

Utilization of waste glass powder as a partial replacement of cement in concrete

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Abstract: Concrete is the most commonly used material in the world, which is a mixture of Portland cement, aggregates (including fine and coarse aggregate), water and with or without admixtures. Many researches are carried out these days on the replacement of Portland cement with waste materials having pozzolanic effect like Fly ash, Bagasse ash, Silica fume and marble powder etc. Waste Glass Powder can also be used as a binder with the partial replacement of cement, it also acts as a filler material. Waste glass when ground to a very fine powder shows pozzolanic properties as it contains high SiO₂ and therefore to some extent can replace cement in concrete and contribute strength development. In this study Glass Powder partially replaced at varying percentage 0 to 40 percent by weight of cement, and tested for its workability and Compressive strength up to 84 days of age and were compared with those of conventional concrete. The overall test results shows that Waste Glass Powder could be utilized in concrete as a good substitute of cement. The research concluded that with the age of testing affects the compressive strength. The reduction of workability was observed with the increase of glass powder content, as the slump value decreased with a constant amount. The initial Strength was less as compared to the conventional concrete, but after 28 days the pozzolanic activity started and the difference of strength between conventional concrete and glass powder concrete reduced to 12 percent. At 15 percent replacement of cement by Glass powder, the concrete gives maximum strength which is about 88.22 percent of the control mix. Thus 15 percent GP content is recommended as optimum replacement content for strength.

Keywords: Pozzolana, Glass Powder, Concrete, Cement Replacement

Introduction:

The use of waste materials in construction industry has significantly increase in the past few years, due to the fact that they do not have any adverse effects on the properties of concrete and thus provide an effective platform for the disposal of waste material in permanent concrete structures. waste glass is also included in such materials category.

In 2005, approximately 12.8 million tons of waste glass was generated in the United States of America, and only 20 percent of that was recycled [1]. Due to lack of landfill sites in the urban areas and increasing cost of land filling, the process of recycling and reuse of the waste material is trending these days.

Many research studies are conducted on the productive use of waste glass in concrete. Crush waste glass have been used for the decorative concrete, and literature reports that it is also used as coarse aggregate in the conventional concrete [2-3]. As glass contains high amount of silica content, which has in turn lead to the laboratory studies on the practicality of using waste glass as a raw material in concrete batching [4-5]. The utilization of finely grounded glass powder as cement replacement has yield positive result in concrete batching [6-10]. Glass is amorphous and with high content of silica, thus making it a good pozzolanic material when the size is reduced then 75 μm [11]. Studies have indicated that finely grounded glass does not adds to alkali-silica reaction [5].

As the cement will be replaced by the waste glass powder, the amount of cement used will be less and great amount of waste glass powder will be utilized in permeant structures like roads, bridges, building etc. Due to less amount of cement used in concrete production, it will counter the hazardous effects produced by the cement manufacturing, in the form of carbon dioxide production that result in global warming and environmental pollution. With the successful employment of waste glass in concrete will encourage the use of non-conventional material that are of local or regional origin.

Research Significance:

The significance of the study reported, is to determine the performance of concrete that is made with the replacement of cement with glass powder. The emphasis of the work is based on ascertain the performance of concrete containing glass powder and to compare it with ordinary plain concrete. The study is expected to provide:

- i. The optimum partially replace of cement content in concrete that will directly influences economy in construction.
- ii. Environmental friendly disposal of waste glass in concrete structures.
- iii. Contribution of waste glass in strength development and durability of concrete.

iv. Will encourage the use of non-conventional materials which are typically of local or regional origin.

Material & Methods:

Concrete is a mixture of Portland cement, aggregates (including fine and coarse aggregate), water and with or without admixtures. For the research purpose, cement was replaced with waste glass powder having a particle size less than 45 µm. The waste glass powder was replaced with in the range of 10 to 40 percent and mix design was carried out for each mix. American Concrete Association (ACI) Absolute Volume Method (ACI 211.1-91) of Concrete Mix Design proportioning was used to compute the mix design. Following are the material details.

Cement:

Ordinary Portland Cement (OPC) was used in the research was of “Cherat Cement Company” and fulfilled the requirements of ASTM C150. Chemical properties of cement are shown in

Table 1

Table 1 Chemical properties of Cherat cement

| S/N | Property | ASTM C150 Ranges | Manufacturers: (Cherat Cement) |
|-----|--|------------------|--------------------------------|
| 1 | Soundness (mm) | <10 | 2 |
| 2 | Fineness | <10 | 8 |
| 3 | Insoluble Residue(I. R) % | 0.75 (Max) | 0 |
| 4 | Loss on Ignition (LOI) % | 3 (Max) | 2 |
| 5 | Magnesium Oxide (MgO) % | 6 (Max) | 1 |
| 6 | Sulphuric Anhydride (SO ₃) | 3.5 (Max) | 2 |

Water:

The water used was potable, fresh, colorless, odorless, and tasteless water that is free from organic matter of any type. Which may later on affect the quality of concrete?

Coarse Aggregate:

The coarse aggregate was gained from nearby accessible stock named Margalla Crush. Various tests were performed on coarse aggregate as indicated by the ASTM standards to get certain properties needed for the mix design of the concrete. The physical properties of the coarse aggregate are shown in Table 2

Table 2 Physical properties of coarse aggregate

| Description | ASTM Standard | Value |
|-----------------------|---------------|-------|
| Bulk Specific Gravity | ASTM C128 | 2.641 |
| Bulk Specific Gravity | ASTM C128 | 2.67 |

| (S.S.D) | | |
|--|-----------|--------|
| Water Absorption (%) | ASTM C128 | 1.03 |
| Available Moisture Content (%) | ASTM C566 | 1 |
| Rodded Unit Weight (lb/ft ³) | ASTM C29 | 100.09 |
| Nominal max. Size of Coarse Aggregate (inch) | ASTM C136 | 3/4 |

Fine Aggregate:

Provincially accessible sand was utilized as fine aggregate in this research. . LawerancePur sand was chosen for the cement blend and the accompanying tests were performed by ASTM Standard. The physical properties of sand is shown in **Table 3**

Table 3 Properties of lawerancepur sand

| Description | ASTM Standard | Value |
|---|---------------|---|
| Moisture Absorption (%) | ASTMC127 | 1.46 |
| Moisture Content (%) | ASTMC127 | 1.09 |
| Bulk Specific Gravity (oven dry) (g/cc) | ASTMC127 | 2.602 |
| Bulk Specific Gravity (SSD)(g/cc) | ASTMC127 | 2.639 |
| Apparent Specific Gravity(g/cc) | ASTMC127 | 2.703 |
| Fineness Modulus | ASTM C136 | 2.51 |
| Organic Impurities | ASTM C87 | Observed Lighter colour of solution then standard |

Waste Glass Powder:

Locally available waste glass was collected and grounded with the help of ball mill to get the desire particle size. In this experiment the particle size used was less than 45 µm as shown in **Figure 2**. To check the chemical composition of the glass powder, XRF was performed and its results are shown in Table 4

Table 4 Chemical analysis of waste glass powder Compound Analysis

| Compound | Percentage |
|--------------------------------|------------|
| SiO ₂ | 78.21 |
| CaO | 15.54 |
| Fe ₂ O ₃ | 3.14 |
| Al ₂ O ₃ | 1.73 |
| K ₂ O | 0.60 |
| ZnO | 0.25 |
| SO ₃ | 0.25 |
| Total | 99.73 |

Chemical Analysis of Glass Powder

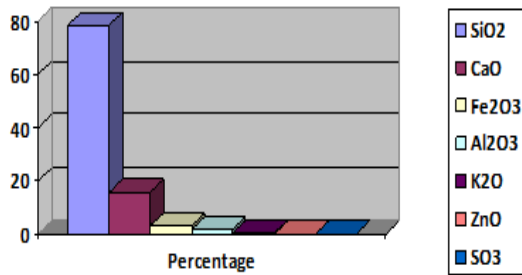


Figure 1 Graphical representation of various compounds present in glass powder



Figure 2 Grounded waste glass powder

Table 5 Mix design specifications (for 1m³ of concrete)

| Material | M1 Mix (0%) | M2 Mix (10%) | M3 Mix (15%) | M4 Mix (20%) | M5 Mix (25%) | M6 Mix (30%) | M7 Mix (40%) |
|-----------------------|-------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Cement (kg) | 375 | 337.5 | 318.7 | 300 | 218.2 | 262.5 | 225 |
| Fine Aggregate (kg) | 761 | 761 | 761 | 761 | 761 | 761 | 761 |
| Coarse Aggregate (kg) | 979 | 979 | 979 | 979 | 979 | 979 | 979 |
| Water (kg) | 206 | 206 | 206 | 206 | 206 | 206 | 206 |
| Glass Powder (kg) | 0 | 37.5 | 56.3 | 75 | 93.8 | 112.5 | 150 |

Mix Design:

To check the impact of glass powder on the concrete behavior, a suitable mix design of concrete needed to be done so to satisfy the conditions, to produce a concrete with required properties in the most economical way, the concrete constituents are intentionally chosen and proportioning is done through a mathematical method which is known as concrete mix design.

Experimental Program:

The plain concrete and the modified mix of concrete with the glass powder incorporation are listed in Error! Reference source not found.. To check the effect of glass powder on the workability of concrete, slump test will be performed in accordance to ASTM –C143. Standard cylinders of 6 x 12 inches are casted for each of the mix. The compressive strength test was performed in accordance to ASTM-C39 at various ages (3, 7,14,28,56, and 84 days) to check the long term effect of the glass powder on the compressive strength of concrete. The unit weight of concrete was done at 84 day days according to ASTM-C642

Results:

Properties of Fresh Concrete:

Slump test was performed on site for all the three concrete mixes in according to ASTM-C143, their results are stated in **Table 6**

Table 6 Slump test of fresh concrete

| Concrete | Slump | |
|----------|-------|------|
| | mm. | Inch |
| | | |

| | | |
|--------|-----|-----|
| M1 Mix | 110 | 4.3 |
| M2 Mix | 100 | 3.9 |
| M3 Mix | 90 | 3.5 |
| M4 Mix | 75 | 3 |
| M5 Mix | 45 | 1.8 |
| M6 Mix | 40 | 1.6 |
| M7 Mix | 10 | 0.4 |

The test result shows a clear decrease in the slump value with the addition of glass powder. The degree of workability is measured with the amount of slump obtained, therefor greater amount of water is required to achieve the same amount of workability as that of the Control Mix (M1).

Properties of Hardened Concrete:

Unit Weight of Concrete:

The unit weight of the concrete cylinder specimens were determined at 84 days of casting. The results of the unit weight is shown in **Table 7** . The unit weight was calculated for all the seven mixes.

Table 7 Unit weight of concrete at 84 day

| Mix Type | Unit Weight | |
|----------|-------------|-------------------|
| | g/cc | Kg/m ³ |
| M1 Mix | 2.390 | 2390 |
| M2 Mix | 2.370 | 2370 |
| M3 Mix | 2.365 | 2365 |
| M4 Mix | 2.357 | 2357 |
| M5 Mix | 2.390 | 2390 |
| M6 Mix | 2.380 | 2380 |
| M7 Mix | 2.340 | 2340 |

With the variation of glass powder in the concrete mix, there is a variation the unit weight of the concrete mix. With the addition of 10 %, 20%, 30% and 40 % glass powder there was a decrease in the unit weight of the concrete, but with 25 % replacement of GP the unit weight was same as that of the M1.

Compressive Strength:

Cylinder specimens were casted for each of the mix and testing was performed at various ages. For each mix 18 cylinders were casted, total 126 cylinders were casted for the testing of compressive strength. The result of various mix for compressive strength is mention under Table 8.

Table 8 Compressive strength of concrete at various ages

| Mix Type | Compressive Strength of Cylinder Specimens (Psi) | | | | | |
|----------|--|---------|---------|---------|---------|---------|
| | 3 days | 7 days | 14 days | 28 days | 56 days | 84 days |
| M1 | 1311.79 | 1889.36 | 2523.47 | 2913.30 | 3459.06 | 3838.49 |
| M2 | 715.52 | 1217.62 | 1858.18 | 2068.68 | 2715.79 | 3373.30 |
| M3 | 1307.22 | 2105.07 | 2123.26 | 2396.14 | 3100.42 | 3386.3 |
| M4 | 906.99 | 1229.25 | 1777.61 | 2193.42 | 2554.66 | 3357.70 |
| M5 | 806.00 | 1221.46 | 1699.65 | 2180.43 | 2754.78 | 3342.12 |
| M6 | 558.75 | 940.78 | 1317.62 | 1567.10 | 1819.19 | 2354.55 |
| M7 | 462.59 | 790.59 | 1114.91 | 1286.43 | 1600.89 | 2253.20 |

Compressive Strength at Various Ages

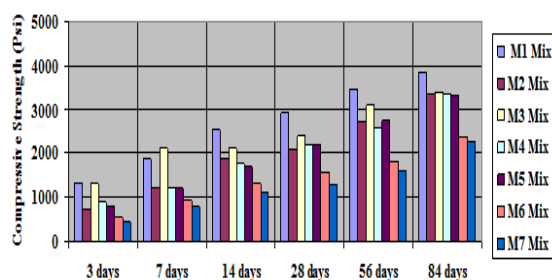


Figure 3 Compressive strength of concrete at various ages

The percent strength achieved by the mixes as compared to the mix M1, is shown in the Table 9. The results shows a clear behavior of the glass powder in the mixes. Initially a decrease in compressive strength is observed but with the passage of time, the strength is gained at a constant rate and at 84 day of testing the mix M2, M3, M4, have reached 88 % compressive strength of M1, thus making the use of glass in concrete between the range of 10 % to 25 %

replacement in cement in concrete upon the expense of 12 % reduction in strength

Table 9 Percent strength achieved by other mix interns of M1

| Days | Compressive Strength (Percent of M1 Mix) | | | | | |
|------|--|-------|------|------|------|------|
| | M2 | M3 | M4 | M5 | M6 | M7 |
| 3 | 4.5% | 99.7% | 9.1% | 1.4% | 2.6% | 5.3% |
| 7 | 9.7% | 11.4% | 5.1% | 4.6% | 9.8% | 1.8% |
| 14 | 3.6% | 84.1% | 0.4% | 7.4% | 2.2% | 4.2% |
| 28 | 1.0% | 82.2% | 5.3% | 4.8% | 3.8% | 4.2% |
| 56 | 8.5% | 89.6% | 3.9% | 9.6% | 2.6% | 6.3% |
| 84 | 7.9% | 88.2% | 7.5% | 7.1% | 1.3% | 8.7% |

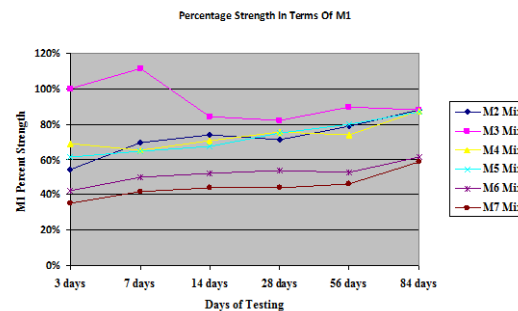


Figure 4 Graph showing the trend of strength development

Conclusion:

The use of pozzolanic materials as a partial replacement of cement affects the compressive strength of the concrete. In this research, the glass powder is used as an artificial Pozzolana. The glass powder is introduced into the cement at different percentage (0, 10, 15, 20, 25, 30 and 40% by weight of cement), the compressive strength was checked for these blended mixes. The results of the blended mixes were compared with the Control Mix. The following conclusions are drawn from this study: The slump test performed indicated that incorporation of glass powder in concrete reduces the workability. The incorporation of glass powder in concrete adversely affected the compressive strength. It is observed that the incorporation of glass powder content (as a partial replacement of cement) decreased the compressive strength at early ages but at later ages, glass powder concrete gives 12% less compressive strength then the CM. At 15% replacement of cement by glass powder, the concrete gives maximum strength which is about 88.22% that of control mix. Thus 15% glass powder content is recommended as optimum content for strength.

Recommendation:

- The cement may be replaced by glass powder within the range of 10 to 25 percent, as an excess replacement may render the strength and affect other properties of concrete.
- To improve the workability of concrete use considerable amount of plasticizers to attain a good workability mix.

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