

Waste-to-Resource: A Comprehensive Review on Ceramic Fines and Recycled Aggregates in Sustainable Concrete

¹Bhupander, ²Harish Chawla, ³Monu Kumar

¹M.Tech. Scholar, ²Assistant Professor, ³Assistant Professor

Department of CE
BRCM College of Engineering and Technology, Bahal (Bhiwani) India

ABSTRACT

India, the globe's second-most populous nation following China, is home to a population exceeding 1.29 billion individuals, constituting 17.6% of the total global population. However, the country only occupies 5% of the world's total area, covering 3,185,263 square kilometers, with 68% of the population residing in rural areas and 32% in urban areas such as towns and cities. To accommodate the growing population, numerous construction activities are taking place, heavily reliant on the natural environment for raw materials like wood, sand, timber, and aggregates. Construction activities generate large amounts of debris. According to estimates from the Indian Government, the country currently produces around 165-170 Million Tonnes (MT) of debris annually, with 12-14.7 MT of Construction and Demolition (C&D) waste generated each year, as reported by the Central Pollution Control Board (CPCB) in March 2017. Over the past 25 years, there has been increasing focus on C&D waste management by academics, researchers, and experts globally. This study focuses on the utilization of Ceramic Tile Waste Powder (CTWP) and Recycled Fine Aggregates (RCFA) as replacements for cement and fine aggregates, respectively, in concrete mixes. Primary objective is to reduce environmental impact by improving the cementitious properties and durability performance of concrete.

1. REVIEW OF EXISTING LITERATURE

The issue of environmental deterioration has become a focal point of global discussions, drawing attention at local, national, and

international levels (Bentivegna *et al.* 2002).

The rise in population and infrastructure, particularly in the built environment, have led to detrimental consequences such as ozone layer depletion, global warming, resource

scarcity, and ecosystem degradation. Consequently, the industry has come under scrutiny due to its substantial environmental impact.

In India, the construction sector is experiencing rapid growth, fueled by population growth, urbanization, industrialization, and the construction of various infrastructure projects.

1.1 IMPACT OF CW ON ENVIRONMENT

Climate change refers to the enduring transformation and modification of the climate within a particular area, region, or the entire planet over an extended period. Throughout Earth's geological history, its climate has undergone substantial fluctuations. It has experienced ice ages characterized by a global mean temperature approximately 5 degrees Celsius lower than the current level, as well as interglacial periods with a mean temperature around one degree higher than the present value. These fluctuations have been triggered by factors such as fluctuations in solar activity, emissions from volcanic activity, and the

presence of GHG (McBean *et al.* 2001). The significant increase in CO₂ concentration is widely regarded as a primary factor contributing to climate change caused by human activities. Significant scientific research has gathered compelling evidence suggesting that a considerable portion of the documented global warming in the last 50 years can be attributed to human activities. The cement industry stands out as

a significant contributor to GHG emissions, with a particular emphasis on CO₂ emissions (Mehta 2002).

Because of its strength, adaptability and longevity, concrete is extensively utilized as the primary construction material worldwide. However, conventional concrete manufacturing process requires raw materials extraction directly from natural sources like gravel and sand, leading to natural resource depletion and substantial adverse effects on the environment. Additionally, the disposal of waste materials, including plastics, glasses, and other wastes, poses challenges and contributes to the problem of waste accumulation (Batayneh *et al.* 2007). The management of construction waste (CWM)

plays a vital role in Sustainable Development (SD), responding to the escalating environmental impact of human activities. The effective management of construction processes, which includes implementing the 3R principles (reduce, recycle, reuse) and ensuring proper waste disposal, has substantial implications for various aspects of a project. These implications encompass the overall cost, time, quality, and environmental footprint (Dania *et al.* 2007). The depth of carbonation, which is the process through which CO₂ is absorbed by concrete, was studied. The results indicated a CO₂ uptake of approximately 3,00,000 metric tons in all existing structures in 2011. This uptake accounted for approximately 17 percent of the total emissions resulting from new cement production. Furthermore, the study predicts a potential increase in the uptake of CO₂ from crushed concrete. Currently, the uptake stands at 12,000 metric tons, but by redesigning waste handling processes, it could reach 2,00,000 metric tons in 2030 and 5,00,000 metric tons in 2050. These findings underscore the significance of enhancing waste management strategies to optimize the capacity of crushed concrete for CO₂ uptake (Andersson *et al.* 2013). The lack of a

coherent framework for the utilization of waste has resulted in both legal and illegal disposal practices, causing harm to the environment, increased energy consumption and the

depletion of finite landfill resources. Recycling CW not only offers an environmentally sustainable solution but also yields economic advantages by decreasing expenses related to waste disposal and environmental cleanup (Marzouk and Azab, 2014). The cement industry is recognized for its substantial role in CO₂ emissions, mainly stemming from the raw materials calcination and fuel combustion in the process of cement production. The aim was to provide a comprehensive view of the environmental hazards associated with cement products and to identify opportunities for optimizing their design to minimize adverse environmental impacts. It also suggested incorporating alternative raw materials and evaluating their CO₂ emissions throughout the concrete production Life Cycle Assessment (LCA) (Zhang *et al.* 2014). LCA modeling was conducted to evaluate the impacts on the environment of managing CW. The assessment considered both the impact of toxic and non-toxic categories, including all

stages of CW until the final disposal of the residues. A critical role played in the toxic impact categories is Leaching. The carbonation process in the CW, corresponding to 15% carbonation, could potentially have GHG impacts from transportation. However, carbonation leads to increased toxicity impacts due to increased leaching of oxyanions (Butera *et al.* 2015). LCA examines the environmental impacts linked to each phase of the waste management process. By methodically documenting energy, fuel, and material inputs, as well as environmental outputs, LCA helps prevent the limited perspective of relying solely on landfilling. According to the study, if the current Business-as-Usual (BaU) landfilling practices persist until 2025, the environmental impact of landfilling is projected to rise by 20.2%. However, recycling can mitigate 46.0% of the overall damages, and by reducing travel distances to Material Recycling

1.2 IMPACT OF CW ON PROJECT AND COST OVERRUN

Construction waste management is essential for cost reduction and promotion of sustainable practices. It is divided into two categories: physical waste, includes solid

materials and non-physical waste, encompasses waste generated during construction that can result in delays and increased costs. To mitigate these cost overruns, incorporation of waste management at an early stage, ideally during pre-contract phase.

The construction industry holds a critical position in various aspects of fostering India's infrastructure and industrial development and shaping the trajectory of society. Nevertheless, country's rapid urbanization and economic growth leads to significant increase in construction activities, resulting in a substantial generation of waste materials. This situation presents not only environmental challenges but also affects project budgets. Therefore, it becomes imperative to efficiently manage construction waste to control project costs. The researcher aims to estimate the financial consequences faced by construction waste and its impact on project expenditures. Furthermore, it offers recommendations to the construction industry for optimizing profits and minimizing waste generation (Sawant Surendra *et al.* 2016). The proposed model implemented using collected data from a construction project in Shenzhen, specifically

focusing on concrete and aggregate materials. The study findings indicate that implementing CW management practices yields overall positive effects, resulting in net benefits.

1.3 CERAMIC POWDER

Vejmelkova *et al.* (2012) focused on investigating the effects of incorporating fine-ground ceramics into High-Performance Concrete (HPC). Concrete mix resistance to de-icing salts is the primary factor that limits the maximum number of ceramics that can be incorporated. Adequate resistance to de-icing salts was observed when fine-ground ceramics were added to the mix of concrete at a level of replacement up to 10 percent. Surprisingly, even when the ceramics were added up to 20 percent, no changes observed in concrete's mechanical properties. Furthermore, concrete maintained its effective toughness fracture, specific energy fracture, and resistance to chemical substances like Magnesium chloride, Ammonium Chloride, Sodium Sulphate, and Hydrochloric acid up to a replacement level of 40 percent. Impressive resistance to frost, transport of water vapor, storage parameters, and properties of thermal, were also exhibited by the concrete, even

when the cement was replaced by ceramics at a level of 60 percent. These findings indicate that incorporating fine-ground ceramics into HPC can enhance specific properties of the concrete without compromising its strength, durability, or resistance.

Heidari and Tavakoli (2013) explored the potential of utilizing waste ground ceramic materials as a pozzolan in concrete manufacturing, which presents a favorable prospect for producing concrete of exceptional quality while simultaneously addressing the critical challenge of waste disposal. The study was divided into two distinct phases, with each phase having a specific research focus to thoroughly investigate this concept. In the initial phase, the study examined the process of incorporating waste ground

ceramics into concrete as a pozzolan. The researchers prepared samples of concrete by replacing a range of 10% to 40% of the cement content with finely ground ceramic powder. The second phase explored the combined effect of adding 0.5% to 1% of nano-SiO₂ (silica nanoparticles) along with ground ceramic powder ranging from 10% to 25%. To

evaluate the performance of concrete, compressive strength and water absorption of concrete were tested. The results indicate that, incorporating ground ceramic powder up to 20% in the mix did not show any significant changes in compressive strength. Furthermore, incorporating any quantity of ground ceramic powder into concrete resulted in reduced absorption capacity of water, which contributes to durability improvement.

1.4 RECYCLED AGGREGATES

Corinaldesi and Moriconi (2009) focus on the usage of waste materials and by-products, specifically in context of sustainable construction materials. One notable example is RAC (Recycled Aggregate Concrete) which incorporates SCM. The research objective aims to evaluate specimen's concrete properties produced by replacing both Fine Aggregate (FA) and Coarse Aggregate (CA) with Recycled Aggregate (RA) obtained from a recycling plant of rubble. Additionally, the study examined RAC formulations with either Fly Ash (FAs + RA) or Silica Fume (SF + RA). Preliminary study findings indicated that, compressive strength

of RAC can match or even exceed conventional concrete. Furthermore, the incorporation of FA was found to be effective highly in chloride ion penetration and carbonation reduction in concrete, including RAC. This utilization of fly ash has the potential to extend the RAC structure's service life by postponing the onset of corrosion reinforcement.

Zega and Di Maio (2011) evaluate the durable behavior of structural concretes that incorporate various percentages of Recycled Fine Aggregates (RFA), specifically 0%, 20%, and 30%. In various countries, the adoption of recycled coarse aggregate in structural concrete has been recommended, primarily due to environmental advantages and promotion of sustainable practices. However, utilization has been limited in the past, as it was believed to significantly alter certain properties of concrete. To fill the gap in knowledge and understanding regarding RFA incorporation in structural concretes, evaluate the durability-related properties of such concretes. Percentages of RFA used are 0%, 20%, and 30%.

Monish *et al.* (2012) focus on a comprehensive

program that aims to evaluate the effects of partially substituting FA with CW on the compressive strength and workability of recycled concrete. The compressive strength of recycled concrete compared with conventional concrete. After 28- days, test results indicate recycled concrete strength of compressive with a replacement of 10% FA by demolished waste lower than conventional concrete. The author concluded that, RAC a viable alternative to conventional concrete and the optimal replacement level of FA with recycled aggregate is 10%.

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