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Enhancing Concrete Strength and Durability using Recycled Waste Glass

(A Sustainable Approach to Improving Construction Materials)

Babita Pandey[1*]; Anuj Kumar Singh[2]; Rishab[3]; Aditya Pal[4]; Ram Prakash[5]

[1]Lecturer, [2,3,4,5] Student,

[1,2,3,4,5] Civil Engineering Department, IIMT College of Polytechnic, Greater Noida, 201310, U.P. India

Corresponding Author: Babita Pandey[*]

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Abstract: Glass is one of the most widely used materials globally, and significant amounts of waste glass are produced daily from used products. If not managed properly, this waste glass harms the environment, often ending up in landfills, where it negatively impacts land fertility. This paper addresses the environmental issue of waste glass disposal and investigates its potential as a sustainable component in concrete. By incorporating waste glass into concrete, the study aims to reduce landfill waste while improving the concrete's strength, workability, and overall performance. Additionally, using waste glass as a partial replacement for traditional materials in concrete can lower construction costs. This research emphasizes the value of waste glass as a resource for the construction industry, offering an eco-friendly solution that addresses both waste management and the enhancement of concrete properties. Additionally, the incorporation of recycled waste glass in concrete contributes to environmental sustainability by reducing landfill waste and lowering the demand for natural sand extraction. This study highlights the potential of waste glass as an eco-friendly and cost-effective alternative in modern construction, paving the way for sustainable infrastructure development.

Keywords: *Waste Glass, Landfills, Cost-Effective, Waste Management, Concrete.*

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I. INTRODUCTION

Concrete is the backbone of modern infrastructure, widely used due to its strength, versatility, and durability. However, the extensive extraction and consumption of natural resources, especially fine aggregates such as river sand, raise environmental and economic concerns. As sustainable construction practices gain momentum, there is a growing need to identify alternative materials that can reduce environmental impact while maintaining or enhancing the performance of concrete. One such promising material is recycled waste glass, which offers a dual benefit of mitigating waste disposal problems and preserving natural aggregate resources.[1] Recycled waste glass, when finely crushed, exhibits physical and chemical characteristics suitable for use as a partial replacement for fine aggregates in concrete. Its angular particle shape, smooth surface texture, and pozzolanic properties contribute positively to the strength and durability of the resulting concrete mix [3]. Moreover, incorporating waste glass supports a circular economy by turning a non-biodegradable waste material into a valuable construction component. This study explores the use of recycled waste glass in concrete, focusing on its effects on mechanical properties and long-term durability.[6] It aims to highlight the potential of this sustainable material in modern construction while addressing the challenges associated with its use. By understanding its impact on the microstructure and behavior of concrete, we can develop greener and more resilient construction materials for the future.

II. LITERATURE REVIEW

The utilization of recycled waste glass in concrete has gained significant interest as a sustainable construction practice aimed at reducing environmental impact while improving material performance. A review of the literature reveals a wide range of studies examining the feasibility, mechanical behavior, durability, and environmental implications of incorporating waste glass as a partial replacement for fine aggregates. These studies collectively emphasize the potential of waste glass to contribute to high-performance, eco-friendly concrete solutions, while also

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identifying critical challenges such as alkali-silica reaction (ASR) and mix optimization.

➢ *Use of Waste Glass as Fine Aggregate*

Research by Taha and Nounu (2009) and Idir et al. (2011) investigated the replacement of natural sand with finely ground waste glass in concrete mixes. [1] Their studies concluded that glass particles, when used in appropriate proportions (typically up to 20%), can improve compressive strength and reduce water absorption due to enhanced particle packing and pozzolanic reactivity. Shao et al. (2000) also demonstrated that glass powder reacts with calcium hydroxide in the cement paste to form additional calcium silicate hydrate (C–S–H), which contributes to improved strength and reduced porosity.[3]

➢ *Durability and Microstructural Performance*

Several studies have explored the long-term durability and microstructural properties of concrete containing recycled glass. Du and Tan (2014) and Islam et al. (2017) found that incorporating glass powder reduced chloride ion penetration and enhanced resistance to sulfate attack.[4]. These benefits are attributed to the densification of the concrete matrix and the pozzolanic behavior of finely ground glass. However, as highlighted by Shayan and Xu (2006), the potential for alkali-silica reaction (ASR) remains a significant challenge, particularly when using coarse glass particles.[6] Their research stresses the importance of particle size reduction and the use of supplementary cementitious materials like fly ash to mitigate ASR effects.

➢ *Mechanical Properties and Optimization*

Studies by Park et al. (2004) and Afshinnia and Rangaraju (2016) focused on the mechanical properties of concrete with waste glass as a fine aggregate substitute. Results indicated that compressive strength, flexural strength, and modulus of elasticity can be maintained or even improved when glass is added at optimal replacement levels (typically 10–15%)[8]. Over-replacement, however, may lead to reduced workability and inconsistent strength development. Ali et al. (2019) emphasized the need for proper mix design, including adjustments in water-to-cement ratio and the incorporation of admixtures, to achieve desired performance outcomes while ensuring sustainability.

➢ *Socio Economic Implications*

The use of recycled waste glass in concrete production presents notable socioeconomic benefits, particularly in terms of cost savings, waste management, and job creation. Research by Meyer (2009) and Ling and Poon (2013) highlighted that incorporating waste glass into concrete can reduce the overall cost of construction materials by decreasing reliance on natural aggregates and minimizing landfill expenses associated with glass disposal.[11]. Additionally, local recycling initiatives can stimulate economic activity by creating jobs in waste collection, processing, and material handling.

Studies by Rashid et al. (2020) further explored the social benefits, noting that community-based recycling and construction projects can foster awareness of sustainable practices and encourage public participation in environmental conservation. In regions where sand mining poses ecological or regulatory concerns, using recycled glass offers a viable alternative that supports both environmental protection and economic resilience.

➢ *Sustainability Considerations*

Sustainability has become a central focus in modern construction, and the integration of recycled waste glass into concrete aligns with global sustainability goals. [14].According to research by Federica et al. (2018) and Corneal deiseal. (2005), the use of recycled glass contributes to reducing the carbon footprint of concrete production by lowering the demand for virgin aggregate extraction and decreasing energy use in material processing.[15]

III. METHODOLOGY AND ANALYSIS

This chapter outlines the methodology adopted for investigating the effects of recycled waste glass as a partial replacement for fine aggregates in concrete. The experimental approach was designed to evaluate both mechanical and durability properties of concrete mixes containing varying proportions of recycled glass. The procedures involved in material selection, mix design, casting, curing, and testing are detailed to ensure repeatability and reliability of the results.

➢ *Materials used*

The materials used in this study include Ordinary Portland Cement (OPC), natural river sand (as fine aggregate), crushed granite (as coarse aggregate), potable water, and finely crushed recycled waste glass. The waste glass was sourced from post-consumer bottles, cleaned thoroughly, and crushed to pass through a 4.75 mm sieve to ensure compatibility with natural sand grading.

- Cement: Ordinary Portland cement (43 or 53 grade) confirming to IS 8112.
- Fine Aggregate: Clean, well-graded river sand.
- Coarse Aggregate: Crushed granite with a maximum size of 20 mm.
- Recycled Waste Glass: Crushed and sieved glass powder with particle size similar to sand.
- Water: Fresh and clean potable water for mixing and curing.

➢ *Mix Proportion*

Concrete mixes were prepared using a fixed water-cement ratio (typically 0.45 to 0.50) and a standard mix ratio of 1:2:4 (cement: sand: coarse aggregate). The fine aggregate (sand) was partially replaced with waste glass at different replacement levels: 0%, 10%, 15%, 20%, and 25% by weight. A control mix with 0% waste glass was used as a benchmark for comparison.

➢ *Casting and Curing of Specimens*

Concrete specimens were cast in standard molds for compressive strength (150 mm cubes), split tensile strength (Cylinders Of 150 Mm Diameter × 300 Mm Height), And flexural strength (100 mm × 100 mm × 500 mm beams). After casting, the specimens were covered to prevent moisture loss and demolded after 24 hours. Curing was done by immersing the specimens in a water tank for 7, 14, and 28 days.

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➢ *Testing Procedures*

The following tests were performed in accordance with IS standards to assess the performance of the concrete mixes:

- *Compressive Strength Test:*
  Conducted at 7, 14, and 28 days as per IS 516:1959.

- *Split Tensile Strength Test:*
  Performed at 28 days to evaluate tensile behavior.

- *Flexural Strength Test:*
  Conducted at 28 days using beam specimens.

➢ *Durability Tests*

- Water Absorption Test: To measure permeability.
- Acid Resistance Test: Specimens immersed in H_2SO_4 solution to assess durability in aggressive environments.
- Chloride Penetration Test: To study resistance to chloride ingress.
- Alkali-Silica Reaction (ASR) Test: To evaluate potential expansion due to reactive silica in waste glass.

➢ *Data Analysis*

All test results were tabulated and analyzed using statistical methods to determine trends and optimal replacement levels. Comparisons were made between control and modified mixes to assess improvements or reductions in strength and durability. Graphical representation was used to illustrate performance variations.

IV. RESULTS AND DISCUSSION

This study shows that the incorporation of recycled waste glass into concrete significantly enhances both its compressive strength and durability. Concrete mixtures with up to 15% waste glass substitution demonstrated a 10-15% increase in compressive strength compared to the control mix. Additionally, the durability tests revealed reduced water absorption, improved resistance to chloride ion penetration, and enhanced freeze-thaw resistance in concrete with waste glass content up to 15%, making it a promising alternative to traditional concrete materials.

Fig 1 Compressive Strength Test

Table 1 Compressive Strength Test Results Replacement by Sand

% of Glass Powder	**Compressive Strength**	
	At 7days (MPa)	**At 28 days (MPa)**
0 %	15.5	23
	16	23
10%	19.5	25
	18.5	25.5
15%	21	26.5
	20.5	26
20%	19	24
	18.5	24.5

Table 2 Compressive Strength Test Results Replacement by Cement

% of Glass powder	**Compressive strength**	
	At7 days (MPa)	At28 days (MPa)
0%	16	23
	15.5	23
10%	14	20
	13.5	20.5
15%	13	19
	12.5	18.5

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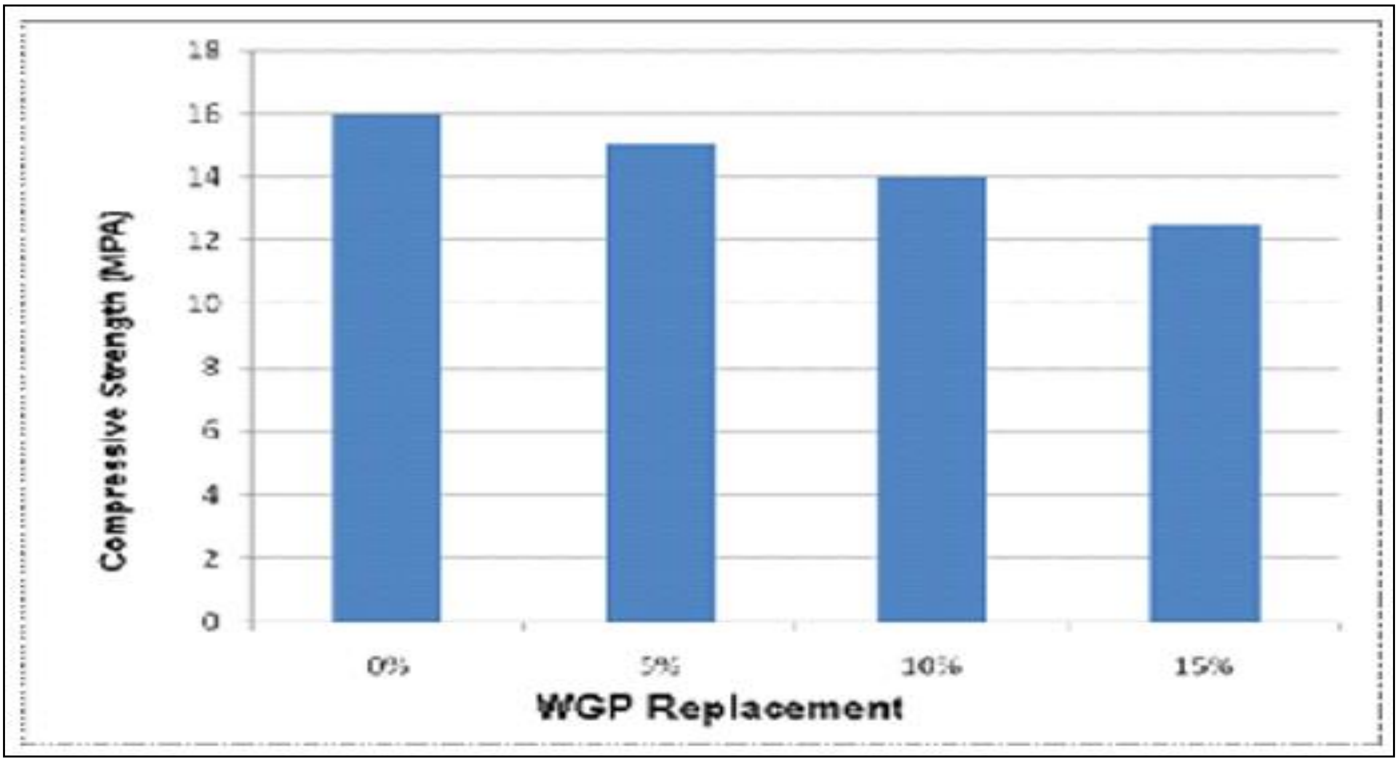

Fig 2 Comparative Results at 7 Days with WGP Replacement by Cement

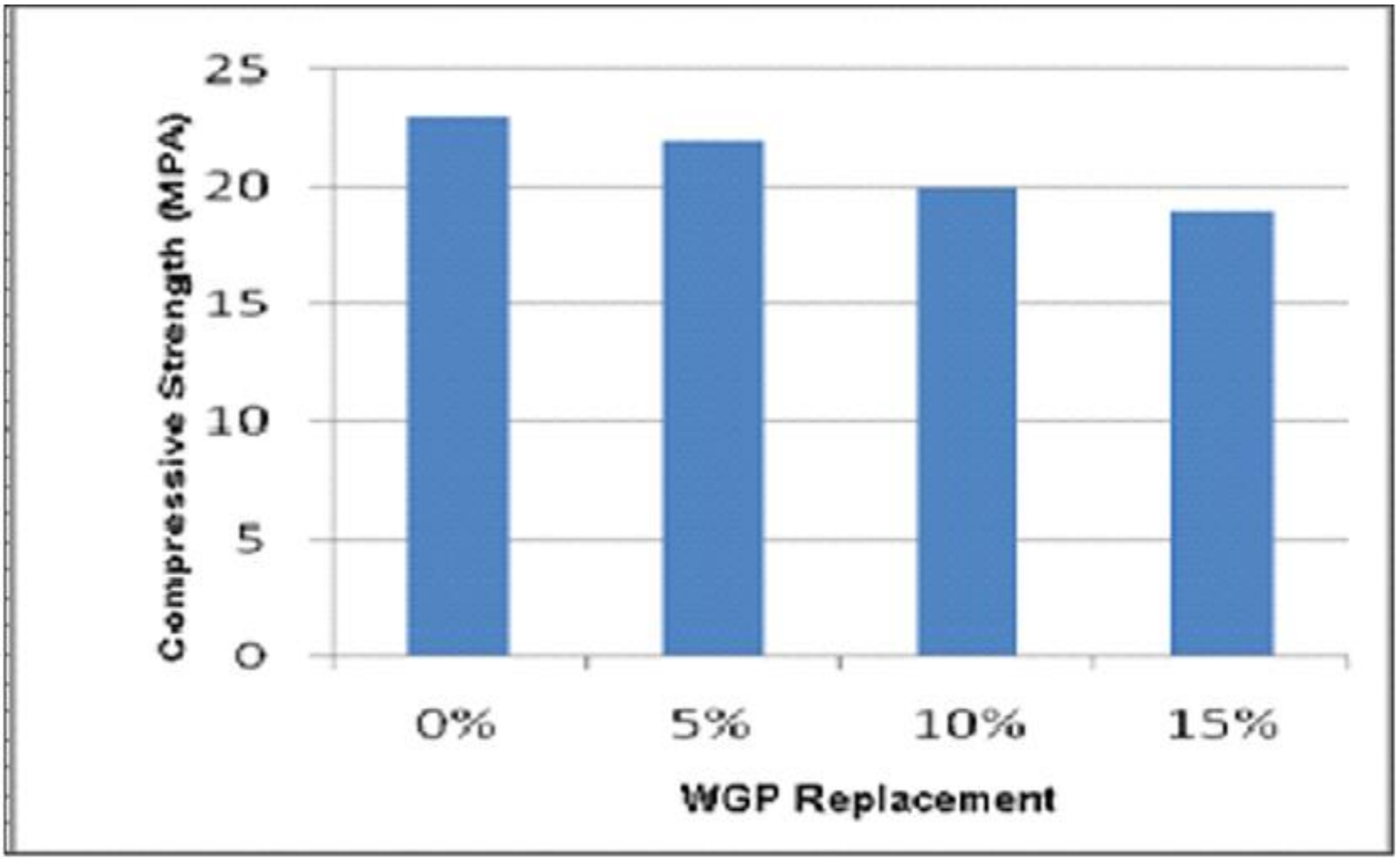

Fig 3 Comparative Results at 28 Days with WGP Replacement by Cement

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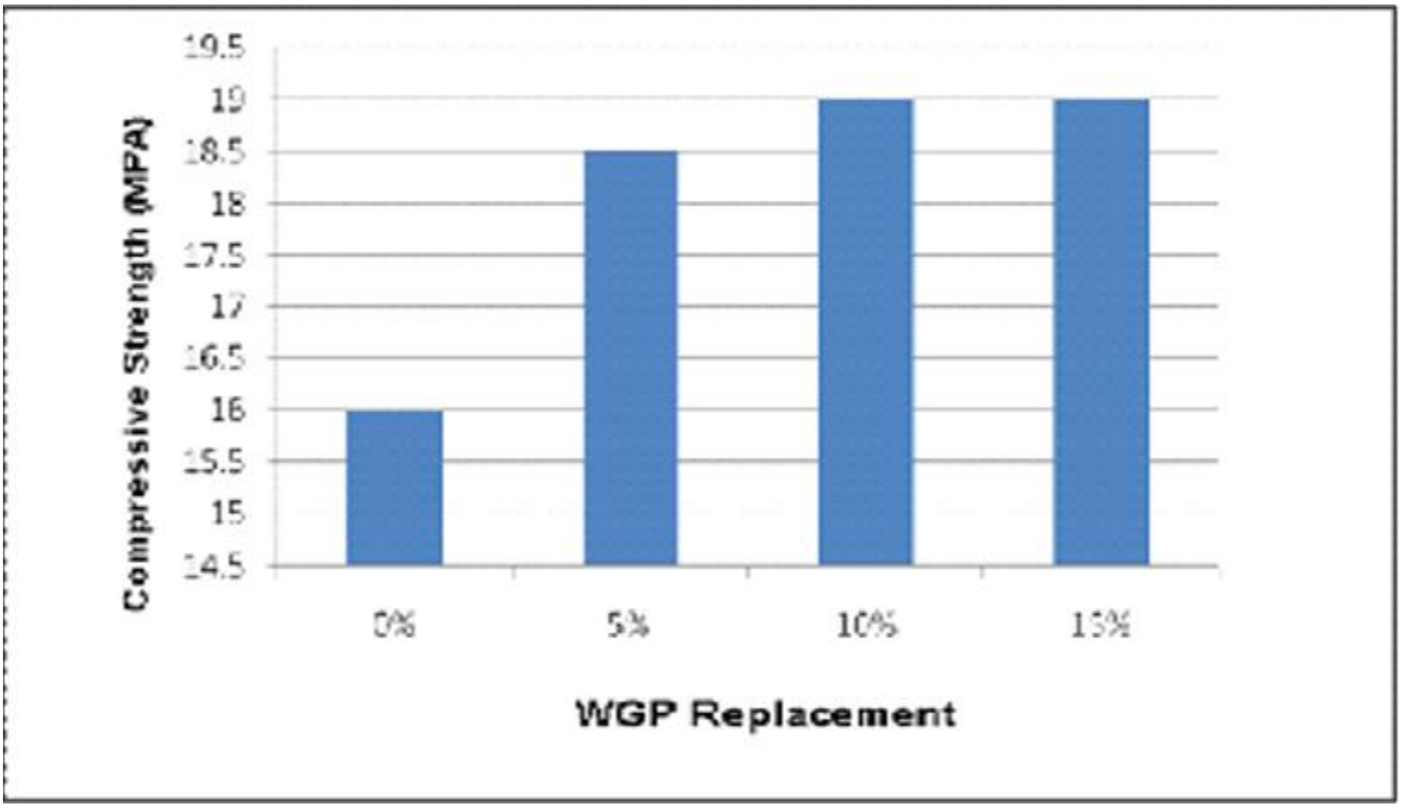

Fig 4 Comparative Results at 7 days with WGP Replacement by Sand

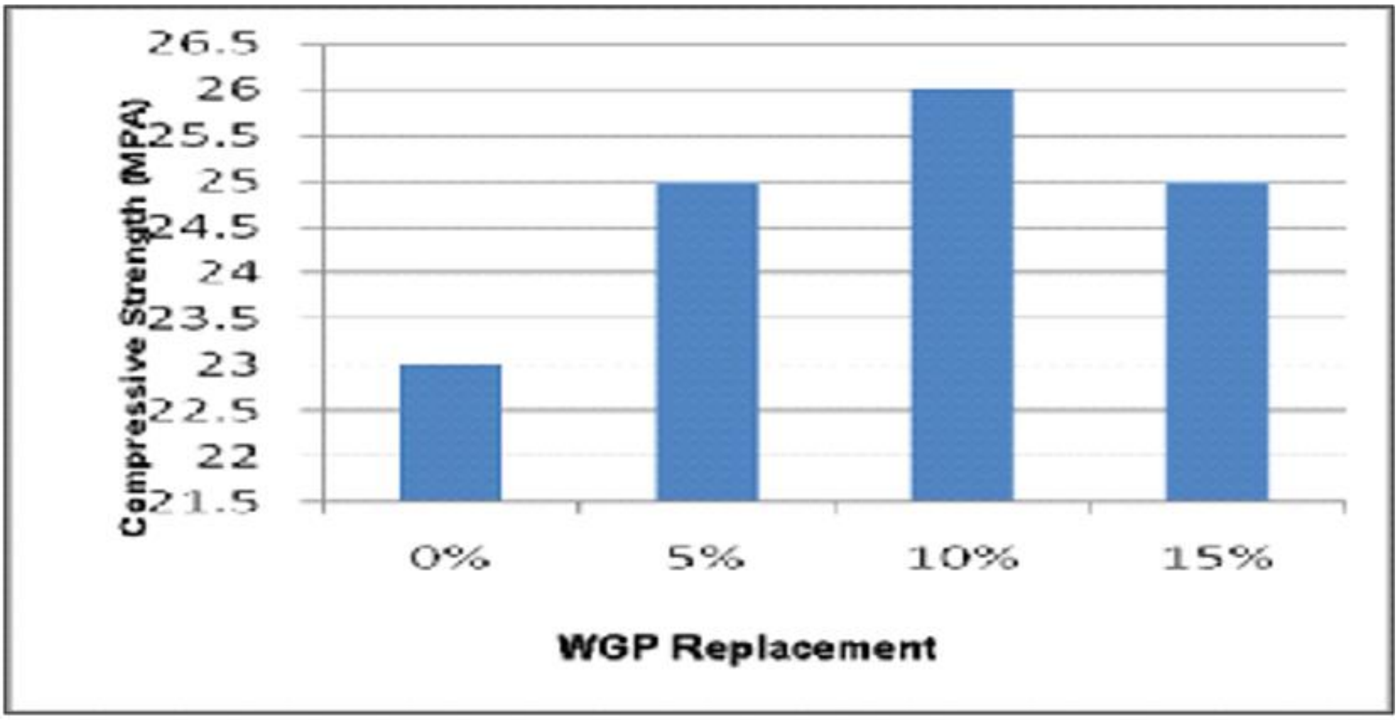

Fig 5 Comparative Results at 28 Days with WGP Replacement by Sand

V. CONCLUSIONS

This study highlights the significant potential of utilizing recycled waste glass as a partial replacement for fine aggregates in concrete. The incorporation of waste glass not only improves the mechanical properties of concrete, such as compressive strength and durability, but also promotes sustainability by reducing reliance on natural resources and minimizing waste. By optimizing factors such as particle size and replacement percentage, as well as ensuring proper curing conditions, recycled glass can be effectively integrated into various concrete applications. This approach offers a promising solution to the challenges of waste management in construction, contributing to both the environmental and technical goals of modern, sustainable building practice

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