ISSN: 2633-4828 Vol. 5 No. S6, (Oct - Dec 2023)

International Journal of Applied Engineering & Technology

GREEN CEMENT PATH TOWARDS SUSTAINABILITY: A REVIEW

Sunil Kumar[1*], Abhishek Chakraborty[2], Shuchi Sharma[3] and Swapna Sarkar[4]
[1,2,3,4]Bhilai Institute of Technology, Durg, Bhilai House, GE Road, Durg, C.G., India, 491001
[1]s.kushwaha@bitdurg.ac.in, [2]abhishek.chakraborty@bitdurg.ac.in, [3]suchisharma@bitdurg.ac.in and [4]swapna.sarkar@bitdurg.ac.in
[1][0000-0002-8395-3899] and [2][0000-0002-8028-9742]

ABSTRACT

Cement, the primary building material in the industrialized world, faces challenges such as depletion of natural fuels, raw material shortages, and climate-related environmental issues. Eight to ten percent of the world's CO_2 emissions come from cement manufacturing. To address these issues, innovative approaches like Nano concrete, incorporating carbon nanotubes or self-sensing CNTs, have emerged to create sustainable alternatives and enhance strength, stiffness, and longevity. Furthermore, the use of various natural pozzolans and the investigation of recycling or waste-material-based concrete have gained traction. Several initiatives have begun to put the green concrete concept into action. This article also addresses issues about the usage of green concrete, including potential barriers. Notably, it highlights the progress made by Indian enterprises, putting them among the world's leading makers of environmentally friendly cement.

Keywords: Green cement, Sustainability, Environmental Challenges, Carbon Emission, Climate Changes.

INTRODUCTION

In the modern era, environmental conservation and preservation have become pressing global issues, particularly in the wake of the World Earth Summit (1997) in Kyoto, Japan. This summit highlighted the need for drastic reductions in CO_2 emissions (Suhendro, 2014). Since then, a few major industrialised nations have come to an agreement. They aim to collaborate and create regulations facilitating the achievement of environmental protection and preservation objectives (Bond, 2012). Approximately 8 to 10% of the carbon dioxide contributing to global climate change is released during the cement-making process in cement plants. This is in contrast to emissions from burning forests or moving cars (Garg, 2006). When limestone and clay are heated to around 1500 degrees Celsius through a chemical process, the gas that is principally responsible for global warming is produced (Ali, 2015). Cement, the most significant building material in the world, is a key component of concrete and is produced at a rate of 4 gigatons annually, which is equal to 8 million international space stations or 12 million Boeing 747 aircraft (MacKay, 2016). India holds the second-largest cement production globally (Mishra, 2022). According to official studies,329 million tonnes (MT) of cement were manufactured in FY20 and 381 MT are expected to be produced in FY22(Chellasamy, 2021). One of the biggest challenges facing conventional Portland cement concrete (PCC) is the widespread worldwide usage of cement and natural coarse aggregates (NCA), leading to resource depletion on the one hand and environmental problems on the other (Azúa, 2019). To address the environmental threat posed by PCC, 'green concrete' (GC) can be used to replace cement with supplementary cementitious materials (SCMs) such as fly ash (FA), silica fume (SF), metakaolin (MK), and ground granulated blast furnace slag (GGBFS), or it can replace non-recycled aggregate (NCA) with recycled coarse aggregates (Al-Hamrani). When calcium carbonate is heated during the cement-making process, lime and carbon dioxide are created, increasing greenhouse gas emissions both directly and indirectly through the use of energy, especially if that energy comes from fossil fuels (Larsen, 2009). The cement business produces approximately 5% of all human-made CO2 emissions, with 50% originating from chemical processes and 40% from fuel burning (Xiaoding, 1996). Nearly 900 kilograms of $CO_2$are released by the cement industry for every 1,000 kg of cement produced (Ige, 2021). It is predicted that cement production would exceed 4.5 million tons by 2050 (Miller, 2018). Since cement manufacturing emits a significant amount of carbon dioxide, the expanding global population and the increased demand for homes have an adverse effect on the environment (Adesina, 2020). As a result, this industry offers plenty of room for innovation. However, cement manufacture is so essential to many aspects of life that it is difficult to envisage a world without it (Aïtcin, 2000). The deployment of smarter, cleaner technology to address the alarming rate of environmental deterioration and its impact on all living forms is encouraged to manage the current situation and move towards a sustainable, clean future based on the same tenets of advancing the idea of sustainable development via science and technology (Kaygusuz, 2012). Green architecture is a trend in the architecture industry that focuses on eco-friendly designs balancing nature and building structures. These designs strive to minimise negative environmental consequences and carbon footprints. Many nations use "GREEN CONCRETE" as a basic component in their concrete mixes, and civil/structural engineering is adjusting to this notion (Khan, 2021). CeraTech, US based firm produces concrete made from fly ash, a chemical process that lasts three times longer and requires half the water compared to Portland cement. The material targets oil and gas businesses needing corrosion and heat resistance. Meanwhile, Sefa Group, has developed a concrete production method using fly ash from earth and coal-fired power stations, aiding in clearing abandoned ash-filled ponds and landfills.

Portland cement serves as the main component of reinforced concrete, typically used in modern projects. When mixed with water, the proportions of the three ingredients—cement, sand, and aggregates—determine the strength of the finished product (Ede, 2017).

Table Fehler! Kein Text mit angegebener Formatvorlage im Dokument.**1:** Concrete Mixing Ratio (Ede, 2017)

Grades of Concrete	*Ratios of Concrete Mix (Cement: Sand: Aggregates)*
M-5	1:5:10
M-7.5	1:4:8
M-10	1:3:6
M-15	1:2:4
M-20	1:1.5:3
M-25	1:1:2
M-30	1:0.75:1.5
M-35	1:0.5:1
M-40	1:0.25:0.5

Ordinary Portland Cement, or OPC, is the main ingredient in concrete. Nevertheless, 1.1 tonnes of CO_2, dust, and other dangerous pollutants are produced during the production of one tonne of cement, potentially resulting in increased environmental harm, such as global warming, and human health effects, including renal failure, respiratory disorders, and lung cancer. Green Concrete, a groundbreaking innovation in Denmark, is set to transform the world forever with its groundbreaking technology (McCausland, 2020).

GREEN CONCRETE AND SUSTAINABILITY

Green concrete is generated when a percentage of Portland cement is replaced with the eco-friendly cementitious ingredient in a concrete mix (Hashmi, 2022). Reducing CO_2emissions, using less energy or fuel derived from fossil sources during the cement manufacturing process, and using fewer chemicals in the concrete mixture that may be hazardous to human health or the environment are the main objectives when it comes to using cleaner technologies to make concrete. Use less cement by substituting leftover flaky ash or other components (Al-Hamrani).

Green concrete is defined as having at least one component derived from waste material or using an environmentally friendly production process(Van den Heede, 2012). High performance and life cycle sustainability should also be present; in other terms, green concrete is concrete that is favourable to the environment (Naik, 2008) Some sustainable construction materials are being explored, including industrial by-products, alternative cements, concrete built with waste as aggregate, carbona table Calcium silicate cement, calcium hydrosilicate base cement, and eggshell waste. Recent cementitious binders can be made from industrial waste, including low-grade limestone or clay, fly ash, and slag (Siddique, et al., 2023). Green concrete enhances environmental, economic, and social sustainability by incorporating Portland cement substitute materials, enhancing manufacturing methods, improving performance, and considering life cycle sustainability implications, thereby enhancing overall sustainability (Suhendro, 2014).

The Green Concrete must follow the principles of reduce, reuse and recycle. The major intention for shifting towards green concrete are: (a) Reduced greenhouse gas emissions created during the manufacturing of conventional cement in cement plants, (b) Reduction in the use of natural resources such as limestone, clay, natural river sand, natural rocks, shale, etc. which cannot be replenished, (c)Recycling of waste materials such as Slag, Fly Ash, Silica Fume which are industrial waste preventing land pollution (Suhendro, 2014).

The term "GREEN" now encompasses not just color but also the environment, introducing the concept of "green concrete" as a new era in the concrete industry (Suhendro, 2014). This was first produced by Dr. WG in Denmark in 1998. The goal of the Centre for Green Concrete is to decrease the harmful environmental consequences of concrete and green concrete technology solutions have emerged, promoting sustainability and eco-friendly manufacturing in the cement and concrete industry. These concepts are gaining global popularity as a solution to the global climate change crisis. This is made feasible by the invention of new technologies. The technique takes into account all elements of performance at each stage of a concrete structure's life cycle, including structural design, specification, manufacture, and maintenance (Van den Heede, 2012).

However, given the current circumstances, more knowledge about green cement and its potential is required. Investing in new products or production techniques is often perceived by manufacturers and customers as a financially hazardous choice. Considerable alterations to industrial configurations have resulted in a continuous rise in costs (Wang, 2022). National governments should encourage green cement manufacturing to fulfil the demands of the building sector. Investors and manufacturers should be given incentives to use ecologically friendly practices. Hiring house inspectors may assist monitor green concrete constructions to ensure certification and contractor payment (Yeheyis, 2013).

DESIDERATUM FOR GREEN CONCRETE

Cement-based materials are the most prevalent kinds of man-made materials to be discovered all over the world (Aïtcin, 2000). A fascinating new trend is the green construction movement that is currently sweeping the country. The potential to build using green concrete offers a tremendous opportunity for society to help the environment (Ali, 2015). One example of the environmental friendliness and contribution of green concrete to environmental preservation is the utilisation of waste products produced by enterprises in various forms, such as rice husk ash, micro silica, and other materials, to generate resource-saving concrete structures (Azúa, 2019). By incorporating waste materials as a partial substitute for cement, ecologically friendly concrete reduces energy usage, emissions, and wastewater production which has been tabulated in Table 2. The production cost of green concrete is minimal as compared to OPC (Aïtcin, 2000). As a result, the amount of energy used to produce each unit of cement is thereby reduced.

Table 2: Alternative Cements in CO2 Reduction (Reproduced from Crossin, et al., 2015)

Type	*Variant*	*Carbon Dioxide (%)*	*Ingredients*	*Concern*
Geo-polymer	Materials activated with alkali	Seventy	Alkaline, Fly Ash, Al or Si wastes	Nascent Technology
Sulfoaluminate	Materials activated with alkali	Thirty to forty	Sand, bauxite, Limestone, Gypsum	Higher cost of Production
Novacem	Magnesium Oxide	>100%	Silicate salt of Magnesium	Low Acceptance in Market
TechEco	Magnesium Oxide	>100%	Oxides of Magnesium, Flyash	Low Acceptance in Market

The strength and durability of green concrete are higher than those of conventional concrete which is briefed in table 3 (Dixit, 2022). In order to assist sustainable growth, industrial wastes are included into green concrete, reducing the use of energy, natural resources, and pollutants emitted into the environment. A sort of filler that may be used in concrete to lessen the overall number of voids in the substance is marble sludge powder. In many parts of the country, natural sand is poorly graded and contains too much silt. Quarry rock dust, on the other hand, is free of silt and organic impurities. According to the needs, it may be manufactured to satisfy the proper gradation and fineness. As a result, the concrete's strength is improved as a result of this.

Table 3: Fehler! Kein Text mit angegebener Formatvorlage im Dokument. Advantages of incorporating some common materials into green concrete

Name	Advantage	Source
Glass	Enhances the overall strength of concrete	(Mustafa, Hanafi, Mahmoud, & Tayeh, 2019)
Husk ash (powder)	Suitable for being utilized as supplementary cementitious material and alkali-activated binder	(Qin, Zhang, Chai, Xu, & Li, 2019)
Plastic	Enhances impact resistance of concrete and also 1% content of plastic contributes towards an increase in overall compressive strength of concrete	(Singh, Kumar, & Goyal, 2019)
Fly ash (powder)	Enhances the compressive strength and permeability of concrete.	(Thorneycroft, Orr, Savoikar, & Ball, 2018)

GREEN CONCRETE: GREENER SIDE

Green concrete offers a cost-effective alternative to regular concrete due to its improved heat and acid resistance, stronger compressive and split tensile strengths, and lower price. It has more workability, faster strength and shrinkage, and can withstand temperatures up to 2400 degrees Fahrenheit, enhancing fire resistance and reducing cement usage. Additionally, it is more resistant to corrosion, addressing pollution's environmental impact (Kumar S. G., 2022). Due to acid rain, conventional building materials have a significantly shorter lifespan. These elements work together to create a structure that is far more resilient than one made of ordinary concrete. Reducing the need for structures to be continually rebuilt lessens the requirement for construction materials. Less damage will be done to the ecology in the neighbourhood.

Fly ash does not need a large increase in energy consumption to manufacture green concrete because it is already produced as a byproduct of another industrial activity (Chouhan, 2021). Because a structure composed of green concrete is more resistant to temperature changes, heating and cooling a building is less expensive. This is one way that green concrete contributes to a decrease in overall energy use. Green concrete manufacturing reduces carbon dioxide emissions by up to 80% when compared to conventional concrete production techniques (Banerjee, 2015). A major step towards attaining the global objective of reducing emissions will be the complete switch to environmentally friendly concrete for use in buildings.

The Paris accord requires global governments to work together to limit global warming to below 2 degrees Celsius, preferably 1.5 degrees Celsius, by cutting greenhouse gas emissions to 'net zero' by around 2050.There are several industries with commitments to keep following COP26. One such sector is the cement and concrete sector. The Global Cement and Concrete Association (GCCA) must now follow through on its promise after unveiling its Concrete Future 2050 plan for net-zero concrete at the Glasgow summit. According to the international trade association, during the past three decades, cement production has reduced its carbon dioxide emissions by a comparable 20%. According to the strategy, carbon emissions will be reduced by the same amount in just ten years. To accomplish complete decarbonisation by the middle of the century, it proposes a proportional decrease of 25% in carbon dioxide emissions by 2030.

FUTURE AHEAD

Some of the biggest names in technology are investing in startups that make low-carbon cement, including John Doerr of Kleiner Perkins, Bill Gates' Breakthrough Energy, and Amazon's Climate Pledge Fund. Over $100 million in venture capital has been invested in cement businesses during the last two years (Chellasamy, 2021). Major cement producers, including Heidelberg Cement in Germany and Holcim in Switzerland, are addressing the issue of mixed cement. GCCA India, along with other members like Orient Cement Ltd, Shree Cement Ltd, Shree Digvijay Cement Ltd, Ultratech Cement Ltd, and Vicat India, is working on a plan to address this issue. JSW Cement has been awarded Green-Pro Certification for Portland Slag Cement for the first time in India by the CII-IGBC. The Energy and Resource Institute (TERI) will provide subject-matter knowledge to GCCA India. The General Manager of GCCA India, Kaustubh Phadke, underlines, "This is not hollow rhetoric. He notes that the world's second largest and most energy-efficient cement industry, India, has cut its carbon dioxide emissions by 40% since 1990 due to policy changes, industries participation and cultural change in the society like accelerated renewable adoption, harnessing solar energy, EV vehicles, resilient indigenous investments in cleantech R&D, Carbon Hubs and storage hubs, National Hydrogen mission and many more. To promote a circular economy, regulatory changes, public procurement reforms, carbon pricing systems, and laws are required. In place of coal and pet coke, the sector will start using green hydrogen in 2030.

LIMITATIONS

The nascent technology in green concrete, low efficiency and high cost of manufacturing per ton leads to limitations to adoption of green concrete at large scale in real estate and construction industries. Some of the limitations are as below

i. The use of coarse recycled materials such as fly ash and husk reduces the compressive strength of the concrete, resulting in reduced split tensile strength

ii. The price of reinforcement rises when stainless steel is used.

iii. Concrete with higher water absorption than regular concrete due to the capability of green concrete have property of moisture absorption of recycled aggregates.

iv. Green concrete constructions have a shorter lifespan than regular concrete ones due to comparatively higher shrinkage rate and acid rain reduces the longevity of the green cement.

Still, the benefit of Green Concrete outweighs its limitations, and it's a recent concept. There is a large scope for innovation, study, and improvement.

CONCLUSION

With its advantages for the environment, high tensile strength, and resistance to corrosion, green concrete is the way of the future for the construction sector. It is highly rated in the green homes grading system, encouraging builders to adopt green practices to reduce the level of pollution and contribute to save the environment similar findings and suggestions were highlighted by (Azúa, 2019), (Wang, 2022). According to I-Mark group the green cement market reached a value of 27.02 billion US dollars in 2021 and they expect it to reach 56.6 by 2027 this is in line with the findings and suggestions by (Dixit, 2022), (Ige, 2021). There aren't many businesses focused on green concrete because the sector is still in its infancy and represents a relatively new solution in terms of technology, dependability, and client confidence. Policy reforms are required at both the corporate and individual levels since green concrete is a sustainable product that reduces carbon emissions. The goal of the current study was to emphasise the crucial role of green cement in attracting further green investment (Kumar, Guha, & Singh, 2021), organisations can integrate eco-friendly goods and green brand mental impressions into their marketing communications and strategy. To develop significant green brand equity, organizations must guarantee that their brands perform at least equal to or better than traditional products in the same category, consistent with the findings of the IBEF report published in 2023.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

ACKNOWLEDGMENTS

This research did not have a main funder or got a grant from any institution. This research was personally financed and the authors were grateful to the institute for providing facility, Bhilai Institute of Technology, Durg.

LIST OF ABBREVIATIONS

CO2 Carbon Dioxide

PCC Portland Cement concrete

MT Million Tonnes

NCA National Coarse Aggregate

GC Green Concrete

GGBFS Ground Granulated Blast Furnace Slag

SCMs Supplementary Cementitious Materials

OPC Ordinary Portland Cement

GCCA Global Cement Concrete Association

TERI The Energy and Resource Institute

R&D Research and Development

IBEF India Brand Equity Foundation

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