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

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Abstract— From past few years as the construction activity is increased by and large, production of cement to fulfill the constructional need has resulted in depletion of natural resources causing environmental problems. The use of supplementary cement materials and fillers become imperative due to the increase in cost of cement and its limitations in terms of high energy requirement for production, high carbon dioxide emission and large consumption of natural resources. Many alternative materials such as fly ash, GGBS, silica fume, lime powder ect. There is a scarcity of fine aggregate (river sand) in the developing countries like India. The present study shows the incorporation of fly ash and slag aggregate as partial replacement for cement and fine aggregate in the proportion of 10%, 20%, 30%, 40% and 20%, 30%, 40%, 50% respectively. The factors selected were water cement ratio, fly ash to cement ratio, slag sand to fine aggregate ratio and 4 levels for each was considered, the w/c levels are 0.30,0.33,0.36 and 0.39 and the levels of other factors are as specified above. By using the Taguchi method of optimization the experimental combinations were reduced to 16 by selecting a L16 orthogonal array. The freshened and hardened properties of concrete were examined at 7 days, 28 days. The test results indicates that the highest strength of concrete is obtained by replacing 10% of cement by fly 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

The concrete construction industry is not sustainable due to one or other reason. First, it consumes huge quantities of virgin materials. Second, the principal binder in concrete is Portland cement, the production of which is a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Third, many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. Use of industry waste like fly ash, silica fume, grounded furnace slag to partly replace cementing material concrete system addresses all three sustainability issues, its adoption will enable the concrete construction industry to become more sustainable. Looking to the production of the Fly ash, worldwide in general and India in particular the utilization of Fly ash is almost negligible. The people and society connected with nation building should look into the matter for innovation, promotion for the alternate source of energy and substituting material to be utilized in the different sectors.

Fly ash, an industrial waste arising from coal fired

Thermal Power Stations currently poses a serious operational constraint and environmental hazard. A 100 MV thermal power plant generates about 0.15 million tones of fly ash per annum when using coals with an ash content of 40%. Fly ash, on the other hand, possesses both ceramic as well as pozzolana properties and therefore it can be utilized in a unique way for manufacturing pozzolana cement, Activated Fly ash Blended Cement, light weight cindered aggregates, High Volume Fly Ash Concrete, Cellular Light Weight Concrete, Fly ash based polymer composites as wood substitute, ready mixed fly ash concrete and fly ash bricks etc.

As we know there is a scarcity for fine aggregate, in this project steel slag is used as a partial replacement material for fine aggregate. Steel slag is industrial waste resulting from steel refining plants in conversion process. There are two methods for steel slag production: Basic Oxygen Steel (BOS) and Electric Arc Furnace (EAF). BOS slag is obtained by blowing high pressure oxygen into a vessel containing molten iron, steel scrap and lime and EAF utilizes high voltage current to generate heat for doing the same process.

High-strength concrete is required in engineering projects that have concrete components that must resist high compressive loads. High-strength concrete is typically used in the erection of high-rise structures. It has been used in components such as columns (especially on lower floors where the loads will be greatest), shear walls, and foundations. High strengths are also occasionally used in bridge applications as well.

In this project, the factors considered are water binder ratio, Fly ash cement ratio and slag sand fine aggregate ratio; the levels of which are 0.30, 0.33, 0.36, 0.39 and 10%, 20%, 30%, 40% and 20%, 30%, 40%, 50% respectively. The total number of combinations for all the above proportions will be 64, therefore to minimize the time and cost of the experiment and to obtain the optimum mix proportion, Taguchi method of optimization is applied. By this method the number of experiments can be reduced and for the selected number of factors and their levels L16 orthogonal array is selected which the number of experiments is reduced from 64 to 16.

II. PROBLEM STATEMENT AND OBJECTIVE OF THE STUDY

1. Problem statement:

Present days construction industries needs faster development and also require high strength of concrete to facilitate the fast construction and economically construction. For that purpose we used high strength of cement, to gain strength of concrete. This demand of high strength gain of concrete put forth the use of low W/C ratio. The production of cement releases enormous amount of greenhouse gas and hence to solve this partial replacement of cement is done by using fly ash. There is a scarcity for the fine aggregate as it is consumed more in concrete as well as in mortar, to overcome this problem, in the present study steel slag aggregate is used as a partial replacement for fine aggregate.

2. Objective of the study
- ❖ To study the effect of fly ash and slag sand as supplementary materials for cement and fine aggregate respectively on properties of high strength concrete.
- ❖ To optimize the mix proportions of high strength concrete using a suitable optimization technique (Taguchi experimental design methodology).
- ❖ To formulate mathematical model between the factors and properties of high strength concrete using

regression analysis materials

Cement:

The cement used is Birla super OPC 53 grade which has a found to be specific gravity of 3.10 and normal consistency of 30%. The initial and final setting time was found to be 45min and 255min respectively. The compressive strength of the cement was found to be 54MPa at 28days.

Fly ash:

The chemical analysis results of Fly ash shows that the silica content is about 72.63%, alumina is about 0.3% and Ferric oxide is about 15.90% and therefore the combination of which is about 88.83% which is greater than 70% as specified by codes. The loss on ignition was found to be 1.22%.

The specific gravity of the Fly ash used was 2.16.

Fine aggregate:
- ❖ Manufactured sand: the manufactured sand used in the projected has a specific gravity of 2.7 and bulk density of 1710kg/m^3.
- ❖ Slag sand: the slag sand was having a specific gravity of 2.52 and bulk density of 1360kg/m^3.

Coarse aggregate:

The coarse aggregate had a specific gravity of 2.66, water absorption of 0.3%, Impact value of 29%, and Los Angeles abrasion of 28%.

Water:

Portable water free from organic matters, turbidity and salts was used for mixing and curing.

III. EXPERIMENTAL DESIGN

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.
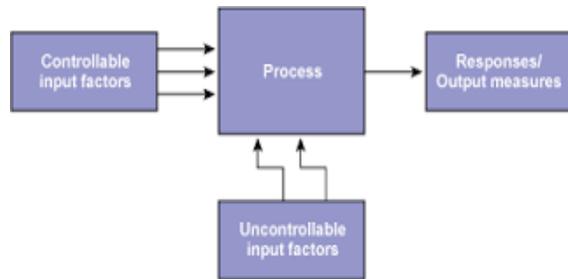
Fig.1 Procedure of DOE

Taguchi method is one widely used design of experiment (DOE) method to investigate the effects of several parameters simultaneously by the minimum experiments. In this study, in order to determine the optimal mix with maximum compressive strength and split tensile strength design of experiments based on Taguchi method was used.

There are ten steps in a systematic approach to the use of Taguchi's parameter design methodology. Figure 2 shows the detail procedure of Taguchi design methodology.
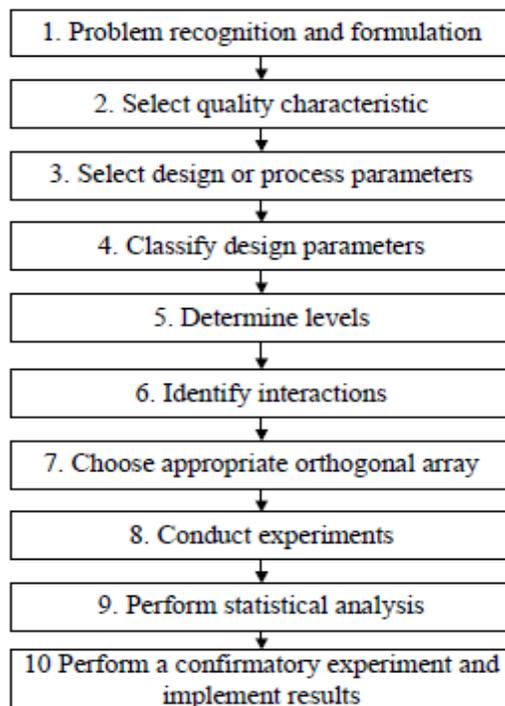

Fig. 2 Taguchi method Algorithm

The significant difference between the Taguchi's approaches with classical methodology is in step 10 of Fig.2 where the orthogonal matrix is employed parameters and levels. The factors selected and their levels are shown in below Table I.

Table I: Factors and Levels

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

W/CM = Water to Cementitious ratio,
FA/CM = Fly ash to Cement ratio,
SA/FA = Slag Aggregates to Fine Aggregate ratio.

Orthogonal arrays are the set of tables used to determine the least number of experiments and their condition. Orthogonal array is selected based on the number of factors and their levels. In this study there are 3 factors with each at 4 levels. Following L16 Orthogonal array has been selected based on the number of factors selected and their levels which is as shown in Table II.

Table II: L16 Orthogonal Array

Experiment No.	Factor 1	Factor 2	Factor 3
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

Table III: L16 Orthogonal array with defined ratios

Experiment No.	W/CM	FA/CM	SA/FA
1	0.30	0.10	0.20
2	0.30	0.20	0.30
3	0.30	0.30	0.40
4	0.30	0.40	0.50
5	0.33	0.10	0.30
6	0.33	0.20	0.20
7	0.33	0.30	0.50
8	0.33	0.40	0.40
9	0.36	0.10	0.40
10	0.36	0.20	0.50
11	0.36	0.30	0.20
12	0.36	0.40	0.30
13	0.39	0.10	0.50
14	0.39	0.20	0.40
15	0.39	0.30	0.30
16	0.39	0.40	0.20

## IV. RESULTS AND DISCUSSION

I. Compressive strength results

a. 7 days compressive strength results:

Table IV: Compressive strength at 7 days

W/CM	FA/CM	SA/FA	Strength (MPa)
0.30	0.10	0.20	64.71
0.30	0.20	0.30	60.53
0.30	0.30	0.40	52.22
0.30	0.40	0.50	51.10
0.33	0.10	0.30	60.95
0.33	0.20	0.20	50.25
0.33	0.30	0.50	44.92
0.33	0.40	0.40	42.92
0.36	0.10	0.40	52.36
0.36	0.20	0.50	48.58
0.36	0.30	0.20	46.43
0.36	0.40	0.30	41.36
0.39	0.10	0.50	39.51
0.39	0.20	0.40	43.93
0.39	0.30	0.30	40.28
0.39	0.40	0.20	34.82
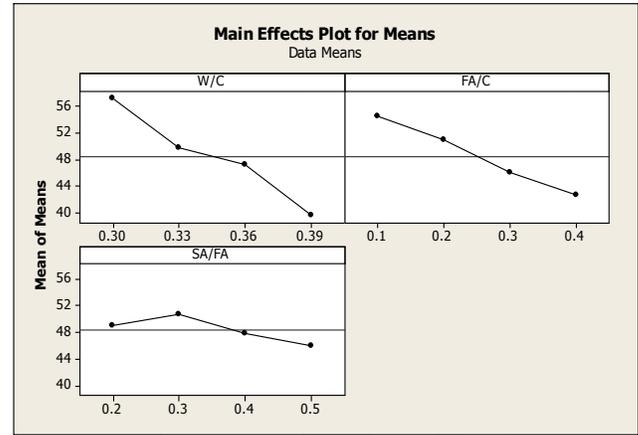
Fig 3: Main effect plot of means for 7 days cube compressive strength

Regression Analysis:

The regression equation is

7day compressive strength =126 - 184 W/CM - 40.4 FA/CM - 12.0 SA/FA

Discussion:

1. From the main effect plot shown in 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. Fly ash contribution at early ages is generally insignificant because of slow rate of pozzolonic reaction.
3. From the plot it shows that the compressive is slighter more at 30% replacement.

b. **28 days compressive strength results**

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Table V: Compressive strength at 28 days

W/CM	FA/CM	SA/FA	Strength (MPa)
0.30	0.10	0.20	82.43
0.30	0.20	0.30	80.98
0.30	0.30	0.40	72.65
0.30	0.40	0.50	72.93
0.33	0.10	0.30	79.14
0.33	0.20	0.20	71.60
0.33	0.30	0.50	69.29
0.33	0.40	0.40	67.08
0.36	0.10	0.40	74.00
0.36	0.20	0.50	69.66
0.36	0.30	0.20	69.91
0.36	0.40	0.30	70.52
0.39	0.10	0.50	65.51
0.39	0.20	0.40	61.21
0.39	0.30	0.30	60.10
0.39	0.40	0.20	57.38

Fig 4: Main effect plot of means for 28 days cube compressive strength

Regression Analysis:

The regression equation is

28days compressive strength =136 - 164 W/CM - 27.8 FA/CM - 6.89 SA/FA

Discussion:

1. From the main effect plot shown in Fig.4 it is seen that as the W/CM ratio is increased, compressive strength decreased.
2. From the main plot cement replacement of 10% by Fly ash is found to give maximum strength.
3. From the plot it shows that there is a small increase in compressive strength at 30% replacement level.

V. SPLIT TENSILE STRENGTH

a. 7days split tensile strength

Table VI: Split tensile strength at 7 days

W/CM	FA/CM	SA/FA	Strength (MPa)
0.30	0.10	0.20	3.45
0.30	0.20	0.30	3.31
0.30	0.30	0.40	3.17
0.30	0.40	0.50	3.51
0.33	0.10	0.30	3.51
0.33	0.20	0.20	3.18
0.33	0.30	0.50	3.58
0.33	0.40	0.40	2.81
0.36	0.10	0.40	3.37
0.36	0.20	0.50	3.65
0.36	0.30	0.20	3.09
0.36	0.40	0.30	2.73
0.39	0.10	0.50	2.66
0.39	0.20	0.40	3.09
0.39	0.30	0.30	2.69
0.39	0.40	0.20	2.48

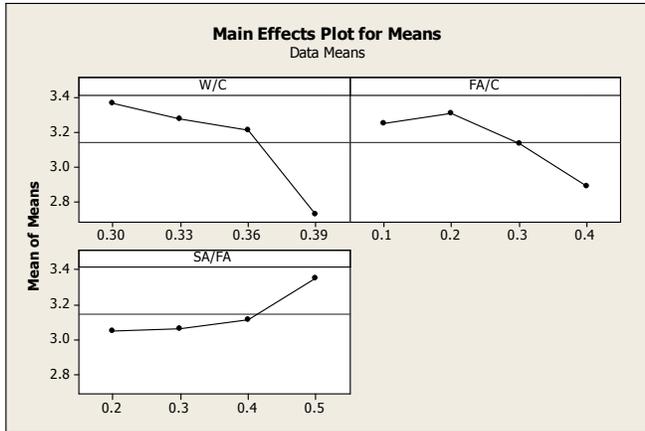*Fig 5: Main effect plot of means for 7 days split tensile strength*

Regression Analysis:

The regression equation is

7days split tensile strength = 5.39 - 6.57 W/CM - 1.26 FA/CM + 0.951 SA/FA

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 20% by fly ash is the 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 VII: Split tensile strength at 28 days

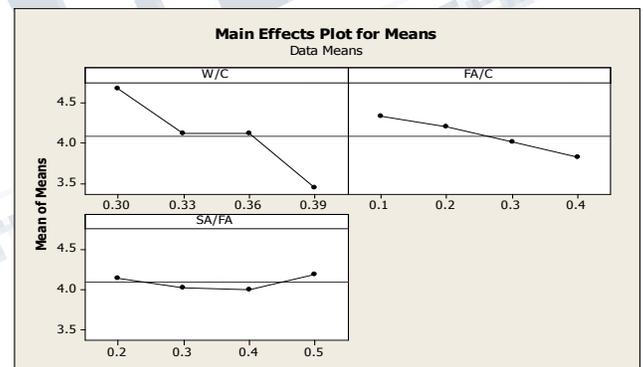| W/CM	FA/CM	SA/FA	Strength (MPa)
0.30	0.10	0.20	5.29
0.30	0.20	0.30	4.69
0.30	0.30	0.40	4.41
0.30	0.40	0.50	4.32
0.33	0.10	0.30	4.19
0.33	0.20	0.20	4.08
0.33	0.30	0.50	4.23
0.33	0.40	0.40	3.96
0.36	0.10	0.40	4.15
0.36	0.20	0.50	4.56
0.36	0.30	0.20	4.00
0.36	0.40	0.30	3.78
0.39	0.10	0.50	3.67
0.39	0.20	0.40	3.48
0.39	0.30	0.30	3.41
0.39	0.40	0.20	3.21

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

Regression Analysis:

The regression equation is

28days split tensile strength = 8.72 - 12.3 W/CM - 1.71 FA/CM + 0.133 SA/FA

Discussion:

1. From the main effect plot shown in Fig. 6 it is seen that as the W/CM ratio is increased, mean split tensile strength decreased.
2. From the main plot cement replacement of 10% by Fly ash is found to be optimum at 28 days

3. From the plot it shows that as the percentage of slag sand increases, the split tensile strength of the concrete also increases.

CONCLUSION

The strength of the concrete is maximum for the mix proportion of 0.30 water binder ratio, 10% cement replaced by Fly 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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