IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 18, April 2026

Impact Factor: 8.2

Strength and Durability Evaluation of Self-Compacting Concret Incorporating Sea Sand and Ternary Binder: A Review

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Abstract: *Concrete, one of the most widely used construction materials, significantly contributes to environmental concerns due to the high carbon emissions associated with cement production. In response, geopolymer concrete (GPC) has emerged as a sustainable alternative by utilizing industrial by-products such as fly ash (FA), ground granulated blast furnace slag (GGBS), and rice husk ash (RHA). This review paper focuses on recent advancements in eco-friendly geopolymer systems, particularly the use of alternative alkali activators and supplementary binders to reduce environmental impact. Traditional activators like sodium silicate (Na_2SiO_3) raise sustainability and cost concerns, prompting the exploration of RHA-based activators as viable substitutes. The study also examines the role of nanosilica (NS) and RHA in enhancing mechanical and durability properties of GPC. Various mix proportions, including FA-GGBS ratios, sodium hydroxide molarity, and activator-to-binder ratios, are analyzed to determine their influence on compressive strength and workability. Findings indicate that an optimized mix comprising 70% FA, 30% GGBS, 13M NaOH, and an activator-to-binder ratio of 0.55 achieves a compressive strength of 38.3 MPa with satisfactory performance. Overall, the review highlights the potential of geopolymer concrete as a sustainable construction material and emphasizes the importance of optimizing material composition for improved structural and environmental performance..*

Keywords: GPC, RHA, GGBS, NS, Compressive Strength, Workability.

I. INTRODUCTION

Geopolymers are amorphous, three-dimensional aluminosilicate binder materials classified under inorganic polymers, formed by a network of silicon (Si) and aluminium (Al) atoms. They are synthesized through the reaction of aluminosilicate-rich materials, such as fly ash and slag, with highly alkaline activating solutions. This process, known as repolymerization, is an exothermic reaction that typically occurs in three stages: dissolution, gel formation, and polycondensation. During dissolution, silica and alumina from the source materials break down in the alkaline medium, releasing reactive ions. These ions reorganize to form monomeric units such as –Si–O–Al–O–, which subsequently undergo polymerization to create a gel-like structure. In the final stage, this gel hardens into a stable, three-dimensional geopolymer network.

Geopolymer concrete (GPC) derived from this process exhibits several superior properties compared to conventional Ordinary Portland Cement (OPC) concrete. It demonstrates higher compressive strength with rapid early strength gain, low drying shrinkage, and excellent resistance to chemical attacks such as acids, sulphates, and chloride ions, thereby enhancing durability and corrosion resistance of reinforcement. Additionally, GPC offers good thermal stability, improved fire resistance, and lower heat of hydration. Its ability to cure under ambient conditions further adds to its practicality. Importantly, the use of industrial by-products and reduced carbon emissions makes geopolymer concrete

DOI: 10.48175/568

an environmentally sustainable alternative, promoting efficient waste utilization while ensuring enhanced structural performance.

Environmental Impacts Due to Sand Mining

Several researchers have investigated, resulted in various suggestions and recommendations, as outlined below;

Gavriletea emphasized the global imbalance between sand supply and demand, with the construction sector as the primary consumer, followed by industries like chemical, ceramic, foundry, glass manufacturing. Sand mining was found to cause significant environmental issues, including habitat loss, vegetation degradation, and increased river water turbidity, and bank erosion. The study advocated for recycled aggregates, crushed glass waste.

Ashraf et al. assessed both the positive and negative impacts of sand mining in Selangor's rivers, focused on sediment transport, grain size distribution, and water column characteristics. Hydraulic modeling, including HEC-RAS simulations, was employed to analyze one-dimensional sediment transport. The study found that sand mining adversely affects water turbidity and quality, habitats, biodiversity, groundwater levels, and structural stability. It recommended mitigation strategies and emphasized the need to limit sand mining to protect the environment, advocated the use of alternatives such as crushed stone and recycled aggregates.

Mattamana et al. [49] investigated sand inflow along stretches of the Periyar river and optimized the extraction and evaluated the effects of irregular sand mining. The study revealed that unregulated mining led to abrupt bed level reduction, uneven river cross-sections, bank failures, and lateral sand drift. These changes adversely impact aquatic ecosystems, navigation, and local economies. The authors emphasized the need to balance sand extraction with natural deposition to preserve riverine biodiversity.

Leeuw et al. adopted remote-sensing imagery to quantify sand extraction from China's Poyang Lake and evaluated its environmental and construction-industry implications. Excessive mining increased water turbidity, degraded aquatic habitats, and threatened Lake Biodiversity. The authors warned that meeting national sand demand in this manner risks irreversible ecosystem damage and urged shifting demand to alternative materials.

Padmalal et al. surveyed sand-mining and storage sites in the Vembanad Lake catchment (south-west India) and estimated annual extraction at about 11.7 Mt. This removal accelerated bank erosion, lowers groundwater levels, degrades surface water and aquatic biota, and destabilizes spillways, abutments, and piers, and also disrupts local communities. The authors urge expanded research into low-cost, easily sourced alternatives to river sand for construction.

Anthony et al. analyzed sand mining–induced erosion along the Mekong River with high-resolution satellite imagery. The study identified sand extraction as a key factor in coastal sediment decline, riverbank erosion, seawater intrusion affecting agriculture, and land subsidence. It warned that continued uncontrolled mining could lead to the depletion of vital natural resources and urged immediate intervention.

Effect of Aluminosilicate Base Materials In GPC

Kanagaraj et al. [73] of industrial by-products as aluminosilicate sources and the environmental advantages of GPC have led to a rise in its adoption. Materials such as FA, GGBS, Corex slag, bottom ash, fuel gas desulfurization gypsum, pulverized fuel ash, palm oil fuel ash, fluidized bed combustion FA, and RHA can be used individually or in combination, enhancing the GPC performance and supporting the waste management. GPC can be designed under. It exhibited similar flow and strength characteristics to OPC, with lower water-to-binder ratios and higher activator concentrations (8M to 16M), which improve the strength through enhanced alumina and silica dissolution. However, its strength often deviates from standard design predictions.

Hardjito et al. [74] investigated fly ash-based GPC by varying sodium hydroxide molarity (8M and 14M), silicate-to-hydroxide ratio (0.4-2.5), curing temperature (30-90 °C), and duration (6-96 hr) at 14M solution with a 2.5 ratio of silicate-to-hydroxide. Strength improved with higher temperatures and longer curing time, but the strength gains marginally beyond 60 °C and 48 hours. Molarity and curing temperature were identified as key factors influencing GPC strength.

Hamidi et al. [75] investigated the influence of flexural strength increased from 3 MPa to 10 MPa as the molarity rose from 4M to 12M, due to the improved dissolution of reactive species from fly ash. However, strength declined beyond 12M, likely due to inefficient geopolymerization at excessively high concentrations. The findings emphasized the critical role of alkaline solution molarity in optimizing the mechanical performance of GPC.

Rao and Rao [76] evaluated mortar activated with NaOH- Na_2SiO_3 solutions with an alkaline solutions of varying FA-GGBS blends under both heat and ambient curing. GGBS replaced FA in increments from 10% to 100%. Results showed that an increase in the GGBS content reduced setting time, while a higher molarity extended it. Compressive strength increased with 100 % GGBS content, under ambient conditions reached 87 MPa, due to strength, with fly ash-based mixes performing better under elevated temperatures. The study concluded that the incorporation of GGBS broadens the applicability of GPC, particularly for cast-in-situ construction.

Cheema and Lloyd [77] examined the impact of GGBS slag addition on fly ash- based GPC under ambient and steam cured at 60 °C. GGBS was used as a partial replacement for FA at 5% and 10%. Under ambient curing, approximately three times higher than that of pure fly ash-based mixes due to formation. However, under steam curing, strength decreased with GGBS addition, likely due to interference in bond formation. The study recommended GGBS-based GPC as a viable material for in-situ construction.

Rao and Rao [78] investigated the effect of GGBS incorporation on the workability and compressive strength of FA-based GPC. GGBS replaced fly ash at levels of 30%, 40%, and 50% showed a reduction in the GGBS to its angular particle shape. However, compressive strength improved under both curing conditions due to the high calcium content in GGBS. The study concluded that the incorporation of GGBS in GPC has the potential to eliminate the requirement for heat curing during production.

Hassan and Ismail [79] cured at ambient temperature, 30°C, and 60°C, incorporating GGBS 50%. The study found that compressive strength increased with curing temperature up to 60 °C. Under ambient conditions, the inclusion of GGBS further enhanced strength due to its high early-age reactivity, and supports the feasibility of in-situ GPC applications.

II. CONCLUSION

The reviewed studies clearly demonstrate that excessive and unregulated sand mining has led to significant environmental degradation, including riverbank erosion, habitat destruction, groundwater depletion, and increased water turbidity. Researchers consistently highlight that the growing demand for construction materials has created an imbalance between natural sand supply and demand, posing serious ecological and socio-economic challenges. These findings emphasize the urgent need to adopt sustainable alternatives such as recycled aggregates, crushed stone, and industrial by-products to reduce dependency on natural sand and mitigate environmental impacts.

In parallel, the investigation into aluminosilicate-based materials for geopolymer concrete (GPC) reveals substantial potential for sustainable construction. The use of industrial by-products such as fly ash (FA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA), and other waste materials not only enhances mechanical properties but also promotes effective waste management. Key factors such as alkaline solution molarity, curing temperature, and material composition significantly influence the strength and workability of GPC. Optimal combinations, particularly the incorporation of GGBS, have been shown to improve compressive strength, reduce setting time, and enable ambient curing, making GPC suitable for practical, in-situ applications.

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