Utilizing Crushed Waste Glass as A Sustainable Replacement for Fine Aggregate in Concrete

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Abstract
Concrete, a vital material in modern construction, combines strength, durability, and fire resistance. However, the conventional use of river sand in concrete is ecologically concerning due to its scarcity and environmental impact. To address this, waste glass is explored as a sustainable replacement for fine aggregate. This study investigates the effects of crushed waste glass on concrete workability, water absorption, compressive strength, and flexural strength. Different glass replacement levels (0%, 10%, 20%, and 30%) and curing periods were considered. The research aims to optimize glass content, evaluate its impact on concrete properties, and compare its environmental effects with traditional methods. The results indicate that waste glass improves workability and reduces water absorption. Compressive and flexural strengths initially increase with glass content but decrease at higher levels, due to potential alkali-silica reaction. The study concludes that waste glass can be effectively utilized in concrete to enhance sustainability and resource conservation. Further research is recommended to explore specific applications and long-term effects.

Keywords: crushed waste glass, fine aggregate replacement, concrete workability, compressive strength, flexural strength, sustainability, environmental impact.

I. INTRODUCTION

Concrete has become indispensable in modern construction due to its exceptional qualities such as strength, permeability, durability, and fire resistance. Unlike other materials, it combines these characteristics effectively (Abrananth & Sankar , 2020). However, the conventional use of river sand in concrete production has become cost-prohibitive and ecologically concerning due to its scarcity and environmental impact (Lineesh, Sivakumar, & Sundaram, 2014). To address these issues, alternative materials are being explored to create eco-friendly and robust concrete (Farendra, Sinha, Mandilwar, & Manas , 2022).

Several alternatives, including marine sand, quarry waste, and crushed stone, have been explored. Among these, glass powder (QSD) stands out as a promising choice, particularly in regions with abundant rock resources (Reddy & M V, 2022). Glass, commonly discarded, poses environmental risks due to its non-biodegradable nature (Ansari, Mishra, & Vanshaj, 2022). Yet, it holds great potential for recycling, contributing to energy savings and growing recycling efforts across industries (Alhaji B., D. N., Yusuf A., & Shehu, 2019). As awareness about recycling increases, using waste glass in various sectors becomes more appealing.

II. SCOPE OF THE STUDY

The material chosen for replacement in our study is waste glass. Though often discarded, glass can be harmful to the environment. Yet, due to specific attributes, it can effectively replace materials in concrete. This incorporation not only boosts affordability but also tackles disposal issues, reducing the impact on rivers and natural aggregates. Recycling such waste offers an eco-friendly disposal solution. Moreover, utilizing these materials can enhance concrete characteristics. Glass waste's use has attracted substantial attention, especially in concrete construction, owing to its notable potential.

III. LITERATURE REVIEW

(Singh & Varinder, 2018) conducted an experiment to make concrete environmentally friendlier and address glass waste landfilling. They replaced fine aggregates with glass powder, also adding fly ash to mitigate alkaline silicate reaction. By using small sieved glass in smaller amounts, they aimed for greener concrete. This discovery highlights glass's potential as a sustainable replacement for fine aggregates.

(Sawant, 2018) investigated substituting glass for fine aggregate in concrete without compromising strength. The study found that 10% waste glass replacement was optimal, with slight strength increase up to 10% replacement after 28 days, decreasing at higher levels (20-30%).

(Reddy & M V, 2022) explored replacing all natural sand in concrete with glass powder. Concrete made with glass powder exhibited around 10% higher compression and flexural strength compared to regular concrete. Strength of glass powder reduced from 1.6% to 1.3% of super plasticizer dose, while M40 grade concrete strength increased for 1% to 1.3% of super plasticizer.

(Upreti & Mandal, 2021) studied substituting fine aggregate with crushed glass in concrete. Replacing 5-10% fine aggregate with crushed glass enhanced strength, lightweight nature, workability, and durability. A 15% replacement slightly reduced both strength and durability.

(Premalatha & Srinivasan, 2019) analysed concrete properties by replacing river sand with glass powder. Testing various concrete grades with up to 50% glass powder replacement for fine aggregate, they found improvement in strength up to 30% replacement. Strength values after 40% and 50% replacements matched control mix.

(Saritha, Haripriya, Harshini, & Reddy, 2018) studied replacing coarse aggregate with waste glass, with 10% replacement rate proving optimal. Marginal strength improvement at 20% replacement up to 28 days; further increase led to strength decline. Concrete form influenced slump and compacting factor, and recycled wine glass particles affected air content. Up to 30% glass incorporation was feasible with additives for desired workability and air content.

IV. RESEARCH GAP

Despite current research highlighting the potential benefits of using waste glass powder as a partial substitute for fine aggregate in concrete, there remain gaps requiring further investigation. Continuous improvement is essential, as underscored by the following conclusions drawn from prior experiments:

a. The optimal percentage of waste glass replacement varies based on concrete grade, particle size, and variables. Additional research is needed to determine suitable replacement levels for diverse concrete mixes.

b. Further study is necessary to assess the impact of additives on concrete properties and address the urgent challenge of alkali-silica reaction, ensuring successful use of crushed glass in various construction applications.

c. Comprehensive examination of concrete workability using varying proportions of crushed glass is essential.

V. OBJECTIVE OF THE STUDY

The research aims to:

a. Study concrete workability with crushed glass.
b. Evaluate waste glass suitability as fine aggregate replacement.
c. Examine glass powder's impact on concrete's physical traits.
d. Optimize crushed glass levels in concrete with various cement types.
e. Gauge environmental effects of glass in concrete vs. traditional methods.

VI. MATERIALS AND METHODOLOGY

Our study aimed to assess workability, water absorption, compressive strength, and flexural strength of concrete. We varied glass powder replacement (0%, 10%, 20%, and 30% by weight) and curing periods (7 and 28 days for compression; 28 days for flexural strength). For compressive strength, 150 mm × 150 mm × 150 mm cubes were cast, while 100×100×500 mm^3 rectangular specimens were used for flexural strength, both incorporating different glass percentages and a control of 0%. Strength of these specimens was compared to conventional concrete after 28 days of moist curing. The concrete mix followed M20 standard with a 0.45 water-cement ratio as per Indian Standards IS 10262 - 2009. Our goal was to identify the optimal demolished waste glass percentage that maintains recycled concrete strength. The materials used in this investigation were:

a. Cement: We used Ordinary Portland Cement (OPC) grade 53 and Portland Pozzolana Cement (PPC) with fly ash base, conforming to IS 1489, sourced locally.
b. Fine Aggregate: Local river sand with minor soil content, conforming to IS: 383 – 1970 zone II, passing a 4.75mm sieve and retained on a 1.2mm sieve.
c. Coarse Aggregates: Selected to pass through a 20mm IS sieve and be retained on a 4.75mm IS sieve, with various shapes and sizes for improved grading, sourced from a nearby construction site.
d. Glass: Waste glass sourced from local dump yards and rag pick shops, primarily white window glass and some green and brown glass bottles. Crushed using a hammer and CTM, then sieved for 15 minutes to use the fraction passing a 4.5mm sieve and retained on a 1.2mm sieve.
e. Water: High-quality water without impurities for mixing and curing, adhering to standard practices for concrete procedures.

Fig.6.1: Crushed waste glass

Fig.6.2: Materials prior to mixing

Fig.6.3: casting of beam

Fig.6.4: casting of cube

6.1 Concrete Mix Design as per IS 10262-2009

Attaining desired concrete strength and properties requires a concrete mix design, which determines constituents and their quantities. This process is vital to overcome challenges during placement, curing, and other phases. Effective mix design also contributes to cost-efficient concrete production. Cement, typically the costliest component, is carefully optimized in mix design. Our study employed M20 grade concrete, utilizing a nominal mix design. Ingredients were selected as per specifications, with proportions defined based on cement-aggregate ratios.

6.2 Tests on fresh mix

We conducted an analysis of the freshly mixed concrete to assess its workability. Workability refers to how easily and uniformly tasks like mixing, placing, compacting, and finishing can be accomplished with the newly mixed concrete or mortar. Among various tests, we chose to perform the slump cone test to determine the workability or consistency of the laboratory-prepared concrete mix.

Fig.6.5: Slump test for workability

6.3 Cube Testing

Hardened cubes underwent the following tests: water absorption, compressive strength, and flexural strength.

6.3.1 Water Absorption

Water absorption tests were conducted for all mixtures to measure percentage water absorption. The average dry weight of cubes post-mould removal and the average weight after 28 days of submersion in water were compared. The resulting percentage reflected durability.

6.3.2 Compressive Strength

Compressive strength testing occurred on $150 \times 150 \times 150 \text{mm}^3$ cubes. After proper tempering to prevent voids, cubes were cured in water for 24 hours post-mould removal. On the 7th and 28th days of curing, specimens were tested using a CTM machine. Load was applied at 140 kg/cm² per minute until failure. Compressive strength (f_c) was calculated as:

$f_c = P/A$ N/mm²

Where:

P = load at failure in N

A = compression area in mm².

Fig.6.6: Setup for Compressive strength

Fig.6.7: Cracks in cube specimen

6.3.3 Flexural strength

Flexural strength assessment utilized 100×100×500 mm³ beams, tested after 28 days of curing. Two equidistant loadings were applied to create pure bending moments, aiming to reach maximum tensile stress in the outermost fiber under tension. Modulus of rupture's value depended on beam dimensions and loading type.

For $a > 133$ mm in 100 mm specimens:

$f_{fb} = Pa / bD^2$

For $a < 133$ mm in 100 mm specimens:

$f_{fb} = 3Pa / bD^2$

Where:

b = beam width

D = beam depth
a = crack-to-nearer-support distance
P = maximum load applied to the specimen in N.

Fig.6.8: Setup for Flexural strength

Fig.6.9: Crack in beam specimen

VII. RESULTS AND DISCUSSION

7.1 Workability

We assessed workability using slump cone tests for various mixes containing 10%, 20%, and 30% waste glass powder, comparing them with the workability of the control mix (0% waste glass). Tabulated below are the results:

Table no.7.1: Slump value for different mixes

Crushed waste glass (%)	Slump value for OPC(mm)	Slump value for PPC(mm)
0%	58	64
10%	63	69
20%	67	71
30%	70	67

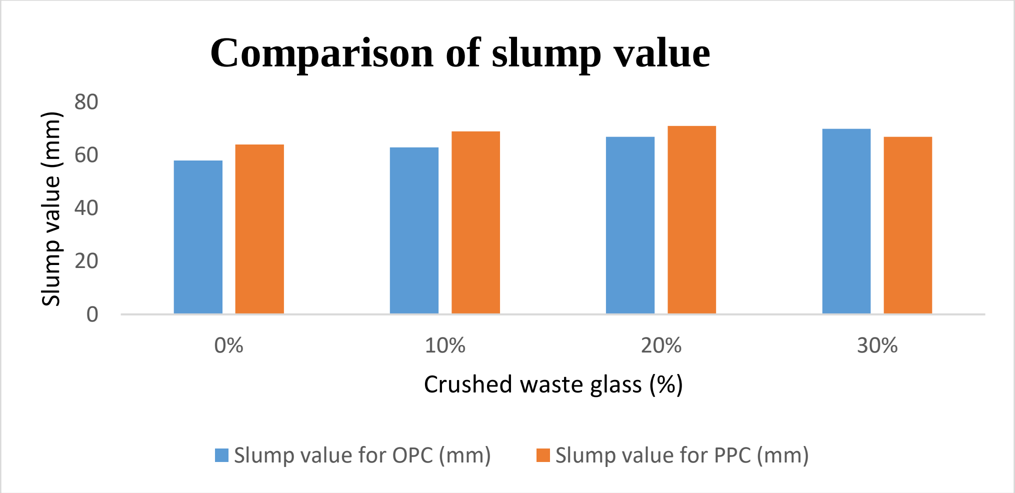

Fig.7.1: Comparison of slump value with different % of glass for OPC and PPC

Discussion: Based on the workability results, it is evident that the concrete mix with glass exhibits higher slump values than the conventional mix. However, minimal disparity in slump values was observed between the two mixes utilizing different types of cement.

7.2 Water absorption

The water absorption test results can aid in selecting the suitable concrete type for a specific project and ensuring its anticipated performance throughout its service life. The table below presents water absorption data for all mixes.

Table no.7.2: Water absorption test results for 150mm x 150mm x 150mm OPC cubes.

Glass Content (%)	Average dry weight before curing (g)	Average wet weight after 28 day curing (g)	Water absorbed (g)	Percentage water absorption (%)
0%	8107	8014	93	1.147
10%	8052	7985	75	0.931
20%	7915	7861	54	0.682
30%	7830	7781	63	0.804

Table no.7.3: Water absorption test results for 150mm x 150mm x 150mm PPC cubes.

Glass Content (%)	Average dry weight before curing (g)	Average wet weight after 28 day curing (g)	Water absorbed (g)	Percentage water absorption (%)
0%	7109	7025	84	1.181
10%	6915	6848	67	0.968
20%	6833	6779	54	0.790
30%	6748	6699	49	0.726

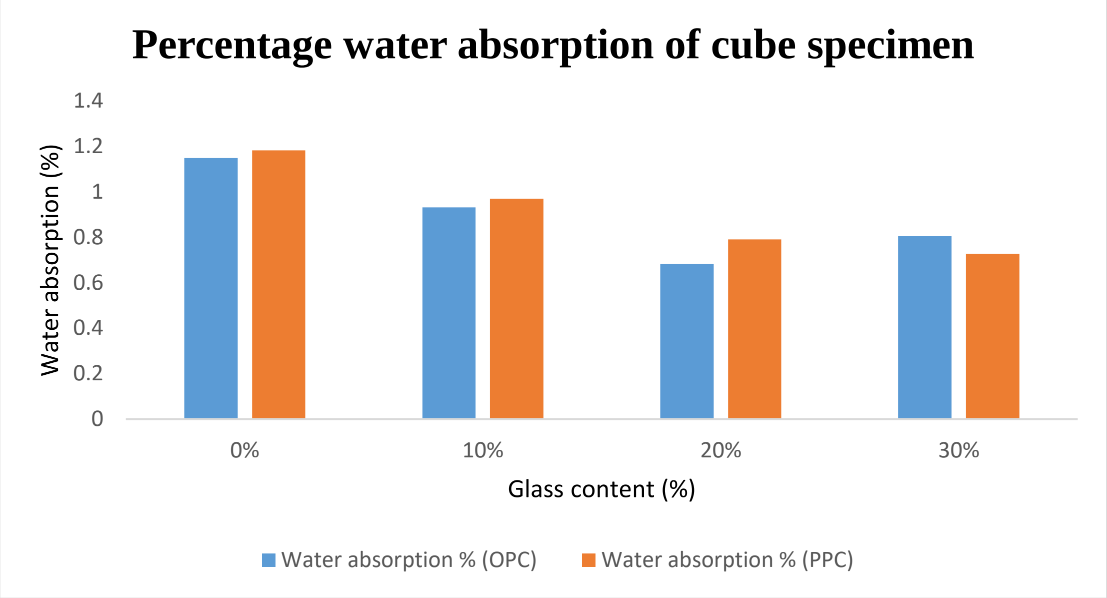

Fig.7.2: Percentage water absorption of cube specimen at 28 days

Discussion: The water absorption test results reveal that increasing glass content in both OPC and PPC mixes leads to a progressive reduction in percentage water absorption. The conventional mix, however, still exhibits the highest water absorption percentage.

7.3 Compressive strength

The table below presents the outcomes of the compressive strength tests conducted on various samples using OPC 53 at both 7 and 28 days.

Table no.7.4: Compressive strength of cube specimen using OPC

Powder glass content (%)	Average Compressive strength obtained in N/mm^2	
	7 day	28 day
0%	17.30	27.65
10%	17.8	29.32
20%	19.24	31.42
30%	17.62	25.98

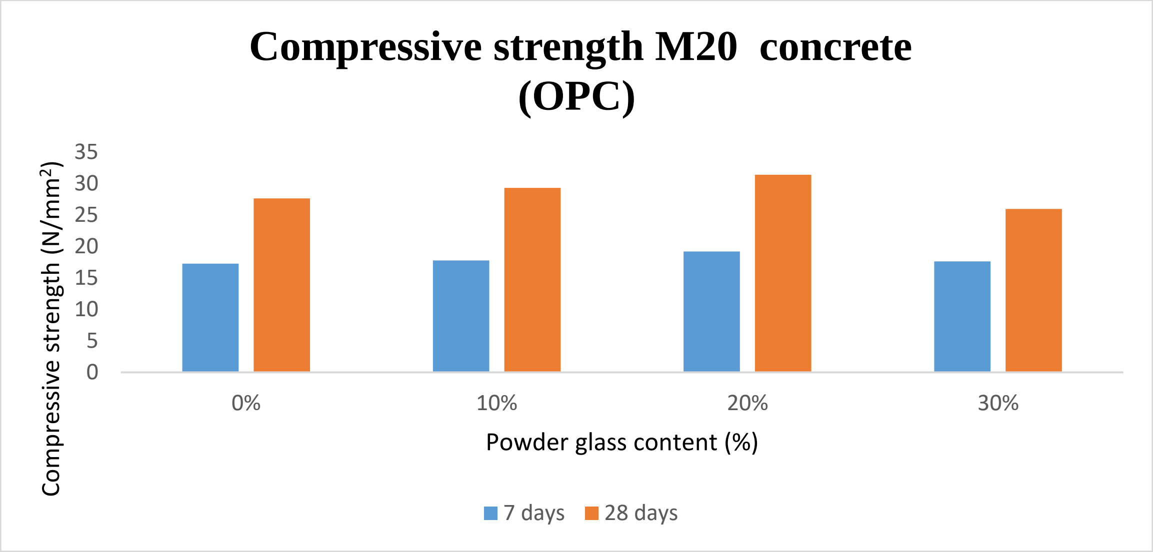

Fig.7.3: Compressive strength on 7th and 28th days (OPC)

Discussion: The compressive strength demonstrates enhancement as waste glass powder content rises continuously. Strength increases at 10% and 20% waste glass powder inclusion, then gradually decreases at 30%, likely due to heightened alkali-silica reaction released during cement hydration. The table below illustrates the findings from compressive tests conducted on various samples using PPC at both 7 and 28 days.

Table no.4.6: Compressive strength of cube specimen using PPC

Powder glass content (%)	**Average Compressive strength obtained in N/mm^2**	
	7 day	**28 day**
0%	14.27	25.53
10%	14.82	26.1
20%	14.53	25.90
30%	13.48	24.74

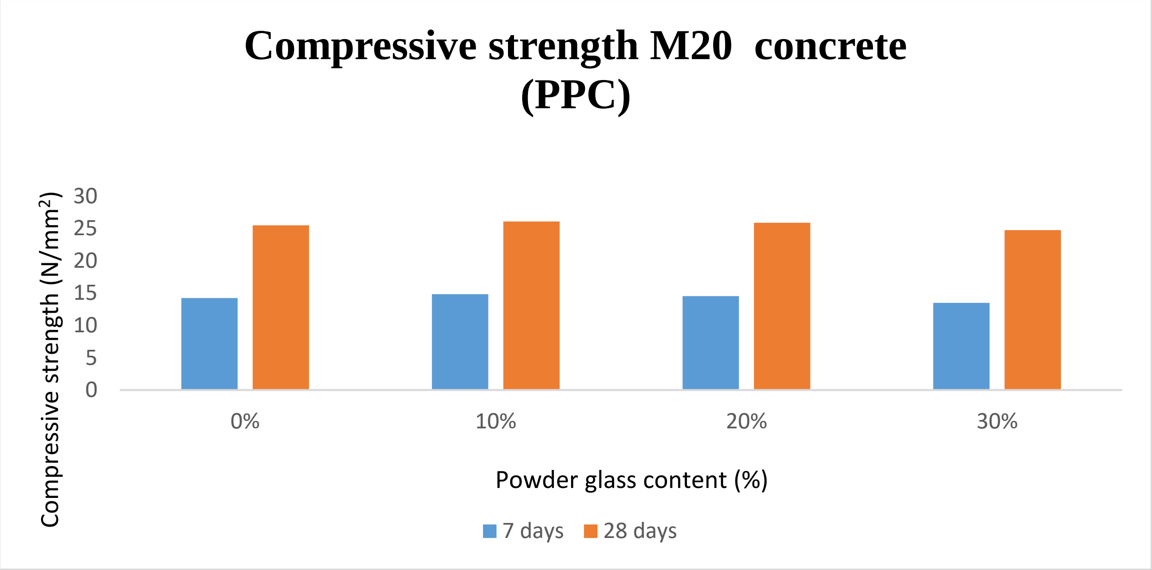

Fig.4.4: Compressive strength on 7th and 28th days (PPC)

Discussion: The strength demonstrates gradual improvement up to 20% glass powder replacement. However, replacing fine aggregate results in a sudden compressive strength drop at 30%, even lower than a normal concrete cube's strength. This decline suggests that increased glass content negatively affects cube properties. Notably, compressive strength using OPC is higher than with PPC for equal waste glass powder replacement percentages.

7.4 Flexural strength

The table below presents the outcomes of the flexural strength tests conducted on various samples using both OPC and PPC at 28 days.

Table no.7.5: Flexural strength of cube specimen

Powder glass content (%)	Flexural strength using OPC	Flexural strength using PPC
0%	3.62	2.4
10%	4.29	3.89
20%	4.70	3.57
30%	3.28	2.73

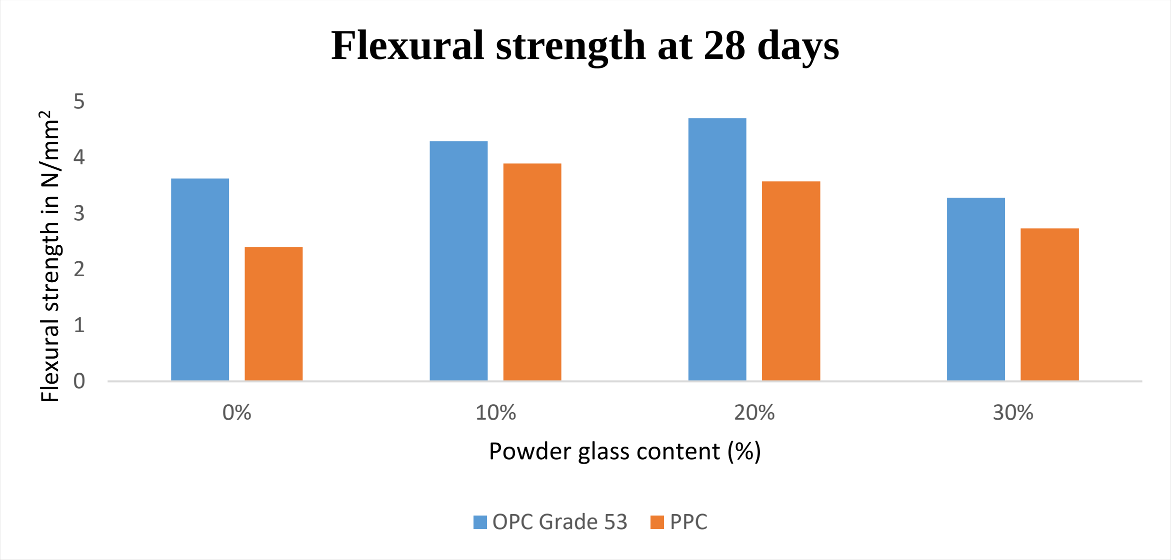

Fig.4.5: Flexural strength at 28 days for OPC and PPC

Discussion: Notably, the flexural strength of the OPC mix significantly surpasses that of the PPC mix for the same level of fine aggregate replacement with waste glass powder at 28 days. Furthermore, the optimal waste glass replacement level varies for the two types of mixes. In the case of OPC, a higher percentage of glass waste can be integrated without compromising flexural strength.

VIII. CONCLUSIONS

8.1 Conclusion

The study aimed to explore the feasibility of employing post-consumer waste glass, which is difficult to recycle and accumulates in landfills, as a concrete aggregate. Based on our findings, the following conclusions were drawn:

a. The optimal replacement of fine aggregate with glass waste for maximum compressive strength is 20% using OPC and 10% using PPC.
b. The optimal replacement of fine aggregate with glass waste for maximum flexural strength is 20% using OPC and 10% using PPC.
c. Glass waste as fine aggregate affects water absorption, showing reduced absorption with increased glass content. Waste glass powder addition enhances hydration, leading to a denser microstructure and improved curing.
d. Crushed glass is a viable fine aggregate substitute, offering potential cost reduction in concrete production by replacing fine aggregate with waste glass.
e. Utilizing waste materials in concrete production conserves energy and primary resources, promoting a safer and sustainable environment through resource conservation.

8.2 Scope for future work

a. Investigate the applicability in marine constructions by evaluating extended-term strength.
b. Further research can focus on studying alkali-silicate reaction effects using PPC.
c. Experiment with various alternative fine aggregates alongside glass, considering different ratios.

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