

# Experimental Investigation on Waste Glass Powder as Partial Replacement of Cement in Concrete for Sustainable Construction

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**Abstract**—The ever-increasing production of waste glass and the high environmental burden associated with cement manufacturing present a dual challenge to sustainable construction. Waste glass, being amorphous and rich in silica, can potentially act as a supplementary cementitious material (SCM) when finely ground. This study investigates the utilization of waste glass powder (WGP) as a partial replacement of cement in concrete to achieve environmental sustainability and improved material performance. Four major studies Islam et al. (2017), Shirzad et al. (2023), Hassani et al. (2023), and the IJERT (2019) experimental report were reviewed to formulate an experimental plan. From literature, it is evident that WGP exhibits pozzolanic reactivity at particle sizes below 75  $\mu\text{m}$ , and optimum performance is generally achieved at 15–25% replacement of cement. The proposed experimental work focuses on analyzing the effect of varying WGP percentages (0%, 10%, 20%, 30%) on the fresh, mechanical, and durability properties of concrete, using locally sourced waste glass from Maharashtra, India. Anticipated outcomes include reduced cement usage, improved long-term strength due to secondary C–S–H formation, and mitigation of landfill waste. This study aims to validate WGP as a sustainable alternative binder, aligning with circular economy principles in the construction industry.

**Index Terms**—Waste glass powder, Supplementary cementitious material, Sustainable concrete, Pozzolanic activity, Compressive strength, Alkali-silica reaction.

## I. INTRODUCTION

Concrete remains the most widely used construction material in the world, but its primary binder Portland cement—has a significant environmental footprint. Cement production alone accounts for nearly 8% of

global CO<sub>2</sub> emissions. On the other hand, waste glass, generated from packaging, construction, and household sources, is non-biodegradable and contributes heavily to landfill accumulation. Most waste glass is underutilized due to difficulties in recycling mixed-colored glass, leading to major environmental problems.

Recent studies have revealed that finely ground glass powder, due to its high silica content ( $\text{SiO}_2 \approx 70\text{--}75\%$ ), can react with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate (C–S–H) gel. This pozzolanic reaction can improve long-term strength and microstructure densification of concrete while reducing cement demand. Thus, glass powder offers a dual advantage: waste valorization and cement reduction.

This research seeks to explore the potential of waste glass powder as a partial cement replacement material, aiming to identify an optimum replacement percentage that maintains or enhances the mechanical and durability performance of concrete while improving sustainability.

## II. LITERATURE REVIEW

### 2.1 Waste Glass Powder as Pozzolanic Material

Islam, Rahman, and Kazi (2017) examined the chemical and physical properties of waste glass powder and confirmed its pozzolanic potential. Their study on mortar and concrete with 0–25% WGP replacement showed an increase in compressive strength up to 20% replacement, attributed to secondary C–S–H formation. The authors also

observed that the workability of mortars improved slightly due to the smooth surface of glass particles. Shirzad et al. (2023) extended this understanding by analyzing the effect of particle size. Finer glass particles ( $< 45 \mu\text{m}$ ) produced higher compressive strengths compared to coarser fractions ( $74 \mu\text{m}$ ). This demonstrates that fineness is critical to enhancing reactivity and achieving positive performance outcomes.

Hassani et al. (2023), in a comprehensive literature review of 78 studies, highlighted that WGP improves strength, density, and resistance to chemical attack when used at optimal fineness and replacement ratios. However, they also identified research gaps in durability, alkali-silica reactivity (ASR) mitigation, and large-scale field applications.

The IJERT experimental study (2019) confirmed that replacing cement with WGP up to 40% can improve mechanical properties under certain mix designs, but results varied significantly based on grinding fineness and curing duration.

### 2.2 Identified Research Gaps

- Lack of region-specific (India-based) data and optimization for locally available glass waste.
- Limited long-term durability and microstructural studies.
- Variation in reported optimum replacement levels due to inconsistent fineness and mix design.
- Minimal assessment of environmental and cost benefits.

Hence, this study aims to experimentally validate WGP as a cement replacement material under controlled conditions with local glass sources, addressing these knowledge gaps.

## III. MATERIALS

- Cement: Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269:2013.
- Fine Aggregate: River sand passing through 4.75 mm sieve.
- Coarse Aggregate: Crushed granite (20 mm maximum size).
- Water: Clean potable water.
- Glass Powder: Recycled waste glass collected from bottle and window waste, crushed and ground to a particle size below  $75 \mu\text{m}$  using a ball mill.

- Admixture: Polycarboxylate ether (if needed) to maintain workability.

Chemical Composition of Glass Powder (XRF results from literature):  $\text{SiO}_2 = 72\text{--}75\%$ ,  $\text{CaO} = 9\text{--}11\%$ ,  $\text{Na}_2\text{O} = 12\text{--}14\%$ ,  $\text{Al}_2\text{O}_3 \approx 1\text{--}2\%$ .

This composition confirms a high silica content suitable for pozzolanic reactions.

### 3.1 Mix Design

An M25 grade concrete mix was designed as per IS 10262:2019. The control mix was prepared with a water-cement ratio of 0.45. Cement was replaced by waste glass powder at 0%, 10%, 20%, and 30% by weight.

Mix ID	WGP Replacement (%)	Water-Cement Ratio	Target Strength (MPa)
M0	0	0.45	25
M1	10	0.45	25
M2	20	0.45	25
M3	30	0.45	25

### 3.2 Specimen Preparation

- Cubes ( $150 \times 150 \times 150 \text{ mm}$ ) for compressive strength.
- Cylinders ( $150 \times 300 \text{ mm}$ ) for split tensile strength.
- Beams ( $100 \times 100 \times 500 \text{ mm}$ ) for flexural strength. All specimens were cured in water for 7, 28, 56, and 90 days before testing.

### 3.3 Tests Conducted

1. Fresh Concrete Tests:
  - Slump test for workability (IS 1199:1959).
  - Fresh density.
2. Hardened Concrete Tests:
  - Compressive strength (IS 516:2014).
  - Split tensile strength (IS 5816:1999).
  - Flexural strength (IS 516:2014).
3. Durability Tests (selected):
  - Water absorption.
  - Rapid chloride permeability (RCPT).
  - Alkali-silica reaction (ASTM C1260) if feasible.

## IV. EXPECTED RESULTS AND DISCUSSION FRAMEWORK

### 4.1 Workability

Workability is expected to slightly decrease with increasing WGP content due to the finer particles'

higher surface area, which increases water demand. However, at low replacement levels (10–20%), the smooth surface of glass powder may offset this effect.

#### 4.2 Compressive Strength

Compressive strength is anticipated to increase up to 20% replacement, aligning with Islam et al. (2017) and Shirzad et al. (2023). Beyond 30%, dilution of cementitious material may reduce early strength. Long-term curing (90 days) may show higher strength due to pozzolanic activity forming secondary C–S–H gel.

#### 4.3 Split Tensile and Flexural Strength

Moderate improvements are expected up to 20% replacement. The dense interfacial transition zone (ITZ) due to fine glass powder may enhance tensile and flexural behavior.

#### 4.4 Durability

Reduced water absorption and chloride permeability are expected as glass powder refines pore structure. However, ASR risk must be monitored; particle size below 75 µm helps mitigate it.

#### 4.5 Environmental and Economic Benefits

- Cement reduction by 20% reduces CO<sub>2</sub> emissions by ~180 kg/ton of cement saved.
- Waste glass recycling diverts non-degradable material from landfills.
- Cost savings arise from replacing a portion of expensive cement with low-cost glass waste after grinding.

### V. CONCLUSIONS

1. Waste glass powder (WGP) possesses high silica content and can effectively act as a pozzolanic material in concrete.
2. Experimental and literature evidence show optimum performance at around 20% replacement of cement by WGP.
3. Finer glass particles (< 45 µm) exhibit enhanced reactivity and mechanical performance.
4. Concrete with WGP shows improved long-term strength and durability with reduced cement consumption.
5. Environmental benefits include reduced CO<sub>2</sub> emissions and effective utilization of waste glass in the circular economy framework.

6. Further studies on ASR mitigation, long-term durability, and field applications are necessary before large-scale use.

### VI. FUTURE SCOPE

- Microstructural analysis (SEM/EDS) to confirm pozzolanic reaction products.
- Life-cycle assessment (LCA) and carbon footprint quantification.
- Durability studies under sulfate/chloride environments.
- Field application trials for pavement or structural concrete.

### REFERENCES

- [1] Islam, G.M.S., Rahman, M.H., & Kazi, N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. *International Journal of Sustainable Built Environment*, 6(1), 37–44.
- [2] Shirzad, M., Behsoodi, M., & Tasal, F. (2023). Utilisation and effects of various particle sizes of waste glass powder as partial replacement of cement in concrete. *International Advanced Researches and Engineering Journal*, 7(3), 191–199.
- [3] Hassani, A., Matos, P., Zhang, X., & Teixeira, J. (2023). Green Concrete with Glass Powder—A Literature Review. *Sustainability*, 15(20), 14864.
- [4] IJERT (2019). Analysis of glass powder as a partial replacement of cement in concrete. *International Journal of Engineering Research & Technology (IJERT)*, Vol. 8, Issue 6.
- [5] IS 10262:2019 – Concrete Mix Proportioning – Guidelines.
- [6] IS 516:2014 – Methods of Tests for Strength of Concrete.