USAGE OF ECO FRIENDLY CONCRETE IN CONSTRUCTION: A REVIEW

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ABSTRACT

As significant contribution was made by the concrete in construction, the research has been conducted on eco-friendly concrete, including geopolymer concrete, Supplementary Cementitious Materials (SCMs), recycled aggregates, and industrial by-product-based binders. This literature review analyzes studies published between 2018 and 2025 by multiple researchers to evaluate advancements in sustainable concrete technology. The reviewed literature highlights that materials such as Fly Ash, Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume, and Alkali-activated binders can significantly reduce CO_2 emissions while maintaining or improving mechanical and durability properties. Geopolymer concrete, in particular, demonstrates high compressive strength, enhanced chemical resistance, and reduced environmental impact compared to conventional concrete. However, challenges such as material variability, lack of standard mix design procedures, high activator cost, and limited field-scale applications remain major barriers. Key research gaps are identified and emphasize the need for standard guidelines, life-cycle assessment studies, and large-scale implementation to support sustainable infrastructure development.

Key words: Geo polymer concrete, Eco friendly concrete, Supplementary Cementitious Materials

1. INTRODUCTION

Concrete is the most widely used construction material in the world due to its strength, durability, and versatility. It is widely reported that production of cement contributes approximately 7–8% of total global CO_2 emissions and makes a critical target for sustainable development initiatives. As global infrastructure demand continues to rise, the environmental burden of conventional concrete has become a major concern.

To address this issue, extensive research has focused on developing eco-friendly concrete alternatives includes the use of SCMs. More advanced solutions include geopolymer concrete, which utilizes industrial by-products activated by alkaline solutions to form a strong binder system without the need for cement. Studies have shown that such alternatives can reduce greenhouse gas emissions by up to 30–80% depending on material composition and mix design, while also improving durability and resistance to chemical attack.

Recent research between 2018 and 2025 has increasingly shifted toward optimizing these materials through micro-structural analysis, life-cycle assessment, and performance-based design approaches. Authors such as David ovits (geopolymer concept pioneer) and later researchers like Zhang et al., Nath, and Ramesh et al. have demonstrated that eco-friendly concrete can achieve comparable or even superior performance to OPC-based concrete under specific conditions. However, challenges such as inconsistent raw material quality, lack of unified standards, and economic feasibility still limit large-scale adoption.

Therefore, this literature review critically examines key studies from 2018 to 2025 to understand developments in eco-friendly concrete, compare different material systems, and identify existing research gaps. The focus is to provide a clear understanding of current trends and future directions for sustainable construction materials.

Literature Review:

Assi et al. (2018) investigated fly ash-based geopolymer concrete as an alternative for OPC. The objective was to evaluate mechanical and durability performance. The methodology included replacing cement with fly ash activated by sodium silicate and sodium hydroxide. Tests such as compressive strength, splitting tensile strength, and acid resistance were conducted. Results showed higher long-term strength and excellent resistance to chemical attack. This indicates that geopolymer concrete reduces CO_2 emissions significantly. However, limitations include sensitivity to curing conditions and variability in fly ash quality. The research gap highlights the need for field-scale validation and standard mix design development.

Zhang et al. (2020) reviewed fly ash/slag-based geopolymer concrete. The objective was to analyze fresh and hardened properties. The methodology involved synthesizing global experimental studies. Materials included fly ash and GGBFS activated with alkaline solutions. Key tests reviewed were workability, strength development, and durability (chloride and sulfate resistance). Findings showed superior mechanical and durability performance compared to OPC concrete. Limitations included inconsistent activator ratios and curing regimes across studies. The research gap identified was the lack of unified standards and predictive models for long-term performance.

Nath (2018) studied geopolymerization behavior of ferrochrome slag and fly ash blends. The objective was to evaluate their suitability as sustainable binders. The methodology involved alkali activation using sodium hydroxide. Tests included compressive strength, XRD, and microstructure analysis. Results showed improved strength with optimized slag-fly ash ratios due to better geopolymer gel formation. However, high chromium content raised environmental concerns. The limitation was toxicity risk and limited large-scale application. The research gap includes safer utilization of industrial slags and long-term leaching behavior studies.

Nuaklong et al. (2018) Nuaklong et al. investigated recycled aggregate geopolymer concrete with nano-SiO_2. The objective was to enhance sustainability using Recycled Concrete Aggregates (RCA). Methodology included replacing natural aggregates with RCA and adding nano-silica. Tests included compressive strength, water absorption, and SEM analysis. Results showed improved microstructure and increases its strength due to nano-filler effects. Limitations include increased water demand and reduced workability. Research gap focuses on optimizing nano-additive dosage and durability under aggressive environments.

Ramesh et al. (2021) studied eco-friendly concrete using municipal solid waste incinerator bottom ash. The objective was waste valorization in structural concrete. Methodology involved partial replacement of sand and coarse aggregates. Tests included compressive strength, durability, and SEM analysis. Findings showed improved strength at optimum replacement levels (5–10%). Limitations include variability in ash composition and potential toxicity concerns. Research gap includes long-term environmental safety and leaching performance.

Tan et al. (2020) examined geopolymer concrete using recycled aggregates and slag. Objective was to develop fully sustainable concrete. Tests included slump, compressive strength, and durability exposure. Results showed acceptable strength but increased porosity. Limitations were higher water absorption and reduced workability when recycled mix aggregates are used. Research gap includes improved mix design and durability enhancement techniques.

Saha (2022) reviewed fly ash-based composites for structural applications. Objective was to analyze mechanical performance trends. Methodology involved literature synthesis of fabrication techniques. Materials included fly ash reinforcements in polymer and cement matrices. Tests reviewed included tensile, compressive, and impact strength. Findings showed improved mechanical properties and sustainability benefits. Limitations include lack of standardized fabrication processes. Research gap includes structure–property correlation development.

Kato et al. (2022) Kato et al. studied mechano-chemical activation of fly ash. Objective was to enhance reactivity in geopolymer systems. Methodology included grinding and chemical activation of fly ash. Tests included particle size analysis, SEM, and dissolution behavior. Results showed improved alumino-silicate dissolution and higher reactivity. Limitations include energy-intensive processing. Research gap focuses on low-energy activation techniques.

Serbource et al. (2024) analyzed SCM using XRD and Raman spectroscopy. Objective was to understand SCM structure-performance relationships. Methodology involved chemical and structural characterization of slag, fly ash, and recycled glass. Tests included spectroscopy and phase analysis. Results showed that glassy phase composition strongly affects reactivity. Limitations include lack of direct correlation with mechanical performance. Research gap includes linking microstructure to long-term durability.

Chanda & Thakkar (2024) conducted a bibliometric study on geopolymer concrete. Objective was to analyze global research trends. Methodology included Scopus-based scientometric mapping. Materials focused on fly ash, slag, and industrial wastes. Findings showed increasing global interest in circular economy materials. Limitations include database restriction (Scopus only). Research gap includes interdisciplinary application studies.

Nuaklong et al. (2016) investigated recycled aggregates in fly ash geopolymer concrete. Objective was sustainability improvement. Tests included compressive strength and durability. Results shows feasible partial replacement. Limitations include reduced workability. Research gap includes optimization of recycled aggregate grading.

Thomas & Gupta (2016) Thomas and Gupta reviewed waste rubber in concrete. Objective was sustainable waste utilization. Methodology included literature analysis. Findings showed improved flexibility but reduced strength. Limitations include poor bonding with cement matrix. Research gap includes surface treatment methods for rubber aggregates.

Hemalatha et al. (2017) reviewed high-volume fly ash concrete. Objective was maximizing SCM usage. Findings showed improved durability and sustainability. Limitation includes slow early strength gain. Research gap includes accelerating admixtures optimization.

Kumar et al. (2020) analyzed geopolymer concrete as OPC replacement. Objective was comparative performance study. Findings showed high thermal and chemical resistance. Limitations include activator cost. Research gap includes cost reduction strategies.

Singh et al. (2019) reviewed SCM-based sustainable concrete systems. Objective was to evaluate environmental impact. Findings confirmed major CO_2 reduction potential. Limitations include variability in waste materials. Research gap includes standardization of mix proportions.

CONCLUSION

The literature review on eco-friendly concrete based on studies from 2018 to 2025 clearly demonstrates that SCMs have significant potential to reduce the environmental impact of the cement and concrete industry. Across the reviewed studies, a consistent finding is that partial or full replacement of ordinary Portland cement (OPC) with SCMs such as fly ash, GGBFS, silica fume, and agricultural or industrial by-products can substantially reduce carbon dioxide emissions while maintaining acceptable mechanical and durability performance.

Geopolymer concrete, in particular, has emerged as one of the most promising alternatives due to its high compressive strength, excellent chemical resistance, and low carbon footprint. Studies reviewed show that alkali-activated binders can achieve performance comparable to or even superior to conventional concrete under controlled conditions. However, issues such as variability in raw material composition, sensitivity to curing conditions, and high cost of alkaline activators limit its widespread adoption.

Research on recycled aggregates and industrial waste incorporation further highlights the potential for circular economy applications in construction. While these materials contribute to waste reduction and resource conservation, they often introduce challenges such as reduced workability, higher water absorption, and inconsistent quality, which must be addressed through optimized mix design and proper processing techniques.

Despite significant advancements, the literature also identifies several critical research gaps. These include the lack of standardized design procedures for eco-friendly concrete, limited long-term field performance data, insufficient durability studies under extreme environmental conditions, and the need for comprehensive life-cycle cost and environmental assessments. Additionally, scalability and industrial implementation remain major challenges.

Overall, the reviewed literature confirms that eco-friendly concrete is a technically feasible and environmentally beneficial alternative to conventional concrete. However, further research focusing on standardization, cost reduction, durability enhancement, and large-scale practical applications is essential to enable its widespread use in sustainable infrastructure development.

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