An Experimental Study for Optimal Usage of Powdered Glass in Concrete as a Cement Replacement Material

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Abstract. The adverse effect of greenhouse emissions like CO2 leads to global warming. As per statistics, the global contribution of the cement manufacturing industry to greenhouse gas emissions is nearly 7%. To address these effects on the nature of the environment associated with cement manufacturing, it is necessary to explore sustainable binders for manufacturing concrete. Hence, extensive research is being conducted in the recent past to replace cement with various materials including waste generated from various sectors. Further, the replacement of fine aggregates and cement in concrete with various proportions of powdered glass is an engrossing topic among researchers for over a decade. The present study aims to the optimal use of glass powder in concrete as a replacement for cement and to enhance the characteristics compressive strength when compared to conventional concrete. Cement was replaced by various percentages of fine glass powder ranging from 10-50 % at an increment of 10%. The concrete cube specimens for 7 and 28 days were evaluated for their compressive strength after curing period, with that of conventional concrete. From the acquired results, it is perceptible that glass powder can be a suitable replacement for cement.

Key Words: Glass powder, Partial replacement, Cement, Strength, Concrete.

1. Introduction

Naturally, almost all industries produce by-products, irrespective of the nature. Therefore, Effective disposal of by-products is a challenging task. In ancient times, solid wastes were disposed in landfills of low-lying areas which is unsustainable. Discarding Industrial by-products like fly ash, silica fume, blast furnace slag, and other by-products of plastics, glass, tiles, and agriculture causes environmental pollution. Therefore, Recycling of wastes is an emerging sector for contributing towards sustainability.

Disposal of industrial wastes viz. fly ash, silica fume, blast furnace, domestic (i.e., plastics and glass), and agricultural wastes lead to environmental pollution. Hence disposal of these waste by-products is a puzzling task. Certain waste by-products such as fly ash, rice husk ash, silica fume, and blast furnace slag have pozzolanic characteristics and have been used as a cement substitute in concrete. The glass powder contains a high amount of silica, thus the cement when mixed with glass powder leads to triggering of pozzolanic reactions which results in an optimum increase of compressive strength, and thus cement usage can be reduced.

2. Glass Powder

The utilization of glass is essential for human development, as the vast quantity of glass waste is produced by humans. The glass is produced by melting silica, soda ash, and CaCO3 at a temperature
range of 1400 – 1500 °C, followed by cooling, which causes solidification without any crystallization. As glass is generally used in our daily routine through manufactured products like sheet glass, bottles, glassware, and vacuum tubes. For the past few years, the total waste glass generation increased due to the ever-growing usage of glass products in day-to-day life. Henceforth, the disposal of this waste glass into landfills is not sustainable as they are not bio-degradable. As an alternative, this waste glass can be employed in construction as an auxiliary for cement.

Figure 1. Glass Powder.

3. Chemical Compositions

Table 1. Chemical compositions of Glass Powder and cement

| Composition (%by mass)/property | Cement | Glass powder |
|--------------------------------|--------|-------------|
| Silica (SiO₂)                  | 20.2   | 72.5        |
| Alumina (Al₂O₃)                | 4.7    | 0.4         |
| Iron oxide (Fe₂O₃)             | 3.0    | 0.2         |
| Calcium oxide (CaO)            | 61.9   | 9.7         |
| Magnesium oxide (MgO)          | 2.6    | 3.3         |
| Sodium Oxide (Na₂O)            | 0.19   | 13.7        |
| Potassium oxide (K₂O)          | 0.82   | 0.1         |
| Sulphur trioxide (SO₃)         | 3.9    | -           |
| Loss of ignition               | 1.9    | 0.36        |
| Fineness%                      | 97.4   | 80          |

4. Objectives

The objectives of this investigation are to evaluate the optimum usage of fine powdered glass in concrete. To evaluate the utility of fine glass powder as a partial replacement of cement in concrete without any decrement in the characteristic compressive strength and to reduce the landfill deposits.

5. Methodology

The present study is to compare the mechanical properties of concrete (Characteristics compressive strength) with conventional concrete in which cement is replaced with different proportions i.e. 10%, 20%, 30%, 40%, 50% of Glass powder at a w/c ratio of 0.39 with Ordinary Portland cement.

The materials used in this investigation are as follow
1. Cement - OPC 53 grade IS 269:2015
2. Fine aggregate - Manufacture sand
3. Coarse aggregate - 20mm size
4. Plasticizer - Conplast SP430 DIS
5. Water/Cement - 0.39

Primary Tests on Materials,
1. The Specific gravity of cement.
2. The Specific gravity of aggregates
3. Impact value of aggregate

5.1 Mix Design Procedure for M30 Grade Concrete as Per Is 10262:2009.

Stipulations for Proportioning
a) Grade designation: M30
b) Type of cement: Ordinary Portland cement conforming to IS 269:2015
c) Type of admixture: Glass powder
d) Maximum nominal size aggregate: 20mm.
e) Minimum cement content: 320 Kg/m³
f) Maximum water-cement ratio: 0.45
g) Workability: 96mm (slump)
h) Exposure condition: Severe
i) Method of concrete placing: Pumpable
j) Degree of supervision: Good
k) Type of aggregate: 20 mm Crushed angular aggregate
l) Maximum cement (OPC) content: 450 Kg/ m³
m) Chemical admixture type: Conplast SP430 DIS (Sulphonated Naphthalene)

5.2 Target Mean Strength for M30 Grade
\[ f_{ck} = f_{ck} + 1.65S \]
Where,
- \( f_{ck} \) = target mean compressive strength at 28 days
- \( f_{ck} \) = characteristics compressive strength
- Standard Deviation, \( S = 5N/mm^2 \)
Therefore,
Target strength = 30 + 1.65 x 5 = 38.25 N/mm²

5.3 Selection of W/C Ratio
As per IS 456-2000, Table 5 the maximum w/c ratio is 0.45. Based on experience, adopt w/c ratio as 0.39.
0.39 < 0.45, hence OK

5.4 Selection of Water Content
As per table 2 of IS 456, the max required water content for Coarse aggregate (20mm) = 186 liters. Estimated water content for 100 mm slump = 186 + (6/100) * 186 = 197 liters as a plasticizer is used; the water content percentage can be reduced up to 20%. Based on the experience and trials for super plasticizer 25% reduction of water content has been achieved. Hence, the arrived water content = 197 * 0.75 = 147.75 liters.

5.5 Calculation of Cement Quantity
Water-cement ratio = 0.39
Cement = \((148/0.39) = 379.48 \text{ kg/m}^3 > 320 \text{ kg/m}^3\)
379.48 kg/m³ > 320 kg/m³, Hence Ok
5.6 Calculation for Volume of Coarse Aggregate and Fine Aggregate

As per IS 10262:2009, the volume of coarse aggregate (20 mm) and fine aggregate (Zone II) for the w/c ratio of 0.50 is 0.62.

In the present study, the water-cement ratio is 0.39. Hence the volume of coarse aggregate needs to be enhanced to decrease the fine-aggregate proportion. As the w/c ratio is lower to 0.11, the proportion of coarse aggregate is increased by 0.02. Therefore, the correct proportion for volume of coarse aggregate for the w/c ratio of 0.39 = 0.62

Note: If the coarse aggregate is not angular, the volume of coarse aggregate can be increased suitably, according to the existing conditions.

For pumpable concrete, the value is reduced by 10%, therefore the volume of Coarse aggregate = 0.64x0.9 = 0.576, and Fine aggregate content = 1-0.576 = 0.424

Table 2. Quantities required for 1 m³

| S.no | Materials            | Quantities       |
|------|----------------------|------------------|
| 1    | Cement               | 379.48Kg/m³      |
| 2    | Water                | 147.75liters     |
| 3    | Fine aggregate       | 793.728Kg/m³     |
| 4    | Coarse aggregate     | 1119.74Kg/m³     |
| 5    | Chemical admixtures  | 3.79Kg/m³        |
| 6    | Water-Cement ratio   | 0.39             |

6. Experimental Programme

In this experimentation, an attempt has been made to compare the mechanical properties (characteristics compressive strength) of concrete where cement is replaced with Glass powder in various percentages viz. 10%, 20%, 30%, 40%, 50% at a w/c ratio of 0.39 with Ordinary Portland cement. In the present work, a comparative study with respect to the workability of 100mm slump criteria is also conducted.

The primary test results for materials used in this investigation are as follow:

1. Specific gravity of cement = 3.15
2. Specific gravity of fine aggregate = 2.65
3. Specific gravity of glass powder is 2.58
4. Specific gravity of coarse aggregate = 2.6
5. Impact value of coarse aggregate = 9.22%

7. TEST PROCEDURES

Compressive strength of concretes

Figure 2. Compressive testing of specimen
8. Results and Discussion

The cement is replaced with glass powder of 10%, 20%, 30%, 40% and 50% respectively in M30 grade concrete and the compression strengths for cubes are tested at 7 and 28 days.

| Sno | Mix (Cement+% of glass powder) | Compressive strength of concrete at 7 days (N/mm²) | Compressive strength of concrete at 28 days (N/mm²) |
|-----|--------------------------------|----------------------------------------------------|-----------------------------------------------|
| 1   | C+0                            | 41                                                 | 45.1                                          |
| 2   | C+10                           | 43                                                 | 47                                            |
| 3   | C+20                           | 45.5                                               | 48.3                                          |
| 4   | C+30                           | 48                                                 | 49.8                                          |
| 5   | C+40                           | 42                                                 | 39.34                                         |
| 6   | C+50                           | 39                                                 | 35.04                                         |

**Figure 3.** Compressive strength of concrete with different % replacement

The compressive strength test data corresponds to the mean value of the compressive strength.

- At 7 days and 28 days, it shows strength of 48 MPa and 49.8 MPa respectively at 30% cement replacement.
- After 30% cement replacement, the strength of concrete reduces as the CaO content gets reduce.
- Therefore, the optimum % for the cement replacement with glass powder is 30%.
9. Conclusion

The conclusions drawn based on the experimental test results are as follows:

- The maximum compressive stress at 7 and 28 days are 48MPa, 49.8MPa respectively attained at 30% replacement of cement with glass powder.
- The increase in strength up to 30% replacement is due to the filling of void spaces by glass powder and increasing the density of concrete.
- The Cao content gets reduces; hence the strength starts to decrease.
- From the results, it is observed that the concrete workability increased which is indicated by a slump value of 96mm.
- Thus, it is concluded that the optimal composition of glass powder for replacement is 30%.

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