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# Prediction of Compressive Strength of the Fibre Reinforced Slag Geopolymer Concrete

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## Abstract

An experimental study was conducted on the slag based geopolymer concrete in both plain and steel fibre reinforced concrete. The various types of curing regime like controlled room temperature, hot air oven at 50°C, 100°C and steam chamber 75°C were adopted to check the performance of the concrete in the compressive strength. The concrete with different binder to total aggregate ratio (B/Ta) of 0.25, 0.33 and 0.45 was used. Based on the results, controlled room temperature curing was adopted for further study. To enhance the strength steel fibre was added in 0.5%, 1% and 1.5% of mass of the concretein the geopolymer concrete. A polynomial regression equation was developed for all the mixturesfrom the test results to predict the 3, 7, 14, 28, 56, and 90 days strength from the one day strength. This will reduce the dependency on experiments.

**Keywords:** Slag Geopolymer concrete, curing regime, steel fibre.

## Introduction

Slag is a waste product from the steel and iron industries in a form of powder. When slag was replaced in cement, it enhances the strength of the concrete and it improves the durability of the concrete. In the field of geopolymer, various industrial by-products were used as the binding materials like flyash, silica fume and rice husk ash etc.Among all the binder, the slag based geopolymer concrete has better strength. To activate the binding property in the slag, the alkali activators were used like sodium hydroxide, sodium silicate and potassium hydroxide, potassium silicate in various ratios. The alkali activators like sodium hydroxide and sodium silicate produces the inorganic polymeric chain in the slag which leads for the binding and it undergoes the polycondensation reaction [1, 3-5]. The slag is the material, rich in calcium; silica and aluminium which produces the binding between the fine aggregate and coarse aggregate [2]. This kind of reaction is very effectively taking place in the heat environment from 50°C to 120° for the duration of maximum 6 to 12 hours [6, 7].

The slag based geopolymer concrete is cured in the heat condition up to 12 hours (maximum), and then the cured samples are kept at the room temperature for the next 28 days. In geopolymer concrete, 70 to 80% of polymeric reaction takes place in the initial hours of binder mixed with the alkali activators [8, 9]. The mechanical property like compressive strength was determined for the various supplementary cementitious materials but slag based geopolymer concrete shows the better results among them [10-14].

In this paper, the steel fibre was used to enhance the mechanical property like strength improvement in the slag based Geopolymer concrete. The properties were found for both plain concrete and the steel fibre reinforced concrete. From the test results the regression equation was found with the experimental test conducted on the specimens. And regression analysis was done for the predicted values through equation [2].

## Experimental Study

The physical and chemical property of the slag which is used in this study is given in the**Table 1**and **Table 2**;

### Slag

The source of the binder slag was from Visakhapatnam, Andhra Pradesh, India. As per the BIS:6699-1992, the slag as the chemical moduli of a) $CaO + MgO + SiO_2 = 80.30$, b) $(CaO + MgO) / SiO_2 = 1.29$, c) $CaO / SiO_2 = 1.06$.

**Table 1:**Chemical Properties of slag

| Sl.No | Description (% by mass) | Results |
|---|---|---|
| 1 | Magnesium Oxide | 8.30 |
| 2 | Sulphur content | 0.31 |
| 3 | Sulphide Sulpher | 0.45 |
| 4 | Loss on Ignition | NIL |
| 5 | Insoluble Residue | 0.34 |
| 6 | Chloride | 0.012 |
| 7 | Moisture content | 0.54 |
| 8 | Manganese content | 0.13 |
| 9 | Glass content (% by Optical Microscopy) | 94.00 |

**Table 2:**Physical Properties of slag

| Sl.No | Test | Test Results |
|---|---|---|
| 1 | Fineness ($m^2$/kg) | 338 |
| 2 | Setting time by Vicat method (initial) | 230 |
| 3 | Soundness (Le-Chatlier Expansion (mm) | NIL |

**Mixing Proportions**

Considering on material properties of Geopolymer concrete, the conceptional mixture proportion of materials was taken. The three mixture proportions like 1.00:1.69:2.82:0.30, 1.00:1.00:2.26:0.30 and 1.00:0.71:2.00:0.30 was used. The binder to total aggregate ratio of 0.22, 0.30 and 0.37, the fine aggregate to coarse aggregate ratio of 0.60, 0.44 and 0.35 was used. The alkali to binder ratio of 0.3 was considered as the constant for all mixture proportions shown in **Table 3**. The best mixture was reinforced with steel fibre of 35mm length, 0.5mm diameter and has aspect ratio of 70. The dosage of steel fibre was 0.5, 1.0 and 1.5%. For the fine aggregate, the sand was collected from the Palar river bed in Vellore, Tamil Nadu and India.

**Table 3:** Geopolymer concrete mixture proportions

| Mix ID | GGBS (kg/$m^3$) | Fine Aggregate (kg/$m^3$) | Coarse Aggregate (kg/$m^3$) | Binder /Alkali Ratio | water (lit/$m^3$) | Sodium Hydroxide (12M) (kg) | Calcium Nitrate (kg/$m^3$) | Sodium Sulfate (kg/$m^3$) | Curing Regime |
|---|---|---|---|---|---|---|---|---|---|
| GC1 | 425 | 720 | 1200 | 0.3 | 127.5 | 40.13 | 4.25 | 42.5 | CRT - 37±2º C |
| GC2 | 425 | 720 | 1200 | 0.3 | 127.5 | 40.13 | 4.25 | 42.5 | HAO at 50°C |
| GC3 | 425 | 720 | 1200 | 0.3 | 127.5 | 40.8 | 4.25 | 42.5 | HAO at 100°C |
| GC4 | 425 | 720 | 1200 | 0.3 | 127.5 | 40.8 | 4.25 | 42.5 | Steam Chamber at 75°C |
| GC5 | 530 | 530 | 1200 | 0.3 | 159 | 50.04 | 5.3 | 53 | CRT - 37±2º C |
| GC6 | 530 | 530 | 1200 | 0.3 | 159 | 50.04 | 5.3 | 53 | HAO at 50°C |
| GC7 | 530 | 530 | 1200 | 0.3 | 159 | 50.04 | 5.3 | 53 | HAO at 100°C |
| GC8 | 530 | 530 | 1200 | 0.3 | 159 | 50.04 | 5.3 | 53 | Steam Chamber at 75°C |
| GC9 | 600 | 425 | 1200 | 0.3 | 180 | 56.65 | 6 | 60 | CRT - 37±2º C |
| GC10 | 600 | 425 | 1200 | 0.3 | 180 | 56.65 | 6 | 60 | HAO at 50°C |
| GC11 | 600 | 425 | 1200 | 0.3 | 180 | 56.65 | 6 | 60 | HAO at 100°C |
| GC12 | 600 | 425 | 1200 | 0.3 | 180 | 56.65 | 6 | 60 | Steam Chamber at 75°C |

Note: GGBS-Slag, CRT-Controlled Room Temperature, HAO – Hot Air Oven

**Casting**

All the mixtures specified in this study were tested for thirty specimens per mixture for different curing age (3, 7, 14, 28, 56 and 90 days). The Geopolymer concrete was

mixed in the pan mixture and cubes of 100mm X 100mm X 100mm were cast for the compressive strength.

**Curing**

The curing of geopolymer concrete plays a major role in the hardening of the concrete. In cement concrete when water is mixed in the dry concrete mixture the setting of concrete takes place. But in the geopolymer concrete when the alkali activators mixed with the dry concrete mixtures, the polymerisation reaction takes place which leads to hardening of the concrete. The effective polymerisation reaction will take place in the heat environment; so three types of curing were followed in this study.

A) Controlled Room Temperature (CRT)

The controlled room temperature curing was done to find the effect of the polymerisation reaction in concrete for the temperature 37°C ± 2°C. This controlled room temperature can maintain the temperature by using the humidity chamber for 37°C in it. The specimens were transferred to the chamber after casting and retained for 6hours.

B) Hot Air Oven

The hot air oven curing, two different temperatures like 50°C and 100°C was used to find the strength gain difference of the concrete and to determinethe effect of the polymerisation reaction in the geopolymer concrete.The specimens were placed in the hot air ovens for 6 hours duration after casting.

C) Steam Chamber

The steam chamber curing is a process in whichhot moist air is liberated inside chamber. The specimens kept in the chamber were cured for the 6 hours at the temperature of 75°C. After 6 hours, the specimens were kept in the room temperature for 28 days.

**Testing of Specimens**

After completion of the curing of the specimens, the compressive strength of slag based geopolymer concrete cubes was determined as per the IS: 516-1959 (Reprint June 2006) by using the compression testing machine (capacity of 2500kN at a loading rate of 2.5kN/sec).

## Results and Discussion

**Compressive Strength Plain Slag Based Geopolymer Concrete**

The compressive strength was determined for all the mixture ratios of slag based geopolymer concrete for 1, 3, 7, 14 and 28 days of curingand the values was shown in **Table: 3**. The lowest B/Ta-0.25 and F/C-0.6 of mix ratio 1.00:1.69:2.82:0.30hasattained35.7MPa in one day immediately after the specimen

was removed from the hot air oven 50°C. Thespecimens cured under the 50°C showed the better compressive strength at 28 days i.e. 52.6MPa. Among thevarious curing,the cube specimens cured under hot air oven curing at 50°C has attained the better strength and is shown in **Table:4.** The slag based geopolymer concrete mixture has the 12M of sodium hydroxide with 1% of calcium nitrate and 10% of sodium sulfate which produces the initial rate of heat in concrete which leads to accelerate the rate geopolymerisation reaction.Further there was a marginal strength difference between the compressivestrength of specimens cured under controlled room temperature (CRT 37±2°C) and hot air oven cured at 50°C specimens;i.e. the specimens cured at CRT 37±2°C have attained the compressive strength of 30.7MPa at 24 hours and 48.2MPa at 28 days of curing. Therefore the CRT was adopted for the further experiments.

**Table 4:** Compressive strength of plain slag based geopolymer concrete

| Mix ID | Proportions | Compressive Strength (MPa) | | | | |
|---|---|---|---|---|---|---|
| | (B:FA:CA) | 1 day | 3days | 7days | 14days | 28days |
| GC1 | 1:1.69:2.82 | 30.7 | 33.9 | 38.4 | 42.9 | 48.2 |
| GC2 | 1:1.69:2.82 | 35.7 | 38.8 | 41.6 | 46.6 | 52.6 |
| GC3 | 1:1.69:2.82 | 24.2 | 29.2 | 32.7 | 35.4 | 37.8 |
| GC4 | 1:1.69:2.82 | 21.2 | 25.2 | 28.7 | 32.9 | 35.4 |
| GC5 | 1:1.00:2.26 | 23.5 | 28.5 | 29.5 | 32.5 | 34.3 |
| GC6 | 1:1.00:2.26 | 19.9 | 22.6 | 24.7 | 27.8 | 29.6 |
| GC7 | 1:1.00:2.26 | 22.7 | 23.6 | 24.2 | 25.2 | 26.6 |
| GC8 | 1:1.00:2.26 | 14.9 | 24.5 | 24.8 | 26.5 | 26.6 |
| GC9 | 1:0.71:2.00 | 19.4 | 20.7 | 21.3 | 21.5 | 24.2 |
| GC10 | 1:0.71:2.00 | 17.6 | 20.3 | 20.4 | 22.4 | 25.9 |
| GC11 | 1:0.71:2.00 | 17.8 | 20.7 | 21.8 | 25.7 | 27.2 |
| GC12 | 1:0.71:2.00 | 22.1 | 22.6 | 23.4 | 25.4 | 26.3 |

Note: B- Binder, FA -Fine aggregate, CA - Coarse aggregate.

**Regression Analysis for plain Geopolymer Concrete**

The compressive strength values were plotted in the graph and the regression line was drawn with respect to 1 day to 3 day strength,shown in **Figure 1. T**he regression equation was determinedfrom the regression plot. Using the one day strength slag based geopolymer concrete; the compressive strength was predicted at 3 days (**Table 5)**. Thepercentage error between the experimental values of compressive strength and predicted values ofcompressivestrength is minimum (maximum error is 1.8% was observed). In the similar manner, the regression plot was developed between 1 and 7 or 14 or 28 day strength (**Figure 2 to 4)**. With this, the later age can be obtained from the one day strength of the slag based geopolymer concrete.

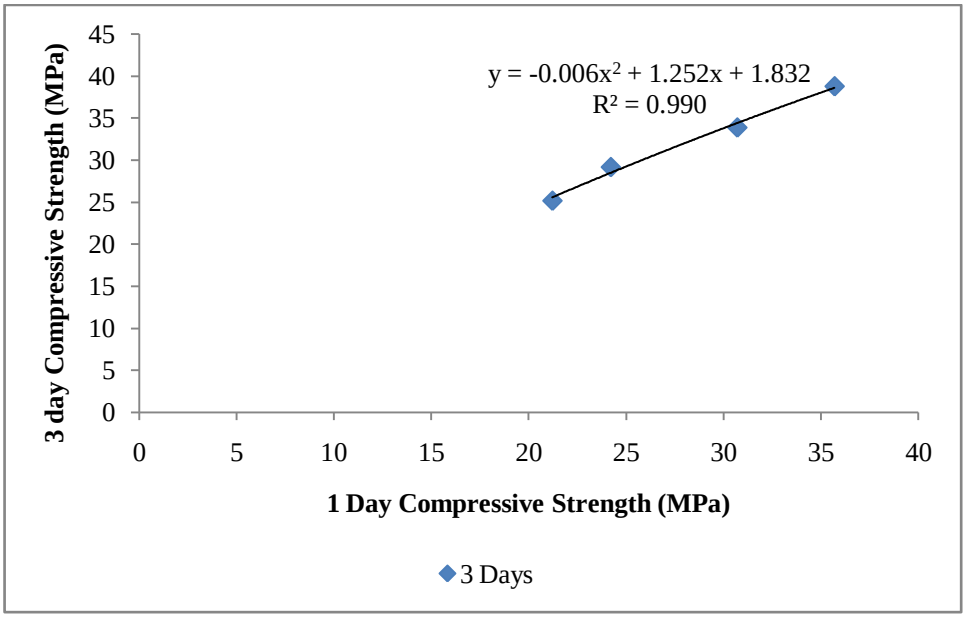


**Figure 1:** The regression plot for plain geopolymer concrete between 1 day to 3days compressive strength

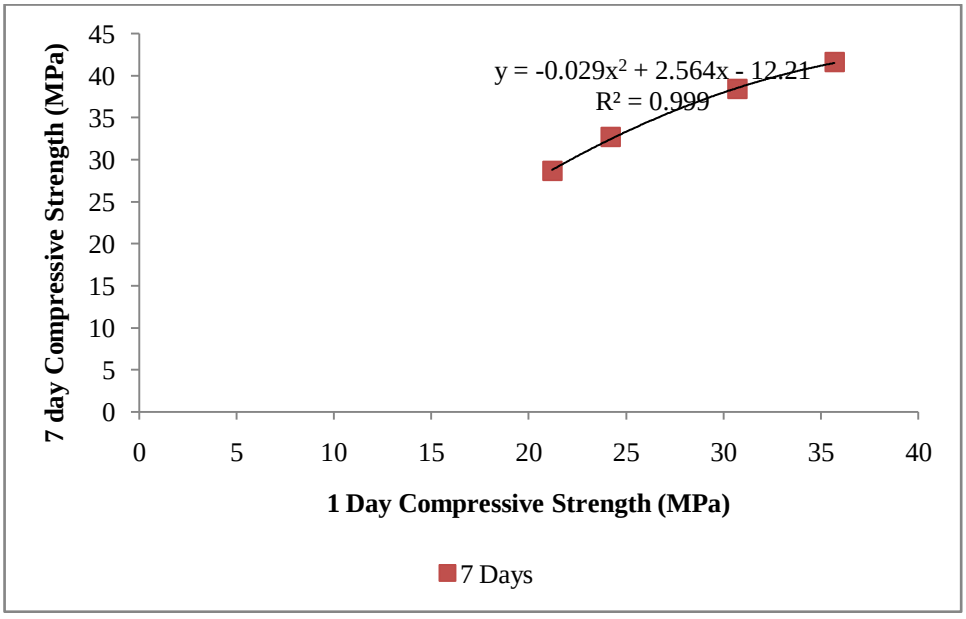


**Figure 2:** The regression plot for plain geopolymer concrete between 1day to 7days compressive strength

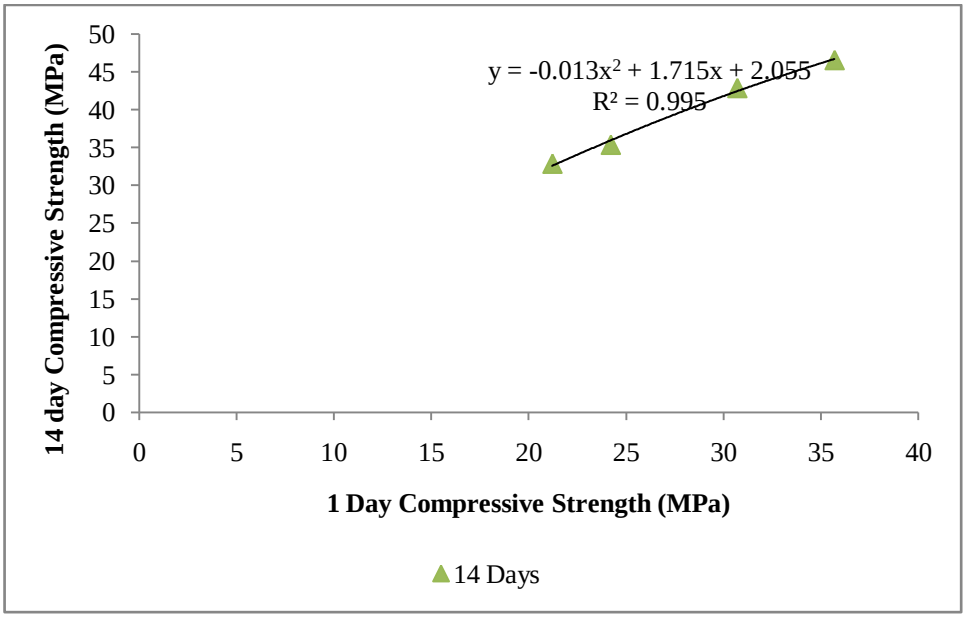


**Figure 3:** The regression plot for plain geopolymer concrete between 1day to 14 days compressive strength

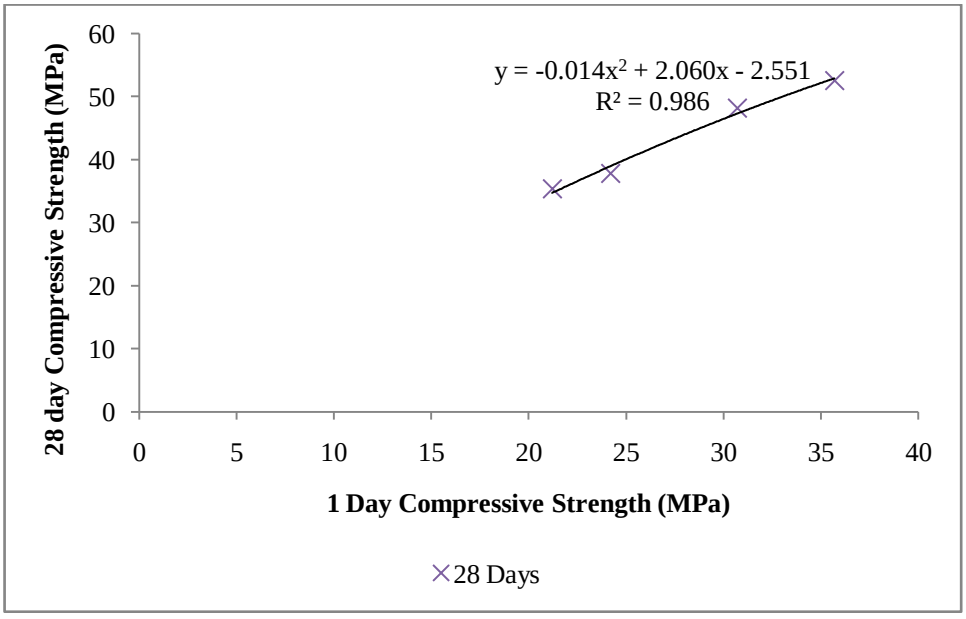


**Figure 4:** The regression plot for plain geopolymer concrete between 1day to 28days compressive strength

**Table 5:** Predicted compressive strength with respect to 1 day strength

| Mix ID | Proportions (B:FA :CA) | Compressive Strength (MPa) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 day | 3 day | | | 7 day | | | 14 day | | | 28 day | | |
| | | Exp | Pre | Exp | % Error | Pre | Exp | % Error | Pre | Exp | % Error | Pre | Exp | % Error |
| GC1 | 1:1.69 :2.82 | 30.7 | 34.4 | 33.9 | -1.6 | 38.5 | 38.4 | -0.3 | 42.5 | 42.9 | 1.0 | 47.3 | 48.2 | 1.8 |
| GC2 | 1:1.69 :2.82 | 35.7 | 38.6 | 38.8 | 0.4 | 41.5 | 41.6 | 0.3 | 46.7 | 46.6 | -0.3 | 52.9 | 52.6 | -0.6 |
| GC3 | 1:1.69 :2.82 | 24.2 | 28.5 | 29.2 | 2.4 | 32.4 | 32.7 | 0.8 | 36.0 | 35.4 | -1.6 | 39.0 | 37.8 | -3.1 |
| GC4 | 1:1.69 :2.82 | 21.2 | 25.6 | 25.2 | -1.5 | 28.8 | 28.7 | -0.4 | 32.6 | 32.9 | 1.0 | 34.7 | 35.4 | 1.9 |
| GC5 | 1:1.00 :2.26 | 23.5 | 27.2 | 28.5 | 4.6 | 27.8 | 29.5 | 5.8 | 29.9 | 32.5 | 8.1 | 31.5 | 34.3 | 8.2 |
| GC6 | 1:1.00 :2.26 | 19.9 | 22.0 | 22.6 | 2.9 | 23.9 | 24.7 | 3.4 | 26.5 | 27.8 | 4.6 | 28.2 | 29.6 | 4.7 |
| GC7 | 1:1.00 :2.26 | 22.7 | 25.5 | 23.6 | -8.1 | 26.6 | 24.2 | -9.8 | 28.9 | 25.2 | -14.6 | 30.6 | 26.6 | -15.0 |
| GC8 | 1:1.00 :2.26 | 14.9 | 24.6 | 24.5 | -0.4 | 24.9 | 24.8 | -0.5 | 26.7 | 26.5 | -0.7 | 26.8 | 26.6 | -0.8 |
| GC9 | 1:0.71 :2.00 | 19.4 | 20.7 | 20.7 | -0.1 | 21.4 | 21.3 | -0.6 | 21.9 | 21.5 | -1.8 | 24.4 | 24.2 | -0.6 |
| GC10 | 1:0.71 :2.00 | 17.6 | 20.5 | 20.3 | -0.9 | 21.0 | 20.4 | -3.1 | 24.1 | 22.4 | -7.8 | 26.7 | 25.9 | -3.0 |
| GC11 | 1:0.71 :2.00 | 17.8 | 20.5 | 20.7 | 1.1 | 21.0 | 21.8 | 3.5 | 23.7 | 25.7 | 7.8 | 26.3 | 27.2 | 3.4 |
| GC12 | 1:0.71 :2.00 | 22.1 | 22.6 | 22.6 | 0.1 | 23.4 | 23.4 | 0.1 | 25.4 | 25.4 | 0.1 | 26.3 | 26.3 | 0.1 |

Note: Exp-Experimental, Pre-Predicted, B-Binder, FA -Fine aggregate,CA-Coarse aggregate.

**Compressive strength of Steel Fibre Reinforced slag based Geopolymer concrete**

The three various mix ratios for compressive strength of plain slag based geopolymer concrete was determined. Among them, the mixture ratio 1.00:1.69:2.82:0.30 was better compared to other mixtures which was cured under the room temperature (CRT 37° ± 2°) with the accelerator of 1.0% calcium nitrate and 10% of sodium sulphate with 12M of sodium hydroxide. For enhancing the performance of the mechanical properties,the concrete was reinforced with steel fibre,the steel fibre was addedin geopolymer concrete for three various dosages like 0.5%, 1.0% and 1.5% of mass of concrete. All the specimens were cured at the controlled room temperature (CRT 37±2°) with 12M of sodium hydroxide with 1.0% of calcium nitrate and 10% of sodium sulfate. The compressive strength of steel fibre reinforced concrete is given in **Table: 6**, the mixture B/Ta-0.25 and F/C-0.60 ratio of 1.0% steel fibre reinforced geopolymer concrete attained the higher compressive strength,i.e. 51.9MPa after 24 hours of curing. Compressive strength of 56.3MPa was gained at 28 days and 60.3MPa at 90 days that was better than the other steel fibre dosages and mixture ratios.

**Table 6:** Compressive strength of steel fibre reinforced slag based geopolymer concrete

| Ratio | Percentage of Steel fibre | Compressive Strength (MPa) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 Day | 7 Day | 14 Day | 28Day | 56 Day | 90 Day |
| Binder / Total Aggregate (0.25), Fine Aggregate / Coarse Aggregate (0.60) | 0% | 38.8 | 41.6 | 44.3 | 46.6 | 46.7 | 52.6 |
| | 0.5 | 46.0 | 47.1 | 47.6 | 48 | 51.6 | 52.9 |
| | 1 | 51.9 | 53.6 | 54.2 | 56.3 | 57.8 | 60.3 |
| | 1.5 | 51.8 | 52 | 52.3 | 52.4 | 53.7 | 53.8 |
| Binder / Total Aggregate (0.33), Fine Aggregate / Coarse Aggregate (0.44) | 0 | 34.5 | 40.9 | 41.0 | 41.0 | 44.0 | 47.6 |
| | 0.5 | 36.6 | 41.5 | 42.2 | 43.5 | 44.6 | 47.9 |
| | 1 | 37.2 | 42.2 | 43.6 | 44.5 | 46.6 | 48.6 |
| | 1.5 | 36.8 | 41.9 | 43.1 | 44.2 | 45.3 | 48.6 |

**Regression Analysis for Steel Fibre Geopolymer Concrete**

The compressive strength of steel fibre reinforced concrete values was plotted in the graph. From the graph, regression line was drawn with respect to 3 days to 7 days strength of concrete and the regression equation was determined. From the regression equation, the compressive strength at 7 days was predicted and isshown in **Figure 5**. Theexperimental values of compressive strength are shown in **Table 7**. The percentage error between the experimental values of compressive strength and predicted values of compressive strength is minimum (maximum error is 5.4%). In the similar manner, the regression plot was developed between 3 and14, 28, 56 and 90 day strength (**Figure 6 to 9)**. With this, the later age can be obtained from the one day strength of the slag based geopolymer concrete.

**Table 7:** Predicted compressive strength of the steel fibre reinforced geopolymer concrete

| Ratio | % of Steel Fibre | Compressive Strength (MPa) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3rd Day | 7th Day | | | 14th Day | | | 28th Day | | | 56th Day | | | 90th Day | | |
| | | Exp | Pre | Exp | % error | Pre | Exp | % error | Pre | Exp | % error | Pre | Exp | % error | Pre | Exp | % error |
| B/Ta (0.25), F/C (0.6) | 0 | 38.8 | 41.5 | 41.6 | 0.2 | 44.2 | 44.3 | 0.1 | 46.6 | 46.6 | -0.1 | 46.8 | 46.7 | -0.2 | 52.6 | 52.6 | 0.1 |
| | 0.5 | 46 | 47.0 | 47.1 | 0.3 | 47.5 | 47.6 | 0.2 | 48.0 | 48 | 0.0 | 51.6 | 51.6 | -0.1 | 52.7 | 52.9 | 0.4 |
| | 1.0 | 51.9 | 52.7 | 53.6 | 1.6 | 53.2 | 54.2 | 1.8 | 54.5 | 56.3 | 3.2 | 55.9 | 57.8 | 3.2 | 57.0 | 60.3 | 5.4 |
| | 1.5 | 51.8 | 52.6 | 52 | -1.2 | 53.1 | 52.3 | -1.5 | 54.4 | 52.4 | -3.7 | 55.9 | 53.7 | -4.0 | 56.9 | 53.8 | -5.8 |
| B/Ta (0.33), F/C (0.44) | 0 | 28.5 | 52.4 | 40.9 | -28.2 | 62.7 | 41 | -52.9 | 37.2 | 41 | 9.1 | 95.4 | 44 | -116.9 | 58.4 | 47.6 | -22.6 |
| | 0.5 | 36.6 | 41.6 | 41.5 | -0.2 | 42.4 | 42.2 | -0.5 | 43.7 | 43.5 | -0.4 | 44.6 | 44.6 | -0.1 | 48.0 | 47.9 | -0.3 |
| | 1.0 | 37.2 | 42.2 | 42.2 | 0.0 | 43.7 | 43.6 | -0.2 | 44.5 | 44.5 | -0.1 | 46.6 | 46.6 | 0.0 | 48.6 | 48.6 | 0.0 |
| | 1.5 | 36.8 | 41.8 | 41.9 | 0.3 | 42.8 | 43.1 | 0.7 | 43.9 | 44.2 | 0.6 | 45.2 | 45.3 | 0.2 | 48.2 | 48.6 | 0.8 |

Note: Exp-Experimental, Pre-Predicted, B/Ta-Binder to Total aggregate, F/C-Fine to Coarse aggregate.

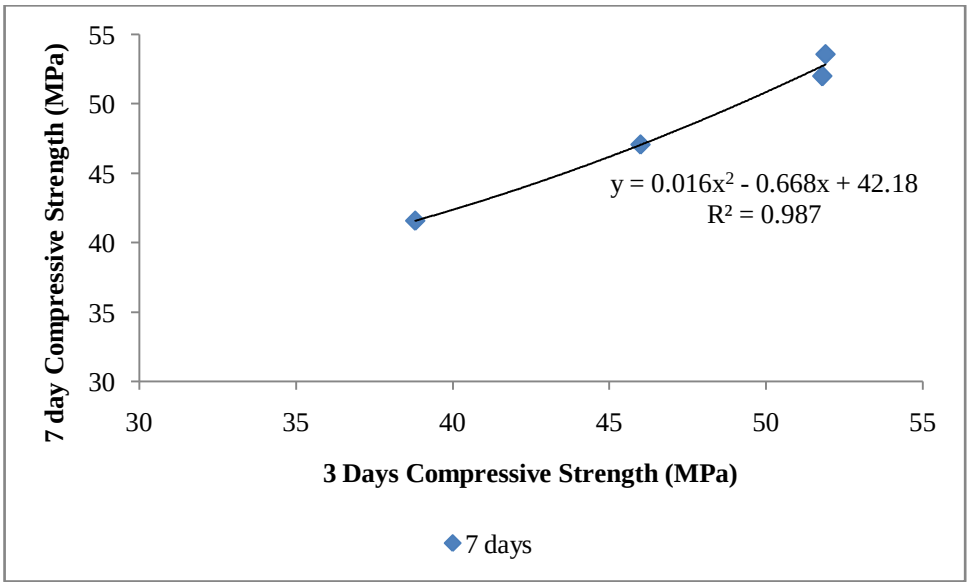


**Figure 5:** The regression plot for steel fibre reinforced geopolymer concrete for 3days to 7days compressive strength

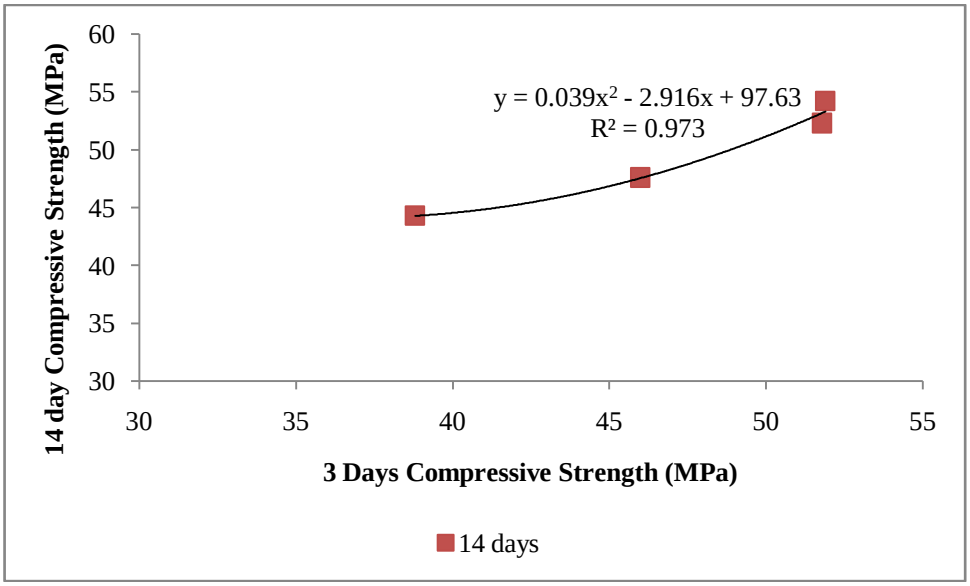


**Figure 6:** The regression plot for steel fibre reinforced geopolymer concrete for 3days to 14days compressive strength

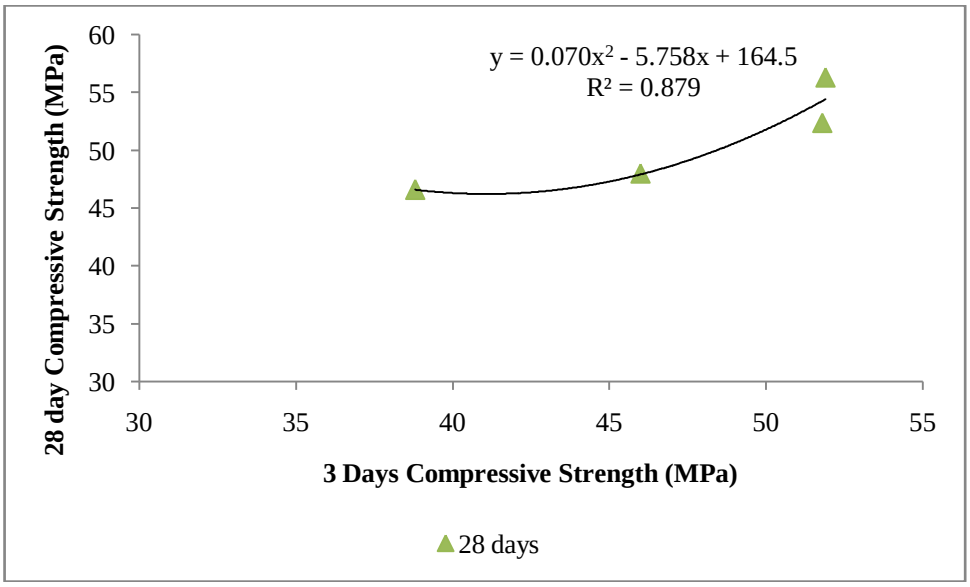


**Figure 7:** The regression plot for steel fibre reinforced geopolymer concrete for 3days to 28days compressive strength

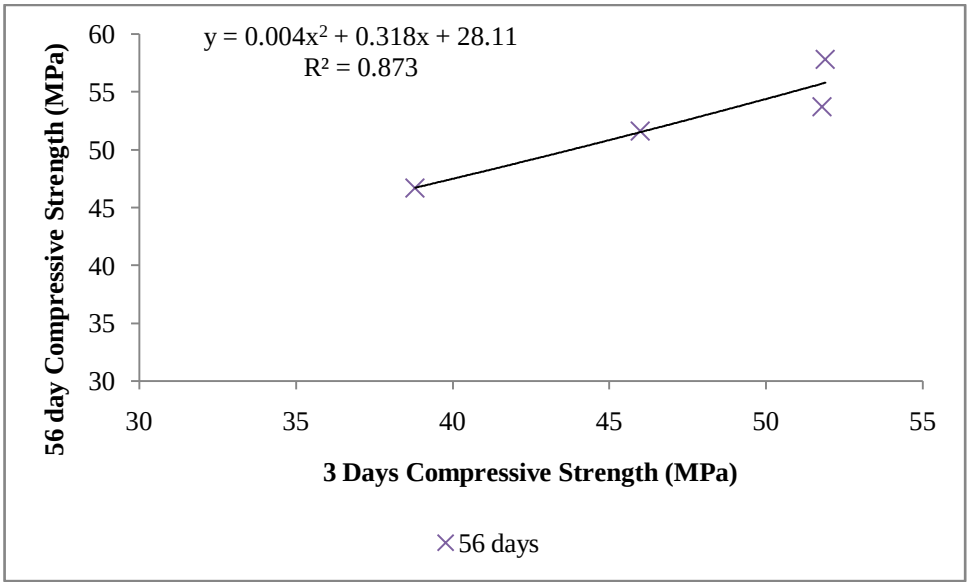


**Figure 8:** The regression plot for steel fibre reinforced geopolymer concrete for 3days to 56days compressive strength

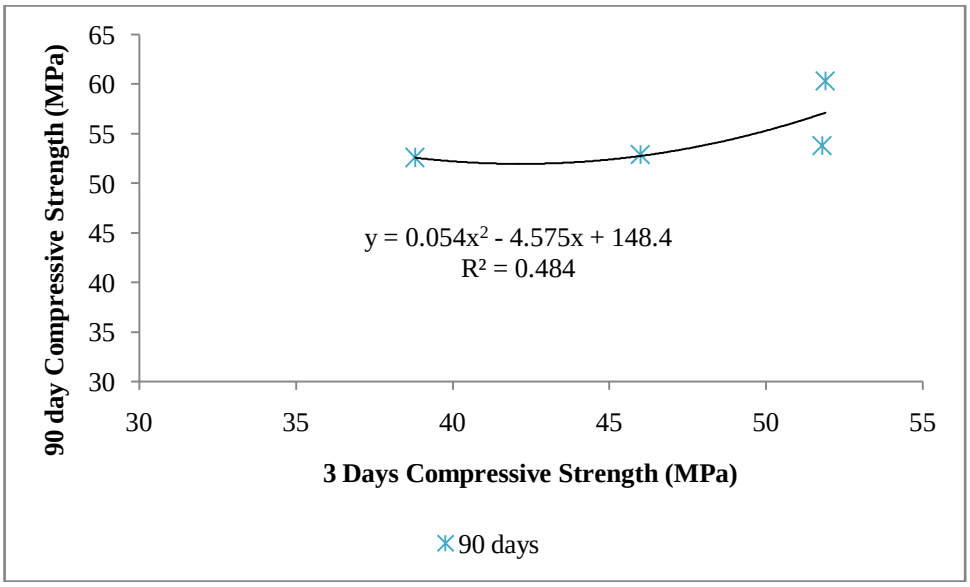


**Figure 9:** The regression plot for steel fibre reinforced geopolymer concrete for 3days to 90days compressive strength

## Conclusion

The compressive strength of the plain and steel fibre reinforced slag based geopolymer concrete was determined by conducting experiments and the following conclusions can be drawn;

- Mix (GC1 – controlled room temperature curing) in the plain geopolymer concrete of B/Ta (0.25) and F/C (0.6) shows the higher actual value of 48.2MPa and predicted value of 47.3MPa.
- Among the various types of curing regime adopted in this study, the strength obtained from the controlled room temperature curing is comparable with other types. Since this is the most economical method with good strength, it can be used in the geopolymer concrete.
- In Geopolymer concrete with 1.0% dosage of steel fibre, compressive strength was 56.3MPa.
- Based on the above experiments, the regression equation was developed for all the mixtures of geopolymer concrete; the predicted compressive strength of all the mixtures is comparable with the experimental values. This will reduce the dependency on experiments.

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