Optimization of High Performance Concrete Mix Incorporating Bagasse Ash and Slag Aggregate Using Taguchi Method

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Abstract— In the present study, the cement is partially replaced by bagasse ash and the fine aggregate is partially replaced by slag sand to produce a high strength concrete. The water cement ratio is one of the important factors to describe the strength of the concrete. Therefore, the factors considered in this study are water binder ratio, bagasse ash to cement ratio and slag aggregate to fine aggregate ratio with 4 levels each and their levels are 0.30, 0.33, 0.36, 0.39 and 10%, 15%, 20%, 25% and 20%, 30%,40%,50% respectively. The mix proportions were obtained from Taguchi method of optimization. The cubes and cylinders were casted for the obtained mix proportions and were tested at 7 and 28 days for compressive strength and split tensile strength. The test results indicates that the highest strength of concrete is obtained by replacing 10% of cement by bagasse ash, 20% of fine aggregate by slag sand with a water cement ratio of 0.3. The regression analysis was done for the obtained results.

*Index Terms*— High strength concrete, bagasse ash, Slag sand, Taguchi method of optimization.

I. INTRODUCTION

In recent years, environmental pollution is a major problem in the society. Concrete is the largely used man made material in the world. Concrete is the important factor which effects the environment. Cement industry is one of the primary producers of carbon-di-oxide, a major greenhouse gas. There is a scarcity of fine aggregate (river sand) in the developing countries like India. To develop the rapid infrastructural growth, the uses of concrete in developing countries are high. Therefore, researchers all over the world today are focusing on using the industrial or agricultural waste as partial replacement materials for cement and sand. Currently Fly ash, silica fumes, blast furnace slag etc. are used as supplementary materials for cement and copper slag, crushed granite fine and recycled glass are used as partial replacement for sand. In the present study, sugarcane bagasse ash and slag sand, a large amount of waste materials produced from the sugar industry and steel manufacturing plants respectively are used as supplementary replacement materials for cement and sand respectively. After crushing of sugarcane in sugar mills and extraction of juice from processed cane by milling, the discarded fibrous matter is called bagasse; this is used as fuel in the cogeneration boiler to generate steam for the production of sugar as well as electricity. Bagasse is burnt at around 850°C in a controlled process to use its maximum fuel value.

Fig 1: Generation of Bagasse ash

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Presently, total steel production in India is about 72.20 million metric tones and the waste generated annually is around 19 million metric tones and 50 million metric tones worldwide. . However, steel slag and slag has not been used efficiently and thoroughly for long, which causes its great accumulation, waste of land, and serious air and water pollution.
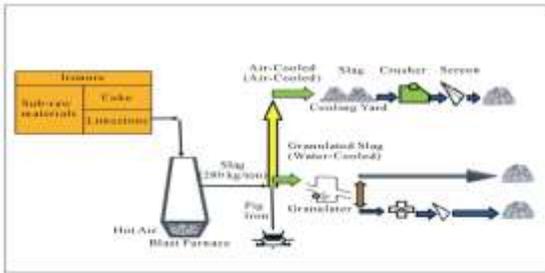
Fig 2: Generation of slag aggregates

For the above considered factors and levels the number of trails required is 64 which consumes a lot of time, money and energy, to minimize this and to obtain the optimum mix proportion, Taguchi method of optimization technique is used from which the number of trails is minimized to 16 for three factors with four levels each and the best mix can be achieved by using this method of optimization.

II. TAGUCHI METHOD

Taguchi method is a statistical method developed by Genichi Taguchi during the 1950's as an optimization process technique. Taguchi's approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost. The first concept of Taguchi that must be discussed is the ''noise factors''. Noise factors are viewed as the cause of variability in performance, including why products fail. The signal–to-noise ratio (S/N) is used in evaluating the quality of the product. The S/N measures the level of performance and the effect of noise factors on performance and is an evaluation of the stability of performance of an output characteristic. Target values may be:

1. Smaller is better, choose when goal is to minimize the response. The S/N can be calculated as given in Equation (1) for smaller the better

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right) \qquad (1)$$

2. Larger is better: choose when goal is to maximize the response. The S/N is calculated as given in Equation (2) for larger the better

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{Y_i^2}\right) \qquad (2)$$

3. Nominal is better: choose when goal is to target the response and it is required to base the S/N on standard deviations only. The S/N is calculated as given in Equation (3) for smaller the better.

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} (Y_i - Y_o)^2\right) \qquad (3)$$

In Equations, (1) – (3), Y shows the measured value of each response. When variability occurs, it is because the physics active in the design and environment that promotes change. Noise factors can be classified into three groups:

- External noise factors: sources of variability that come from outside the product,

- Unit-to-unit noise: due to the fact that no two manufactured components or products are ever exactly alike,

- Internal noise: due to deterioration, aging, and wear incurred in storage and use. The objective is to select the best combination

The objective is to select the best combination of the control parameters so that the product or process is most robust with respect to noise factors. The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. An orthogonal array significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusions drawn from small-scale experiments are valid over the entire experimental region spanned by the control factors and their settings.

In this study, the following parameters are considered in the mix proportions

- ❖ Water Cement ratio (W/CM),
- ❖ Bagasse ash cement ratio (BA/AM),
- ❖ Slag sand to fine aggregate ratio (SA/FA).

The variation levels for the considered parameters are shown in Table I.

Table I: Parameters and their levels

Parameters	Levels			
W/CM	0.30	0.33	0.36	0.39
BA/CM	0.10	0.15	0.20	0.25
SA/FA	0.20	0.30	0.40	0.50

Table II shows the details of the variables used in the experiment. Note that the parameters are at four levels. Only 16 experiments are needed to study the entire experimental parameters using L16 (4^3) orthogonal arrays.

Table II (a): Standard L16 orthogonal array for three factors with four levels each

Factor A	Factor B	Factor C
1	1	1
1	2	2
1	3	3
1	4	4
2	1	2
2	2	1
2	3	4
2	4	3
3	1	3
3	2	4
3	3	1
3	4	2
4	1	4
4	2	3
4	3	2
4	4	1

Table II (b): L16 orthogonal array for selected factors and levels

W/CM	BA/CM	SA/FA
0.3	0.1	0.2
0.3	0.15	0.3
0.3	0.2	0.4
0.3	0.25	0.5
0.33	0.1	0.3
0.33	0.15	0.2
0.33	0.2	0.5
0.33	0.25	0.4
0.36	0.1	0.4
0.36	0.15	0.5
0.36	0.2	0.2
0.36	0.25	0.3
0.39	0.1	0.5
0.39	0.15	0.4
0.39	0.2	0.3
0.39	0.25	0.2

Material characterization

Materials used in the project are:

- ❖ Cement,
- ❖ Bagasse ash,
- ❖ Fine aggregate (Manufactured sand),
- ❖ Fine aggregate (Slag sand),
- ❖ Coarse aggregate.

1. *Properties of Cement:* The cement used in the project is Birla super OPC 53 grade. Table III shows the properties of cement used in the project.

Table III: Properties of Cement

Tests	Results
Specific Gravity	3.10
Compressive strength (MPa) @ 28 days	54
Normal consistency (%)	30
Initial setting time (min)	45
Final setting time (min)	255

2. *Properties of Bagasse ash:* Table IV shows the chemical properties of bagasse ash and Table V shows the properties of bagasse ash.

Table IV: Chemical Composition of Bagasse ash.

Chemical Composition	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	LOI %
Bagasse Ash	70.16	0.26	6.67	1.78	11.25

Therefore, the combined chemical composition of SiO2+Al2O3+Fe2O3=77.06%, satisfies the Codal requirement.

Table V: Properties of Bagasse ash.

Test	Result
Specific Gravity	1.88
Bulk Density (Kg/m^3) a. Loose b. Compacted	208 311

3. Properties of fine aggregate: Table VI shows the properties of the manufactured sand and Table VII shows the properties of the slag sand.

Table VI: Properties of manufactured sand

Test	Result
Specific Gravity	2.7
Bulk Density (kg/m^3)	1710
Fineness modulus	2.2

Table VII: Properties of Slag Sand

Test	Result
Specific Gravity	2.52
Bulk Density (kg/m^3)	1360
Fineness modulus	2.65

4. Properties of Coarse Aggregate: Table VIII shows the properties of coarse aggregate.

Table VIII: Properties of Coarse Aggregate

| Test	Obtained values
Specific Gravity	2.66
Water Absorption	0.3%
Aggregate Impact Value	29%
Crushing Strength	29%
Los Angeles Abrasion	28%

Analysis of results and discussion

I. Compressive strength

a. 7 days Compressive Strength results:

Table IX: Compressive strength at 7 days

W/CM	BA/CM	SA/FA	Strength (MPa)
0.3	0.1	0.2	59.93
0.3	0.15	0.3	44.56
0.3	0.2	0.4	47.38
0.3	0.25	0.5	32.18
0.33	0.1	0.3	50.81
0.33	0.15	0.2	42.69
0.33	0.2	0.5	43.14
0.33	0.25	0.4	37.71
0.36	0.1	0.4	40.15
0.36	0.15	0.5	38.67
0.36	0.2	0.2	36.19
0.36	0.25	0.3	34.82
0.39	0.1	0.5	37.60
0.39	0.15	0.4	34.82
0.39	0.2	0.3	27.53
0.39	0.25	0.2	25.06
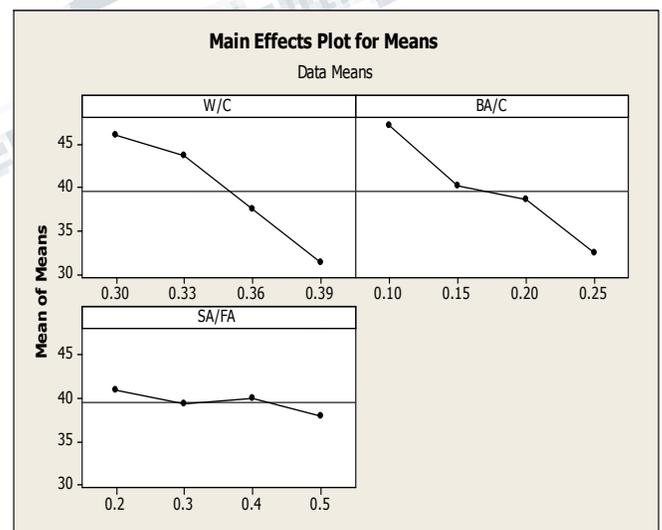
Fig 3: Main effect plot of means for 7 days cube compressive strength

Regression Analysis:

The regression equation is

**7day compressive strength** =116 - 168 W/CM - 91.3 BA/C

M- 8.63 SA/FA

Discussion:

1. From Fig. 3, mean 7 days Compressive strength is decreased as the W/CM is increased which is the consequence of Abraham's law and is due to increase in porosity with increase in W/CM.

2. Bagasse ash contribution at early ages is generally insignificant because of slow rate of pozzolonic reaction. It was seen from main effect plots that the compressive strength slowly decreases.

3. From the plot it is clear that the replacement level of Slag sand doesn't affect the strength of the concrete.

4. From the Regression analysis equation it is seen that the results have a normal probability curve.

b. 28 days Compressive Strength results:

Table X: Compressive Strength at 28 days

W/CM	BA/CM	SA/FA	Strength (MPa)
0.3	0.1	0.2	82.80
0.3	0.15	0.3	78.24
0.3	0.2	0.4	68.96
0.3	0.25	0.5	58.96
0.33	0.1	0.3	70.70
0.33	0.15	0.2	67.66
0.33	0.2	0.5	59.94
0.33	0.25	0.4	53.67
0.36	0.1	0.4	65.45
0.36	0.15	0.5	59.84
0.36	0.2	0.2	52.18
0.36	0.25	0.3	47.81
0.39	0.1	0.5	57.04
0.39	0.15	0.4	51.53
0.39	0.2	0.3	43.04
0.39	0.25	0.2	39.77
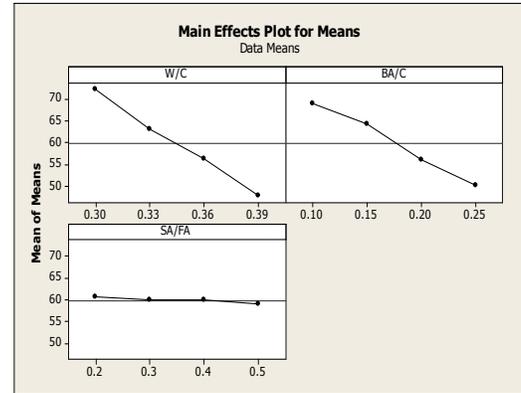
Fig 4: Main effect plot of means for 28 days cube compressive strength

Regression Analysis:

The regression equation is

28day Compressive Strength = 176 - 266 W/CM - 130 BA/CM - 5.02 SA/FA

Discussion:

1. From Fig. 4, maximum mean 28 days compressive strength is obtained for W/CM of 0.30; the strength is decreased for further increment of W/CM.

2. Bagasse ash is having a higher compressive strength upto 10% replacement, after which there is a sudden decrease in the strength.

3. The increase in the Slag sand content does not vary the Compressive strength of the concrete.

II. SPLIT TENSILE STRENGTH

a. 7days Split tensile strength
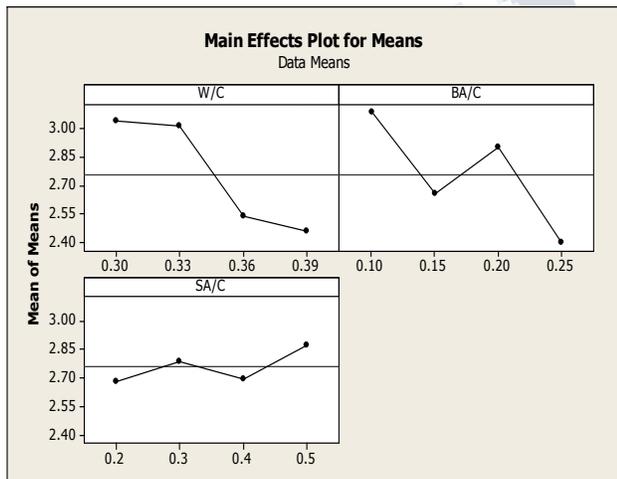
Table XI: Split tensile strength at 7 days

W/CM	BA/CM	SA/FA	Strength (MPa)
0.3	0.1	0.2	3.49
0.3	0.15	0.3	2.90
0.3	0.2	0.4	3.06
0.3	0.25	0.5	2.69
0.33	0.1	0.3	3.30
0.33	0.15	0.2	2.73
0.33	0.2	0.5	3.48
0.33	0.25	0.4	2.52
0.36	0.1	0.4	2.69
0.36	0.15	0.5	2.48
0.36	0.2	0.2	2.54
0.36	0.25	0.3	2.42
0.39	0.1	0.5	2.85
0.39	0.15	0.4	2.49
0.39	0.2	0.3	2.51
0.39	0.25	0.2	1.97

Fig 5: Main effect plot of means for 7 days split tensile strength

Regression Analysis:

The regression equation is

7days Split tensile strength = 5.83 - 7.40 W/CM - 3.62 BA/CM + 0.485 SA/C

Discussion:

1. From the main effect plot shown in Fig. 5, it is seen that as the W/CM ratio is increased, mean split tensile strength decreased. This decrease may be due to the increase in porosity.

2. From the main plot cement replacement of 10% by Bagasse ash is found to be optimum at 7 days

3. From the plot it shows that as the percentage of Slag sand increases, the Split tensile strength of the concrete also increases.
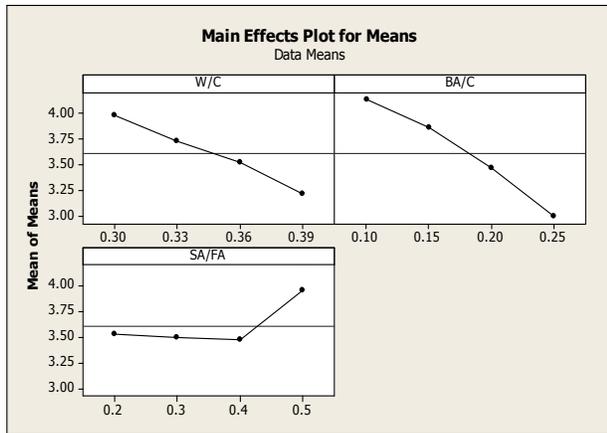
b. *28days Split tensile strength*

Table XI: Split tensile strength at 28 days

W/CM	BA/CM	SA/FA	Strength (MPa)
0.3	0.1	0.2	4.56
0.3	0.15	0.3	4.23
0.3	0.2	0.4	3.82
0.3	0.25	0.5	3.31
0.33	0.1	0.3	3.92
0.33	0.15	0.2	3.84
0.33	0.2	0.5	3.91
0.33	0.25	0.4	3.24
0.36	0.1	0.4	3.64
0.36	0.15	0.5	4.19
0.36	0.2	0.2	3.26
0.36	0.25	0.3	2.99
0.39	0.1	0.5	4.40
0.39	0.15	0.4	3.17
0.39	0.2	0.3	2.83
0.39	0.25	0.2	2.45

Fig 6: Main effect plot of means for 28 days split tensile strength

Regression Analysis:

The regression equation is

28days Split tensile strength = 7.50- 8.34W/CM - 7.61 BA/CM + 1.25 SA/FA

Discussion:

1. The Split tensile strength of the concrete decreases with increase in water cement ratio.
2. The split tensile strength of the concrete is higher for 10% replacement of bagasse ash.
3. The tensile strength of the concrete increase with increase in percentage of slag sand.

CONCLUSION

The Strength of the Concrete is maximum for the mix proportion of 0.30 water binder ratio, 10% cement replaced by bagasse ash and 20% manufactured sand replaced by slag sand.

The regression equation can be used to obtain the required strength of concrete by changing the percentage of materials and water cement ratio.

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