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Utilisation of Waste Materials in the Construction Industry – A Critical Review

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Abstract:- With a significant increase in both commercial and residential waste, as well as industrial byproducts such as fly ash, silica fume, and ground granulated blast furnace slag, there is a growing recommendation for utilising these materials in concrete construction. This not only helps reduce pollution but also enhances the characteristics of concrete. The global trend of utilising waste materials in civil structures construction is gaining momentum, aiming to decrease the consumption of natural building materials per unit volume of concrete. Moreover, substituting a portion of cement with waste products can potentially reduce the energy consumption associated with concrete production. Incorporating mineral admixtures in concrete mixes has improved compressive strength, pore structure, permeability, and construction costs. This article comprehensively reviews recent studies on using waste materials in the construction industry.

Keywords:- Waste Materials, Construction Industry, Concrete Properties, Supplementary Cementitious Materials, Sustainable Practices

1. INTRODUCTION

Concrete exhibits remarkable durability under harsh environmental conditions. However, in certain situations, it may exhibit subpar characteristics. Therefore, engineers worldwide continuously seek ways to enhance their properties through the use of admixtures and waste materials, often referred to as alternative building materials. Concrete mixtures incorporating these alternative building materials can partially replace traditional cement constituents. One significant advantage of utilising waste materials is their ability to substitute basic ingredients partially or entirely in concrete while still providing binding properties. Incorporating waste materials helps utilise these resources effectively and enhances concrete properties in fresh and hydrated states. The most commonly used waste materials are fly ash and silica fume, known for improving concrete's compressive strength and durability.

Concrete is formed by mixing binding materials, water, aggregates, and sometimes admixtures in specific proportions. Upon placement and curing, the mixture hardens into a rock-like mass known as concrete. The hardening process is driven by chemical reactions between water and cement, resulting in increasing strength over time. Hardened concrete can be likened to artificial stone, with voids of larger particles filled by smaller particles and fine aggregate voids filled with cementitious binding materials. Cement, utilised in mortar and concrete, is a crucial infrastructure element recognised as a resilient construction material.

Pozzolanic materials, lacking inherent cementitious properties, can react with ordinary Portland cement (OPC) to form cementitious compounds when added to concrete mixtures. Partial substitution of Pozzolana reduces the need for Portland cement, leading to decreased construction costs, energy consumption, and waste emissions such as carbon dioxide. This reduction in energy consumption contributes to mitigating global warming.

2. LITERATURE REVIEW

Several researchers worldwide are investigating the utilisation of waste materials in concrete. One such material, Marble Dust Powder (MDP), passing through 90 microns, has been studied for its impact on hardened concrete properties. Ranjan Kumar et al. [1] examined the effect of different percentages of MDP replacement on compressive strength, splitting tensile strength (indirect tensile strength), and flexural strength. Their project presented the findings on how MDP affects concrete strength. They prepared five concrete mixtures with varying percentages of MDP (0%, 5%, 10%, and 20%) as a replacement for cement by weight.

Additionally, Sharma et al. [2] explored using marble powder in concrete. Despite its potential environmental concerns, marble powder, containing high levels of calcium oxide with cementing properties, can partially replace cement in cement-sand mixes. The researchers collected waste marble powder from industries and investigated its effects on cement-sand mixes at different proportions. They also compared the compressive, split tensile, and flexural strengths, workability, and durability of the cement-sand mix.

An investigation conducted by Pawar et al. [3] focused on the significance of partial replacement of cement with waste marble powder. They studied the effect of using marble powder as a constituent of fines in mortar or concrete by partially reducing cement quantities and analysing relative compressive, tensile, and flexural strengths. Saravanan et al. [4] addressed the strength behaviour of polypropylene fibre-reinforced fly ash concrete (PFRFAC). They considered polypropylene fibre content (0.25% to 0.50%) and 10% fly ash as a cement replacement in all concrete mix proportions. Test results indicated that mechanical properties improved with 0.40% polypropylene fibre and 10% fly ash content. Rishi et al. [5] observed that combining marble dust with other ingredients resulted in higher modulus or compressive strength than using marble dust alone at 7 and 28 days. Hamdy et al. [6] found that the addition of Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC), either with short discrete fibres or continuous long fibres, to the cement-based matrix exhibited superior properties compared to high-performance concrete (HPC). UHPFRC showed improvements in compressive behaviour, tensile behaviour, workability, toughness, ductility, and durability. Southararajan et al. [7] conducted a study on the effect of lime content in waste marble powder for producing high-strength concrete. They investigated using MDP up to 10% by weight of cement for hardened concrete properties.

Additionally, they evaluated the effect of different percentages of MDP replacement on compressive strength, splitting tensile strength, and flexural strength. The study emphasised that the fine-to-coarse aggregate ratio and cement-to-total aggregate ratio significantly influenced the improvement in strength properties. The scope of this investigation involves examining the strength properties of concrete containing polypropylene fibre and Class C fly ash in various proportions. Murahari et al. [8] conducted experiments using different Class C fly ash mixtures at 30%, 40%, and 50%, along with polypropylene fibre volume fractions ranging from 0.15 to 0.30 for all fly ash concrete mixes. Shirulea et al. [9] highlighted the environmental problems caused by directly leaving waste materials in the environment. Therefore, emphasis has been placed on reusing waste materials by producing new products or using them as admixtures to improve resource efficiency and protect the environment from waste deposits. Patel et al. [10] identified two major drawbacks of concrete: low tensile strength and a destructive, brittle failure. In order to address these issues and enhance concrete ductility and energy absorption, polypropylene fibre-reinforced concrete (PFRC) was introduced. This study was part of a research program evaluating the performance of PFRC. Numerous studies have investigated the benefits of utilising pozzolanic materials to improve concrete properties. Thomas and Shehata [11] studied the bending behaviour of cementitious materials such as Portland cement, fly ash, and silica fume, highlighting their advantages over other blends and plain Portland cement. Sandor [12] conducted experimental studies using Portland cement-fly ash-silica fume systems in concrete, concluding various beneficial effects of adding silica fume to fly ash cement mortar, including improvements in workability, strength, and ultrasonic velocity. Bijen [13] examined the benefits of adding slag and fly ash to concrete, while Lam et al. [14] assessed the effect of fly ash and silica fume on the compressive and fracture performances of concrete, concluding that the strength properties of concrete improve with different proportions of fly ash and silica fume. Gonen and Yazicioglu [15] investigated the influence of binary and ternary blends of mineral admixtures on the short- and long-term performance of concrete, finding improvements in both fresh and hardened states. Mateusz and Nantung [16] studied the effect of mixture composition and initial curing conditions on the scaling resistance of ternary concrete, analysing the impact of varying constituents on concrete scaling resistance at low temperatures. Barbhuiya et al. [17] studied the properties of fly ash concrete modified with hydrated lime and silica fume, concluding that adding lime and silica fume enhances early compressive strength, long-term strength development, and durability of concrete. Cabrera and Linsdale [18] conducted experimental work on oxygen and water vapour transport in cement pastes, finding that oxygen flow follows the Darcy equation, whereas water vapour flow does not. They observed that oxygen transmission rates are spread over a wider range than water vapour, with some samples almost impermeable to oxygen. An experimental study conducted by Patel [19] explored the application of steel slag aggregate in concrete and concluded that it possesses the ability to withstand freeze-thaw environments. However, the study observed that steel slag aggregates exhibit expansive properties, potentially leading to concrete cracking. The results indicated that including 50% to 70% of steel slag aggregates in traditional concrete would not significantly alter its durability. To assess the influence of mineral admixtures on the short and long-term performance of concrete, Thanongsak [20] conducted experimental investigations. The study concluded that silica fume contributes to both short- and long-term concrete characteristics, while fly ash demonstrates beneficial effects over a relatively longer duration.

Additionally, adding both silica fume and fly ash slightly increases compressive strength. In another study, Patel et al. [21] researched the utilisation of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. The study found that test roads exhibited exceptional performance after two years of service, with abrasion and friction coefficients of 55 BPN and a surface texture depth of 0.8 mm. Yun-feng et al. [22] conducted experimental work comparing the properties of steel slag and crushed limestone aggregate concrete. The study revealed that the durability of steel slag cement concrete surpassed that of crushed limestone aggregate concrete.

3. DISCUSSION ABOUT RESEARCH

The extensive examination of various studies underscores the significant environmental repercussions of the prevalent reliance on Portland cement as a primary component in concrete construction. Portland cement's production and application contribute substantially to CO2 emissions, thereby exacerbating the issue of greenhouse gas emissions. This direct correlation between cement consumption and greenhouse gas production accentuates the pressing need to explore alternative methodologies that curtail Portland cement usage without incurring exorbitant construction expenses. Numerous research endeavours have been undertaken to address these environmental challenges associated with Portland cement. Among the most promising strategies is the partial replacement of Portland cement with supplementary cementitious materials. Incorporating these materials into concrete mixes at optimal proportions yields manifold benefits, including enhancements in concrete properties, cost reduction, energy conservation, and mitigation of waste emissions. Adopting supplementary cementitious materials offers a viable pathway towards sustainable concrete construction practices. By judiciously integrating these materials into concrete formulations, notable improvements can be achieved in various aspects, such as compressive strength, durability, and environmental impact.

Additionally, using supplementary cementitious materials reduces greenhouse gas emissions associated with concrete production, aligning with broader sustainability objectives. Overall, the discussion underscores the imperative of transitioning towards more sustainable practices in concrete construction. Through innovative approaches like the partial replacement of Portland cement with supplementary cementitious materials, the industry can mitigate its environmental footprint while simultaneously enhancing the performance and longevity of concrete structures. Such initiatives represent tangible steps towards achieving a more sustainable built environment and mitigating the adverse impacts of construction activities on the environment.

4. CONCLUSIONS

In conclusion, synthesising findings from the reviewed studies highlights several key insights regarding using waste materials in concrete construction. Firstly, it is evident that the incorporation of waste materials at various proportions significantly influences multiple properties of concrete, including compressive strength, workability, compaction, and flexural strength. This indicates the potential of waste materials to enhance the characteristics of formed binder mixes, thereby offering opportunities for improving concrete performance. Moreover, adding waste materials demonstrates notable benefits in terms of concrete properties. Specifically, it contributes to fly ash cement's early strength gain and enhances its later age strength. These findings underscore the pivotal role of waste materials in augmenting the overall performance and durability of concrete structures, suggesting their viability as valuable additives in concrete formulation.

In summary, using waste materials presents a promising strategy for addressing environmental concerns associated with Portland cement usage in concrete construction. By strategically incorporating waste materials into concrete mixes, it is feasible to enhance concrete properties and mitigate the environmental impact of construction activities. This underscores the importance of further research and implementation efforts to maximise waste materials' potential in promoting sustainable practices within the construction industry.

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