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*Research Paper*

# A STUDY ON EFFECT OF SILICA FUME ON THE MECHANICAL PROPERTIES OF STEEL SLAG AGGREGATE CONCRETE

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Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues those together (NSA, 1982). Production of sand and gravel has increased at an annual rate of less than 1 percent. In essence the amount of crushed stone to be produced in the next 20 years will equal the quantity of all stone produced during the previous century, i.e., about 36.5 billion metric tons. Therefore the use of alternative sources for natural aggregates is becoming increasingly important (NSA, 1982). In the present study the mechanical properties of concrete by replacing cement with different percentages of Silica fume and aggregate by different percentages of Steel slag are studied. The results thus obtained are analyzed using Regression analysis. Results indicated that the replacement of cement by silica fume to the extent of 15% exhibited improved mechanical properties. Further, it has been also observed that with 15% replacement of cement by silica fume and replacement of natural aggregates by steel slag aggregates to the extent of 25% to 50% have shown improved strength compared normal concrete i.e. the concrete with 0% silica fume and 0% steel slag aggregates. Regression analysis has been carried out to compare the experimental results.

***Keywords:*** Concrete, Steel slag, silica fume, properties of concrete, regression analysis

## INTRODUCTION

Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete (Maslehuddin *et al.*, 2003).

Abdullah (2004) has concluded that supplementary cementing materials, such as silica fume may be advantageously used in situations where good quality aggregates are not available. Saud al Otaibi (2008) has

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studied on replacement of sand by steel mill has concluded that 40% replacement of sand with steel mill scale gave the highest increase in compressive strength. Li Yun feng (2009) found that concrete with good performance can be produced using mineral admixtures consisting of steel slag powder and blast furnace slag.

In the present paper an experimental investigation on the mechanical properties of concrete has been made with 0% to 20% replacement of cement by silica fume and 0% to 75% replacement of natural aggregate by steel slag. Results exhibited that concrete with 15% silica fume and up to 50% replacement of natural aggregate by steel slag, show better mechanical properties.

## MATERIAL AND METHODS

A wide range of materials can be used as an alternative to natural aggregates. When any new material is used as a concrete aggregate, three major considerations are relevant: (1) economy, (2) compatibility with other materials and (3) concrete properties. The economical use of non-traditional materials in concrete depends on various factors, like transportation required to bring the materials from industry to the site of construction, quantity available, and the mix design requirements. In many situations sources are located very far from their potential markets for concrete with high transportation costs. The separation of any useful materials from undesired substances would be costly as well. Crushing the aggregates to particular sizes is also an important issue. The aggregates should not react adversely with other constituents of the concrete mixture. They should not change the properties of the concrete adversely. The aggregates have vital role in concrete and provide strength and durability to concrete. The use of industrial byproducts in the concrete has received increasing attention in the recent years. Blast furnace slag has been used as an aggregate for asphalt concrete and also as a cementitious material in concrete. Steel slag which is also an industrial byproduct has a potential to be utilized as an aggregate in concrete as well.

Steel slag is a byproduct obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Steel slag is defined by the American Society for Testing and Materials as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces. The two states producing the most steel slag in the U.S. are Ohio and Indiana. The chemical composition and cooling of molten steel slag have a great effect on the physical and chemical properties of solidified steel slag (Tables 1 and 2) (Maslehuddin *et al.*, 2003).

Silica fume is a by-product resulting from the production of silicon or ferrosilicon alloys or other silicon alloys. Silica fume is light or dark gray in colour containing high content of amorphous silicon dioxide. Silica fume powder as collected from waste gasses without further treatment is sometimes referred to as undensified silica fume to distinguish it with other forms of treated silica fume. Undensified silicon fume consists of very fine vitreous spherical particles with average diameter about 0.1micro meter, which is 100 times smaller than the average cement particle. The undensified silica fume is almost as fine as cigarette ash and the bulk density is only about 200-300 kg/$m^3$ and relative density of typical silica fume particle is 2.2 to 2.5. Because the extreme fineness and high silicon content, silica fume is a highly effective Pozzolona (Table 3) (Dotto *et al*., 2004).

The mix design procedure adopted to obtain a M25 grade concrete is in accordance with IS 10262- 2009. The specific gravities of the materials used were as tabulated in the Table 4. The mix proportion adopted was given in Table 5.

**Table 1: Sieve Analysis of Steel Slag**

| Sieve size (mm) | Wt Retain (g) | Cum Wt Retain (kg) | % Cu Wt Retain (kg) | % of Passing |
|---|---|---|---|---|
| 20 | 270 | 0.270 | 5.4 | 94.6 |
| 12.5 | 3522 | 3.792 | 75.84 | 21.16 |
| 10 | 790 | 4.582 | 91.64 | 8.36 |
| 4.75 | 334 | 4.916 | 98.62 | 1.68 |
| Total | 5000 | | | |

**Table 2: Physical Properties of Steel Slag**

| Property | Value |
|---|---|
| Specific Gravity | 3.2-3.6 |
| Water Absorption | 0.85% |
| Clay lumps and friable particles | 0.12% |
| Loss on abrasion | 11.60% |

**Table 3: Chemical Composition of Silica Fume**

| | |
|---|---|
| $SiO_2$ | 92.85 |
| $Al_2O_3$ | 0.61 |
| $Fe_2O_3$ | 0.94 |
| CaO | 0.39 |
| MgO | 1.58 |
| $K_2O$ | 0.87 |
| $Na_2O$ | 0.5 |

**Table 4: Specific Gravities of Materials Used**

| Material | Specific Gravity |
|---|---|
| Cement | 3.15 |
| Fine aggregate | 2.64 |
| Coarse aggregate | 2.72 |

**Table 5: Mix Proportion**

| W/C ratio | Cement | Fine Aggregate | Coarse Aggregate |
|---|---|---|---|
| 0.50 | 372 | 662 kg/$m^3$ | 1212 kg/$m^3$ |
| 0.50 | 1 | 1.77 | 3.25 |

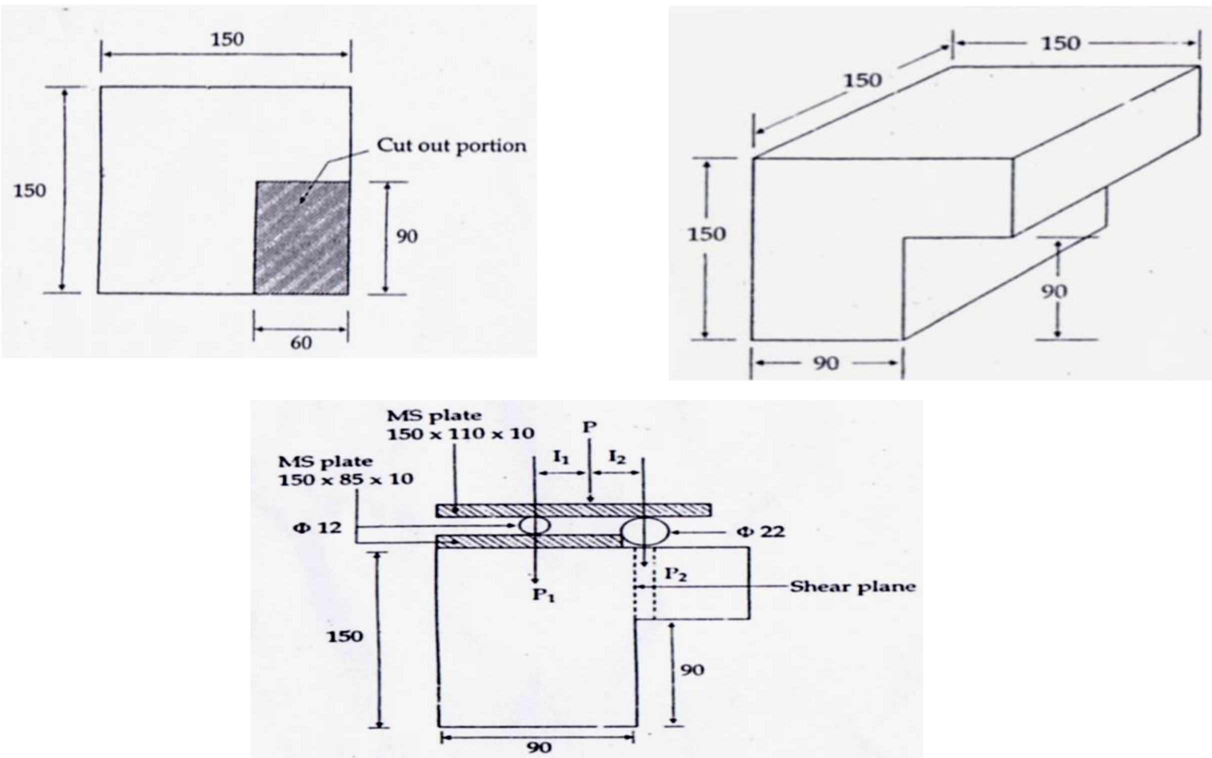
## Casting of Specimens and Testing Procedure

Cement, sand and aggregate were taken in mix proportion 1:1.77:3.25 which correspond to M25 grade of concrete. Cement has been replaced with Silica fume (0%, 5%, 10%, 15%, and 20%) and coarse aggregate has been replaced with Steel slag (0%, 25%, 50%, 75%, and 100%). All the ingredients were dry mixed homogeneously. To this dry mix, required quantity of water was added (w/c = 0.48) and the entire mix was again homogeneously mixed. This wet concrete was poured into the moulds which was compacted through hand compaction in three layers and then kept into the vibrator for compaction. After the compaction, the specimens were given smooth finishes and were covered with gunny bags. After 24 h, the specimens were demoulded and transferred to curing tanks where in they were allowed to cure for 28 days.

To study the effects of replacements of cement and natural aggregates, have been studied on compressive strength, splitting tensile strength, flexural strength and shear strength as per IS 5816-1999 and IS 516-1959.

For evaluating the shear strength, L shaped specimens were prepared. A diagrammatic representation of the specimen is as shown in Figure 1. These specimens were tested on 2000 kN capacity compression testing machine. A loading arrangement was made such that a direct shearing force was applied on the shorter arm of the 'L' shaped specimen (i.e. over an area of 150mm × 60mm). The maximum applied load (P) was noted down.

**Figure 1: Shear Test Specimen Arrangement**



The failure load (F) due to the applied shear force is obtained by using the relation

Failure load (F) = $Pl_1/(l_1 \times l_2)$

where, P = Failure load in kN

$l_1$ = 25mm

$l_2$ = 25mm

The shear strength is given by the relation

Shear strength = F/A

where, F= Failure load

A = Area on which shear force is applied = 150mm 60mm

# RESULTS AND DISCUSSION

## Compressive Strength

- From Figure 2 it has been observed that there is increase in compressive strength with the increase in silica fume up to 15% beyond which it has shown downward trend. From Table 6 it has been observed that maximum increase in compressive strength of 11.69% was observed at 15% replacement of cement with silica fume alone. When natural aggregate were also replaced with steel slag in addition to the replacement of cement by silica fume, it has been observed that the compressive strength is more than the reference concrete up to 50% replacement of natural aggregates.
- It may be due to the fact that silica fume has smaller particle size which fills the voids and increases the strength or it may due to pozzolanic reaction between cement and silica fume.
- The compressive strength decreases when the percentage of steel slag increases from 0% to 75% to replace the natural aggregates. This is because of the porous nature of the steel slag.

## Split Tensile Strength Test Results

- From Figure 3 it has been observed that the 15% replacement of cement with silica fume and 25% replacement of natural aggre-gates with steel slag show higher percentage of improvement in splitting tensile strength than compressive strength.
- Figure 3 shows similar variation in splitting tensile strength of concrete with replacement of cement with silica fume and natural

**Figure 2: Variation of Compressive Strength**

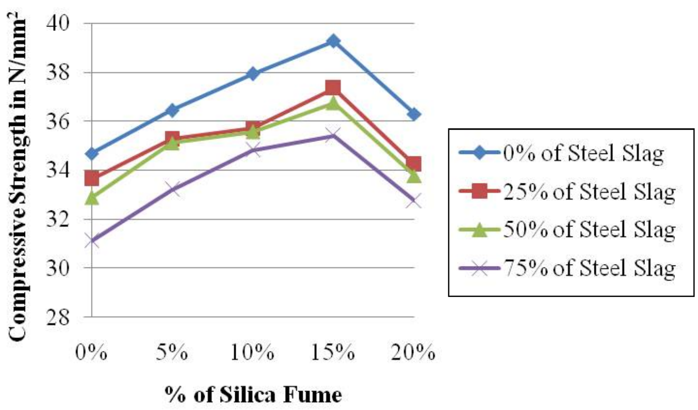


**Table 6: Variation of Compressive Strength of M25 Concrete with Different Percentage of Replacement of Cement By Silica Fume and Natural Aggregate by Steel Slag Content**

| Percentage Replacement of cement by Silica Fume | Percentage Replacement of NA by Steel Slag | Average Compressive Strength in N/mm$^2$ | Percentage Variation w.r.t Normal Concrete |
|---|---|---|---|
| 0% | 0% | 34.67 | 0 |
| | 25% | 33.63 | -2.99 |
| | 50% | 32.89 | -5.13 |
| | 75% | 31.11 | -10.26 |
| 5% | 0% | 36.44 | 4.85 |
| | 25% | 35.26 | 1.67 |
| | 50% | 35.11 | 1.25 |
| | 75% | 33.19 | -4.26 |
| 10% | 0% | 37.93 | 8.59 |
| | 25% | 35.70 | 2.88 |
| | 50% | 35.56 | 2.50 |
| | 75% | 34.81 | 0.40 |
| 15% | 0% | 39.26 | 11.69 |
| | 25% | 37.33 | 7.12 |
| | 50% | 36.74 | 5.63 |
| | 75% | 35.41 | 2.08 |
| 20% | 0% | 36.30 | 4.49 |
| | 25% | 34.22 | -1.29 |
| | 50% | 33.78 | -2.56 |
| | 75% | 32.74 | -5.56 |

aggregate with steel slag, but show less reduction in strength at higher steel slag compared to compressive strength.

- The splitting tensile strength decreases when the percentage of steel slag increases from 0% to 75% to replace the natural aggregates. This is because of the porous nature of the steel slag aggregates.

## Flexural Strength Test Results

- From Figure 4 it has been observed that there is increase in flexural strength with replacement of cement by silica fume alone

**Figure 3: Variation of Split Tensile Strength**

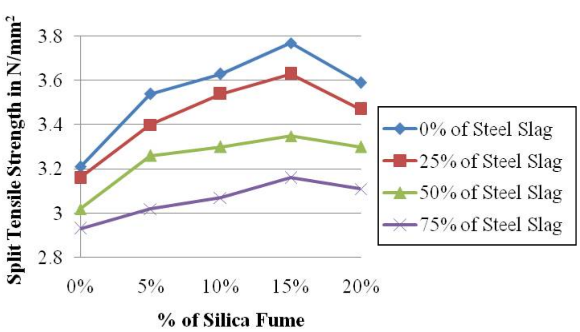



**Figure 4: Variation of Flexural Strength**

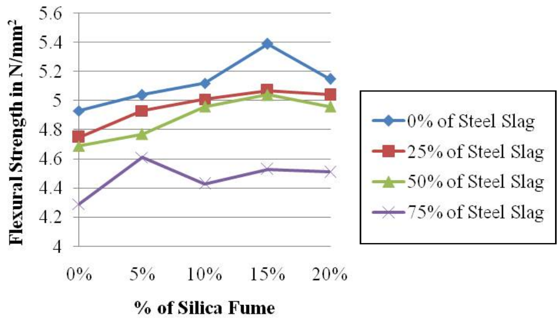



**Table 7: Variation of Splitting Tensile Strength of M25 Concrete With Different Percentage of Replacement of Cement by Silica Fume and Natural Aggregate by Steel Slag Content**

| Percentage Replacement of cement by Silica Fume | Percentage Replacement of NA by Steel Slag | Average Compressive Strength in N/mm² | Percentage Variation w.r.t Normal Concrete |
|---|---|---|---|
| 0% | 0% | 3.21 | 0 |
| | 25% | 3.16 | -1.55 |
| | 50% | 3.02 | -5.91 |
| | 75% | 2.93 | -8.72 |
| 5% | 0% | 3.54 | 9.32 |
| | 25% | 3.4 | 5.58 |
| | 50% | 3.26 | 1.53 |
| | 75% | 3.02 | -5.91 |
| 10% | 0% | 3.63 | 11.53 |
| | 25% | 3.54 | 9.32 |
| | 50% | 3.3 | 2.27 |
| | 75% | 3.07 | -4.36 |
| 15% | 0% | 3.77 | 14.85 |
| | 25% | 3.63 | 11.53 |
| | 50% | 3.35 | 4.17 |
| | 75% | 3.16 | -1.55 |
| 20% | 0% | 3.59 | 10.58 |
| | 25% | 3.47 | 7.49 |
| | 50% | 3.3 | 2.27 |
| | 75% | 3.11 | -3.11 |

and with natural aggregates by steel slag at 25% and 50% replacement, compared to normal concrete.

- From Table 8 it has been observed that 15% replacement of cement by silica fume and 25% replacement of natural aggregates by steel slag show highest increase in flexural strength. It has been observed that the contribution of silica fume and steel slag in increasing flexural strength at this replacement is marginal compared to the increase in compressive and splitting tensile strength.
- The flexural strength decreases when the percentage of steel slag increases from 0% to 75% to replace the natural aggregates. This is because of the porous nature of the steel slag.

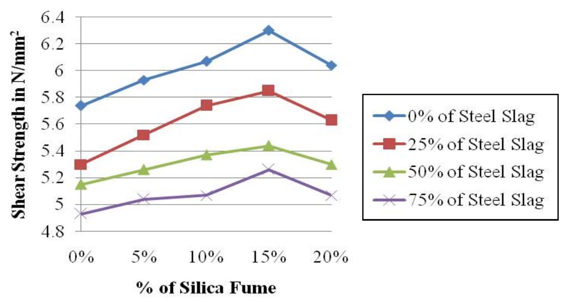
**Table 8: Variation of Flexural Strength of M25 Concrete With Different Percentage of Replacement of Cement by Silica Fume and Natural Aggregate by Steel Slag Content**

| Percentage Replacement of cement by Silica Fume | Percentage Replacement of NA by Steel Slag | Average Compressive Strength in N/mm$^2$ | Percentage Variation w.r.t Normal Concrete |
|---|---|---|---|
| 0% | 0% | 4.93 | 0 |
| | 25% | 4.75 | -3.65 |
| | 50% | 4.69 | -4.86 |
| | 75% | 4.29 | -12.98 |
| 5% | 0% | 5.04 | 2.18 |
| | 25% | 4.93 | 0 |
| | 50% | 4.77 | -3.24 |
| | 75% | 4.61 | -6.49 |
| 10% | 0% | 5.12 | 3.17 |
| | 25% | 5.01 | 1.59 |
| | 50% | 4.96 | 0.60 |
| | 75% | 4.43 | -10.14 |
| 15% | 0% | 5.39 | 8.53 |
| | 25% | 5.07 | 2.76 |
| | 50% | 5.04 | 2.18 |
| | 75% | 4.53 | -8.11 |
| 20% | 0% | 5.15 | 4.27 |
| | 25% | 5.04 | 2.18 |
| | 50% | 4.99 | 1.20 |
| | 75% | 4.43 | -10.14 |

## Shear strength test results

- From Figure 5 it has been observed that the maximum shear strength is achieved at the 15% replacement of cement by silica fume as observed in the case of compressive strength and tensile strength of M25 concrete. But the replacement of cement by silica fume and natural aggregates by steel slag, show higher strength at 15% and 50% replacement respectively.

**Figure 5: Variation of Shear Strength**




- The Shear strength decreases when the percentage of steel slag increases from 0%

**Table 9: Variation of Shear Strength of Concrete With Different Percentage of Replacement of Cement By Silica Fume and Natural Aggregate by Steel Slag Content**

| Percentage Replacement of cement by Silica Fume | Percentage Replacement of NA by Steel Slag | Average Compressive Strength in N/mm² | Percentage Variation w.r.t Normal Concrete |
|---|---|---|---|
| 0% | 0% | 5.74 | 0 |
| | 25% | 5.3 | -7.66 |
| | 50% | 5.15 | -10.27 |
| | 75% | 4.93 | -14.11 |
| 5% | 0% | 5.93 | 3.20 |
| | 25% | 5.52 | -3.83 |
| | 50% | 5.26 | -8.36 |
| | 75% | 5.04 | -12.19 |
| 10% | 0% | 6.07 | 5.43 |
| | 25% | 5.74 | 0 |
| | 50% | 5.37 | -6.44 |
| | 75% | 5.07 | -11.67 |
| 15% | 0% | 6.3 | 8.88 |
| | 25% | 5.85 | 1.88 |
| | 50% | 5.44 | 5.22 |
| | 75% | 5.26 | -8.36 |
| 20% | 0% | 6.04 | 4.96 |
| | 25% | 5.63 | -1.91 |
| | 50% | 5.3 | -7.66 |
| | 75% | 5.07 | -11.67 |

to 75% to replace the natural aggregates. This is because of the porous nature of the steel slag.

- It has been observed that the maximum decrease in shear strength is obtained for 75% replacement of aggregates by steel slag.

## REGRESSION ANALYSIS

Correlation between experimental strength and computed strength in the form of linear equation.

The linear equation is computed using Microsoft excel which uses the transformed regression model method of analysis.

The equation of the linear curve is

$Z = a + bX_1 + cX_2 + dX_3 + eX_4$

The normal equations are given by

$S\Sigma = an + b\Sigma X_1 + c\Sigma X_2 + d\Sigma X_3 + e\Sigma X_4$

$\Sigma ZX_1 = a\Sigma X_1 + b\Sigma X_1^2 + c\Sigma X_1X_2 + d\Sigma X_1X_3 + e\Sigma X_1X_4$

$\Sigma ZX_2 = a\Sigma X_2 + b\Sigma X_2X_1 + c\Sigma X_2^2 + d\Sigma X_2X_3 + e\Sigma X_2X_4$

$\Sigma ZX_3 = a\Sigma X_3 + b\Sigma X_3X_1 + c\Sigma X_3X_2 + d\Sigma X_3^2 + e\Sigma X_3X_4$

$\Sigma ZX_4 = a\Sigma X_4 + b\Sigma X_4X_1 + c\Sigma X_4X_2 + d\Sigma X_4X_3 + e\Sigma X_4^2$

### Compressive Strength

From the above linear equation, correlation coefficient for compressive strength equation is

$Z_c = -0.0911X_1 + 0.4493X_3 + 0.406X_4$

here, $Z_c$ = Computed 28-day strength,

$X_1$ = Percentage of Cement,

$X_2$ = Percentage of Silica Fume,

$X_3$ = Percentage of natural aggregate,

$X_4$ = Percentage of Steel Slag.

**Table 10: Correlation Coefficient and Standard Error for Compressive Strength**

| % of Cement $X_1$ | % of Silica Fume $X_2$ | % of NA $X_3$ | % of Steel Slag $X_4$ | Exp. Strength Z | $X_1^2$ | $X_2^2$ | $X_3^2$ | $X_4^2$ | $X_1X_2$ | $X_1X_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 0 | 100 | 0 | 34.67 | 10000 | 0 | 10000 | 0 | 0 | 10000 |
| 100 | 0 | 75 | 25 | 33.63 | 10000 | 0 | 5625 | 625 | 0 | 7500 |
| 100 | 0 | 50 | 50 | 32.89 | 10000 | 0 | 2500 | 2500 | 0 | 5000 |
| 100 | 0 | 25 | 75 | 31.11 | 10000 | 0 | 625 | 5625 | 0 | 2500 |
| 95 | 5 | 100 | 0 | 36.44 | 9025 | 25 | 10000 | 0 | 475 | 9500 |
| 95 | 5 | 75 | 25 | 35.26 | 9025 | 25 | 5625 | 625 | 475 | 7125 |
| 95 | 5 | 50 | 50 | 35.11 | 9025 | 25 | 2500 | 2500 | 475 | 4750 |
| 95 | 5 | 25 | 75 | 33.19 | 9025 | 25 | 625 | 5625 | 475 | 2375 |
| 90 | 10 | 100 | 0 | 37.93 | 8100 | 100 | 10000 | 0 | 900 | 9000 |
| 90 | 10 | 75 | 25 | 35.7 | 8100 | 100 | 5625 | 625 | 900 | 6750 |

Table 10 (Cont.)

| % of Cement $X_1$ | % of Silica Fume $X_2$ | % of NA $X_3$ | % of Steel Slag $X_4$ | Exp. Strength Z | $X_1^2$ | $X_2^2$ | $X_3^2$ | $X_4^2$ | $X_1X_2$ | $X_1X_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 10 | 50 | 50 | 35.56 | 8100 | 100 | 2500 | 2500 | 900 | 4500 |
| 90 | 10 | 25 | 75 | 34.81 | 8100 | 100 | 625 | 5625 | 900 | 2250 |
| 85 | 15 | 100 | 0 | 39.26 | 7225 | 225 | 10000 | 0 | 1275 | 8500 |
| 85 | 15 | 75 | 25 | 37.33 | 7225 | 225 | 5625 | 625 | 1275 | 6375 |
| 85 | 15 | 50 | 50 | 36.74 | 7225 | 225 | 2500 | 2500 | 1275 | 4250 |
| 85 | 15 | 25 | 75 | 35.41 | 7225 | 225 | 625 | 5625 | 1275 | 2125 |
| 80 | 20 | 100 | 0 | 36.3 | 6400 | 400 | 10000 | 0 | 1600 | 8000 |
| 80 | 20 | 75 | 25 | 34.22 | 6400 | 400 | 5625 | 625 | 1600 | 6000 |
| 80 | 20 | 50 | 50 | 33.78 | 6400 | 400 | 2500 | 2500 | 1600 | 4000 |
| 80 | 20 | 25 | 75 | 32.74 | 6400 | 400 | 625 | 5625 | 1600 | 2000 |
| 1800 | 180 | 1250 | 750 | 702.08 | 163000 | 3000 | 93750 | 43750 | 17000 | 112500 |

| $X_1X_4$ | $X_2X_3$ | $X_2X_4$ | $X_3X_4$ | $Z^2$ | $X_1Z$ | $X_2Z$ | $X_3Z$ | $X_4Z$ | Computed Strength $Z_c$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1202.01 | 3467 | 0 | 3467 | 0 | 35.82 |
| 2500 | 0 | 0 | 1875 | 1130.98 | 3363 | 0 | 2522.25 | 840.75 | 34.74 |
| 5000 | 0 | 0 | 2500 | 1081.75 | 3289 | 0 | 1644.5 | 1644.5 | 33.66 |
| 7500 | 0 | 0 | 1875 | 967.83 | 3111 | 0 | 777.75 | 2333.25 | 32.57 |
| 0 | 500 | 0 | 0 | 1327.87 | 3461.8 | 182.2 | 3644 | 0 | 36.28 |
| 2375 | 375 | 125 | 1875 | 1243.27 | 3349.7 | 176.3 | 2644.5 | 881.5 | 35.19 |
| 4750 | 250 | 250 | 2500 | 1232.71 | 3335.45 | 175.55 | 1755.5 | 1755.5 | 34.11 |
| 7125 | 125 | 375 | 1875 | 1101.58 | 3153.05 | 165.95 | 829.75 | 2489.25 | 33.03 |
| 0 | 1000 | 0 | 0 | 1438.68 | 3413.7 | 379.3 | 3793 | 0 | 36.73 |
| 2250 | 750 | 250 | 1875 | 1274.49 | 3213 | 357 | 2677.5 | 892.5 | 35.65 |
| 4500 | 500 | 500 | 2500 | 1264.51 | 3200.4 | 355.6 | 1778 | 1778 | 34.57 |
| 6750 | 250 | 750 | 1875 | 1211.74 | 3132.9 | 348.1 | 870.25 | 2610.75 | 33.48 |
| 0 | 1500 | 0 | 0 | 1541.35 | 3337.1 | 588.9 | 3926 | 0 | 37.19 |
| 2125 | 1125 | 375 | 1875 | 1393.53 | 3173.05 | 559.95 | 2799.75 | 933.25 | 36.10 |
| 4250 | 750 | 750 | 2500 | 1349.83 | 3122.9 | 551.1 | 1837 | 1837 | 35.02 |
| 6375 | 375 | 1125 | 1875 | 1253.87 | 3009.85 | 531.15 | 885.25 | 2655.75 | 33.94 |

Table 10 (Cont.)

| $X_1X_4$ | $X_2X_3$ | $X_2X_4$ | $X_3X_4$ | $Z^2$ | $X_1Z$ | $X_2Z$ | $X_3Z$ | $X_4Z$ | Computed Strength $Z_c$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 2000 | 0 | 0 | 1317.69 | 2904 | 726 | 3630 | 0 | 37.64 |
| 2000 | 1500 | 500 | 1875 | 1171.01 | 2737.6 | 684.4 | 2566.5 | 855.5 | 36.56 |
| 4000 | 1000 | 1000 | 2500 | 1141.09 | 2702.4 | 675.6 | 1689 | 1689 | 35.48 |
| 6000 | 500 | 1500 | 1875 | 1071.91 | 2619.2 | 654.8 | 818.5 | 2455.5 | 34.39 |
| 67500 | 12500 | 7500 | 31250 | 24717.69 | 63096.1 | 7111.9 | 44556 | 25652 | 702.15 |
| | | | | | | | | | S = 1.31<br>r = 0.72 |

## Standard Deviation ($S_d$)

The standard deviation is calculated as follows

$$S_d = \sqrt{\frac{\Sigma Z^2}{n} - \left(\frac{\Sigma Z}{n}\right)^2}$$

$$S_d = \sqrt{\frac{24717.69}{20} - \left(\frac{702.08}{20}\right)^2}$$

$S_d = 1.895$

## Standard Error (S)

The standard error is computed as follows

$$S = \sqrt{\frac{(\Sigma Z - Zc)^2}{n}}$$

$$S = \sqrt{\frac{(702.08 - 702.15)^2}{20}}$$

$S = 1.31$

## Correlation Coefficient (r)

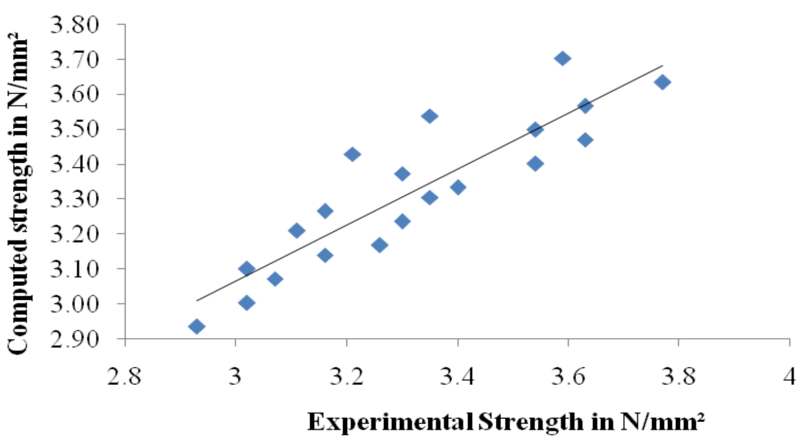
The coefficient of correlation is computed as follows

$$r = \sqrt{\frac{S^2}{S_d^2}}$$

$$r = \sqrt{1 - \frac{1.31^2}{1.89^2}}$$

$r = 0.72$

**Figure 6: Best fit curve for Compression strength**



## Split Tensile Strength

The best-fit linear equation for split tensile strength is

$$Z_c = -0.0137X_1 + 0.048X_3 + 0.0414X_4$$

### *Standard Deviation*

**SD = 0.23**

### *Standard Error*

S = 0.011

### *Correlation coefficient*

r = 0.89

## Flexural Strength

The best-fit linear equation for flexural strength is

$$Z_c = -0.0137X_1 + 0.0639X_3 + 0.0558X_4$$

### *Standard Deviation*

**SD = 0.27**

### *Standard Error*

**S = 0.12**

### *Correlation coefficient*

***r* = 0.91**

**Figure 7: Best fit curve for Split Tensile Strength**

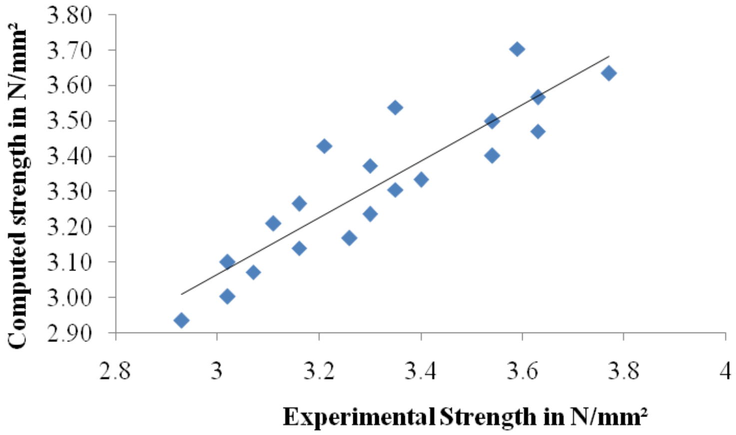
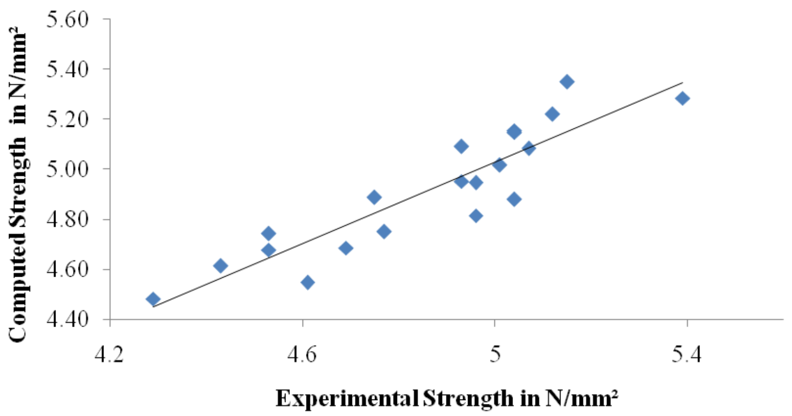



**Figure 8: Best fit curve for flexural Strength**



### Shear Strength

The best-fit linear equation for shear strength is

$$Z_c = -0.0147X_1 + 0.0729X_3 + 0.0604X_4$$

### *Standard Deviation*

**SD = 0.38**

### *Standard Error*

S = 0.12

### *Correlation Coefficient*

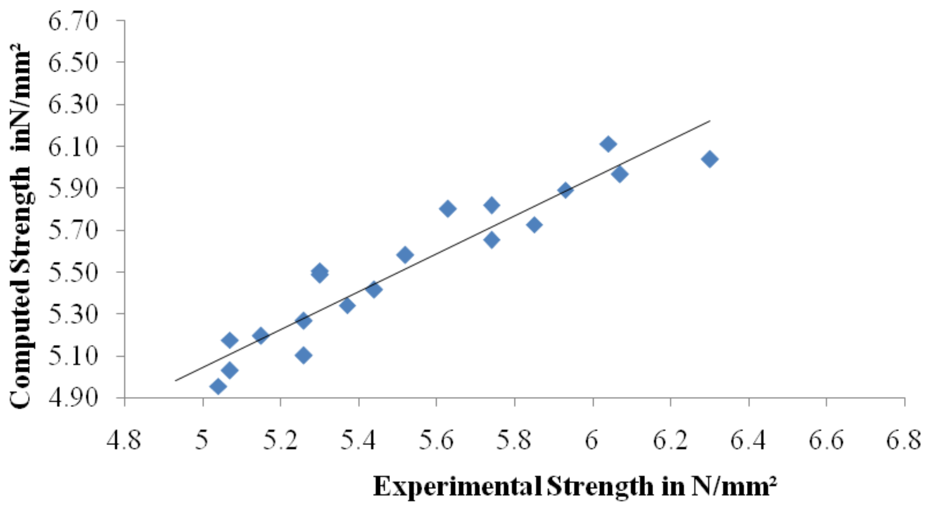
**r = 0.95**

## CONCLUSION

Based on the experimental results obtained for different percentages of replacement of cement and aggregates in concrete the following conclusions may be drawn.

1. Replacement of cement with silica fume up to 15% increases the compressive strength, splitting tensile strength, flexural strength and shear strength of M25 concrete.
2. Replacement of cement by 15% with silica fume and natural aggregates by up to 50% Steel slag shows improved compressive strength, Tensile strength, Flexural strength and Shear strength than the normal concrete.
3. The specimens are failed in 100% replacement of aggregate by steel slag.
4. As the percentage of Steel slag increases there is decrease in workability of concrete. Especially replacement beyond 50%
5. Regression analysis of the experimental results, it can be seen that linear relationship gives permissible coefficients of correlation and it may be preferred for its simplicity and suitability to statistical analysis.
6. The standard deviation of the steel slag concrete is in the range of 0.23 to 1.89. This standard deviation of the experimental results is well within the permissible limits.

**Figure 9: Best fit curve for shear Strength**



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