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Sustainable Utilization of Waste Ceramic as Partial Aggregate Replacement In M-40 Concrete: A Comprehensive Review on Strength and Durability Enhancements

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ABSTRACT

The increasing demand for sustainable construction materials has led to extensive research on the utilization of waste materials as partial replacements in conventional concrete. Among these, waste ceramic materials have gained attention due to their pozzolanic properties and potential to improve concrete performance. This review explores the effectiveness of waste ceramic as a partial aggregate replacement in M-40 concrete, emphasizing strength and durability enhancements. Various studies indicate that ceramic waste improves compressive, tensile, and flexural strengths while enhancing durability characteristics such as water absorption, chloride resistance, and sulfate attack resistance. The integration of waste ceramics in concrete aligns with the principles of sustainability by reducing environmental burdens associated with ceramic waste disposal and decreasing the reliance on natural aggregates. This review consolidates recent findings on the mechanical and durability aspects of ceramic-based concrete and identifies potential research gaps for further studies.

Keywords: Sustainable construction materials, waste ceramic, Partial replacements

1. INTRODUCTION

Concrete is the most widely used construction material globally, but its production significantly impacts the environment due to excessive natural resource consumption and high carbon emissions (Mehta and Monteiro, 2014). The replacement of natural aggregates with waste materials such as ceramic waste has been recognized as an effective approach to sustainability in the construction sector (Gonzalez-Corominas and Etxeberria, 2016). Ceramic waste, originating from construction debris, defective ceramic tiles, and sanitary ware, exhibits favorable mechanical properties that make it suitable for incorporation into concrete (Medina et al., 2017). Studies have shown that ceramic waste, when used as a partial replacement for natural aggregates, contributes to improved concrete strength, enhanced durability, and reduced permeability (Bektas et al., 2009).

Several researchers have investigated the impact of ceramic waste on the mechanical properties of concrete, particularly in high-strength grades such as M-40. Compressive strength is a crucial parameter in assessing concrete performance. Studies indicate that partial replacement of coarse and fine aggregates with ceramic waste up to 20% results in comparable or even improved compressive strength due to enhanced interfacial bonding and reduced porosity (Torgal and Jalali, 2011). Medina et al. (2018) reported that M-40 concrete containing 10% ceramic waste exhibited a 5% increase in compressive strength at 28 days compared to conventional concrete. The tensile and flexural strengths of ceramic-based concrete also exhibit improvements, primarily due to the angular shape of ceramic particles, which promotes better particle interlocking (Silva et al., 2017). A study by Pacheco-Torgal et al. (2012) demonstrated that ceramic waste substitution up to 15% enhances split tensile strength while maintaining acceptable workability. However, at higher replacement levels, a reduction in strength is observed, likely due to increased void content and weaker matrix cohesion (Senthamarai et al., 2011). Durability is a fundamental criterion for evaluating the long-term performance of concrete structures. Ceramic waste has been found to enhance resistance

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to chloride penetration and sulfate attack due to its lower permeability and chemical stability (Bravo and Brito, 2012). Research by Letelier et al. (2017) indicates that ceramic aggregate replacement reduces water absorption, thereby mitigating issues related to freeze-thaw cycles and alkali-silica reaction (ASR). Additionally, studies have demonstrated that ceramic waste improves carbonation resistance, prolonging the service life of reinforced concrete structures (Medina et al., 2016).

The water absorption capacity of ceramic-based concrete is generally higher than that of conventional concrete due to the porous nature of ceramic aggregates. However, this can be controlled by using superplasticizers and optimized mix designs (Correia et al., 2018). High sulfate resistance has been attributed to the chemical inertness of ceramic waste, which prevents expansion and cracking in sulfate-rich environments (Kou et al., 2011). These durability improvements make ceramic-based concrete a viable alternative for infrastructure exposed to aggressive environmental conditions. The incorporation of ceramic waste in concrete contributes to environmental sustainability by reducing landfill disposal and decreasing the depletion of natural aggregates (Khatib, 2016). The ceramic industry generates a significant amount of waste during manufacturing and construction processes, and its reuse in concrete aligns with circular economy principles (Xavier et al., 2019). Life-cycle assessments (LCA) have shown that ceramic waste concrete reduces CO2 emissions and energy consumption compared to traditional concrete (Marinković et al., 2017). Additionally, ceramic-based concrete offers economic benefits by reducing material costs and promoting waste valorization (Duarte et al., 2020).

The construction industry is one of the largest consumers of natural resources, leading to environmental degradation and depletion of raw materials. The increasing generation of ceramic waste from industries and demolished structures presents an opportunity for sustainable utilization in concrete production (Silva et al., 2019). Ceramic waste, due to its pozzolanic properties and high compressive strength, has been explored as a potential alternative to natural aggregates in concrete, aiming to improve mechanical and durability properties (Medina et al., 2017).

2. EFFECT OF WASTE CERAMIC ON COMPRESSIVE STRENGTH

Several studies have investigated the effect of ceramic waste as a partial replacement for aggregates in M-40 concrete. The compressive strength results indicate that incorporating ceramic waste up to a certain percentage enhances the strength properties of concrete. Medina et al. (2017) reported that concrete with 40% ceramic waste aggregate achieved a compressive strength of 45.20 MPa at 28 days, compared to 32.44 MPa for the control mix. Similarly, Pacheco-Torgal and Jalali (2011) found that a 15% replacement of cement with ceramic powder in M-40 concrete resulted in an increase in compressive strength, reaching 51.25 MPa at 28 days.

3. EFFECT OF WASTE CERAMIC ON SPLIT TENSILE STRENGTH

The tensile strength of concrete also exhibits variations with the incorporation of ceramic waste aggregates. According to Silva et al. (2019), a 15% replacement of cement with ceramic powder resulted in a split tensile strength of 4.56 MPa at 28 days. A study by Venkatesan and Pazhani (2016) found that using 20% ceramic aggregate led to a marginal reduction in tensile strength compared to conventional concrete, but the values remained within acceptable limits.

4. EFFECT OF WASTE CERAMIC ON FLEXURAL STRENGTH

Flexural strength, an essential parameter for concrete in structural applications, has been found to be slightly reduced when ceramic waste is used. However, this reduction is marginal, and the material remains structurally viable. According to Pacheco-Torgal and Jalali (2011), a concrete mix with 40% fine ceramic aggregate exhibited a flexural strength of 6.1 MPa at 28 days.

5. DURABILITY PROPERTIES

The durability of concrete is critical for long-term performance, and ceramic waste incorporation has shown promising results. According to Medina et al. (2017), concrete with 40% ceramic aggregate exhibited improved resistance to chloride penetration, reduced water absorption, and enhanced resistance to sulfate attack. Silva et al. (2019) observed that ceramic waste concrete demonstrated higher resistance to freeze-thaw cycles compared to conventional concrete.

6. CONCLUSION AND FUTURE SCOPE

The experimental and analytical studies indicate that waste ceramic materials can effectively replace conventional aggregates in M-40 concrete while maintaining structural integrity. The findings reveal that replacing up to 20-30% of aggregates with ceramic waste provides an optimal balance between strength, durability, and sustainability.

Future research should focus on:

1. Long-term durability performance of ceramic waste concrete under aggressive environmental conditions.
2. Optimization of mix proportions to enhance both mechanical properties and workability.
3. Investigation of ceramic waste as a supplementary cementitious material to further reduce carbon footprint.

By incorporating ceramic waste, the construction industry can move towards a more sustainable and environmentally friendly approach, reducing dependency on natural resources while managing industrial waste effectively.

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