# Study on Mechanical Properties of Partially Replaced Slag and Slag Sand to OPC and M-Sand in Concrete

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**Abstract**

*Concrete is the most used building material in the world. As a sustainable approach, this project explores the potential benefits of incorporating slag and slag sand in concrete mixtures. The objective is to study the mechanical properties of slag and slag sand at the end of 7, 28, 56 and 90 days of curing for M20 at replacement levels of 10%, 20%, 30%, 40%, and 50%. The combinations were designed using Taguchi's array and the results were analyzed using Anova. The best combinations resulted for Compressive strength, was 20% Slag, 30% Slag Sand, 1.5% SP, resulted 24.8N/mm$^2$, Split tensile strength, was 20% Slag, 20% Slag Sand, 2% SP, resulted 18.6N/mm$^2$, and Flexural strength was 20% Slag, 30% Slag sand, 1.5% SP, resulted 3.05N/mm$^2$ optimum results was observed.*

***Key Words:*** *Slag, Slag Sand, Mechanical Properties, Taguchi, Anova*

## 1. INTRODUCTION

The embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, through usage of alternative or supplementary material having similar properties of cement, natural fine and coarse aggregate. To maneuver exploitation and green house effects caused by the concrete, by-products generated from different iron ore industries such as GGBFS and GBFSS resembling the properties of cement and natural fine aggregate can be used as alternative materials in concrete production, leading to technological, economic and environmental benefits. This also results in achieving global sustainable development and lowest possible environmental impact.

GGBFS is a by-product of iron manufacturing industry. Major steel plants in India generate 7760561 MT of GGBFS per annum. Iron ore, coke and limestone fed into the blast furnace at a temperature of 15000˚C to 16000˚C produces molten slag that floats above the molten iron. The molten slag is water-quenched rapidly after the molten iron is trapped off. This results in the formation of a glassy granulate which consists of siliceous ($SiO_2$: 30%-40%), aluminous ($Al_2O_3$: 3%-8%), Lime (CaO: 40%) and other residues (10%-20%). This glassy granulate is dried, ground to coarse grain size particle and powder form and designated as GBFSS and GGBFS respectively.

## 2. MATERIALS AND METHODS

There are many types of mortar are available, created by varying the proportions of the main ingredients below. In this way or by substitution for the cementitious and aggregate phases, the finished product can be tailored to its application with varying strength, density, or chemical properties.

The following materials were used in this research work

- OPC 43 grade (Brand - Coramandala)
- R-Sand, M-Sand, and Coarse Aggregate
- GGBFS (Slag) and GGBFS (Slag Sand), (Source: Quality Poly tech, Mangalore)
- Water (Concrete lab tap water Source: bore well)
- Acids and alkaline solutions for weak (Nacl) and strong ($H_2SO_4$) acid (5%, 10% and 15%)

The methodology explains about the step by step procedure that is going to be done in the project.

Here the methodology adopted/ DOE using Taguchi

- The study includes casting of 3 cubes, 3 beams and 3 cylinders for comparing mechanical of concrete with % replacement of slag as fine aggregate.
- To know the compressive strength of cubes, flexural strength using beams and split tensile strength of concrete specimens using cylinders were tested and noted concordant values.
- Finally, the fresh and hardened properties were compared with normal concrete for analysing the maximum increase in properties such specimens

## 2.1 Taguchi (DOE)

Taguchi design of experiments (DOE) is a method used to optimize the quality of concrete by finding the best combination of factors. It's used to identify the optimal mix of ingredients for concrete, such as the amount of water, fly ash, and sand.

**How it works**

- Select factors: Choose the factors that affect the quality of the concrete, such as water-to-binder ratio, Slag, Slag Sand and R-Sand
- Select levels: Decide on the levels for each factor
- Design the experiment: Use an orthogonal array to design the experiment
- Conduct the experiment: Run the experiment using the designed orthogonal array
- Analyze the results: Use a signal-to-noise ratio to analyze the results
- Identify the optimum mix: Based on the results, determine the best combination of factors for the concrete

**Benefits**

- The Taguchi method reduces the number of experiments needed, which saves time and money
- It helps to identify the most influential factors on the quality of the concrete

**Taguchi using Minitab**

Conducting a Taguchi designed experiment can have the following steps:

1. Choose **Stat** > **DOE** > **Taguchi** > **Create Taguchi Design** to generate a Taguchi design (orthogonal array). Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values identify the factor settings for the run. By default, Minitab's orthogonal array designs use the integers 1, 2, 3, to represent factor levels. If you enter factor levels, the integers 1, 2, 3, will be the coded levels for the design. You can also use **Stat** > **DOE** > **Taguchi** > **Define Custom Taguchi Design** to create a design from data that you already have in the worksheet. **Define Custom Taguchi Design** lets you specify which columns are your factors and signal factors. You can then easily analyze the design and generate plots.
2. After you create the design, you can display or modify the design:
    - Choose **Stat** > **DOE** > **Display Design** to change the units (coded or uncoded) in which Minitab expresses the factors in the worksheet.
    - Choose **Stat** > **DOE** > **Modify Design** to rename the factors, change the factor levels, add a signal factor to a static design, ignore an existing signal factor (treat the design as static), and add new levels to an existing signal factor.
3. Conduct the experiment and collect the response data. The experiment is done by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, beside the factor settings for that run of the control factors in the inner array.
4. Choose **Stat** > **DOE** > **Taguchi** > **Analyze Taguchi Design** to analyze the experimental data.
   **Note**
   You should analyze each response variable separately with Taguchi designs. Although Taguchi analysis accepts multiple response columns, these responses should be the same variable measured under different noise factor conditions.

5. Choose **Stat** > **DOE** > **Taguchi** > **Predict Taguchi Results** to predict signal to noise ratios and response characteristics for selected new factor settings.

## 3. RESULTS AND DISCUSSION

### 3.1 Basic properties

The materials used in concrete specimens were having equally diverse properties and behaviour. The properties of materials were determined in the laboratory as per standard specifications and represented in Table 3.1.1.

The specific gravity of fine aggregates, cement and GGBFS are within the specified limits. Standard consistency and Fineness of cement and GGBFS confirms to BIS. Initial setting time and final setting time of cement is within the specified limits whereas, GGBFS exceeded the threshold due to lack of calcium chloride content. Fineness Modulus, Water absorption and % air voids of fine aggregates were as per the specifications.

**Table 3.1.1.:** Basic test results of R-Sand, M-Sand, GGBFSS, Cement and GGBFS

| Property | Cement | GGBFS | M-Sand | GBFSS | Coarse Aggregate | Threshold Value | Specification |
|---|---|---|---|---|---|---|---|
| Specific gravity | 3.14 | 2.91 | 2.71 | 2.61 | 2.68 | Fine Aggregate: 2.6-2.8 Coarse Aggregate 2.5-3 | IS 2386 - 3(1963) IS 4031 - 11(1988) |
| Standard consistency (%) | 32.3 | 30.3 | - | - | - | 26-33 | IS 4031 - 4 (1988) |
| Initial setting time (min.) | 39.7 | 80.3 | - | - | - | 30 | IS 4031 - 5 (1988) |
| Final setting time (min.) | 497 | 1080 | - | - | - | 600 | IS 4031 - 5 (1988) |
| Fineness (%) | 5.4 | 5.2 | - | - | - | <10 | IS 4031 - 1 (1996) |
| Fineness Modulus | - | - | 2.81 | 2.7 | - | Fine sand: 2.2-2.6 Medium sand: 2.6-2.9 Coarse sand: 2.9-3.2 | IS: 383 (1970) |
| Water absorption (%) | - | 0.62 | 0.38 | 0.56 | - | Fine Aggregate:<2 | IS 2386 - 3 (1963) |
| Bulk density, (g/cc) | - | - | 1.43 | 1.4 | - | - | IS 2386 - 3 (1963) |
| % air voids | - | - | 27.1 | 2.9 | - | - | IS 2386 - 3 (1963) |

### 3.1.2 Sieve analysis of M-Sand and GBFSS

Table 3.1.2 represents the sieve analysis of M-Sand and GBFSS. M-Sand and GBFSS as fine aggregates and were conformed to the grading zone II as per IS: 383-1970 was used.

**Table 3.1.2.:** Sieve analysis of R-Sand, Slag Sand, and M-Sand

| Sieve Size(mm) | R-Sand | Slag Sand | M-Sand | Zone II Limits |
|---|---|---|---|---|
| 4.75 | 96.35 | 100 | 100 | 100-90 |
| 2.36 | 93 | 99 | 99 | 100-75 |
| 1.18 | 75 | 87 | 89 | 90-55 |
| 0.6 | 45 | 49 | 45 | 59-35 |
| 0.3 | 13.87 | 10 | 9 | 30-8 |
| 0.15 | 3.19 | 0.6 | 0.45 | 10-0 |

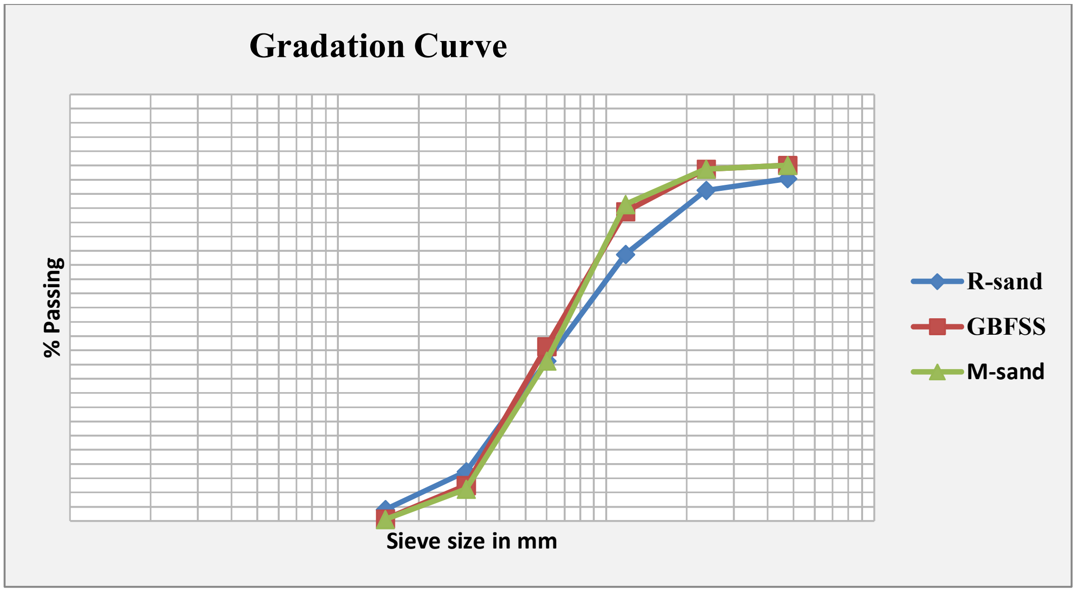



Figure 3.1.1: Gradation curve of R-Sand, Slag Sand, and M-Sand

The sieve analysis of R-Sand, M-Sand and GBFSS confirms to Zone II (IS 2386-1 (1963))

**Table 3.1.3: Mix Proportions**

| Sl.No. | Materials | Volume (kg/m³) |
|---|---|---|
| 1 | Cement | 419 |
| 2 | Fine Aggregate | 675 |
| 3 | Coarse Aggregate | 1137 |
| 4 | Water | 167 |
| 5 | W/C Ratio | 0.4 |
| 6 | Chemical admixture | 3.75 |

Mix proportion: 1: 1.61: 2.71: 0.4

### 3.2 Characteristics/Compositions of GGBFS

Table 6.3.1 represents the Characteristics/Compositions of GGBFS which conforms the IS 12089:1987 specifications.

**Table 3.2.1:** Characteristics/Compositions of GGBFS (Conforms IS 12089:1987)

| Sl No. | Characteristics | Requirements as Per IS : 12089 | Test Results |
|---|---|---|---|
| 1 | $SiO_2$ (%) | - | 33.30 |
| 2 | $Al_2O_3$ (%) | - | 21.74 |
| 3 | $Fe_20_3$ (%) | - | 0.80 |
| 4 | Cao (%) | - | 34.50 |
| 5 | Mgo (%) | 17.0 (Max) | 8.30 |

| | | | |
|---|---|---|---|
| **6** | Loss on Ignition (%) | - | 0.33 |
| **7** | IR (%) | 5.0 (Max) | 0.31 |
| **8** | Manganese Content (%) | 5.5 (Max) | 0.09 |
| **9** | Sulphide Sulphur (%) | 2.0 (Max) | 0.45 |
| **10** | Glass Content (%) | 85 (Min) | 90 |
| **11** | Moisture Content (%) | - | 11.74 |
| **12** | Particle Size Passing 50.0 mm | 95% | 100% |
| **13** | Chemical Mouli (CaO + MgO + $Al_2O_3$)/ $SiO_2$ | Greater than or equals to 1.0 | 1.93 |

**(Source:** JSW Cement Ltd.**)**

### 3.3 Slump Test Results

**Control Mix and Varied Mix Proportions**

The slump cone test results are tabulated in the table 6.4.1 with the increase in grade the increase in slump was observed. With the increase in the dosage of super plasticizer the increase in the slump was observed.

**Table 3.3.1:** Slump cone test results of control mix

| Sl. NO | Concrete Grades | Slump (mm) |
|---|---|---|
| 1 | M20 | 102 |
| 2 | M30 | 124 |
| 3 | M40 | 132 |
| 4 | M50 | 145 |

**Table 3.3.2: Slump test results for different grades of concrete with varied mix proportions**

| Sl. NO | Grade of Concrete | Slag | Slag Sand | Super Plasticizer (%) | Slump (mm) |
|---|---|---|---|---|---|
| 1 | M20 | 10 | 40 | 2 | 148 |
| 2 | M30 | 10 | 40 | 2 | 154 |
| 3 | M40 | 10 | 40 | 2 | 163 |
| 4 | M50 | 10 | 40 | 2 | 178 |

### 3.4 Mechanical Properties of M20 Grade Concrete

#### 3.4.1 Compressive Strength Analysis

**Table 3.4.1.1 Compressive Strength analysis**

| Sl. No | Slag | Slag Sand | Super Plasticizer (%) | Curing Age | Compressive Strength (N/mm2) | FITS | SNRA12 |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 0.1 | 7 | 12.2 | 15.18604 | 21.7272 |
| 2 | 10 | 20 | 1 | 28 | 21.3 | 18.50155 | 26.56759 |
| 3 | 10 | 30 | 1.5 | 56 | 23.7 | 22.52349 | 27.49497 |
| 4 | 10 | 40 | 2 | 90 | 25.2 | 27.32792 | 28.02801 |
| 5 | 20 | 10 | 1 | 56 | 22.1 | 21.47815 | 26.88785 |
| 6 | 20 | 20 | 1.5 | 90 | 24.8 | 25.55992 | 27.88903 |
| 7 | 20 | 30 | 2 | 7 | 14.3 | 15.82853 | 23.10672 |
| 8 | 20 | 40 | 1.5 | 28 | 22.01 | 18.42139 | 26.8524 |
| 9 | 30 | 10 | 1.5 | 90 | 23.8 | 25.60758 | 27.53154 |
| 10 | 30 | 20 | 2 | 56 | 23.84 | 21.54383 | 27.54613 |
| 11 | 30 | 30 | 0.1 | 28 | 20.67 | 17.02374 | 26.30681 |
| 12 | 30 | 40 | 1 | 7 | 10.3 | 14.86185 | 20.25674 |
| 13 | 40 | 10 | 2 | 28 | 19.88 | 17.21723 | 25.96833 |
| 14 | 40 | 20 | 1.5 | 7 | 11.57 | 14.33269 | 21.26667 |
| 15 | 40 | 30 | 1 | 90 | 23.1 | 25.01124 | 27.27224 |
| 16 | 40 | 40 | 0.1 | 56 | 21.88 | 20.22484 | 26.80095 |

**Linear Model Analysis: SN ratios versus Slag, Slag Sand, Super Plasticizer (%), Curing Days**

**Estimated Model Coefficients for SN ratios**

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 8.85049 | 0.1368 | 64.716 | 0.000 |
| Slag 10 | 0.31230 | 0.2369 | 1.318 | 0.279 |
| Slag 20 | 0.02681 | 0.2369 | 0.113 | 0.917 |
| Slag 30 | 0.24388 | 0.2369 | 1.030 | 0.379 |
| Slag San 10 | -0.37418 | 0.2369 | -1.580 | 0.212 |
| Slag San 20 | -0.09961 | 0.2369 | -0.421 | 0.702 |
| Slag San 30 | 0.10954 | 0.2369 | 0.462 | 0.675 |
| Super Pl 0.5 | -0.04492 | 0.2369 | -0.190 | 0.862 |
| Super Pl 1.0 | 0.19961 | 0.2369 | 0.843 | 0.461 |
| Super Pl 1.5 | -0.27350 | 0.2369 | -1.155 | 0.332 |
| Curing D 7 | -0.34947 | 0.2369 | -1.475 | 0.237 |
| Curing D 28 | -0.12335 | 0.2369 | -0.521 | 0.639 |
| Curing D 56 | 0.39496 | 0.2369 | 1.667 | 0.194 |

**Model Summary**

| S | R-Sq | R-Sq(adj) |
|---|---|---|

0.5470 84.49% 22.44%

### Analysis of Variance for SN ratios

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Slag | 3 | 1.9904 | 1.9904 | 0.6635 | 2.22 | 0.265 |
| Slag Sand | 3 | 1.1785 | 1.1785 | 0.3928 | 1.31 | 0.414 |
| Super Plasticizer (%) | 3 | 0.5231 | 0.5231 | 0.1744 | 0.58 | 0.666 |
| Curing Days | 3 | 1.1976 | 1.1976 | 0.3992 | 1.33 | 0.409 |
| Residual Error | 3 | 0.8977 | 0.8977 | 0.2992 | | |
| Total | 15 | 5.7874 | | | | |

### Response Table for Signal to Noise Ratios

Larger is better

| Level | Slag | Slag Sand | Super Plasticizer (%) | Curing Days |
|---|---|---|---|---|
| 1 | 9.163 | 8.476 | 8.806 | 8.501 |
| 2 | 8.877 | 8.751 | 9.050 | 8.727 |
| 3 | 9.094 | 8.960 | 8.577 | 9.245 |
| 4 | 8.267 | 9.215 | 8.969 | 8.928 |
| Delta | 0.895 | 0.738 | 0.473 | 0.744 |
| Rank | 1 | 3 | 4 | 2 |

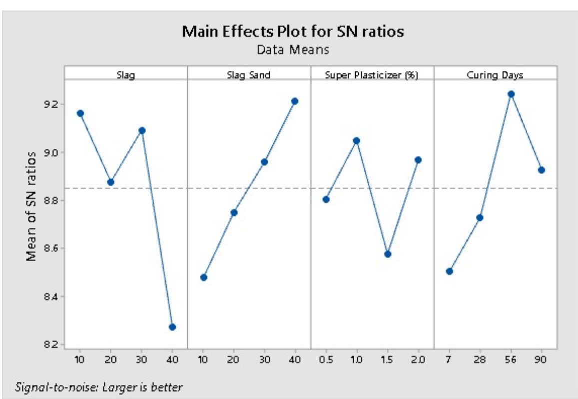



Figure 3.4.1.1 Main effects plot for SN ratios

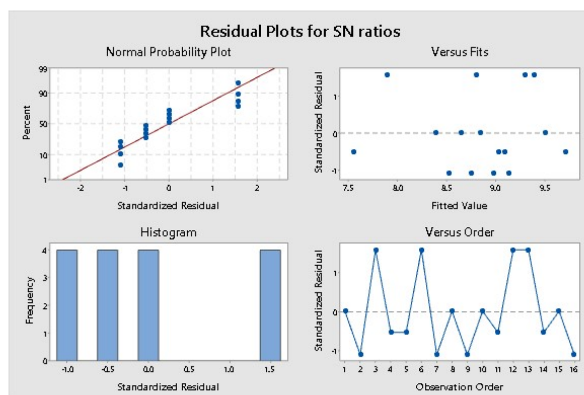



**Figure 3.4.1.2:** Residual Plots for SN ratios

### 3.4.2 Split Tensile Strength Analysis

**Table 3.4.2.1:** Split Tensile Strength Analysis

| Sl. No | Slag | Slag Sand | Super Plasticizer (%) | Curing Age | Compressive Strength (N/mm2) | FITS | SNRA12 |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 0.1 | 7 | 12.2 | 15.18604 | 21.7272 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | 10 | 20 | 1 | 28 | 21.3 | 18.50155 | 26.56759 |
| 3 | 10 | 30 | 1.5 | 56 | 23.7 | 22.52349 | 27.49497 |
| 4 | 10 | 40 | 2 | 90 | 25.2 | 27.32792 | 28.02801 |
| 5 | 20 | 10 | 1 | 56 | 22.1 | 21.47815 | 26.88785 |
| 6 | 20 | 20 | 0.1 | 90 | 24.8 | 25.55992 | 27.88903 |
| 7 | 20 | 30 | 2 | 7 | 14.3 | 15.82853 | 23.10672 |
| 8 | 20 | 40 | 1.5 | 28 | 22.01 | 18.42139 | 26.8524 |
| 9 | 30 | 10 | 1.5 | 90 | 23.8 | 25.60758 | 27.53154 |
| 10 | 30 | 20 | 2 | 56 | 23.84 | 21.54383 | 27.54613 |
| 11 | 30 | 30 | 0.1 | 28 | 20.67 | 17.02374 | 26.30681 |
| 12 | 30 | 40 | 1 | 7 | 10.3 | 14.86185 | 20.25674 |
| 13 | 40 | 10 | 2 | 28 | 19.88 | 17.21723 | 25.96833 |
| 14 | 40 | 20 | 1.5 | 7 | 11.57 | 14.33269 | 21.26667 |
| 15 | 40 | 30 | 1 | 90 | 23.1 | 25.01124 | 27.27224 |
| 16 | 40 | 40 | 0.1 | 56 | 21.88 | 20.22484 | 26.80095 |

## Linear Model Analysis: SN ratios versus Slag, Slag Sand, Super Plasticizer, Curing Age

### Estimated Model Coefficients for SN ratios

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 7.68520 | 0.2663 | 28.865 | 0.000 |
| Slag 10 | 0.50120 | 0.4612 | 1.087 | 0.357 |
| Slag 20 | 1.06592 | 0.4612 | 2.311 | 0.104 |
| Slag 30 | 0.38665 | 0.4612 | 0.838 | 0.463 |
| Slag San 10 | 0.08790 | 0.4612 | 0.191 | 0.861 |
| Slag San 20 | 0.17464 | 0.4612 | 0.379 | 0.730 |
| Slag San 30 | 0.25421 | 0.4612 | 0.551 | 0.620 |
| Super Pl 0.5 | -0.51293 | 0.4612 | -1.112 | 0.347 |
| Super Pl 1.0 | -0.16938 | 0.4612 | -0.367 | 0.738 |
| Super Pl 1.5 | 0.38897 | 0.4612 | 0.843 | 0.461 |
| Curing A 0 | 1.08357 | 0.4612 | 2.350 | 0.100 |
| Curing A 7 | -1.54649 | 0.4612 | -3.353 | 0.044 |
| Curing A 28 | 0.25578 | 0.4612 | 0.555 | 0.618 |

### Model Summary

| S | R-Sq | R-Sq(adj) |
|---|---|---|
| 1.0650 | 92.11% | 60.54% |

### Analysis of Variance for SN ratios

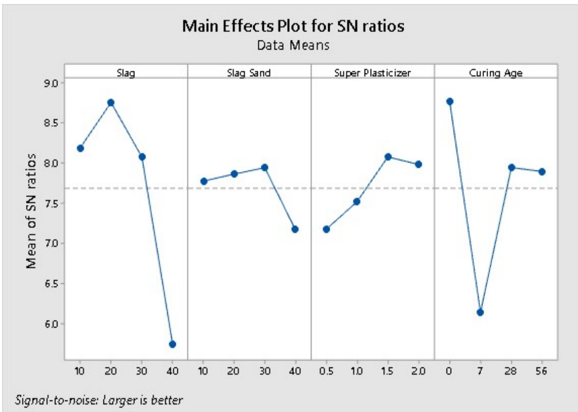
| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Slag | 3 | 21.416 | 21.416 | 7.1388 | 6.29 | 0.083 |
| Slag Sand | 3 | 1.480 | 1.480 | 0.4932 | 0.43 | 0.744 |
| Super Plasticizer | 3 | 2.117 | 2.117 | 0.7055 | 0.62 | 0.647 |
| Curing Age | 3 | 14.696 | 14.696 | 4.8988 | 4.32 | 0.130 |
| Residual Error | 3 | 3.403 | 3.403 | 1.1342 | | |
| Total | 15 | 43.112 | | | | |

## Response Table for Signal to Noise Ratios

Larger is better

| Level | Slag | Slag Sand | Super Plasticizer | Curing Age |
|---|---|---|---|---|
| 1 | 8.186 | 7.773 | 7.172 | 8.769 |
| 2 | 8.751 | 7.860 | 7.516 | 6.139 |
| 3 | 8.072 | 7.939 | 8.074 | 7.941 |
| 4 | 5.731 | 7.168 | 7.979 | 7.892 |

| | | | | |
|---|---|---|---|---|
| Delta | 3.020 | 0.771 | 0.902 | 2.630 |
| Rank | 1 | 4 | 3 | 2 |



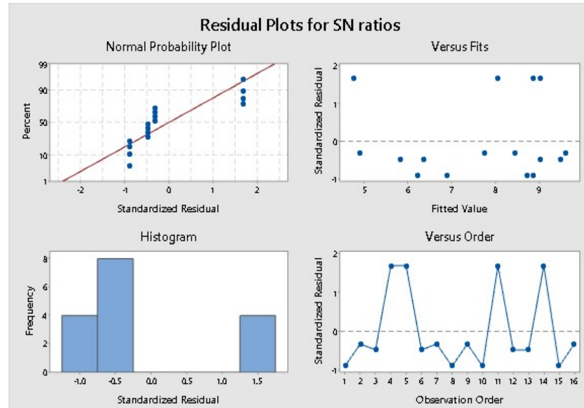




**Figure 3.4.2.1** Main effects plot for SN ratios

**Figure 3.4.2.2** Residual Plots for SN ratios

### 3.4.3 Flexural Strength Analysis

**Table 3.4.3.1:** Flexural Strength Analysis

| Sl. No | Slag | Slag Sand | Super Plasticizer (%) | Curing Days | Flexural Strength (N/mm2) | SNRA3 |
|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 0.5 | 7 | 2.63 | 8.399115 |
| 2 | 10 | 20 | 1 | 28 | 2.78 | 8.880896 |
| 3 | 10 | 30 | 1.5 | 56 | 3.08 | 9.771014 |
| 4 | 10 | 40 | 2 | 90 | 3.02 | 9.600139 |
| 5 | 20 | 10 | 1 | 56 | 2.81 | 8.974126 |
| 6 | 20 | 20 | 0.5 | 90 | 2.88 | 9.18785 |
| 7 | 20 | 30 | 2 | 7 | 2.66 | 8.497633 |
| 8 | 20 | 40 | 1.5 | 28 | 2.77 | 8.849595 |
| 9 | 30 | 10 | 1.5 | 90 | 2.59 | 8.265995 |
| 10 | 30 | 20 | 2 | 56 | 2.99 | 9.513424 |
| 11 | 30 | 30 | 0.5 | 28 | 2.79 | 8.912084 |
| 12 | 30 | 40 | 1 | 7 | 3.05 | 9.685997 |
| 13 | 40 | 10 | 2 | 28 | 2.59 | 8.265995 |
| 14 | 40 | 20 | 1.5 | 7 | 2.35 | 7.421357 |
| 15 | 40 | 30 | 1 | 90 | 2.71 | 8.659386 |
| 16 | 40 | 40 | 0.5 | 56 | 2.73 | 8.723253 |

**Linear Model Analysis: SN ratios versus Slag, Slag Sand, Super Plasticizer (%), Curing Days**

**Estimated Model Coefficients for SN ratios**

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 8.85049 | 0.1368 | 64.716 | 0.000 |

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| | | | | |
|---|---|---|---|---|
| Slag 10 | 0.31230 | 0.2369 | 1.318 | 0.279 |
| Slag 20 | 0.02681 | 0.2369 | 0.113 | 0.917 |
| Slag 30 | 0.24388 | 0.2369 | 1.030 | 0.379 |
| Slag San 10 | -0.37418 | 0.2369 | -1.580 | 0.212 |
| Slag San 20 | -0.09961 | 0.2369 | -0.421 | 0.702 |
| Slag San 30 | 0.10954 | 0.2369 | 0.462 | 0.675 |
| Super Pl 0.5 | -0.04492 | 0.2369 | -0.190 | 0.862 |
| Super Pl 1.0 | 0.19961 | 0.2369 | 0.843 | 0.461 |
| Super Pl 1.5 | -0.27350 | 0.2369 | -1.155 | 0.332 |
| Curing D 7 | -0.34947 | 0.2369 | -1.475 | 0.237 |
| Curing D 28 | -0.12335 | 0.2369 | -0.521 | 0.639 |
| Curing D 56 | 0.39496 | 0.2369 | 1.667 | 0.194 |

## Model Summary

| S | R-Sq | R-Sq(adj) |
|---|---|---|
| 0.5470 | 84.49% | 22.44% |

## Analysis of Variance for SN ratios

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Slag | 3 | 1.9904 | 1.9904 | 0.6635 | 2.22 | 0.265 |
| Slag Sand | 3 | 1.1785 | 1.1785 | 0.3928 | 1.31 | 0.414 |
| Super Plasticizer (%) | 3 | 0.5231 | 0.5231 | 0.1744 | 0.58 | 0.666 |
| Curing Days | 3 | 1.1976 | 1.1976 | 0.3992 | 1.33 | 0.409 |
| Residual Error | 3 | 0.8977 | 0.8977 | 0.2992 | | |
| Total | 15 | 5.7874 | | | | |

## Response Table for Signal to Noise Ratios

Larger is better

| Level | Slag | Slag Sand | Super Plasticizer (%) | Curing Days |
|---|---|---|---|---|
| 1 | 9.163 | 8.476 | 8.806 | 8.501 |
| 2 | 8.877 | 8.751 | 9.050 | 8.727 |
| 3 | 9.094 | 8.960 | 8.577 | 9.245 |
| 4 | 8.267 | 9.215 | 8.969 | 8.928 |
| Delta | 0.895 | 0.738 | 0.473 | 0.744 |
| Rank | 1 | 3 | 4 | 2 |

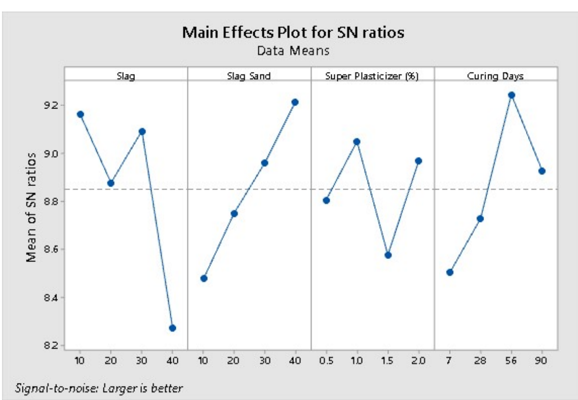


**Figure 3.4.3.1** Main effects plot for SN ratios

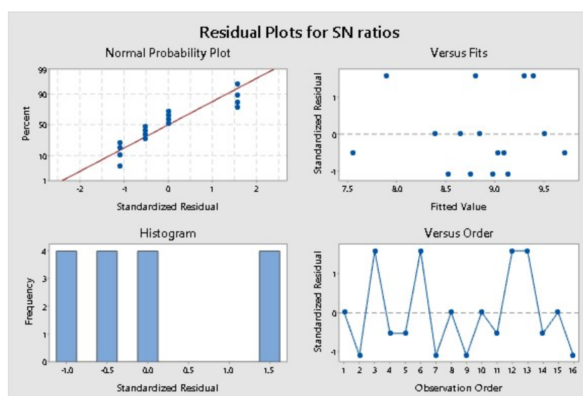


**Figure 3.4.3.2** Residual Plots for SN ratios

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**Signal to Noise ratio**

S/N ratio is used as measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. In practice, the target mean value may change during the process development. Two of the applications in which the concept of S/S ratio is useful are the improvement of quality through variability ant the improvement of measurement. The S /N ratios characteristics can be divided into three categories.

- Larger is best characteristic

Larger is best is adopted for Ultimate Axial load & smaller is best is adopted for % of failure for the Taguchi's analysis as shown in figures. From the Response table of S/N ratio, it can be clearly seen that Diameter is the main parameter ranked 1 among 3 of the parameters.

**Regression Analysis**

After conducting the initial nine experiments (each in triplicate trial), linear regression model were developed for all curing ages and mechanical prosperities. The REGRESSION equation is developed. The equation can be used to predict the ultimate load carrying capacity of the remaining samples used in the experimental program. To verify the accuracy of such prediction of load carrying capacity of samples the remaining experiments are conducted and a comparison of experimental values is made with the predicted values. It is observed that regression model based on initial nine experiments were reasonably well. The residual plots for regression were obtained from Minitab as shown in Figure.

## CONCLUSION

- Initial and Final setting time of GGBFS exceeded the threshold values
- For different grades of concrete W/B, workability was achieved with the addition of super plasticizer
- Maximum compressive strength, split tensile strength, and Flexural strengths obtained for different combinations are higher than that of the control mix
- The important parameters affecting the load-deformation behavior are Slag, Slag Sand, Super Plasticizer (%), and Curing Age
- From regression analysis, the Ultimate load carrying capacity can be well predicted

- From Taguchi's analysis, for maximum axial load carrying capacity using the response of means and response of S./N ratios, the predominate factor curing age
- The optimum results was observed for Compressive strength, was 20% Slag, 30% Slag Sand, 1.5% SP, resulted 24.8N/mm$^2$
- The optimum results was observed for Split tensile strength, was 20% Slag, 20% Slag Sand, 2% SP, resulted 18.6N/mm$^2$
- The optimum results was observed for Flexural strength was 20% Slag, 30% Slag sand, 1.5% SP, resulted 3.05N/mm$^2$

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