# High Performance Concrete using Steel Fiber and Partial Replacement of Sand by Glass Powder

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**Abstract -** *The growing population has led to the high demand of materials in construction field. The resources are limited and we cannot depend completely on only one material always. So, we need to search for alternatives to these construction materials. The alternative of sand can be waste glass powder. Nowadays, a major waste of big city is glass in different forms like glass cuttings from shops, bottles, glassware, vacuum tube which are not recycled and dumped in landfills. This can create environmental hazards. Also, the exploitation of sand from river beds is lowering the ground water table and leading to ecological disturbance. Using waste glass powder (GP) in concrete can reduce the dependence on sand and sustain the environment. The objective of this project is to present the results of experimental study on M40 grade concrete made with waste glass powder and steel fibers. The steel fibers have been incorporated to achieve high performance concrete in context of strength. Natural sand was replaced partially by glass powder from 0% to 40% with an increment of 5%. Steel fiber was added 3% by weight of cement with aspect ratio 50. Compressive and flexural strength were tested and compared with conventional concrete. The optimum percentage of sand replacement was 40% observed with steel fiber and glass powder mixed concrete. Maximum compressive and flexural strength was for MIX E achieved at 20% replacement of sand by GP. Concrete showed high performance regarding strength.*

***Key Words***: Sand replacement, glass powder, steel fiber, high performance concrete, compressive and flexural strength

## 1. INTRODUCTION

Concrete, the most abundantly used construction material in the world. Global usages of concrete are increasing in enormous scale. Worldwide, over ten billion tons of concrete are produced each year. Concrete comprises of basic constituents like water, cement, coarse aggregate and fine aggregate. Among these, fine aggregate is an important ingredient of concrete. The common source of fine aggregates is river and the fine aggregates which are scraped from the rivers are generally termed as river sand. Nowadays, due to extensive use of river sand, it is on the verge of depletion. The natural river beds are being exploited and the ground water table is lowering deep down the earth crust. This is creating the adverse effect on the biodiversity and ecology, threatening the environmental stability. The country like India is facing the scarcity of river sand. The price in the local market has raised high. To maintain environmental sustainability and overcome scarcity of river sand, we need to move on in search of alternatives. The need for alternative material can be fulfilled from waste glasses. The sources can be landfills where direct dumping of waste glasses are done which increases landfill area and environmental problems in return. Other sources can be waste glasses collected from the shops. Waste material (waste glasses) can be utilized effectively in concrete and construction sector. Using this material has dual benefits, one from environmental aspect and other as source of sand. The problem of dumping and disposing the waste glasses which affects environment can be solved as well as the scarcity of sand can also be fulfilled to a large extent. In New York City, it cost taxpayers approximately 60 million dollars to dispose of its waste glasses. There is a misconception that disposing waste glass in the landfills is cheaper than recycling them. By showing the economic feasibility of concrete production as a viable secondary market for waste glass, we hope to change the above misconception.

Incorporating waste glass powder in concrete as sand can reduce production cost. The waste glasses can be crushed to fine aggregate size on a large scale. These crushed waste glass powder when sized and processed properly can exhibits characteristics similar to that of natural sand. Fine powder of glass when mixed with concrete increases density and strength also. Using steel fiber can further improve the strength. To achieve better performance in terms of strength, glass powder and steel fiber both can be used. This is one of the combinations to make high performance concrete. The performance of concrete can be improvised in different aspect like strength, workability, durability, resistance to fire or chemical attacks etc. This is called high performance concrete.

## 2. Materials and Methodology

### 2.1 Materials used

Cement: Ordinary Portland Cement (OPC) of 53 grade Priya cement conforming to IS 12269:1987 was used throughout the experiment.

**Table -1:** Properties of Cement

| S.No | Properties | Result |
|---|---|---|
| 1 | Normal consistency | 32% |
| 2 | Initial setting time | 33 mins |
| 3 | Specific gravity | 3.12 |
| 4 | Fineness of cement | 2.37% |

Coarse Aggregates: The coarse aggregate used in this experiment was mostly angular between 20mm and 10mm size crushed granite aggregate conforming to IS 383:1970. Specific gravity of coarse aggregate obtained was 2.85.

Fine Aggregates: The fine aggregate used in this experiment was clean river sand conforming to IS 383:1970. Sand was found to be finer after sieve analysis.

**Table -2:** Properties of Fine Aggregates

| S.No | Properties | Result |
|---|---|---|
| 1 | Specific gravity | 2.56 |
| 2 | Fineness modulus | 1.9 |
| 3 | Grading zone | IV |

Glass Powder: The glass powder was used to replace the sand by some percentages. Waste Glass bottles were collected from nearby shops. Label on bottles were removed and washed thoroughly. Washed bottles were placed in the drum of Los Angeles Abrasion Testing machine and 10 abrasive charges placed inside. Lid of drum was closed and allowed to 200 revolutions. The glass bottles were crushed inside and then it was sieved on 2.36mm size sieve. The particles of glass powder were all 2.36mm passing. The process was repeated until required quantity of glass powder was obtained for the experiment.

**Table -3:** Properties of Glass powder

| S.No | Properties | Result |
|---|---|---|
| 1 | Specific gravity | 2.32 |
| 2 | Fineness modulus | 2.87 |
| 3 | Grading zone | II |

**Fig -1:** Crushing and grinding of waste glass using Los Angeles Abrasion Testing machine and sieving using 2.36mm size sieve

Steel Fibers: Steel fibers used in this experiment were made by cutting binding wires adopting aspect ratio of 50. The fibers were straight cut.

**Fig -2:** Steel fibers

Water: Water is one of the most important ingredients for concrete. Its quality and quantity can change the strength of concrete. Potable water was used in this experiment.

### 2.2 Experimental Methodology

The project is basically on the replacement of river sand with glass powder while making high performance concrete in terms of strength using steel fibers in it. It's an effort to make high performance concrete. The different proportion of glass powder (GP) was taken and 3% steel fiber (SF) by weight of cement was used in the experiment and the result was compared with conventional concrete. The concrete was designed for M40 grade. Mix design was done as per the guidelines specified in IS 10262:2009. Water cement ratio adopted was 0.4 and mix ratio 1:1.24:2.68. The details of the mix design have been shown in the table 4 below.

**Table -4:** Details of Mix Proportions in Kg per Cu.M

| Mix | GP % | Cement | Sand | Glass Powder (GP) | Total Fine Agg. | Coarse Agg. |
|---|---|---|---|---|---|---|
| A | 0% | 465 | 575 | 0 | 575 | 1242 |
| B | 5% | 465 | 546 | 29 | 575 | 1242 |
| C | 10% | 465 | 517 | 58 | 575 | 1242 |
| D | 15% | 465 | 488 | 87 | 575 | 1242 |
| E | 20% | 465 | 460 | 115 | 575 | 1242 |
| F | 25% | 465 | 431 | 144 | 575 | 1242 |
| G | 30% | 465 | 402 | 173 | 575 | 1242 |
| H | 35% | 465 | 373 | 202 | 575 | 1242 |
| I | 40% | 465 | 345 | 230 | 575 | 1242 |
| Steel fiber, 3% of cement is 13.95 Kgs per Cu.M added to all mixes except Mix A (Conventional mix) | | | | | | |

**Fig -3:** Mixing of cement, sand, aggregate, glass powder and steel fiber.

**Fig -4:** Curing of cubes and beams

## 2.3 Compressive Strength Test:

Cube of 150mm x 150mm x 150mm dimensions was used for the experiment. The moulds were filled with 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% glass powder with 3% of steel fiber for all mix except Mix A along with other remaining ingredients. The mixes were thoroughly blended with water and placed in the moulds. Vibration was applied to the moulds using table vibrator. The top surface of specimen was leveled and finished well. After 24 hours, moulds were loosened and cubes were directly placed to the curing tank where they were allowed to cure for 7 days, 14 days and 28 days. After the curing period was over, the cubes were tested on digital compression testing machine (CTM) as per IS 516:1959. The failure load was noted. For each mix, three cubes were casted and tested and their average value was reported. Compressive strength was calculated as follows.

Compressive Strength (MPa) = Failure load (N) / cross sectional area (mm$^2$)

**Fig -5:** Testing of cube in CTM

## 2.4 Flexural Strength Test:

Beam of 150mm x 150mm x 750mm dimensions was used for the experiment. Hand compaction was done using tamping rod. The top surface of specimen was leveled and finished well. After 24 hours, moulds were loosened and beams were directly placed to the curing tank where in they were allowed to cure for 7 days, 14 days and 28 days. After the curing period was over, the beams were tested on universal testing machine (UTM) as per IS 516:1959. The beams were tested for single point loading. The failure load was noted. For each mix, three beams were casted and tested and their average value was reported. Flexural strength was calculated as follows.

Flexural Strength (MPa) =1.5(P x L) / (b x d$^2$),

Where, P = Failure load (N), L = centre to centre distance between the support = 700mm, b = breadth of beam =

150mm, d = depth of beam = 150mm. The factor 1.5 is used for single point loading.

**Fig -6:** Testing of beam in UTM

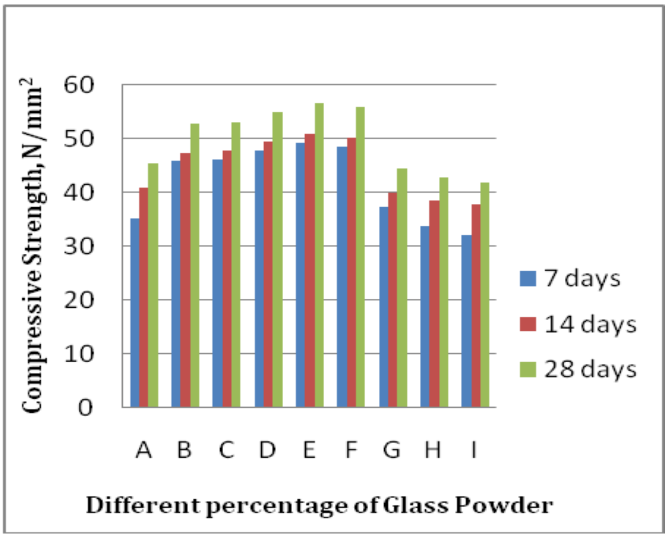


**Chart - 1:** Compressive strength of cube (N/mm$^2$) for 7 days, 14 days and 28 days

## 3. Results and Discussion

### 3.1 Compressive Strength

The comparison of compressive strength of conventional concrete (Mix A) with that of steel fiber and partially replaced by Glass powder concrete has been represented using a bar chart in chart 1.

**Table -5:** Compressive strength of cubes (N/mm$^2$) for different curing period

| Mix | 7 days | 14 days | 28 days |
|---|---|---|---|
| A | 35.25 | 40.99 | 44.54 |
| B | 45.87 | 47.49 | 52.76 |
| C | 46.19 | 47.81 | 53.12 |
| D | 47.91 | 49.59 | 55.1 |
| E | 49.33 | 51.06 | 56.73 |
| F | 48.60 | 50.30 | 55.89 |
| G | 37.28 | 40.02 | 44.47 |
| H | 33.78 | 38.60 | 42.88 |
| I | 32.13 | 37.76 | 41.95 |

The compressive strength gradually increased with the increase in replacement of sand by glass powder to 20% (MIX E). After Mix E, there was gradual decrease in compressive strength but not below characteristics compressive strength (40MPa). The maximum compressive strength gained was 49.33 MPa, 51.06 MPa and 56.73 MPa at 7 days, 14 days and 28 days of curing respectively for MIX E. Except conventional concrete and higher percentage of glass powder like MIX G, MIX H and MIX I, specimen gained their characteristics compressive strength within 7 days curing period. The compressive strength also increased with increased curing period.

### 3.2 Flexural Strength

The comparison of flexural strength of conventional concrete (Mix A) with that of steel fiber and partially replaced by Glass powder concrete has been represented using a bar chart in chart 2.

**Table -6:** Flexural strength of beams (N/mm$^2$) for different curing period

| Mix | 7 days | 14 days | 28 days |
|---|---|---|---|
| A | 7.13 | 8.01 | 8.48 |
| B | 7.47 | 8.22 | 8.6 |
| C | 7.94 | 8.74 | 9.14 |
| D | 8.09 | 8.9 | 9.31 |
| E | 8.32 | 9.1 | 9.49 |
| F | 8.09 | 8.9 | 9.31 |
| G | 7.78 | 8.56 | 8.95 |
| H | 7.63 | 8.4 | 8.78 |
| I | 7.16 | 7.88 | 8.24 |

The flexural strength gradually increased with the increase in replacement of sand by glass powder to 20%. After 20% replacement by glass powder (MIX E), there was gradual decrease in flexural strength but not below conventional concrete strength. The maximum flexural strength gained was 8.32 N/mm$^2$, 9.01 N/mm$^2$ and 9.49 N/mm$^2$ for 7 days, 14 days and 28 days respectively for MIX E. The flexural strength also increased with increased curing period.

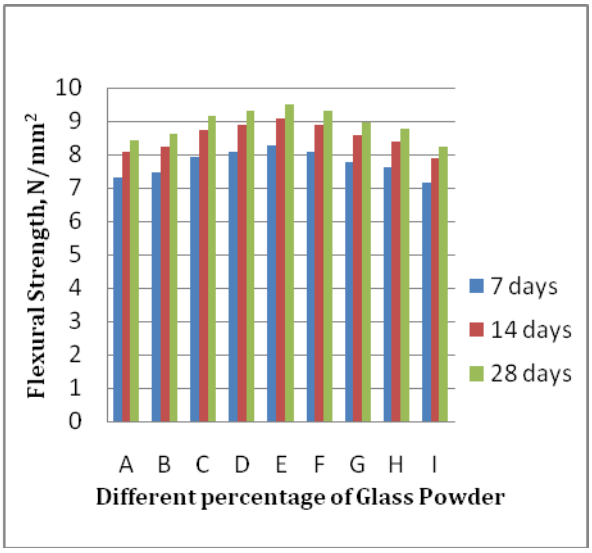


**Chart - 2:** Flexural strength of cube (N/mm²) for 7 days, 14 days and 28 days

## 4. CONCLUSIONS

Based on the experimental test results, the following conclusions and recommendations are extracted:

1. Most of the mix like MIX B, MIX C, MIX D, MIX E and MIX F achieved their characteristics strength (M40) just in 7 days of curing except conventional concrete. This is because the steel fiber added to the concrete helped to gain higher strength in early days.
2. Therefore, steel fiber concrete can be recommended where characteristics strength is required in early days. This shows the property of rapid hardening concrete.
3. Even if steel fiber was added in equal proportion to all mix except MIX A (no steel fiber added), there is an incremental gain in strength for lower percentages of GP. This is because of glass powder itself.
4. For higher percentage of GP, there was decrease in strength even if steel fiber was in equal proportion but not below 40 MPa. The reason is grain size of GP (2.36mm passing used in this experiment).
5. The fine grains of GP likely between 90u to 600u which did not further breakdown filled the voids of concrete, increased the density and strength but the grain size likely between 600u to 2.36mm filled the void but could not resist higher load and easily broke down into further fine particles because glasses are brittle in nature.
6. The grain size of 600u to 2.36mm of GP were very less at lower percentage of GP mixed concrete and resulted in better strength whereas the grain size of 600u to 2.36mm of GP were more at higher percentages of GP mixed concrete and resulted in slightly lower strength compared with lower percentage of GP mixed concrete used.
7. So, it can be recommended to use finer grain size of GP for more better compressive and flexural strength.
8. Maximum compressive strength was for MIX E achieved at 20% replacement of sand by GP.
9. Compressive strength increased by 39.94%, 24.57% and 27.37% in 7 days, 14days and 28 days of curing when 20% of sand was replaced by GP compared with conventional concrete (MIX A).
10. Maximum flexural strength was for MIX E achieved at 20% replacement of sand by GP.
11. Flexural strength increased by 16.69%, 13.61% and 11.9% in 7 days, 14days and 28 days of curing when 20% of sand was replaced by GP compared with conventional concrete (MIX A).
12. It is recommended to use glass powder up to 40% of sand replacement using steel fibers since MIX I also gained its characteristics strength.
13. Finally, concrete showed high performance regarding strength up to 56.73 MPa.

At last, there is further scope to study for higher percentage of sand replacement by glass powder (greater than 40% of GP).

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