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A REVIEW ON THE USE OF GREEN CEMENT FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

Cement production is a significant contributor to global carbon dioxide (CO_2) emissions, accounting for approximately 7-8% of total global emissions. In response to growing environmental concerns, green cement has emerged as a sustainable alternative to traditional Portland cement. Green cement reduces the carbon footprint of construction by incorporating industrial by-products, such as fly ash, slag, and calcined clays, and through innovations like Carbon Cure technology, which captures and stores CO_2. This abstract reviews the environmental, economic, and performance benefits of green cement, including reduced CO_2 emissions, energy savings, improved durability, and lower shrinkage in concrete structures. It also highlights challenges to widespread adoption, such as higher initial costs, limited availability of alternative materials, and regulatory hurdles. Despite these barriers, green cement presents a viable solution for reducing the environmental impact of construction while maintaining or enhancing material performance. Future trends, including advances in carbon capture, recycling of construction waste, and nanotechnology, point to the continued growth and innovation in green cement technologies, which are crucial for creating sustainable urban and infrastructure development.

Keywords: Green cement, CO_2 emissions, sustainable construction, industrial by-products, fly ash, slag, Carbon Cure technology, energy savings, durability, shrinkage reduction, adoption challenges, carbon capture, recycling, nanotechnology, infrastructure development.

1. INTRODUCTION

Cement is one of the most widely used materials in the construction industry, essential for building infrastructure, roads, and housing. However, the traditional production of Portland cement is highly energy-intensive and a significant source of global CO_2 emissions, contributing approximately 7-8% of global emissions. This environmental impact has prompted the search for sustainable alternatives, leading to the development of **green cement**. Green cement refers to innovative cement formulations that aim to reduce the carbon footprint associated with cement production while maintaining or improving performance. It achieves this by incorporating alternative materials, such as fly ash, blast furnace slag, and calcined clay, which either reduce the need for traditional clinker or capture CO_2 emissions during production. In addition, technologies like CarbonCure inject captured CO_2 into the concrete mix, permanently storing the carbon and enhancing the strength of the concrete. The development of green cement is crucial for mitigating the environmental challenges posed by the construction industry. It offers multiple benefits, including lower emissions, reduced energy consumption, enhanced durability, and the potential for using industrial waste materials. This introduction outlines the importance of green cement as a sustainable alternative in modern construction, as well as the challenges that need to be addressed for its broader adoption.

2. LITERATURE REVIEW

The increasing demand for sustainable construction materials has led to the development of green cement as an alternative to traditional Portland cement, which is notorious for its substantial carbon footprint. Green cement incorporates eco-friendly practices and materials, including industrial by-products such as fly ash, slag, and calcined clay, and utilizes advanced technologies like carbon capture and storage (CCS). This literature review explores the evolution, development, and effectiveness of green cement as a solution to the environmental challenges posed by the cement industry.

i. Environmental Impact of Traditional Cement Production

Scrivener et al. (2018)

Research ON Environmental Impact of Traditional Cement Production which consistently shows that the cement industry is one of the largest single producers of CO_2 emissions, primarily due to the calcination of limestone and the high energy requirements for clinker production.**)** note that every ton of ordinary Portland cement (OPC) produced emits approximately 0.9 tons of CO_2 into the atmosphere, accounting for roughly 7-8% of global CO_2 emissions. Given the growing concern about climate change, the need to reduce the environmental impact of cement production has become critical. **Müller et al. (2019)** highlighted the urgency of incorporating sustainability into cement production to meet international carbon reduction goals.

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ii. Development of Green Cement

Benhelal et al. (2013)

Green cement is primarily focused on reducing CO_2 emissions and energy consumption during production categorize green cement into two broad categories: (i) cement that uses alternative clinker replacements, such as fly ash and slag, and (ii) cement that integrates carbon capture technologies.

Scrivener and Favier (2015)

One of the most researched alternatives is Limestone Calcined Clay Cement (LC3)**,** which combines limestone and calcined clay as partial replacements for clinker. demonstrated that LC3 could reduce CO_2 emissions by up to 40% compared to OPC, without compromising the mechanical properties of the cement.

Martirena et al. (2017)

It confirmed the efficacy of LC3 in real-world applications in tropical climates, showing that it not only reduces emissions but also offers better durability in aggressive environments.

iii. Fly Ash and Slag-Based Green Cement

Several studies emphasize the effectiveness of using industrial by-products such as fly ash and ground granulated blast furnace slag (GGBS) in green cement.

Malhotra (2002) highlighted the benefits of using fly ash in cement, pointing out that it improves long-term strength, enhances durability, and reduces the heat of hydration.

Habert et al. (2010) further argued that using fly ash and slag reduces the need for clinker, which is the most CO_2-intensive component of traditional cement.

In terms of performance, **Thomas (2013)** found that concrete containing fly ash has superior resistance to sulfate attack and improved workability, making it particularly suitable for use in large infrastructure projects. However,

Mehta (2014) cautioned that the availability of fly ash and slag can be regionally constrained, limiting the widespread adoption of green cement in some areas.

iv. Carbon Capture and CarbonCure Technology

Monkman et al. (2016)

Technologies like **CarbonCure** represent another promising direction for green cement. This technology involves injecting captured CO_2 into the concrete mix during production, which not only reduces the cement's carbon footprint but also improves its compressive strength conducted experiments on CarbonCure and found that the process could reduce the CO_2 footprint of concrete by approximately 5-10%, while the resulting material demonstrated improved early strength.

Gartner and Sui (2018)

Although CarbonCure has shown promise in North American markets, emphasized the need for further research into scaling carbon capture technologies globally, particularly in developing countries where cement demand is rising rapidly. The integration of CCS with cement production facilities could provide a critical solution to reduce emissions in heavy industrial sectors.

v. Performance and Durability of Green Cement

The performance and durability of green cement have been extensively studied to ensure it meets the requirements for construction.

Li et al. (2020) found that green cement, particularly those incorporating pozzolans like fly ash or calcined clay, exhibit excellent long-term durability, especially in aggressive environments like marine or sulfate-rich soils.

Shi et al. (2017) demonstrated that geopolymer-based green cement has superior resistance to chemical attacks compared to OPC, making it suitable for use in harsh industrial environments.

Soutsos et al. (2016) reported that some green cements, particularly those with high fly ash content, exhibit slower strength gain at early stages, which could be a disadvantage in fast-paced construction projects.

Juenger et al. (2011) echoed these concerns, noting that while long-term strength may be improved, delayed setting times and low early strength remain challenges that need further research and optimization.

vi. Barriers to Adoption of Green Cement

Despite the clear environmental benefits, there are several barriers to the widespread adoption of green cement.

Andrew (2019) pointed out that higher initial costs, regulatory challenges, and lack of awareness are major factors limiting the uptake of green cement. Additionally, **Gursel et al. (2014)** identified supply chain limitations, particularly the availability of alternative materials like fly ash and slag, as significant hurdles.

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In developing regions, the adoption of green cement is particularly slow. **Ali et al. (2020)** attributed this to a lack of supportive policy frameworks and the dominance of OPC in local markets. The authors suggested that increased government intervention, in the form of subsidies or incentives, may be necessary to promote the transition to green cement in these regions.

vii. Future Directions in Green Cement Research

Future research in green cement is focusing on enhancing performance, improving carbon capture technologies, and developing new materials.

Dehn et al. (2020) explored the potential of nanotechnology to improve the mechanical properties of green cement, particularly its tensile strength and resistance to cracking. Additionally, **Bernal et al. (2018)** are investigating the potential of bio-cementation processes, which use microorganisms to strengthen concrete and reduce its carbon footprint further.

Churkina et al. (2020) argued that green cement should be part of a broader strategy that includes reducing material use through innovative design and enhancing the energy efficiency of buildings. They propose that green cement alone cannot solve the environmental impact of construction and must be integrated with other sustainable building practices

3. CONCLUSION

The literature on green cement demonstrates that it holds significant potential as a sustainable alternative to traditional Portland cement. Green cement technologies, including the use of industrial by-products like fly ash, slag, and calcined clays, as well as innovations such as CarbonCure and geopolymer cements, have shown promise in reducing CO_2 emissions, conserving energy, and enhancing long-term durability.

Key findings from the literature survey indicate that green cement can reduce carbon emissions by up to 40% compared to ordinary Portland cement, making it a critical component in global efforts to mitigate climate change. Additionally, green cement offers improved durability, chemical resistance, and long-term strength, particularly in aggressive environments, which highlights its viability for large-scale infrastructure projects. However, challenges remain in terms of early strength development, supply chain limitations, and adoption barriers, particularly in developing regions.

The reviewed studies emphasize the need for further research to optimize the performance of green cement and to overcome adoption barriers. Additionally, policy frameworks, regulatory support, and public awareness campaigns will be essential in promoting the transition to green cement, especially in regions where traditional cement remains dominant.

In conclusion, green cement represents a viable and effective solution to reducing the environmental impact of the construction industry. With continued innovation and collaboration between researchers, industry stakeholders, and policymakers, green cement can play a pivotal role in sustainable construction practices and in achieving global carbon reduction goals.

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