

INVESTIGATION OF STRENGTH AND DURABILITY OF CONCRETE INCORPORATED WITH CUPOLA FURNACE SLAG AND WASTE GLASS CULLETS AS FINE AGGREGATE REPLACEMENT.

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Abstract— The rising demand for concrete in modern infrastructure has led to environmental concerns stemming from the depletion of natural resources. This paper explores a shift towards sustainable concrete production by incorporating industrial waste materials. A comprehensive literature review highlights successful studies on substituting fine aggregates with Cupola slag, glass waste, and demonstrating improved concrete properties and reduced environmental impact. The study involved replacing fine aggregate with glass cullets at varying levels of 5%, 10%, 15%, 20%, and 25%, while for slag, replacement levels were set at 25%, 30%, and 35%. The research evaluated the effects of these replacement levels on concrete properties, including workability, compressive, split tensile, and flexural strengths, alongside durability tests such as Water Permeability, Wenner, and Acid tests. After a 28-day curing period, the specimens underwent specialized testing to assess their performance. Notably, a significant increase in compressive strength was observed, with a 17.82% improvement at 15% glass replacement and a 9.9% enhancement at 30% slag replacement for fine aggregate. These findings contribute substantially to advancing the understanding of sustainable concrete practices, emphasizing the potential of industrial waste materials to bolster structural performance and diminish environmental impact. This underscores the relevance of such initiatives in guiding the construction industry towards a more resilient and environmentally responsible future.

Keywords— Sustainable concrete, Optimised concrete mix, Cupola furnace slag, Glass cullets, Durability studies

I. INTRODUCTION

Concrete is vital in construction but its high demand, especially for fine aggregates, raises concerns about resource depletion and environmental impact. Relying solely on natural resources aggravates issues like deforestation and carbon emissions. Using industrial waste as substitutes presents a promising solution to this issue. This approach has also been observed to enhance concrete properties while simultaneously mitigating environmental impact. By utilizing industrial byproducts, we not only tackle resource scarcity and waste management but also promote a more sustainable construction industry. This transition marks an important advancement in promoting environmentally responsible practices within the construction sector. Waste glass,

being inert, can seamlessly integrate into concrete without altering its chemical properties. It can effectively replace fine aggregate, filling small gaps in concrete. Recycling of this waste by converting it to aggregate, not only saves landfill space but also reduces the demand for extraction of natural raw material for construction activity. Additionally, finer waste glass may exhibit pozzolanic properties or serve as an inert filler material. Cupola slag is an industrial by-product that can be constructively used as partial substitute to aggregates in concrete. A cupola furnace is a device usually used in foundry industries for the melting of cast iron, bronze etc. In a cupola furnace, for every one-ton of molten metal about 50 kg of slag is produced. Slag being produced in large quantities; its disposal has become an environmental concern. Incorporation of slag in concrete as a substitute to natural sand helps in making the environment sustainable by minimizing the excess of landfill. In addition, further energy required for refining or extraction purpose of aggregates will be reduced thereby significantly reducing the release of greenhouse gases into the atmosphere. This transition marks a pivotal moment in reshaping the construction industry's approach to sustainability, emphasizing the importance of minimizing environmental impact through innovative solutions.



Figure 1 Glass cullets



Figure 2 Cupola Slag

II. MATERIAL PROPERTIES

A. CEMENT

Cement, a binding agent used in construction, typically comes in different types like Portland Pozzolana Cement (PPC). PPC exhibits consistent mixing, fine particle size aiding in strength development, moderate setting time for convenient application, and soundness ensuring stability post- setting. It's a versatile choice for various construction needs.

TABLE I PROPERTIES OF PPC

Properties	Results obtained	
Standard consistency of cement	31%	
Initial setting time of cement	124 min	
Final setting time of cement	218 min	
Fineness of cement	1 %	
Soundness	1 mm	

B. FINE AGGREGATE

Fine aggregate, usually sand or crushed stone smaller than 5mm in diameter, is a vital component in concrete and mortar mixes. It fills voids between coarse aggregates, enhancing density and durability, while also influencing texture and finish. Maximum % Bulking of sand refers to the increase in volume when dry sand absorbs moisture, up to a certain point. Moisture content at max bulking indicates the level of moisture where sand reaches its maximum volume before compaction occurs.

TABLE II PROPERTIES OF FINE AGGREGATE

Properties	Results obtained
Maximum % Bulking of sand	32%
Moisture content at max bulking	6%

C. SPECIFIC GRAVITY

Specific gravity is vital for construction materials like aggregates and cement. It measures their density compared to water. It has a considerable role in mix design

TABLE III SPECIFIC GRAVITY

Properties	Results obtained
Cement	2.95
Sand	2.70
Glass cullets	2.43
Cupola slag	2.90
Coarse aggregate	2.74

D. COMPRESSIVE STRENGTH OF CEMENT MORTAR CUBE

The compressive strength of cement mortar cubes is a crucial measure of its load-bearing capacity. It indicates the maximum load a cubic specimen of cement mortar can bear before failure under compression. This property is essential in assessing the structural integrity and durability of cement-based materials.

TABLE IV COMPRESSIVE STRENGTH OF CEMENT MORTAR CUBE

Days	Cube 1(MPa)	Cube 2(MPa)	Cube 3(MPa)
3	22.4	22.8	23.7
7	29.6	29.8	30.2
28	44.9	45.3	45.3

III. MIX DESIGN

A good concrete mix design forms the foundation of a solid infrastructure by providing stable construction material. For obtaining the necessary strength and

durability, concrete should be designed properly. Mix design was done for casting three cubes (150mmx150mmx150mm), three cylinders (150mmx300mm) and three beams (500mmx100mmx100mm) under the codal provision of IS 10262: 2019. Grade chosen was M30 and the target strength was 38.25MPa.

TABLE V MIX DESIGN VALUES

Item	Quantity (Kg/g)
Mass of cement	11.34 Kg
Mass of Water	4.80 Kg
Mass of Coarse aggregate	34.63 Kg
Mass of Fine aggregate	19.70 Kg
Mass of Chemical Admixtures	90.70 Kg
Water cement ratio	0.43

IV. WORKABILITY

The workability of concrete is an important parameter that defines the mix's quality. It refers to the ease with which freshly mixed concrete can be handled, placed, and compacted without segregation or excessive bleeding. The water- cement ratio, aggregate size and shape, sand grading, admixtures, cementitious materials and number of fine particles are all important factors that influence the workability. The slum cone test is used to determine the workability of fresh concrete. It is observed that the slump value changes from medium to high slump as the replacement percentage increases in case of glass cullets and high slump to medium in case of cupola slag

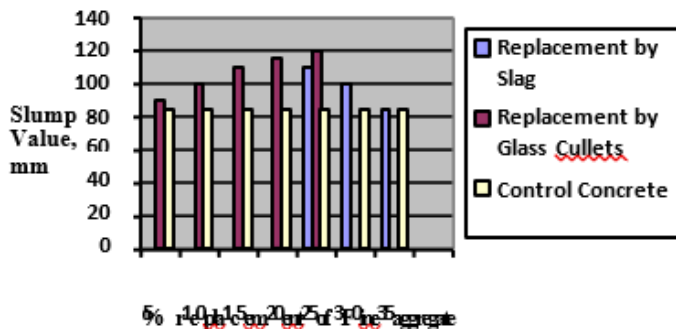


Figure 3 Graphical representation of slump test results

Glass cullets exhibit improved workability owing to their low or zero water absorption property, while slag, characterized by relatively high water absorbance(0.8%), diminishes workability with increasing slag content. it is subjected to during its life cycle. This is measured using compression testing machine of capacity 3000 kN on cubical specimens of 150 mm size in Indian standards. This test was performed on conventional concrete and on concrete with fine aggregates replaced by waste glass cullets and cupola slag at a 28-curing period. After 28 days maximum compressive strength was obtained for concrete with 15% replacement of fine aggregates in case of glass cullets and 30% for cupola slag. Both glass incorporated and slag incorporated concrete showed better compressive strength than that of conventional concrete.

**TABLE VI
 COMPRESSIVE STRENGTH OF GLASS INCORPORATED CONCRETE CUBE**

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	44.88
5%	45.33
10%	46.22
15%	52.88
20%	48.88
25%	46.44

**TABLE VII
 COMPRESSIVE STRENGTH OF SLAG INCORPORATED CONCRETE CUBE**

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	44.88
25%	46.66
30%	49.33
35%	44.44

V HARDENED CONCRETE PROPERTIES

A. COMPRESSIVE STRENGTH

The compressive strength of concrete is a measure of its capability to withstand compressive loads that tensile strength of concrete specimens. It is determined by subjecting a cylindrical concrete

specimen to a compressive force along its length until failure occurs by splitting apart along the length. The maximum tensile strength was obtained for the replacement of 15% fine aggregate with glass cullets and 30 % with cupola slag.

TABLE VIII
SPLIT TENSILE STRENGTH OF GLASS INCORPORATED CONCRETE CUBE

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	18.4
5%	18.7
10%	19.6
15%	19.8
20%	18.5
25%	17.9

TABLE IX
SPLIT TENSILE STRENGTH OF SLAG INCORPORATED CONCRETE CUBE

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	18.4
25%	18.6
30%	19.2
35%	18.4

C. FLEXURAL STRENGTH

Flexural strength is one of the indirect indications of the tensile nature of concrete, which is very weak in tension; it is also the measurement of the maximum tensile stress a concrete member can take during its lifespan before failure. A flexural test on an unreinforced concrete sample (500mm×100mm×100mm beam) shows its ability to withstand bending. The maximum flexural strength is observed for 15% fine aggregate replacement with glass cullets and 30% with cupola slag.



Figure 4 Flexural strength test of concrete beam

TABLE X
FLEXURAL STRENGTH OF GLASS INCORPORATED CONCRETE CUBE

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	7.95
5%	8.74
10%	9.27
15%	9.42
20%	8.31
25%	7.36

TABLE XI
FLEXURAL STRENGTH OF SLAG INCORPORATED CONCRETE CUBE

Percentage replacement of Fine Aggregate	Result Obtained (N/mm ²)
0%	7.95
25%	8.24
30%	9.196
35%	8.166

V. DURABILITY TESTS

The durability of concrete refers to its ability to resist deterioration and maintain its intended performance over time when exposed to various environmental and service conditions. Durability tests conducted were water permeability test, acid test and Wenner test. These tests were conducted on concrete cubes of 150 mm size cured for 28 days. The glass incorporated concrete cube is observed to have higher resistivity compared to slag incorporated and conventional concrete.

A. WATER PERMEABILITY TEST

Water permeability test determines the resistance of concrete against water under hydrostatic pressure. Test is performed on 150 mm size cubes. A 5 bar pressure is applied on the top of the cube by adjusting air pressure through a valve system. This pressure is kept constant for a period of three days. After three days, the pressure is released and the specimens were removed from the permeability cell. The specimens are then split into two and the maximum and average



Figure 6 Water permeability apparatus

depth of water penetration are recorded.

TABLE XII

TABLE XII WATER PERMEABILITY TEST RESULTS

Concrete Type	Average Depth of Water Penetration (mm)	Maximum Depth of Water Penetration (mm)
Control Mix	2.88	6.3
Glass Incorporated Concrete	1.74	5.8
Slag Incorporated Concrete	2.62	6.2

As the penetration of water into the cube increases, the lesser will be its durability. It was observed that the depth of penetration was less in glass incorporated concrete cube (15% replacement) than that of slag incorporated (30% replacement) concrete. Conventional concrete cube showed the deepest penetration.

B. ACID TEST

Concrete cubes of 150 mm size after 28 days of

curing were immersed in 5.5 (v/v percent) of Sulphuric



Figure 5 Acid Test Setup

Acid for 28 days. Loss in weight due to corrosion caused by acid attack is calculated.

TABLE XIII ACID TEST RESULTS

Concrete Type	Weight Before Immersing In Acid kg	Weight After Immersing In Acid for 28 days kg	Loss In Weight kg
Control Mix	8.655	7.795	0.860
Glass Incorporated Concrete	8.730	8.655	0.075
Slag Incorporated Concrete	8.690	8.315	0.375

From the test results it was observed that, concrete cube with glass replacement of 15% showed the least mass loss compared to the control concrete and the concrete with slag replacement of 30%. However, the cube with slag showed less mass loss than the conventional concrete cube.

C. SURFACE RESISTIVITY TEST

The Wenner probe method measures concrete resistivity using a probe with four electrodes. Glass and slag refine pore structure, reducing void connectivity and enhancing resistivity. Test results indicated that concrete made with 15% replacement of glass cullets and 30% replacement with cupola slag, both, showed higher resistivity than conventional.

TABLE XIV CLASSIFICATION OF CORROSION RATE BASED ON RESISTIVITY ((ACI 222R, 2001)

Concrete Resistivity (k.Ω.cm)	Corrosion Activity
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>20	Low
10-20	Low to Moderate
5-10	High
<5	Severe

TABLE XV
SURFACE RESISTIVITY TEST RESULTS

Concrete Type	Average surface resistivity value (k.Ω.cm)
Control Mix	55.937
Glass Incorporated Concrete	71.225
Slag Incorporated Concrete	63.700

VI. CONCLUSION

The study investigated the properties of concrete incorporating cupola furnace and waste glass cullets, comparing them with conventional concrete. Optimal results were observed with fine aggregate replacement of 15% with glass cullets and 30% with slag. Concrete with 15% glass replacement exhibited a 17.82% increase in compressive strength, 9.42% increase in split tensile strength, and 7.6% increase in flexural strength compared to conventional concrete. For slag replacement at 30%, there were increases of 9.9%, 4.3%, and 15.7% respectively. Slag showed a comparatively higher water absorbance, compared to glass cullets, which affected the workability. Increasing glass replacement improved workability, whereas slag replacement decreased it. Both glass and slag integrated concrete showed enhanced durability, with glass incorporation yielding the best results.

ACKNOWLEDGMENT

We would like to acknowledge the support and facilities provided by DST SAIF Cochin and RIT Kottayam for this project. We extend our gratitude to the HOD, Faculty members and all the laboratory staff of the Department of Civil Engineering, Government Engineering College, Thrissur, Kerala.

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