iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VIII **Month of publication:** August 2025

DOI: https://doi.org/10.22214/ijraset.2025.73902

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

Exploring Waste Glass as Fine Aggregate Replacement in Concrete Block

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Abstract:** Solid waste management is a major environmental concern around the world, with post-consumer glass accounting for a significant amount of that waste stream. However, the difficulty in locating viable markets for glass recycling exacerbates the problem, resulting in environmental consequences from theaccumulation of wasted glass. Thus, investigating the possibility of using crushed waste glass as a replacement for fine aggregate in concrete emerges as an appealing way to address waste disposal difficulties while conserving natural resources.To address these problems, this study conducted fundamentalexperimental research to determine the viability of adding crushed waste glass into concrete. Various properties of concrete were investigated through extensive experimentation, including slump, unit weight, compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, ultrasonic pulse velocity, dry density, water absorption, and alkali-silica reaction, over 7, 14, and 28-day curing periods. Four concrete mixes were created, with replacement levels of discarded glass ranging from 0% to 20% by weight of sand. At 28 days, the results showed that concrete specimens with 20% waste glass substitution outperformed the control mix. These specimens had higher compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity, with increases of 5.28%, 18.38%, 8.92%, and 9.75%, respectively. This suggests that using waste glass as a fine aggregate replacement in concrete can improve its mechanical characteristics and overall performance.By explaining the benefits of mixing discarded glass into concrete and undertaking extensive experimentation, this work gives useful insights into sustainable waste management techniques and natural resource conservation. Furthermore, it emphasises the significance of researching alternative materials in order to reduce environmental issues and encourage the use of eco-friendly construction procedures.

I. INTRODUCTION

The global problem of discarded glass recycling has motivated study into mixing waste glass into concreteas a partial replacement for traditional materials, addressing both waste management and environmental concerns. Studies have focused on replacing fine aggregate with crushed waste glass in concrete mixtures, resulting in "glass concrete" to reduce resource depletion and environmental hazards. While colour sorting efficiency and contamination remain issues for glass recycling, techniques such as glascrete manufacture have evolved. However, the alkali-silica reaction (ASR) presents a substantial problem, which can be addressed using a variety of ways. Using leftover glass in concrete has both environmental and economic benefits, including decreased disposal costs, resource conservation, and increased landfill life. For example, New York City's yearly 100,000-ton waste glass may be recycled for $45 per tonne. Incorporating waste glass into concrete production promotes sustainable waste management.

II. OBJECTIVES

1) To determine the durability and long-term performance of concrete that contains waste glass.
2) To evaluate the impact of various curing techniques on the mechanical properties of glass-incorporated concrete.
3) To assess the environmental and sustainability effects of using waste glass in concrete manufacturing.
4) To investigate potential solutions for mitigating the alkali-silica reaction (ASR) in glass-containing concrete.

III. LITERATURE REVIEW

1) Weitz (2005) As per Weitz's 2005 research, the American Association of State Highway and Transportation Officials (AASHTO) recognised the feasibility of incorporating recycled materials into pavement and unveiled a novel specification named "Glass Cullet Use for Soil Aggregate Base Course." According to this specification, glass cullet that has been prepared correctly can provide road or highway bases with enough stability and load support. Known as "glassphalt," crushed glass cullet

has been used as aggregate in bituminous concrete pavements and road building since the early 1970s. According to field tests, glassphalt holds heat longer than conventional asphalt, which is useful for operations in cold climates or lengthy transportation distances. Furthermore, the glass particles improve visibility at night by raising the reflectivity of the road surface.

2) Corinaldesi et al. (2005) looked into this by employing 30–70% waste glass as fine aggregate in concrete. Their findings indicate that the reaction between cement paste and crushed waste glass, which has particle sizes of up to 100 µm, has not been shown to have any detrimental effects at a macroscopic level. Conversely, a notable enhancement in the mechanical performance of the mortar was noted, owing to the waste glass's beneficial influence on the micro-structural characteristics. With particle sizes up to 100 µm, no alkali-silica (ASR) reaction was detected, indicating that leftover glass can be used as fine aggregate in mortars and concrete.
3) Bashar et al. (2007) According to research conducted by Bashar et al. (2007), adding more recycled glass sand (RGS) to concrete can decrease its permeability and decrease the amount of water it contains. However, the consistency of the cement paste and the adhesive binding between the components in the concrete mix will be diminished if recycled glass sand (RGS) is present. It was stated that adding recycled glass sand (RGS) to concrete may decrease its workability and compaction factor when compared to a controlled mix, which will have a negative impact on the concrete's strength attributes.
4) Özkan et al. (2007) investigated the effects of fly ash (FA) and granulated blast furnace slag (GBFS) on the expansion of concrete using ground waste glass in three different colours: clear, green, and brown. At 14 days, mortar bar expansion was found to be greater than 0.2%, and according to ASTMC1260's limits, expansions beyond 0.2% are suggestive of possibly harmful expansion. The largest expansion was noted while utilising up to 50% waste glass as fine aggregate; however, when 50% fly ash was added to the mixture, the expansion was observed to be reduced. It was found that using waste glass in combination with fly ash (FA) or granulated blast furnace slag (GBFS) works better than using waste glass by itself. Conversely, waste glass can replace cement by up to 30% when it is used alone, without any combination of fly ash (FA) or granulated blast furnace slag (GBFS). However, if waste glass was mixed with fly ash (FA) or granulated blast furnace slag (GBFS), the replacement ratio might rise to 50%.
5) Hathaichanok Warnphen (30,sep,2019); The study emphasises the advantages of using recycled glass trash into concrete mixtures, which can help minimise the demand for river sand quarries while conserving resources. Despite a modest reduction in workability, concrete compositions including glass debris remain functional and environmentally benign. The addition of 20% glass debris greatly increases compressive strength, making it comparable to normal concrete due to increased bonding between glass particles and cement paste. Although split tensile strength falls with increasing glass waste content, combinations with up to 20% replacement exhibit very modest losses when compared to control mixes, guaranteeing structural integrity.
6) Awham Jumah Salman (25-12-2020) The experimental results lead to many conclusions: First, concrete with additional glass powder has much higher compressive strength than ordinary concrete. Second, increasing the amount of glass replacement improves the workability of concrete, whether for fine aggregate or cement. Finally, replacing fine glass powder with cement has a greater effect on compressive strength and slump than replacing coarse glass powder with fine aggregate. Overall, the data show that glass powder improves concrete qualities, particularly strength and workability, with differences based on the type and amount of glass powder utilised.
7) Sudarshan Upreti feb 2021: This study assesses the effects of using discarded glass as a substitute for fine aggregate in concrete. The smooth surface of glass particles improves workability up to a specific replacement level, while fine glass powder boosts compressive strength. However, larger replacement rates can compromise strength and workability due to angularity and poor bonding. Up to 10% replacement causes modest decreases in workability and strength across different concrete grades, ensuring durability. Notably, replacing 5% of the M20 grade concrete improves its durability. Overall, careful substitution of fine aggregate with finer glass particles improves workability, compressive strength, and sustainability while preserving durability.
8) Ghadeer Jabbar Kassed 27 aug 2021 The key findings on employing recovered glass debris in concrete mixtures are as follows: First, substituting river sand with glass trash reduces the environmental impact of sand quarries and resource depletion. Second, concrete mixtures including glass waste remain viable despite a modest drop in workability, providing a more sustainable option. Third, adding 20% glass waste increases bonding between glass particles and cement paste, resulting in compressive strength comparable to conventional concrete. Finally, mixtures with up to 20% replacement have only a modest drop in split tensile strength compared to control mixtures, showing structural integrity, though split tensile strength decreases with increasing glass waste content.

9) Najm, H.M. 7 sep,2022; Incorporating waste glass (WG) into concrete changes its characteristics, needing a detailed understanding prior to structural applications. WG can reduce workability, but it can also maintain usability. The decreased density of WG affects the overall density of concrete. The elastic modulus values vary, and mechanical property changes are inconsistent. Bonding difficulties typically result in a loss in compressive, splitting tensile, and flexural strengths. Optimal WG substitution levels are approximately 20% balancing benefits and strength reduction. Despite the limitations, WG has the ability to improve mechanical qualities, reduce dead load, and provide an environmentally friendly alternative. The research intends to optimise the usage of WG in concrete while also resolving its limits.
10) Raha Nadoal Shahril dec, 26,2022 The experimental results led to a few conclusions: First, when the amount of waste glass in concrete grows, the slump value lowers. Second, glass waste concrete absorbs somewhat more water than M15 Grade regular cement concrete, with the G2(5%) mix having the lowest absorption at 2.22%. Glass waste concrete has better compressive strength, with the G-1(5%) mix reaching 25.90 N/mm². The G-5(5%) mix has a maximum splitting tensile strength of 2.115 N/mm², which is somewhat greater than normal cement concrete. Both types of concrete have comparable densities, with the G-4(20%) mix having the maximum density (2380.4 kg/m³).
11) Aniket S. Mulmuley (4-04-2023) The comparison aims to evaluate concrete strength while taking into account environmental impact. The results showed that compressive strength decreased after an initial rise with up to 20% fine aggregate substitution with glass powder. The increase is related to improved bonding between the angular glass particles. Higher glass powder content improves workability, and because glass powder absorbs less water than fine aggregate, it absorbs less water in total. Using leftover glass in concrete is both cost-effective and environmentally advantageous, as it addresses trash disposal difficulties while also increasing the sustainability of concrete building by lowering reliance on natural resources such as river sand.

IV. MATERIALS USED

The materials employed in this investigation include cement, coarse aggregate, fine aggregate, crushed waste glass as a fine aggregate replacement, and water.

V. TESTING OF SPECIMENS

There are two sorts of tests: fresh mortar and hardened mortar test.

A. Test of Fresh Mortar

The slump and unit weight tests were carried out on fresh mortar after the concrete had been mixed.

1) The Slump Test

The slump test measures the workability of concrete after it has been mixed. This test involves a waste rag, a flat metal base plate, a tiny scoop, a steel float, a 600 mm slump rod, a standard slumpcone, and a 300 mm ruler. Concrete is poured into the slump cone in three layers and compacted with 25 strokes of the tamping rod's rounded end. After the top layer is levelled and cleaned, carefully raise the slump cone up from the concrete. The resultant slump measurement is then recorded and evaluated.

2) Unit weight test

The unit weight for all mixtures was measured on fresh concrete and computed using the followingequation:

Df = Mc-Mm/Vm (3-1)

where

Df = fresh unit weight of concrete (kg/m³). Mc = mass of mould filled with concrete (kg)Mm = mass of mould (kg).

Vm represents the volume of the mould (m³).

Hardened concrete tests include non-destructive (ultrasonic pulse velocity, water absorption, dry density, ASR) and destructive (compressive, splitting tensile, modulus of elasticity, flexural strength)procedures using averages from three specimens.

1) Density test: Weigh one metre of concrete cubes using a machine after cleaning with water to calculate their mass. The weighing results are consistent in both air and water.
2) Compressive Strength Test: A digital machine with a 3000 kN capacity was used to test 100 x 100x 100 mm cubes after 7, 14, and 28 days.

3) Flexural Strength Test: Using 100 x 100 x 500 mm prisms and four-point loading, results are computed at 7, 14, and 28 days.
4) The Splitting Tensile Strength Test, done on -100 mm diameter by 200 mm height cylinders at 7, 14, and 28 days, measures tensile strength based on maximum load, cylinder diameter, and length.
5) The ASTM-C-469 modulus of elasticity test was done on 100 mm diameter x 200 mm height cylinders at 7, 14, and 28 days.
6) Test for water absorption and porosity: Weighs, dries, vacuum-saturates, and analyses water absorption and porosity in air and water using 100 mm diameter by 35 mm thick cylinders.
7) Ultrasonic Pulse Velocity Test: A portable ultrasonic non-destructive indicating tester (PUNDIT) was used to assess pulse velocity on 100 x 100 x 500 mm prisms after 7, 14, and 28 days. The pulse velocity was calculated based on transit time.
8) Alkali-Silica Reaction (ASR) Test: ASTM C1260 requires an accelerated mortar bar test to determine resistance to alkali medium and high temperatures. Expansions more than 0.2% after 14 days indicate potential concerns.

VI. RESULTS IN THE EXPERIMENT

A. Slump Test

Table 6.1 illustrates the results of the slump tests. The slump values fall marginally when the waste glass ratio increases when compared to the controlled mix. Table shows that samples containing 5%, 15%, and 20% waste glass had slump values of 65, 56.5, and 52 mm, respectively. This decrease in slump values can be attributed to the poor geometry of the waste glass, which results in less fluidity in the mixes as well as a fall in fineness modulus. In a prior study, Park et al. (2004) discovered that increasing the ratio of waste glass reduces the slump of concrete because waste glass aggregates have sharper and more angular grain forms and are larger than sands, resulting in reduced fluidity.

Table 6.1: Results of slump test

No	Mix	W/C	Slump (mm)
1	Control	0.55	80
2	5% Replacement	0.55	65
3	15% Replacement	0.55	56.5
4	20% Replacement	0.55	52

B. Unit Weight Test

The results of the unit weight test for all mixtures are shown in Table 6.2, and they reveal that the unit weight values (density) drop when the waste glass ratio increases relative to the controlled mix. Glass aggregate has a lower specific gravity than sand, which accounts for this difference. Similar findings were reported by Hamemrnik et al. (1991).

Table 6.2 : Fresh density for all mixes

Mix	Control	5%	15%	20%
Fresh density (kg/m³)	2442.3	2426	2405.29	2398.6

C. Compressive Strength Test

Table 6.3 summarises the compressive strength test findings for controlled and waste glass concrete mixtures at days 7, 14, and 28. It shows a comparison of compressive strength values for the identical mixes, also demonstrates the evolution of compressive strength over time. Incorporating waste glass boosted concrete strength, with a maximum 28-day strength of 34.22 MPa achieved with 20% waste glass fine aggregate, representing a 5.28% improvement over the controlled mix. Strength increased continuously with age, especially with increasing amounts of glass aggregate replacement, demonstrating significant strength enhancement due to pozzolanic effects at 28 days.

Table 6.3 : Compressive strength (MPa) for all mixes

Compressive strength (MPa) at ages of

Mix	7 days	14 day	28 day
Control	24.77	29.2	32.41
5% waste glass	26.15	29.63	31.59
15% waste glass	24.5	29.87	31.84
20% waste glass	25.65	28.81	34.22

D. Splitting Tensile Strength

The concrete containing glass is equally fragile as regular concrete (Meyer 2000). The tensile strength attribute of concrete containing glass is particularly important since it is the most visible expression of the alkali-silica reaction. More precisely, in damp conditions, the akali-silica gel may expand and cause tensile stress within the concrete structure. According to Hadlington (2002), this is the primary cause of concrete damage. Table 6.4 shows the splitting tensile strength of all mixes after they have been cured for 7, 14, and 28 days.

Table 6.4: Splitting tensile strength (MPa)

Mix	Tensile strength (MPa)		
	7 days	14 day	28 day
Control	2.139	2.396	2.548
5% waste glass	2.043	2.207	2.569
15% waste glass	1.347	1.767	2.927
20% waste glass	1.652	1.980	3.122

Table 6.5: Percentage of reducing and increasing in splitting tensile strength ofmixescontaining waste glass compared with controlled mix

Mix	Percentage reducing / increasing in tensile strength(%)		
	7 days	14 day	28 day
5% waste glass	-4.48	-7.88	+0.81
15% waste glass	-37.02	-26.25	+12.9
20% waste glass	-22.76	-17.36	+18.38

E. Flexural Strength

Table 6.6 presents the flexural strength test results for 7, 14, and 28-day concrete mixtures. Overall, flexural strength increased consistently with age across all combinations. It shows a clear trend of increased flexural strength over time. Furthermore, it shows that mixes including waste glass performed better than the control mix, with the increase equal to the percentage of glass aggregate replacement. Specifically, the 28-day flexural strength values exceeded thecontrolled mix by 3.54%, 5.03%, and 8.92% with 5%, 15%, and 20% waste glass content, respectively, showing considerable pozzolanic reaction throughout this period.

Table 6.6 : Flexural strength (MPa) for all mixes

Mix	Flexural strength (MPa) at ages of		
	7 days	14 day	28 day
Control	3.265	4.127	4.90
5% waste glass	3.781	4.376	5.08
15% waste glass	3.499	4.258	5.16
20% waste glass	3.843	4.213	5.38

F. Modulus of Elasticity

Table 6.7 shows the modulus of elasticity for waste glass concrete mixes at 7, 14, and 28 days, demonstrating a constant increase with age, Mixes including waste glass outperform the control, with improvements corresponding to glass aggregate replacements. The 28-day modulus of elasticity values with 5%, 15%, and 20% waste glass content outperform the plain mix by 2.54%, 5.45%, and 9.75%, respectively. These increases suggest superior characteristics due to glass's higher modulus of elasticity than natural sand.

Table 6.7: Modulus of elasticity for all mixes

Mix	Modulus of elasticity (MPa) at ages of		
	7 days	14 day	28 day
C ontrol	18.21	23.3	26
5% waste glass	16.67	23.45	26.68
15% waste glass	18.42	24.47	27.5
20% waste glass	19.35	24.87	28.81

G. Ultrasonic pulse velocity (U.P.V)

Table 6.8 shows the results of the ultrasonic pulse velocity test for all combinations over 7, 14,and 28 days.

Table 6.8: Ultrasonic pulse velocity (km/sec) for all mixes

Mix	Ultrasonic pulse velocity (km/sec) at ages of			Quality of concrete at ages of		
	7 days	14 day	28 day	7 days	14 day	28 day
Control	3.98	4.01	4.26	Good	Good	Good
5% waste glass	4.11	4.13	4.23	Good	Good	Good
15% waste glass	3.84	4.03	4.13	Good	Good	Good
20% waste glass	3.63	3.88	4.00	Good	Good	Good

According to the general classification of concrete quality based on pulse velocity, as shown inTable 6.9, the quality of concrete mixes can be considered good.

Table 6.9 : Classification of quality of concrete

Pulse Velocity (km/second)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

H. Water Absorption and Porosity

Table 6.10 shows the water absorption test results for all mixes at 7, 14, and 28 days, indicating that larger concentrations of glass aggregate in mixes result in lower water absorption compared to the control. Water absorption reduces with age in concrete mixes including waste glass as fine particles in varied concentrations. Continuous hydration decreases concrete porosity by filling gaps between cement particles and aggregates, lowering average pore diameter and thus reducing water absorption. For example, at 28 days, water absorption decreases for mixes containing 5%, 15%, and 20% waste glass compared to the control are 4.68%, 9.16%, and 14.86%, respectively. This effect is linked to the impermeable character of glass aggregate in comparison to natural sand.

Table 6.10 : Water absorption for all mixes

Mix	Water absorption % at ages of		
	7 days	14 day	28 day
Control	5.87	5.28	4.91
5% waste glass	5.53	4.99	4.68
15% waste glass	5.21	4.73	4.46
20% waste glass	4.94	4.51	4.18

I. Dry Density

Table 6.11 shows the dry density values for all blends after 7, 14, and 28 days of curing. It shows that as the waste glass ratio increases, the dry density decreases in comparison to the controlled mix. This is due to the decreased density of glass aggregate compared to natural sand.

Table 6.11 : Dry density for all mixes

Mix	Dry density kg/m³ at ages of		
	7 days	14 day	28 day
Control	2365	2378.6	2398
5% waste glass	2358.5	2364.3	2374.2
15% waste glass	2354.8	2362.9	2366.1
20% waste glass	2351.4	2359.7	2360.2

J. ASR Test

The quick mortar bar test, as per ASTM C1260, subjected mortar bars to high temperature andhigh alkali conditions for 14 days to assess potential volumetric changes. Table 6.12 shows theexpansion values of waste glass concrete mixtures at three, seven, and fourteen days. It shows a decrease in growth with increasing waste glass content, especially at 14 days. The reduction ratios of expansion for 5%, 15%, and 20% waste glass mixes compared to the control were 20%, 56.25%, and 70%, respectively. Despite variances, all specimens showed expansions of less than 0.1%, indicating that no deleterious expansion occurred in waste glass specimens per ASTM C1260, which was attributed to lower alkali availability and system alkalinity due to lime consumption by finely ground waste glass.

Table 6.12 : Expansion for all mixes

Mix	Expansion % at ofages		
	3 days	7 day	14 day
Control	0.015	0.03	0.08
5% waste glass	0.009	0.02	0.064
15% waste glass	0.0085	0.015	0.035
20% waste glass	0.008	0.01	0.024

VII. CONCLUSION

The use of discarded glass as a fine aggregate replacement in concrete resulted in noticeable modifications in a variety of characteristics. Despite a decrease in slump due to increasing waste glass content, the concrete retained outstanding workability. Higher ratios of waste glass resulted in improved compressive strength, with a 20% replacement producing 5.28% more strength than the control mix after 28 days. Similarly, at 28 days, 20% waste glass replacement had the highest compressive, tensile, and flexural strength. Water absorption decreased with increased waste glass content, particularly by 14.68% with 20% glass aggregate replacement, indicating lower porosity. The ultrasonic pulse velocity was significantly lower in mixes including waste glass, but it remained over 4 km/s, suggesting excellent concrete. Furthermore, waste glass inclusion reduced alkali-silica reaction (ASR) expansion, with all specimens showing expansions less than 0.1%, indicating that no harmful expansion occurred. Overall, the findings support the use of waste glass as a sustainable aggregate replacement in concrete, increasing numerous critical attributes while maintaining performance.

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