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Utilization of Waste Glass as Partial Replacement of Fine Aggregate in Concrete: An Experimental Investigation

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Abstract : The construction industry faces the dual challenge of managing increasing solid waste and diminishing natural sand resources. Waste glass, an abundant and non-biodegradable material, has potential as a partial replacement for fine aggregate in concrete, promoting sustainability. This investigation evaluates the effect of replacing fine aggregate with crushed waste glass on concrete's workability, mechanical strength, and durability. Concrete mixes of M25 grade were prepared with glass content varying between 0-50% by weight of fine aggregate. Experimental tests including slump for workability, compressive strength at 7 and 28 days, and qualitative durability assessments were conducted. Results reveal an optimal glass replacement level of 10% for improved compressive strength, with higher replacements leading to strength reductions, likely due to alkali-silica reaction (ASR). The findings support the viability of sustainable glass incorporation in concrete at controlled levels to reduce environmental impact and resource consumption.

Keywords: Waste glass, fine aggregate replacement, concrete, compressive strength, alkali-silica reaction, sustainability.

1. Introduction

The surge in urbanization and industrialization has led to an exponential increase in construction activities and solid waste production globally. Glass waste is a significant fraction of urban solid waste and poses serious disposal challenges due to its non-biodegradability. Simultaneously, the extraction of natural sand for concrete is causing depletion of riverbeds and ecological imbalance. The construction sector, a major consumer of natural aggregates, seeks alternatives to conventional materials that minimize environmental footprints and promote circular economy principles.

Reusing waste glass in concrete as a partial substitute for fine aggregates offers an environmentally beneficial solution. Glass is primarily composed of silica, which can act as a pozzolanic material under certain conditions, potentially improving concrete strength and durability. However, concerns exist regarding alkali-silica reaction (ASR), which can lead to expansion and cracking in concrete, particularly with high glass content or unsuitable particle sizes.

This study investigates the effects of replacing natural fine aggregate with crushed waste glass at different percentages on concrete's behavior. The goal is to establish an optimal replacement level that balances mechanical performance and sustainability considerations.

2. Literature Review

Research on waste glass in concrete indicates mixed outcomes depending on glass particle size, replacement ratio, and curing conditions. Shao et al. (2000) observed that finely ground glass powder exhibits pozzolanic activity enhancing strength and reducing ASR risks. Ismail and Hassan (2009) reported that fine glass sand replaced up to 20% of natural sand without significant strength loss. Meanwhile, Abdallah et al. (2014) demonstrated that glass sand improved compressive strength but warned against ASR-induced durability issues, recommending limits on glass content and particle size control.

Recent studies by Maek et al. (2020) and Jahami et al. (2022) reinforced these findings, showing that up to 10-20% glass sand replacement can be beneficial, provided that the glass is properly processed and mixed. Surface treatments and supplementary cementitious materials are recommended to mitigate ASR for higher replacement percentages.

Still, there is a research gap regarding practical guidelines for substitution rates and the corresponding performance impacts under regional material and climatic conditions, particularly in India. This study contributes by experimentally evaluating M25 grade concrete with locally sourced waste glass.

3. Materials and Methods

3.1 Materials

Cement: Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112.

Fine Aggregate: Natural river sand confirming to IS 383.

Coarse Aggregate: Crushed stone aggregates of 20 mm maximum size.

Waste Glass: Collected from post-consumer sources, crushed, and sieved to match fine aggregate grading.

Water: Potable water used for mixing and curing.

3.2 Mix Design

Concrete mix was designed for M25 grade as per IS 10262 guidelines. The water-cement ratio was maintained at 0.48. Fine aggregate was replaced by waste glass at 0%, 10%, 20%, 30%, 40%, and 50% by weight. Six batches were prepared accordingly.

3.3 Sample Preparation

Concrete cubes of 150 mm dimensions were cast for each mix. After 24 hours, specimens were demolded and immersed in water for curing. Tests were conducted at 7 and 28 days of curing.

3.4 Tests Conducted

Workability: Measured using slump test as per IS 1199.

Compressive Strength: Tested using a compression testing machine on cubes according to IS 516.

Durability Observations: Visual inspection for cracks and physical deterioration to qualitatively assess ASR influence.

4. Results

4.1 Workability

Slump values decreased with increasing waste glass content, indicating reduced workability due to the angular and non-absorbent nature of glass particles.

SLUMP VALUES	
Percentage (%)	**Value (mm)**
0	108
10	105
20	104
30	103
40	101
50	101

4.2 Compressive Strength

The compressive strength at 7 days showed an increase from 21 MPa to 24 MPa at 10% glass replacement. Beyond 10%, strength gains plateaued or declined.

At 28 days, the strength peaked at 32.80 MPa for 10% replacement compared to 32.15 MPa for control. Strength dropped to 28.50 MPa at 50% replacement.

Cube Designation	7 Days Compressive Strength (Mpa)	28 Days Compressive Strength (Mpa)	Glass %
1	21	32.15	0
2	24	32.8	10
3	23.8	32.75	20
4	21.67	30.2	30
5	21.33	29.67	40
6	23.25	28.5	50

Table 1: Compressive Strength at different composition of glass

4.3 Durability Observations

Specimens with 40% and 50% glass showed minor surface cracks after 28 days, indicative of ASR effects.

It is observed that on replacing fine aggregate by 20% glass waste on average there is an increase in compressive strength at 7day by 13.33% however, at 28day; increase in compressive strength is 1.86%. It is seen that there is an increase in compressive strength at 7day by about 1.57% whereas at 28day compressive strength is decreased marginally at 30% and 40% replacement level.

5. Discussion

The improvement in compressive strength at low replacement levels is attributed to better particle packing and pozzolanic reaction between glass silica and cement hydration products. The reduction at higher replacements likely results from poor bonding at the glass-cement interface and ASR expansion. Decrease in workability is consistent with findings in literature due to glass particle shape and surface properties.

Controlled replacement up to 10% is recommended to balance mechanical properties and sustainability benefits. Further processing of glass particles or use of additives may enable higher substitution rates.

6. Conclusion

This study confirms that waste glass can be effectively used as a partial replacement of fine aggregate in concrete up to 10% by weight without compromising strength or durability. This can lead to reduced environmental impact through waste utilization and conservation of natural sand. However, higher glass contents risk ASR and strength loss, necessitating careful mix design and additional mitigation measures.

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