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Optimization of Pulverized Glass Content for Sustainable and Durable Concrete Production

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Abstract

This study aims to investigate the potential of using pulverized glass as a partial substitute for fine aggregate in concrete, focusing on how it affects the mechanical properties of the resulting composite. By exploring various replacement levels of pulverized glass, the project identified an optimal balance that enhances both the sustainability and performance of concrete.

An experimental work was performed to study the slump, unit weight, compressive strength, dry density and water absorption of concrete partially substituted with pulverized glass. A concrete mix with a target mean strength of 20N/mm² was designed using a standard 1:2:4 mix ratio. Pulverized glass was used to partially replace the fine aggregate at replacement percentages of 0%, 5%, 10%, and 15% in accordance to relevant literature. The concrete was then cast into cubes and allowed to cure for 7, 14, and 28 days at room temperature in a laboratory.

The results indicate that workability increases with higher pulverized glass content, with slump values rising from 30 mm for the control mix to 46 mm at 15% replacement. However, compressive strength generally decreased as the replacement percentage increased. The 5% replacement mix achieved the highest compressive strength among the modified mixes, with an average 28-day strength of 19.72 N/mm² compared to 20.68 N/mm² for the control mix. Nine concrete mixes were examined using discarded glass in place of 0%, 5%, and 15% of the weight of sand. The study concludes that, crushed glass can substitute up to 5% of fine aggregate in concrete, which helps lessen the effects of sand mining. This concrete can be regarded as eco-friendly since it uses less raw materials and has fewer negative environmental effects.

Keywords: Pulverized glass, Fine aggregate replacement, Sustainable concrete, Workability, Compressive strength, Waste glass recycling, Eco-friendly concrete, Green construction materials, Partial substitution

INTRODUCTION

Reusing used glass is a significant concern in many nations because of the rise of solid waste in the environment. Glass is regarded as a significant solid waste that is present in most nations worldwide. Its presence causes environmental issues and is not much impacted by weather (Caijun et al., 2007). Therefore, it is necessary to identify appropriate ways to address this issue. In order to demonstrate the potential of using waste glass as a building material and substituting it partially in the concrete mixture without compromising the quality of the concrete, important research has been done. As a result, concrete can be made with suitable qualities. The goal of many investigations is to substitute a specific percentage of crushed waste glass for fine aggregate in the concrete mixture. These studies also examine the potential use of waste glass as a partial or complete substitute for traditional concrete materials, which has two benefits. The first is that it lessens the depletion of nature's resource riches. The second is lowering environmental hazards by creating glass Crete, a type of unconventional concrete.

Unlike other inert materials, glass may be recycled repeatedly without losing its chemical composition. Unfortunately, a large amount of glass becomes unsuitable for recycling; the effectiveness of this procedure is influenced by a number of factors.

First, how well do different glass hues be collected and sorted? If different colors (such clear, green, amber, etc.) are mixed together, they can't be used to make new glass containers. Second, the amount of contaminants that may be present in the stockpile has an impact, followed by the cost of shipping. since not every city in a nation has a recycling factory. Thus, the main aim of environmental authorities is to reduce, as far as possible, the disposal of post-consumer glass in landfill or recycle to glass products. Therefore, it has been supposed that, if glass could be incorporated in concrete production, it would greatly reduce the disposal of waste glass or its use in lower valued works such as fill or road base materials (Shayan, 2002). The main issue with using glass in concrete, however, is the alkali-silica reaction, which occurs when silica-rich glass particles (glass aggregate) react with the alkali in cement (Shao et al. 2000). Around the world, there has been a lot of interest in using recovered waste glass in concrete. Sadly, post-consumer glass makes up a significant amount of solid waste, and because it can be challenging to find suitable markets that would accept glass collected for recycling, its presence and buildup have had an adverse effect on the environment. The United States released over 9.2 million metric tons of post-consumer glass in 1994. Over 100,000 tons of glass waste are collected each year in New York City alone, with container glass accounting for the majority of this waste. According to Chesner et al. (1997), the Material Recycling Facilities Company (MRFC) pays up to $45 per ton for the disposal of these wastes. These factors make research on the impacts of employing waste glass necessary to determine whether it may be used in place of waste glass as a fine aggregate in concrete.

Through this study, we aim to provide valuable insights into the potential benefits of utilizing recycled glass in concrete, including reduced reliance on natural resources, cost-effectiveness, and the reduction of waste that would otherwise contribute to landfill accumulation. Ultimately, this research will contribute to the development of more sustainable construction practices, promoting environmental protection while maintaining the performance standards required in modern concrete applications.

MATERIALS AND METHOD

A. MATERIALS USED

The materials used in this study include:

1. Cement
2. Coarse aggregate (granite)
3. Fine aggregate (sand)
4. Crushed waste glass (as fine aggregate replacement)
5. Water.

Cement

Ordinary Portland Cement (OPC) conforming to NIS: 1325.2015 was used in this study. The cement was sourced from a reputable Local manufacturer.

Fine Aggregate

Natural River sand conforming to Nis: 1325.2015 was used as control fine aggregate. The sand was sourced from a local river bed and the fine aggregate was natural sand of 4.75 mm maximum size.

Pulverized Glass

Glass was collected from waste dump. It was then pulverized to a fine powder using an impact crusher and jet mills. The physical and chemical properties of the pulverized material were determined as per relevant Nigerian Standards.

Coarse Aggregate

Crushed granite aggregate Conforming to to NIS 132: 2015 was used. The maximum size of the aggregate used was 12mm.

Water

Potable water was used for mixing gotten from tap in the civil engineering laboratory, University of Benin.

Mix Design

The Concrete mixes were designed based on the guidelines of NIS 494:2015. The control mix was designed for a target compressive strength of 20 N/mm^2 at 28 days. The control concrete mix ratio was 1:2:4 with cement (325 kg/m3), sand (650 kg/m3), gravel (1300 kg/m3), and water (195 kg/m3) for a water-cement ratio of 0.6 computed for 9 cubes. The pulverized glass was used as a partial replacement of fine aggregate ranging from 0%, 5%, 10% and 15%.

Table 1: Mix proportions

No	Mix	W/C	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Glass (kg/m^3)
1	Control mix	0.6	325	1300	650	0
2	5% Replacement	0.6	325	1300	617.5	32.5
3	10% Replacement	0.6	325	1300	585	65
4	15% Replacement	0.6	325	1300	552.5	97.5

B. SPECIMEN PREPARATION

0.1 m³ rotary type mixer was used for the mixing process. An electronic balance with great precision was used to weigh the materials. In the mixer, all of the materials are combined with the concrete for a minimum of three to four further minutes. Each combination was made in a clean, lubricated mould that was set on a vibrating table. For around 30 seconds, the samples were kept on the vibration table. For the first twenty-four hours, the samples were kept at room temperature in the mould. They were then carefully taken out of the mould, making sure that none of the edges were broken, and put in the curing tank to cure at room temperature.

RESULTS

A. SLUMP TEST

In Table 4.1, the slump test results are illustrated. When the waste glass ratio rises in comparison to the controlled mix, it is evident that the slump values decrease. For samples with 0%, 5%, 10%, and 15% waste glass, the slump values were 30, 34, 43 and 46 mm respectively, as illustrated in Figure 4.1. One possible explanation for this drop in slump values is the waste glass's poor geometry, which lowers the fineness modulus and reduces the fluidity of the mixes.

Table 2: Results of slump test

No	Mix	W/C	Slump (mm)
1	Control	0.6	30
2	5% Replacement	0.6	34
2	10% Replacement	0.6	43
3	15% Replacement	0.6	46

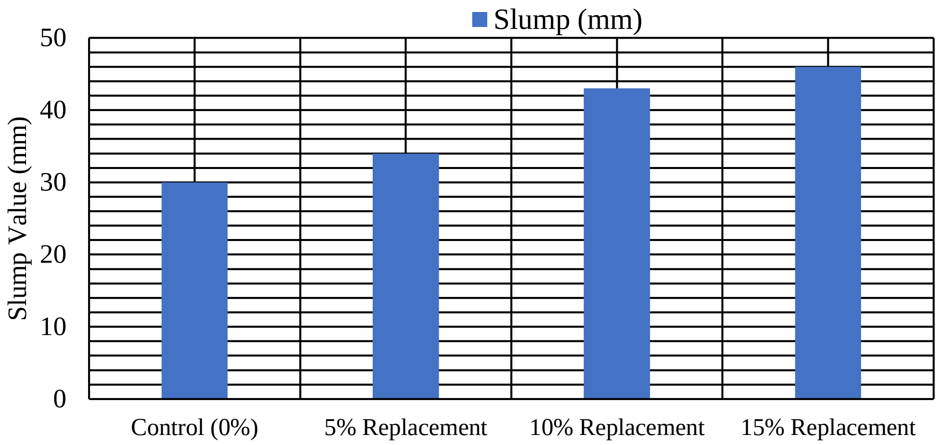

Figure 1: Result of slump value at varying % replacement

B. HARDENED CONCRETE RESULT

Compressive Strength Test

In Table 4.2- 4.4, it shows the compressive strengths of the waste and controlled glass concrete mixtures at 7, 14, and 28 days respectively. Figure 4.2 displays a comparison of the compressive strength values for the identical blends. Figure 4.3 illustrates the evolution of compressive strength over time for controlled mixes and mixes that partially replace sand with glass aggregate at 5%, 10%, and 15%. It is evident that the concrete's compressive strength decreases when pulverized glass is added. According to the results, the concrete mix containing 5% waste glass fine aggregate gave the optimum 28-day compressive strength values. With age, the strength of all glass and controlled aggregate mixes increases steadily. It is evident that as glass aggregate replacement increases, the percentage increase in compressive strength with age generally increases as well. This demonstrates that when the pozzolanic effect became noticeable at a late age of 28 days.

Table 3: Average Compressive Strength Obtained after 7 days of Curing with Pulverized Glass replacement of 0%, 5%, 10%, and 15%.

Replacement %	Sample No	Weight (Kg)	Density (Kg/m³)	Failure load (KN)	Compressive Strength (N/mm²)	Average strength (N/mm²)
0%	1	2.643	2643	142.53	14.253	16.2027
	2	2.676	2676	199.82	19.982	
	3	2.621	2621	143.73	14.373	
5%	1	2.510	2510	176.57	17.657	15.452
	2	2.610	2610	142.67	14.267	
	3	2.685	2685	144.32	14.432	
10%	1	2.735	2735	113.22	11.322	14.7094
	2	2.736	2736	165.79	16.579	
	3	2.742	2742	162.273	16.2273	
15%	1	2.414	2414	158.82	15.882	14.3927
	2	2.447	2447	123.07	12.307	
	3	2.528	2528	149.89	14.989	

Table 4: Average Compressive Strength Obtained after 14 days of Curing with Pulverized Glass replacement of 0%, 5%, 10%, and 15%.

Replacement %	Sample No	Weight (Kg)	Density (Kg/m³)	Failure load (KN)	Compressive Strength (N/mm²)	Average strength (N/mm²)
0%	1	2.625	2625	162.43	16.243	18.2933
	2	2.585	2585	211.63	21.163	
	3	2.59	2590	174.74	17.474	

5%	1	2.631	2631	184.67	18.467	16.7477
	2	2.617	2617	181.93	18.193	
	3	2.603	2603	135.83	13.583	
10%	1	2.581	2581	169.35	16.935	15.801
	2	2.457	2457	163.46	16.346	
	3	2.571	2571	141.22	14.122	
15%	1	2.491	2491	162.27	16.227	
	2	2.486	2486	136.32	13.632	
	3	2.477	2477	159.05	15.905	15.2547

Table 5: Average Compressive Strength Obtained after 28 days of Curing with Pulverized Glass replacement of 0%, 5%, 10%, and 15%.

Replacement %	Sample No	Weight (Kg)	Density (Kg/m³)	Failure load (KN)	Compressive Strength (N/mm²)	Average strength (N/mm²)
0%	1	2.665	2665	190.35	19.035	20.675
	2	2.635	2635	230.01	23.001	
	3	2.677	2677	199.89	19.989	
5%	1	2.653	2653	200.8	20.08	19.722
	2	2.591	2591	199.85	19.985	
	3	2.596	2596	191.01	19.101	
10%	1	2.587	2587	155.86	15.586	16.2597
	2	2.565	2565	172.35	17.235	
	3	2.757	2757	159.58	15.958	
15%	1	2.651	2651	153.86	15.386	
	2	2.673	2673	159.35	15.935	
	3	2.684	2684	151.58	15.158	15.493

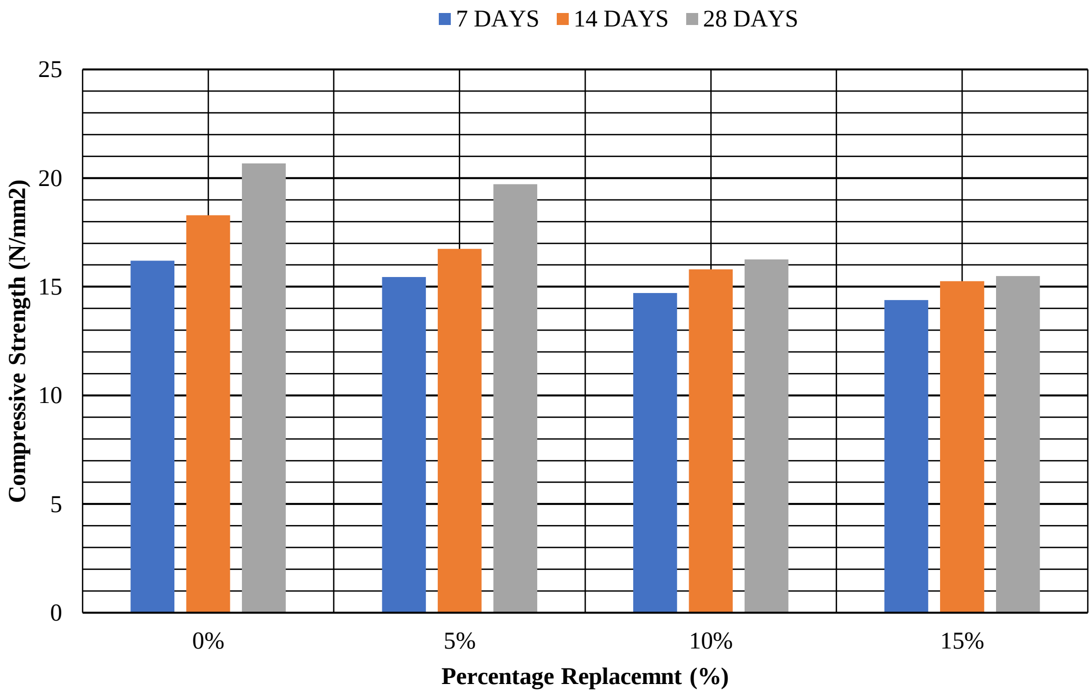

Figure 2: Chart showing comparison between the values of Average Compressive Strength for different glass aggregate replacements for three ages curing

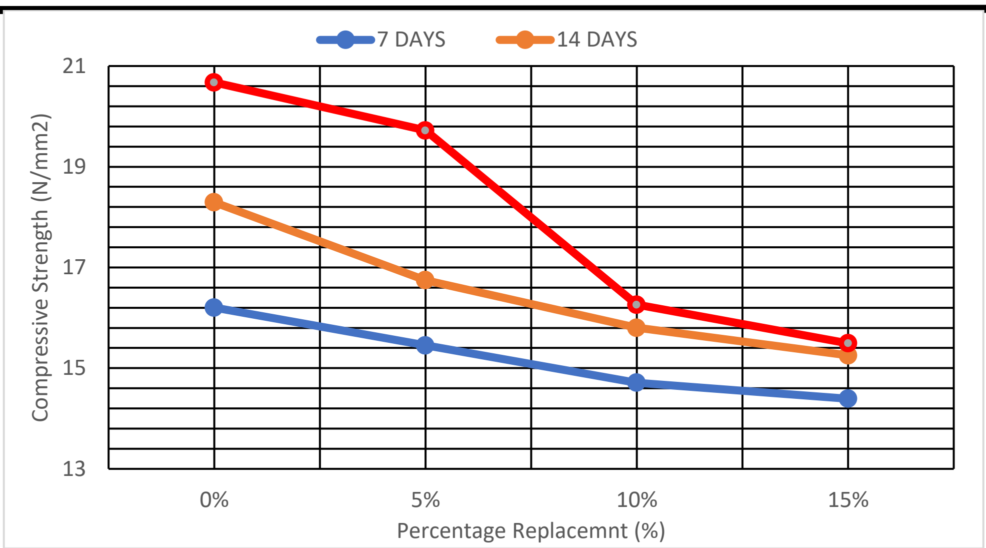

Figure 3: Graph showing Result comparison between the values of Average Compressive Strength for different glass aggregate replacements for three ages curing

C. PARTICLE SIZE DISTRIBUTION

Sieve Analysis

The sieve analysis results are presented in Table 4.5 and 4.6 for natural fine aggregates (sand) and pulverized glass respectively to determine their particle size distribution. The purpose of this analysis was to assess the suitability of pulverized glass as a partial replacement for fine aggregates in concrete. The results obtained from the sieve analysis, including the particle size distribution curves are discussed below.

Table 6: Result from Sieve Analysis for fine aggregate Total Mass of sand tested = 100.00g

SIEVE SIZE (MM	MASS RETAINED (G)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
2.36	0.30	1.26	0.11	96.21
2.00	0.15	0.15	2.71	94.22
1.18	2.26	6.627	9.408	90.59
600	19.28	31.66	41.068	58.93
425	6.68	18.96	41.068	58.93
300	10.73	22.92	82.948	17.05
212	21.90	12.05	94.998	5.00
150	3.95	0.69	95.688	4.31
75	3.97	1.52	97.208	2.79
Pan	1.25	0.269	95.477	1.5

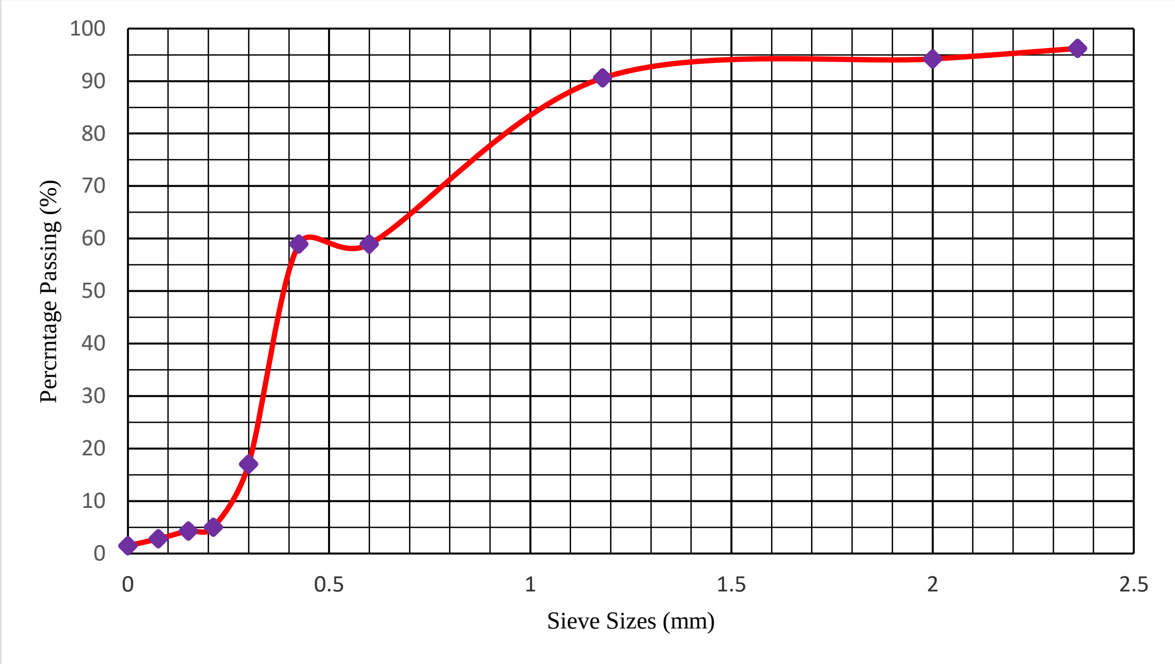

Figure 4: Graph showing fine aggregate variation of % passing with respect to different sieve size.

Table 7: Result from Sieve Analysis for Pulverized Glass aggregate Total Mass of sand tested = 100.00g

SIEVE SIZE (MM	MASS RETAINED (G)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
2.36	0.30	1.26	0.11	99.83
2.00	0.15	0.15	2.71	94.04
1.18	2.26	6.627	9.408	90.97
600	19.28	31.66	41.068	58.95
425	6.68	18.96	41.068	58.63
300	10.73	22.92	82.948	15.07
212	21.90	12.05	94.998	4.5
150	3.95	0.69	95.688	3.53
75	3.97	1.52	97.208	2.19
Pan	1.25	0.269	95.477	1.3

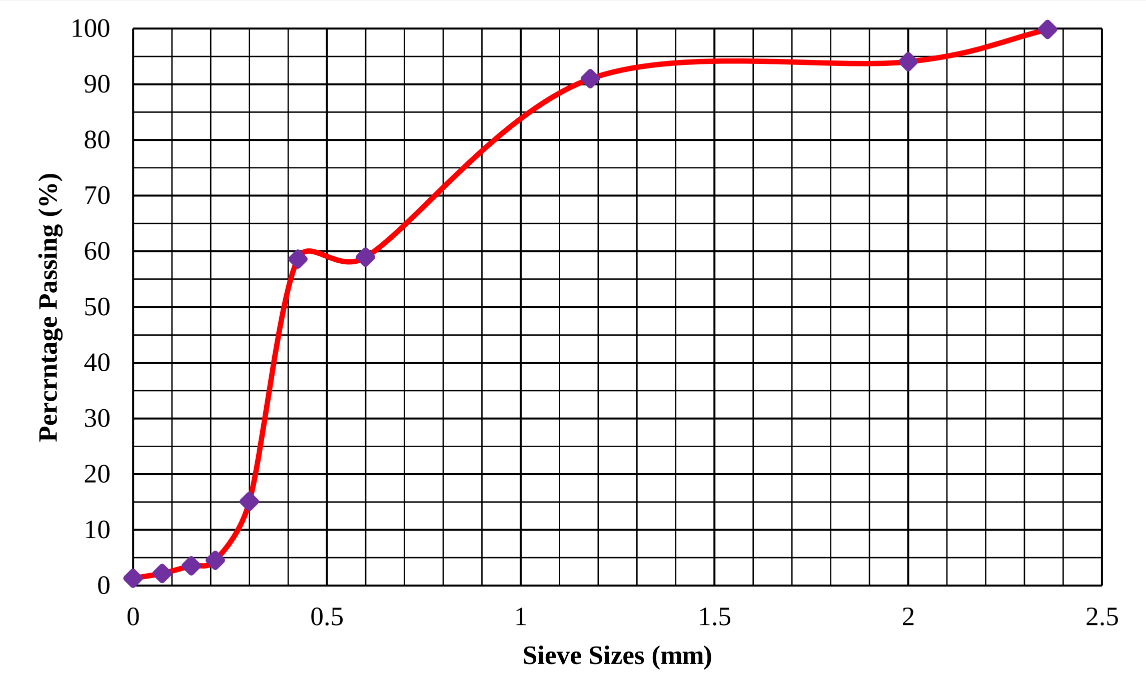

Figure 5: Graph showing glass aggregate variation of % passing with respect to different sieve size.

CONCLUSION

In conclusion, this study set out to investigate the mechanical behavior of concrete when pulverized glass is introduced as a partial substitute for fine aggregates, with the overall aim of assessing its performance, suitability, and potential environmental benefits as a sustainable construction material. The experimental results presented in Chapter Four provided important insights into the influence of pulverized glass on both the workability and strength characteristics of concrete. It was observed that as the percentage of glass replacement increased, there was a notable reduction in the slump value of the concrete mixes. Although the slump values declined, particularly by approximately 11.7%, 30.2%, and 34.8% at 5%, 10%, and 15% replacements respectively compared to the control mix, the overall workability of the mixes still remained within an acceptable range for practical application. This indicates that while the introduction of glass reduces the fluidity of fresh concrete, it does not render the material unusable, provided the replacement proportion is carefully controlled.

Furthermore, the compressive strength behavior revealed a progressive decline as the proportion of waste glass increased, suggesting that higher levels of substitution compromise the ability of the concrete to develop strength over time. Despite this general reduction, an interesting trend was identified at the 28-day curing period where the 5% replacement of finely ground glass with sand exhibited the most favorable compressive strength among the replacement mixes. This finding highlights the possibility that small proportions of pulverized glass may positively contribute to strength development by improving particle packing and enhancing certain microstructural interactions, while excessive replacement levels diminish the mechanical performance of the concrete.

Overall, the study demonstrates that pulverized glass can indeed be incorporated into concrete as a partial substitute for fine aggregates, but its effectiveness is strongly dependent on the replacement percentage. While higher substitution levels result in reduced workability and compressive strength, a modest replacement, particularly at 5%, achieves an optimal balance by maintaining acceptable workability and yielding competitive strength at later curing ages. Beyond its mechanical implications, the incorporation of glass into concrete presents a promising pathway toward sustainability by promoting recycling and reducing environmental burdens associated with waste glass disposal and natural aggregate depletion.

Conflicts of Interest: All authors declare that they have no conflict of interest associated with this research work.

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