazem and Fawzi [34] investigated pervious concrete mixes with a 10 percent and a 20 percent pozzolanic cement of glass or ceramic waste replacement. Their findings are consistent with [33], demonstrating that the ceramic waste significantly decreases the strength at high replacement levels, whereas with the glass waste the strength is mainly affected at the early-age. In all cases, permeability stays at the level of the allowable, thus supporting the potential use of these materials in the production of low-carbon pervious concrete.

Liu et al. [35] presented a review paper in which they discuss and compare a number of solid waste materials that have been utilized in pervious concrete, such as slag, fly ash, recycled concrete aggregate, and recycled brick. They focus on the impact of these wastes on compressive strength, permeability, durability, and water filtration. The main point of the review is that majority of these materials bring clear sustainability benefits, however, the disadvantage of strength-porosity tradeoffs is often present.

5. Glass

When applied in controlled amounts, waste glass - whether it is used as fine ground powder or as crushed aggregate - has been demonstrated to positively impact concrete properties. Glass powder is pozzolanic in nature and contributes to pozzolanic activity, while the crushed glass maintains sufficient permeability and develops compressive strength values nearly equal to traditional concrete mixes. Shen et al. [36] researched the use of waste glass in the production of pervious concrete by using waste glass in place of a large portion of the coarse aggregate. They determined that an increase in waste glass content or aggregate-to-binder ratio will reduce compressive strength but increase permeability, as even their mixes with completely substituted coarse aggregate met the requirements of engineering standards and exhibited little expansion as a result of alkali-silica reaction.

Khoshnaw et al. [37] investigated the utilization of waste porcelain in lieu of natural sand in the creation of recycled-aggregate pervious concrete. Their multi-scale investigation found that using waste porcelain as a binder provides enhanced hydration and increased formation of C-S-H, which contributes to increased compaction. The presence of a high percentage of waste porcelain leads to an increase in compressive strength but lower permeability. When completely replacing raw materials with waste porcelain, the compressive strength was approximately 24.19 MPa and the permeability still fell within acceptable ranges.

Ahmed et al. [38] studied the effect of waste glass powder on the cement pastes up to 50 percent in cement replacement. The maximum strength is found at the 20 percent replacement level, which gives a strength increase by about 8 percent compared to the control after 56 days of curing. The strength drops with higher substitution levels. The microstructural changes reveal the denser matrix and better durability parameters due to the pozzolanic reaction of the glass particles of the fine fraction.

Safi et al. [39] discussed the mechanical and durability aspects of glass powder addition to concrete. The paper points out that glass powder which is rich in silica and has very fine grains is highly effective in the improvement of compressive, tensile, and bending strengths, if glass powder is used in the range of 10-20 percent. Besides, the glass powder is effective in limiting alkali-silica reaction because the microstructure is denser due to the higher C-S-H content.

Shirzad et al. [40] explored the case of 20 percent waste glass powder cement substitution with two different particle sizes: 74 micrometers and 44 micrometers. They find that the smaller size particles help in raising compressive strength and also change the workability, thus showing that particle size

plays a significant role in the performance of glass powder used as a cement replacement.

Jain et al. [41] explored the combined effect of waste glass powder and recycled steel fibers on concrete. They indicate that the concrete containing 15 percent glass powder and 30 percent granite powder not only achieves the strength but also shows a great potential for durability improvement. Besides, the tests on self-compacting and foam concrete further show that glass powder, especially when the dosage is lower than about 20 percent, increases strength over time and decreases creep.

Table 1. Important findings of the previous studies on different waste materials used in construction applications.

Waste Material	Replacement Type	Strength Effect
Olive waste	Cement or fine or coarse aggregate	Generally reduced strength (low)
Pumice stones	Cement or fine or coarse aggregate	Improved strength in several mixes
Ceramic waste	Cement or fine or coarse aggregate	Maintained or improved strength at optimum levels
Glass waste (powder or particles)	Cement or fine or coarse aggregate	Improved strength at 10–20 percent replacement; may reduce early strength at higher levels

6. Conclusions

The demand for construction materials is increasing; at the same time, the global population is rising rapidly. Therefore, the stress on our natural resources continues to increase. The latest research demonstrates that by incorporating both unprocessed and recycled materials from industrial processes into concrete there will be fewer negative impacts on the environment as well as additional engineering advantages through their use in concrete. The reductions in the amount of construction waste that goes into landfills will provide a more sustainable method of producing concrete. The studies indicate that olive waste produces lower compressive strength and flexural strength. However, under certain conditions, olive waste improves thermal characteristics and contributes positively to durability and workability when exposed to extreme conditions. Pumice performs well as both a lightweight aggregate and an additive for cement. Its use improves insulation, microstructure, and long-term durability, and in many mixes, it increases compressive strength, especially when used as a fine aggregate or blended with materials such as metakaolin. Ceramic waste provides consistent mechanical performance when used at optimized replacement levels. Its low water absorption, high strength, and availability make it a reliable alternative to natural aggregates and, in some cases, an enhancer of durability. Glass waste shows similar promise. Finely ground glass can

contribute to pozzolanic activity, leading to denser microstructure and improved long-term strength. When used as a partial cement or aggregate replacement, waste glass can maintain or improve compressive strength and enhance durability, although higher replacement ratios may reduce early-age strength.

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Conflict of interest

“The authors declare that there are no conflicts of interest regarding the publication of this manuscript”.

AI Declaration Statement

The authors confirm that the manuscript has been written without the assistance of generative AI or AI-based writing tools.

Author Contribution Statement

All authors contributed to writing and editing the manuscript. Dalia Adil Rasool, Manal Hamed Jasem and Balsam Mahmood Shaker proposed the research problem and supervised the work. All authors participated in preparing the introduction, structuring the manuscript, discussing the findings, and finalizing the paper.

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