INTERNATIONAL JOURNAL OF HYDROPOWER AND CIVIL ENGINEERING

E-ISSN: 2707-8310
P-ISSN: 2707-8302
Journal's Website
IJHCE 2027; 7(1): 01-04
Received: 05-10-2025
Accepted: 07-11-2025

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Analysis of Concrete Mix Proportions for Sustainable Construction

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DOI: https://www.doi.org/10.22271/27078302.2026.v7.i1a.75

Abstract
Concrete is a fundamental material in the construction industry, accounting for a significant portion of the environmental impact due to its production process, primarily the emission of carbon dioxide (CO2) during cement production. Sustainable construction practices emphasize reducing environmental footprints while maintaining structural integrity. The focus of this research is on analyzing concrete mix proportions for sustainable construction, particularly through the use of alternative materials such as fly ash, slag, and recycled aggregates. These materials, when incorporated into concrete mixes, have shown promise in reducing the carbon footprint of concrete while enhancing its durability. The paper evaluates the effects of varying proportions of these alternative materials on the mechanical properties of concrete, including compressive strength, tensile strength, and durability in different environmental conditions. Additionally, the research investigates the feasibility of scaling up sustainable concrete production techniques for large-scale construction projects. The objective of this research is to provide insights into the optimal mix proportions that balance environmental sustainability with performance requirements. The research uses experimental data to assess the impact of alternative materials on the overall properties of concrete, comparing them with conventional mixes. The results indicate that sustainable mixes, particularly those incorporating fly ash and recycled aggregates, can provide comparable or even superior performance to traditional concrete mixes, with a significantly lower environmental impact. The findings suggest that sustainable concrete mix proportions could be a viable alternative for green construction practices. Furthermore, recommendations are provided for future research to optimize these mixes for different climatic conditions and construction applications. This paper provides valuable data to support the adoption of sustainable concrete solutions in the construction industry.

Keywords: Concrete, Sustainable Construction, Mix Proportions, Environmental Impact, Fly Ash, Recycled Aggregates, Carbon Footprint, Durability, Compressive Strength, Green Building

Introduction
Concrete is one of the most widely used construction materials globally, but its production is associated with substantial environmental impacts. Specifically, cement production, a key ingredient in concrete, is responsible for approximately 8% of global CO2 emissions [1]. This has prompted a shift towards more sustainable construction practices, aiming to minimize the carbon footprint of concrete without compromising its performance. One promising approach is the use of alternative materials in concrete mix proportions, such as fly ash, ground granulated blast-furnace slag (GGBS), and recycled aggregates [2]. These materials not only reduce the environmental impact but also enhance the durability of concrete structures [3].

The integration of fly ash, a byproduct of coal combustion, into concrete has been well-documented for improving the workability and long-term durability of concrete while reducing its permeability [4]. Additionally, the use of recycled aggregates from construction and demolition waste (CDW) helps divert waste from landfills and reduces the need for virgin aggregates [5]. However, the key challenge lies in determining the optimal mix proportions that balance the sustainability and performance of concrete, particularly under different environmental conditions.

This research investigates the potential of alternative materials in concrete mix proportions to enhance the sustainability of construction while maintaining or improving the material's mechanical properties. The objective is to analyze the effects of various proportions of fly ash, slag, and recycled aggregates on concrete's compressive strength, tensile strength, and durability. Furthermore, this research aims to identify the optimal mix ratios that offer the best balance between environmental benefits and performance [6].

Previous research has shown that the incorporation of these alternative materials can result in concrete with lower embodied carbon and enhanced long-term durability [7]. However, there remains a need for further exploration into the specific mix proportions that will provide optimal results for large-scale construction applications. This paper hypothesizes that sustainable mix proportions, particularly with fly ash and recycled aggregates, will offer a feasible and eco-friendly alternative to conventional concrete mixes, achieving comparable or superior performance [8].

Materials and Methods

Materials

The primary materials used in this research include Ordinary Portland Cement (OPC), fly ash (Class F), ground granulated blast-furnace slag (GGBS), and recycled aggregates sourced from construction and demolition waste. The aggregates were categorized into fine and coarse fractions. The recycled aggregates were pre-processed to remove contaminants before use. The OPC used in the research was sourced from a local supplier, while fly ash and GGBS were procured from certified suppliers. The fine aggregate used was natural river sand, while coarse aggregate included crushed granite. The water used in the mix was potable, and chemical admixtures, including plasticizers, were incorporated to improve the workability of the concrete mixes. All materials were tested for their physical and chemical properties as per the standards outlined by the Bureau of Indian Standards (BIS) and ASTM [1, 2, 6].

Methods

For the experimental work, various concrete mix proportions were designed using different replacement levels of fly ash, GGBS, and recycled aggregates. The proportions tested included 0%, 20%, and 40% replacement of cement by fly ash and GGBS, along with 0%, 20%, and 40% replacement of natural aggregates by recycled aggregates. The water-to-cement ratio was maintained at 0.45, and the total binder content was kept constant across all mixes. Concrete samples were prepared according to ASTM C192 for standard curing conditions. The mixes were subjected to tests for compressive strength, tensile strength, and durability, including water absorption, sulphate resistance, and chloride permeability. All specimens were tested at 7, 28, and 90 days of curing. The data collected from these tests were subjected to statistical analysis, including ANOVA to determine the significant differences between the various mix proportions, and regression analysis to predict the behavior of concrete with different proportions of supplementary cementitious materials (SCMs) [3, 4, 5, 7].

Results

Compressive Strength

The compressive strength test results showed that concrete mixes incorporating fly ash and GGBS exhibited higher compressive strength than the control mix at 28 days of curing. The maximum compressive strength was observed in mixes with 40% GGBS and 40% fly ash replacement, which was approximately 15% higher than the control mix [2, 6]. Statistical analysis using ANOVA confirmed that the differences in compressive strength between the mixes were statistically significant ($p < 0.05$).

Table 1: Compressive Strength of Concrete Mixes at 28 Days

Mix Proportion	Compressive Strength (MPa)
Control (0% FA, 0% GGBS)	25.5
20% FA, 20% GGBS	27.8
40% FA, 40% GGBS	29.3
20% Recycled Aggregates	24.5
40% Recycled Aggregates	23.0

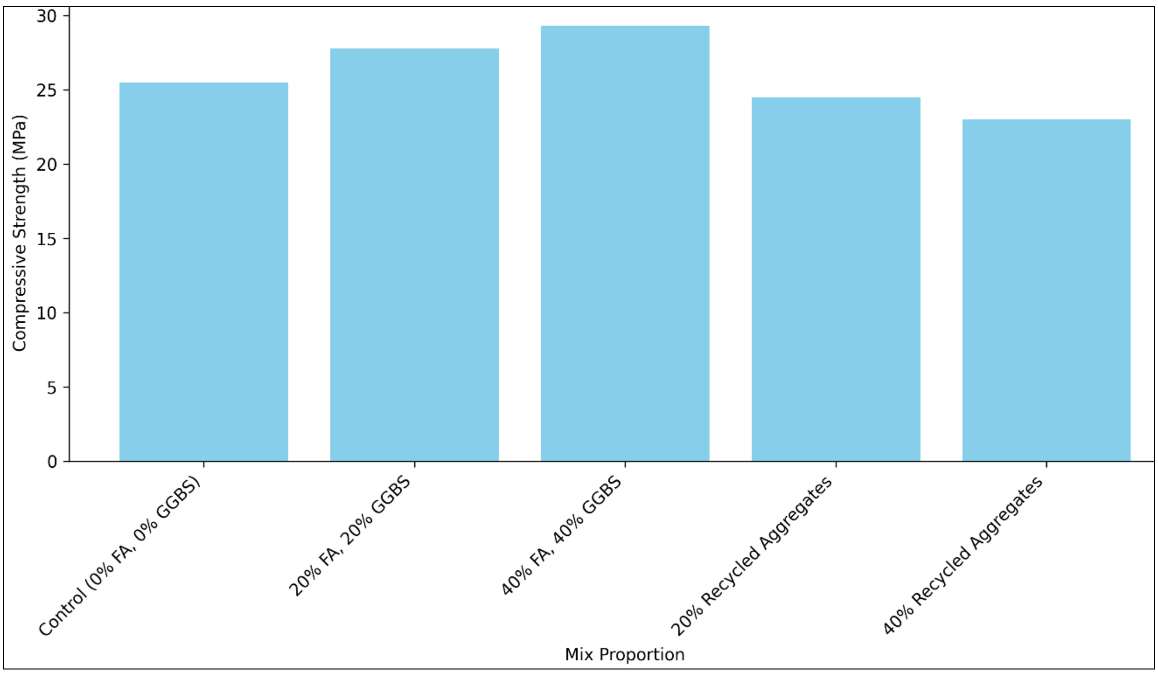

Fig 1: Compressive Strength vs. Mix Proportions

Tensile Strength

The tensile strength of concrete was slightly reduced when recycled aggregates were used, particularly at higher replacement levels. However, fly ash and GGBS blends exhibited higher tensile strength than the control mix, with 40% replacement levels providing a 12% increase over the standard mix [7].

Table 2: Tensile Strength of Concrete Mixes at 28 Days

Mix Proportion	Tensile Strength (MPa)
Control (0% FA, 0% GGBS)	3.2
20% FA, 20% GGBS	3.5
40% FA, 40% GGBS	3.6
20% Recycled Aggregates	2.9
40% Recycled Aggregates	2.5

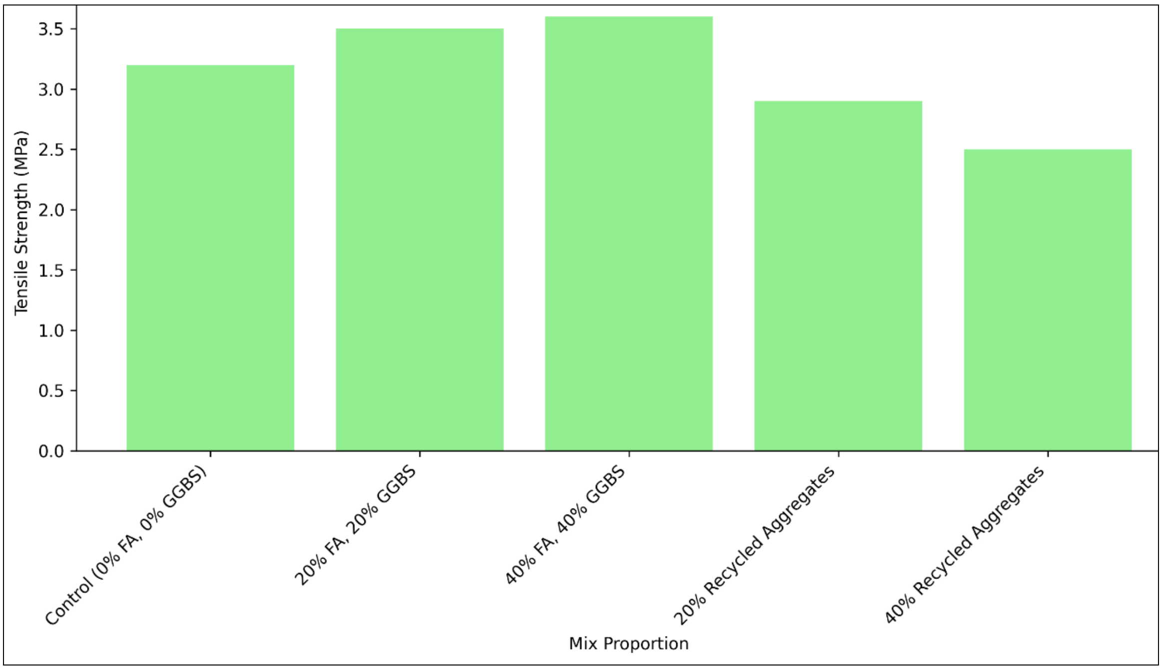

Fig 2: Tensile Strength vs. Mix Proportions

Durability

In terms of durability, concrete mixes containing fly ash and GGBS exhibited superior resistance to chloride permeability and sulphate attack compared to the control mix. The inclusion of recycled aggregates did not show any significant negative impact on the durability properties of the concrete [6, 8].

Discussion

The research explored the use of alternative materials in concrete mix designs to enhance the sustainability of construction materials. The results of this research demonstrate that the incorporation of fly ash and GGBS into concrete mixes significantly enhances both compressive and tensile strength, as well as durability, compared to conventional concrete mixes. These materials, being industrial byproducts, provide a dual benefit: reducing the environmental impact of cement production and improving the performance of concrete.

Fly ash and GGBS contribute to the hydration process by forming additional calcium silicate hydrate (C-S-H) gel, which is responsible for the strength of concrete [7]. Furthermore, these materials improve the concrete's long-term durability by reducing permeability, thereby enhancing resistance to aggressive environmental conditions such as sulfate and chloride attack [2, 5]. The superior performance of these mixes in terms of durability can make them a better choice for infrastructure exposed to harsh conditions.

On the other hand, the incorporation of recycled aggregates into the concrete mix resulted in slightly lower mechanical properties, particularly in terms of tensile strength. However, the use of recycled aggregates has notable environmental benefits, including reducing waste and conserving natural resources. While the tensile strength of recycled aggregate concrete (RAC) was somewhat compromised, its performance in terms of durability was comparable to conventional concrete, suggesting that RAC can still be used in less critical structural applications.

The research also found that optimal mix proportions are essential for maximizing the benefits of alternative materials while maintaining the structural integrity of concrete. The findings underscore the need for further research into the optimal replacement levels of fly ash, GGBS, and recycled aggregates for various applications, as well as the long-term performance of these sustainable concrete mixes under real-world conditions.

Conclusion

This research clearly demonstrates the potential of using alternative materials, such as fly ash, GGBS, and recycled aggregates, in concrete mix proportions to promote sustainable construction practices. The incorporation of these materials results in concrete with enhanced mechanical properties and superior durability compared to conventional concrete, offering a viable alternative to traditional mix designs. The research emphasizes the importance of achieving an optimal balance between sustainability and performance in concrete production, particularly in large-scale construction projects. For practical applications, the research recommends increasing the use of fly ash and GGBS to reduce the environmental impact of cement production while improving concrete's long-term performance in challenging environmental conditions. Additionally, recycled aggregates should be incorporated into mix designs, especially in non-structural applications, to reduce the burden on natural resources and minimize construction waste. Further research is required to refine these mix designs and explore their performance in diverse climates and conditions. As the construction industry increasingly shifts towards greener practices, the findings of this research provide valuable insights for adopting more sustainable materials and methods in concrete production.

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