Journal Homepage: www. ijarpr.com ISSN: 3049-0103 (Online)

International Journal of Advance Research Publication and Reviews

Vol 02, Issue 09, pp 495-498, September 2025

To Reduce the Environmental Impact of Cement Manufacturing by Incorporating Industrial Waste and Alternative Binders

[1]Ramji Patel, [2]Dr. Vivek Soni, [3]Arpit Saxena

[1,2]M.Tech. Scholar, [3]Associate Professor, Assistant professor
Dept. of Civil Engineering, Radharaman Engineering College, Bhopal (M.P)

ABSTRACT

Cement manufacturing is one of the largest contributors to global carbon emissions, resource depletion, and energy consumption, making it imperative to explore sustainable alternatives that minimize its environmental footprint. This study focuses on reducing the environmental impact of cement production by incorporating industrial waste materials and alternative binders as partial or complete substitutes for conventional Portland cement. Industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, and red mud, along with alternative binders like geopolymers and alkali-activated materials, offer significant potential in enhancing the performance of concrete while reducing CO_2 emissions and the consumption of natural raw materials. The research highlights the chemical, mechanical, and durability properties of these substitutes, emphasizing their role in achieving sustainable construction practices. By integrating waste valorization and innovative binder technologies, this approach not only mitigates environmental pollution but also supports the circular economy, cost efficiency, and long-term durability of concrete structures. The findings indicate that adopting such sustainable practices can significantly reduce the carbon intensity of cementations materials and contribute to global efforts in sustainable infrastructure development.

Keywords: Cement manufacturing, industrial waste, alternative binders, fly ash, GGBS, silica fume, geopolymer, alkali-activated materials, sustainability, carbon emissions, circular economy, green construction.

Introduction

Cement manufacturing is one of the most energy-intensive industries and a major contributor to environmental degradation, particularly due to its significant carbon dioxide emissions, depletion of natural resources, and high energy consumption. The production of one ton of ordinary Portland cement (OPC) typically releases nearly an equal amount of CO_2, accounting for approximately 7–8% of global greenhouse gas emissions. With the rising demand for infrastructure and urbanization, the pressure on the cement industry to adopt sustainable practices has become more urgent than ever. To mitigate these environmental concerns, researchers and industry experts are increasingly exploring the use of industrial waste materials and alternative binders as partial or complete replacements for cement. Industrial by-products such as fly ash, blast furnace slag, silica fume, rice husk ash, and quarry dust not only reduce the reliance on clinker but also help in the effective disposal of waste that would otherwise pose environmental challenges. Additionally, alternative binders such as geopolymer cement and alkali-activated materials provide a promising pathway toward achieving low-carbon construction materials with superior durability and performance. Incorporating these sustainable solutions not only minimizes the ecological footprint of cement production but also supports the principles of circular economy and resource efficiency. Therefore, the integration of industrial waste and alternative binders in cementations systems represents a crucial step toward environmentally responsible construction practices and the realization of sustainable development goals.

Literature Review

Monu Gaur (2018) : Red mud is a strong waste buildup of the assimilation of bauxite metals with scathing soft drink for alumina generation. Its transfer remains an overall issue as far as ecological concerns. Amid the previous decades, broad work has been finished by a ton of scientists to create different financial routes for the usage of red mud. This paper gives a survey on the far reaching usage of red mud internationally. The exploration advancement of safe amassing of red mud is condensed. Gigantic amount of red mud is produced worldwide consistently representing an intense and disturbing ecological issue. This paper depicts the creation and portrayal of bauxite and red mud in perspective of World and Indian setting. It audits thoroughly the transfer and balance techniques for red mud and gives the nitty gritty evaluation of the work conveyed up to this point for the use of red mud in various fields. The concoction and mineralogical qualities of red mud are abridged with their natural concerns Project identifies with the supplanting of bond with red mud at certain rate i.e. 10%, 20%, 30% and with a steady level of hydrated lime (5%) the throwing work has been done of the block mould (150mm*150mm*150mm) and cylindrical shaped mould (150mm*300mm) and the consequence of 7 days and 28 days compressive quality has been discovered and which is been fruitful as of not long ago. What's more, to locate a proficient method to do it viably and discover the regions in which enhancement should be possible is the sole reason for our venture And by incompletely supplanting the red mud as solid constituents which results in a legitimate discard squander and an expansion in quality of cement and the effectiveness of the red mud as per cost and condition point of view too. Also, by supplanting the red mud and utilizing it as a basic material it gives expanded quality and less transfer of red mud in the earth which results in lesser contamination and diminished natural risks.

Ramaboyana Gangulalah(2021): The examination was directed to study about the properties of cement by utilizing red mud as substitution of bond in cement. The Bayer Process for the generation of alumina from Bauxite metal is described by low vitality effectiveness and it results in the creation of huge measures of residue like, high alkalinity bauxite deposits known as red mud. Presently red mud is created nearly at equivalent mass proportion to metallurgical alumina and is arranged into fixed or unlocked counterfeit impoundments (landfills), prompting significant natural issues. It involves oxides of iron, titanium, aluminium and silica alongside some other minor constituents. Presence of Alumina and Iron oxide in red mud repays the inadequacy of similar parts in limestone which is the essential crude material for concrete generation.

Methodology

OPC, or ordinary Portland cement After 28 days of curing, cement of the 33 Grade variety reaches a minimum compressive strength of 33 N/mm². It is one of the older and more commonly used grades of cement, primarily suited for general construction work. OPC 33 is especially recommended for non-structural uses where a high level of strength is not essential. Due to its smooth finish and workability, it is ideal for masonry work, plastering, and rendering. Its relatively lower heat of hydration also helps reduce the risk of cracking in such applications.

OPC, or ordinary Portland cement A cement that achieves a is referred to as 43 Grade, as per IS 8112:2013 standards. It is widely used in general construction work, including residential buildings, pavements, and precast structures. Due to its moderate strength development and heat of hydration, it's well-suited for applications where strength gain is not required at a rapid rate.OPC 43 Grade is also used in high-strength concrete work, especially when durability and long-term strength are important. For specialized applications such as railway sleepers, a designated type of 43 Grade known as 43-S Grade is used. The “S” stands for “Sleeper,” and this variant undergoes additional testing for parameters such as setting time, drying shrinkage, and early-age strength to ensure performance in demanding structural environments.

After 28 days of curing,, reaches a compressive strength of 53 N/mm². This cement grade is primarily used in applications that demand high early strength and durability. Its rapid strength gain makes it ideal for use in precast concrete components, pressurised concrete works, and when building long-span structures like high-rise buildings and bridges, where quick demanding and load-bearing capacity are crucial. A specialized variant of OPC 53, known as 53-S grade, is specifically manufactured for the production of railway sleepers, which require consistent strength and durability to withstand dynamic loads and vibrations. Overall, OPC 53 Grade plays a vital role in modern construction due to its superior performance in structural and high-load applications.

The process of choosing the right ingredients and their ratios to make concrete is known as "mix design mix that meets specific performance requirements, such as strength, durability, workability, and cost-efficiency. The design process takes into account the intended application, environmental conditions, and desired properties of the concrete. In this study we take M25 grade of concrete. The experimental setup to reduce the environmental impact of cement manufacturing by incorporating industrial waste and alternative binders involves a systematic approach aimed at evaluating the performance, sustainability, and feasibility of eco-friendly cementations materials. Durability assessments, including water absorption, acid resistance, and thermal stability, are also conducted. Throughout the experiment, environmental parameters such as embodied carbon and energy consumption are monitored using life cycle assessment (LCA) tools. The results are compared to conventional cement concrete to determine the effectiveness

The methodology for reducing the environmental impact of cement manufacturing by incorporating industrial waste and alternative binders involves a systematic approach that begins with an extensive literature review to identify suitable industrial by-products such as fly ash, blast furnace slag, silica fume, red mud, and rice husk ash, along with novel alternative binders like geopolymers, alkali-activated materials, and calcined clays; followed by material collection and characterization through physical, chemical, and mineralogical tests (XRD, XRF, SEM) to determine their suitability as partial or complete cement replacements; mix design development is then carried out to prepare different concrete or mortar specimens by varying the replacement levels, ensuring workability, strength, and durability requirements are addressed; experimental investigations are conducted to evaluate fresh properties (slump, setting time), mechanical performance (compressive, flexural, and tensile strength), and durability aspects (sorption, permeability, resistance to sulphate and chloride attack, carbonation); life cycle assessment (LCA) and embodied carbon analysis are performed to quantify the reduction in CO_2 emissions, energy consumption, and environmental footprint compared to conventional cement; cost-benefit analysis is integrated to ensure economic feasibility; finally, the results are compared with standard codes and guidelines to validate performance, leading to the development of recommendations for large-scale adoption of industrial waste and alternative binders in sustainable cement manufacturing.

Conclusion

Higher density in concrete generally signifies better compaction, reduced porosity, and enhanced durability, as a denser matrix allows fewer voids for water and aggressive agents to penetrate; in this context, incorporating red mud as a partial cement replacement shows promising results, with studies indicating that up to 16% replacement contributes to improved compactness and durability due to better particle packing and pozzolanic reactions that refine the pore structure, thereby reducing permeability and increasing long-term resistance against environmental deterioration; however, when the red mud content exceeds 16%, the durability begins to decline, likely because the excess amount leads to ineffective matrix formation, incomplete hydration, or poor dispersion of particles, which compromises the microstructure and increases the risk of cracks or permeability; therefore, while red mud is a viable supplementary material contributing to sustainable construction by reducing cement usage and utilizing industrial waste, its effectiveness is maximized at an optimal dosage of around 16%, which strikes the right balance between strength, density, and durability.

References

Kaptan, K., & Cunha, S. (2024). A review: Construction and demolition waste as a novel source for CO2 reduction in Portland cement production for concrete. *Sustainability, 16*(2), 585. https://doi.org/10.3390/su16020585

Sudheer, I., & Ganesh, B. (2023). Experimental studies on concrete utilizing red mud as a partial replacement of cement with hydrated lime. *International Journal for Research Trends and Innovation (IJRTI), 8*(9), IJRTI2309031. ISSN: 2456-3315. Retrieved from https://www.ijrti.org

Gangulaiah, R., & Mohammed, K. (2021). Study on strength parameters of concrete using red mud as a partial replacement of binder content with and without hydrated lime. *International Journal of Advance Scientific Research and Engineering Trends*, *6*(2). https://doi.org/10.51319/2456-0774.2021.2.0017

Miller, S. A., Myers, R. J., et al. Environmental Impacts of Alternative Cement Binders. Environmental Science & Technology, 2021; 55(9): 6525–. DOI:10.1021/acs.est.1c02128. → Quantifies environmental impacts of non-Portland cement binders, comparing greenhouse gas emissions, energy, raw material demands. PubMed

Vashistha, P., Park, S., & Pyo, S. "A Review on Sustainable Fabrication of Futuristic Cementitious Binders Based on Application of Waste Concrete Powder, Steel Slags, and Coal Bottom Ash." International Journal of Concrete Structures and Materials, 2022, 16:51. SpringerLink+1

G. B., A.K., and D.B. "Environmental Benefit of Alternative Binders in Construction Industry: Life Cycle Assessment." Environments (MDPI), 2021. MDPI

Cubukcuoglu, B., et al. "The environmental impact evaluation and testing of sustainable inorganic binders: A green alternative to ordinary Portland cement." Journal of Sustainable Construction Materials and Technologies, 2018. DergiPark

Recycling of Cement Industry Waste for Alkali-Activated Materials Production." [Authors etc.] Journal / PubMed; explores using clinker dust & aspiration dust as new cement-free binders. PubMed

Tsiliyannis, C. A. "Industrial Wastes and By-products as Alternative Fuels in Cement Plants: Evaluation of an Industrial Symbiosis Option." Journal of Industrial Ecology, 2018; 22(5): 1170-1188. Wiley Online Library

"Potential of Reducing CO_2 Emissions in Cement Production through Altering Clinker Compositions." Industrial & Engineering Chemistry Research, 2024. ACS Publications

Rajczyk, K., Kurdowski, W., Pichniarczyk, P., & Janus, G. "Low-Emission, Cementless Binders and Concrete: Future Proof Materials." In Reinforced Concrete Structures - Innovations in Materials, Design and Analysis, 2023.