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Partial Replacement of Coarse Aggregate with Waste Glass and Cement with Glass Powder

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***Abstract*: The depletion of natural resources is a widespread occurrence in developing nations such as India, attributed to the rising levels of urbanization and industrialization, which entail the construction of infrastructure and other facilities. The environmental and economic concern is the biggest challenge concrete industry is facing. The issues of environmental and economic concern are addressed by the use of waste glass as partial replacement of coarse aggregates in concrete. Cement was replaced by waste glass powder as 0%, 5%, 10%, 15%, 20% by weight for M-25 mix. The concrete specimens were tested for mechanical tests and durability (water absorption) at 28 days of age. The waste materials considered to be recycled in this study is amber glass (beer bottle). Glass was used to replace partially of coarse aggregates as 0%, 25%, 50%, 75%, 100% in concrete mixes. These tests included workability, flexural strength test, tensile strength, compressive strength and water absorption test. The compression test done at 7 days and 28 days. The other mechanical test done only at 28 days. It was observed that the compressive strength values are higher than normal concrete up to 25% replacement of coarse aggregate with waste glass and 5% glass powder and further increase in glass reduces the strengths gradually.**

***Keywords*: waste glass, glass power, amber glass, coarse aggregate, mechanical tests.**

1. Introduction

The global issue of solid waste accumulation in landfills, compounded by the enduring nature of glass waste, necessitates urgent attention to waste management practices. Recycling waste glass for reuse in concrete production has emerged as a pivotal solution, garnering significant interest worldwide. Extensive research endeavors have been dedicated to exploring the feasibility of integrating waste glass into concrete formulations, thereby offering a sustainable alternative to traditional building materials. By substituting a portion of conventional aggregates with recycled glass, concrete can maintain, and even improve, its performance characteristics while simultaneously curing the consumption of natural resources and reducing landfill burden. Embracing waste glass as a viable building material represents a promising avenue for addressing environmental concerns and advancing sustainable practices within the construction sector. Consequently, continued research efforts and widespread adoption of eco-friendly concrete production methods are imperative for fostering a more sustainable built environment. Incorporating waste glass into concrete enhances its density, consequently decreasing water absorption and enhancing the concrete's durability. Introducing waste glass and glass powder into concrete leads to enhanced compressive strength and decreased water absorption. The integration of glass into concrete can be achieved by partially substituting one or more ingredients in various forms.

2. Materials and Methodology

A. Materials

1) Cement

Cement, a chemical substance serving as a binder in construction, undergoes a process of setting, hardening, and adherence to other materials. When combined with fine aggregate, cement yields mortar for masonry, while its mixture with sand and gravel results in concrete. Concrete stands as the most extensively utilized material globally, trailing only water as the planet's most-consumed resource. For our project, we utilize OPC 53 grade cement, specifically the Dalmia brand.

2) Fine aggregate

Fine aggregates refer to the natural sand particles obtained from mining operations. They comprise either natural sand or crushed stone particles. Fine aggregate materials, derived from natural sand or crushed rock, are employed in various construction applications such as concrete and asphalt production, road base construction, and other civil engineering projects. M-Sand, a type of manufactured sand, is also suitable for use as a fine aggregate. Its composition varies depending on its source. Defined by its size, sand falls between gravel and silt, being finer than the former and coarser than the latter.

3) Coarse aggregate

Coarse aggregates of 20mm diameter are utilized in RCC structures to enhance concrete pourability, facilitating the construction process. Proper vibration using a vibrating needle is essential when employing small to medium-sized aggregates. This practice minimizes the formation of honeycombing and reduces the occurrence of voids. It is the integral part of any concrete works. It provides strength and durability to the concrete mix and resistance to wear and tear.

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4) Waste glass pieces

Waste glass, sourced from disposals and scrap, predominantly consists of beer bottles. Upon collection, the bottles undergo a process where unwanted materials, such as labels, are meticulously removed. Subsequently, the bottles are manually crushed into smaller sizes, typically averaging 19mm and 12mm. The fragmented glass is then subjected to a cleaning procedure to eliminate dirt and other impurities. Following this, it undergoes further manual crushing and is sieved through a 20mm IS sieve to ensure uniformity.

5) Glass powder

The waste glass material, referred to as glass powder (GP), undergoes a granulation process through sieving after being crushed in a breaker and milled. This finely crushed glass essentially resembles very pure sand. Upon collection, the powder is sieved to determine its size, which measures at 90 microns. Waste glass sourced from local shops is collected and processed into glass powder. The glass powder is then separately mixed with cement before being dry mixed with other materials. The physical properties of the glass powder are assessed, while its chemical composition is detailed in Table 1.

Table 1
Chemical composition of GP

Composition	Percentage
Bound metal oxides (Ca, Mg, Na, K, Al)	20-25
Bound Amorphous Silica	75
Other metal oxides	<1

B. Methodology

Experiments were carried out on concrete by partially replacing coarse aggregate with waste glass and cement with glass powder of particle sizes 90µm. The replacement levels of waste glass were 0%, 25%, 50%, 75% and 100% of coarse aggregate and glass powder were 0%, 5%, 10%, 15% and 20% of the binder, and the mix designs were formulated. These results were compared with those of nominal concrete (0% replacement of glass powder). Various tests were conducted on cement, fine aggregate, and coarse aggregate, alongside workability measurements using different methods. Observations were tabulated, and the results were calculated. Graphs were plotted if necessary, using appropriate data points.

The different parameters of the strength characteristic and durability studied are,

1. Compressive strength
2. Tensile strength
3. Flexural strength
4. Water absorption

1) Compressive strength test

The dimension of specimen is 150x 150 x 150mm.Testes shall be made at recognized ages of the test specimens, in this project taken as 7 and 28 days. It is calculated by the equation using,

$$F = P/A$$

Where,
P= Maximum load applied (N)
F= Compressive strength (MPa)
A= Cross sectional area of the specimen (mm^2)

Fig. 1. Compressive strength test

2) Tensile strength test

Tensile strength is a measure of a material's ability to withstand a stretching force without breaking or deforming permanently. The dimension of cylindrical specimens of diameter 150mm and length 300mm were prepared. It is calculated by the equation using,

$$F = 2P/ (\pi D L)$$

Where,
P= Load at failure (N)
L = Length of the specimen (mm)
F = Tensile strength (MPa)
D = Diameter of the specimen (mm)

Fig. 2. Tensile strength test

3) Flexural strength test

Flexural strength, also known as modulus of rupture, is a material property that measures its ability to withstand bending without breaking. The dimension specimens 100x100x500mm were prepared. It is calculated by the equation using,

$$F = 3PL/(bd^2)$$

Where,
P= Failure load (N)
F= Flexural strength (MPa)
L= Effective span of the beam
b= Breadth of the specimen

Fig. 3. Flexural strength test

4) Water absorption

Water absorption of concrete is a critical property that affects its durability and performance. Concrete is inherently porous, meaning it can absorb water to varying degrees depending on its composition, porosity, and other factors. The water absorption of concrete is typically measured by the weight of water absorbed by the concrete specimen over a specific period, often expressed as a percentage of the dry weight of the specimen. It is calculated by the equation using,

$$W = \frac{B-A}{A}$$

Where,
B=Wet weight (kg)
A=Dry weight (kg)
W=Water absorption

5) Workability

a) Slump test

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete.

$$\text{Slump value} = H_{SC} - H_S$$

Where,
H_{SC}=Height of slump cone
H_S=Height of slump

b) Compaction factor test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. The method applies to plain and air-entrained concrete, made with lightweight, normal weight or heavy aggregates having a nominal maximum size of 40 mm or less but not to aerated concrete or no-fines concrete. The test is carried out as per IS: 1199-1959.

$$FC = \frac{\text{Partially compacted concrete}}{\text{Fully compacted concrete}}$$

Where,
FC=Compaction factor

3. Result and Discussion

A. Compressive Strength Test Results

Table 2
Result of compressive strength

Percentage of replacement	Compressive Strength (N/mm²)	
	7th day	28th day
GC1	37.30	42.8
GC2	35.9	43.47
GC3	20.14	27.23
GC4	14.72	23.1
GC5	13.92	22.06

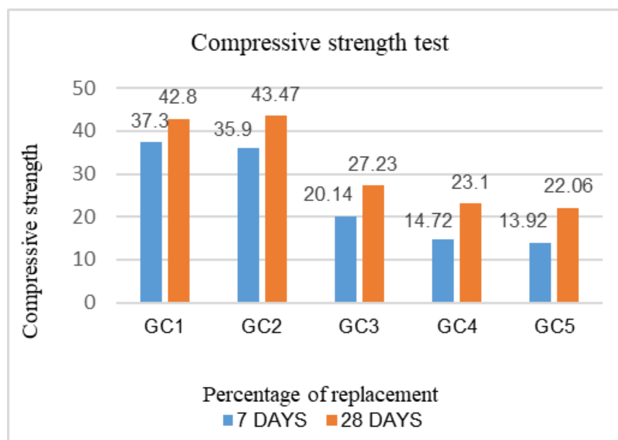

Fig. 4. Graph of compressive strength test result

B. Tensile Strength Test Results

Table 3
Result of tensile strength

Percentage of replacement	Split tensile strength (N/mm²) 28 days
GC1	3.50
GC2	3.04
GC3	2.75
GC4	2.54
GC5	2.52

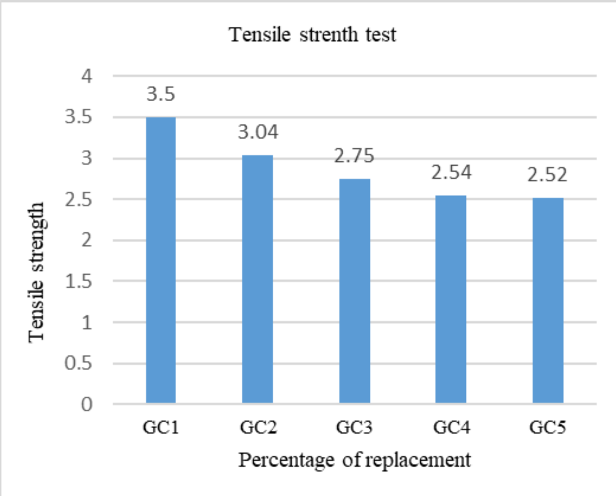

Fig. 5. Graph of tensile strength test result

C. *Flexural Strength Test Results*

Table 4
Result of flexural strength

Percentage of replacement	Split tensile strength (N/mm^2) 28 days
GC1	7.24
GC2	6.46
GC3	5.71
GC4	5.03
GC5	4.24

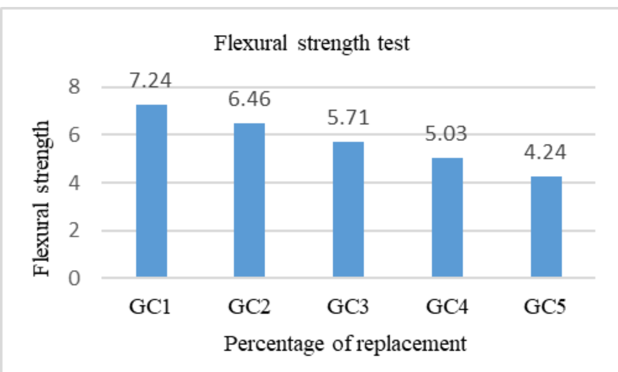

Fig. 6. Graph of flexural strength test result

D. *Water absorption test*

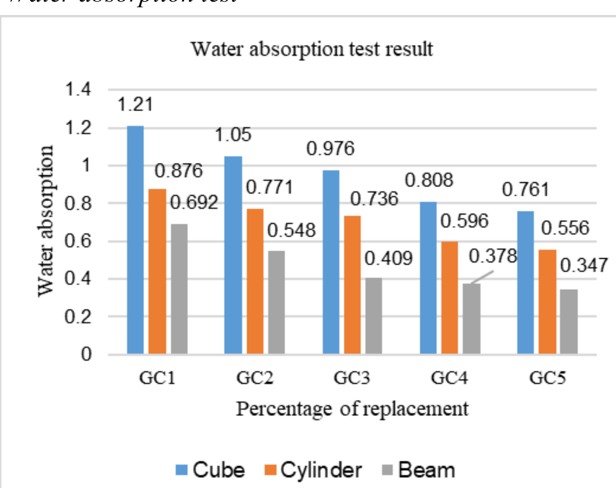

Fig. 7. Graph of water absorption test result

Table 5
Result of water absorption strength

Percentage of replacement	Cube	Cylinder	Beam
GC1	1.21	0.876	0.692
GC2	1.05	0.771	0.548
GC3	0.976	0.736	0.409
GC4	0.808	0.596	0.378
GC5	0.761	0.556	0.347

4. Conclusion

Compare to conventional concrete, glass concrete has 1.5% increase in compressive strength at 25% coarse aggregate replaced with glass piece and 5% glass powder (GC2). Flexural strength and tensile strength value of concrete is decreasing with increasing percentage of replacement but all values are within the limit of M25 mix. Workability of the glass concrete is increased with increasing percentage of replacement due to the angular edged glass piece. That is when compare to GC1, all other replacement percentage has low slump with high workability. Based on the result, water absorption of glass concrete is less than that of conventional concrete. That means the glass concrete is more durable than conventional concrete. Glass concrete's enhanced durability and resistance to corrosion can reduce the need for frequent repairs and replacements, thereby lowering long-term environmental impacts associated with maintenance activities.

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