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COMBINED EFFECTS OF FLY ASH AND FERRO SAND ON PROPERTIES OF CONCRETE DESIGNED BY TAGUCHI METHOD

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Abstract - *Purpose of this study is to evaluate physical and mechanical properties of the concrete using fly ash and ferro sand. Fly ash is classified as a waste by product of coal power plants. Ferro sand is the industrial by product from the steel making industries. Taguchi method uses a special set of arrays called orthogonal arrays, which gives minimum number of experiment with maximum information about all the factors that affect the outcome. Cement was replaced with fly ash at the ratio of 10%, 20% and 30% by weight as a supplementary cementious material. Natural Fine aggregate were replaced by ferro fine sand at the ratio of 15%, 30% and 50% by weight. A total nine number of experiments were conducted according to the L9 orthogonal array which was proposed by the Taguchi Method. On fresh concrete slump cone test were performed. On the hardened concrete unit weight, compressive strength, flexural strength and splitting tensile strength were determined. The test results showed that use of fly ash decreases strength of concrete and usage of ferro sand aggregate increases strength of concrete. The Taguchi showed best results about the use of 10% fly ash replaced with cement and 30% of ferro sand replaced with natural fine sand mix in concrete with 28 days curing by using Minitab software.*

Key Words: Ferro Sand, Fly Ash, Orthogonal Array, Taguchi Method, Design of Experiment, mean S/N ratio

1. INTRODUCTION

Coal power plants produce waste fly ash that cause environmental problem and threaten people health. In India, the amount of fly ash produced from thermal power plants is nearly 80 million tons every year. The annual generated production of fly ash worldwide is estimated around 600 million tons. Moreover, its deposing costs are high and also need relatively large areas. Recycling is an aim to consume waste content left from several industries. Fly ash has been used in concrete as a partial replacement of cement now a day. In concrete technology fly ash has been used as supplementary cementious material or replacement material with a portion of cement.

The increase demand of sand results in non-availability of good quality sand and especially in India, deposits of natural sand are being exhausted which create an major hazard to the environment. Fast withdrawal of sand from waterway bed, brings about such a large number of problem like losing water holding soil strata, extending to the sliding of the banks of river. The extractions of sand from the waterway increase the cost of sand and severely affected the financial viability of the construction industry. Therefore finding an alternate material to natural sand has got to be imperative. As the industrialization increases, the amount of waste material product is also increasing, which has turned into an ecological major problem that must be managed.

1.1 Fly ash

Fly ash is finer than portland cement and lime. Fly ash consists of silt-sized particles which are usually spherical, typically ranging in size between 10 and 100 micron. These small glass spheres become better the fluidity and workability of fresh concrete. Fineness is one of the most significance properties contributing to the pozzolanic reactivity of fly ash.

1.2 Ferro Sand

Ferrochrome slag a waste bi-product come during the manufacturing of ferrochrome alloy. Ferrochrome alloy is manufactured in a submerged electric arc furnace by physiochemical action at the temperature of 1700°C. Separately the molten liquids of the ferrochromium and slag flow out into dippers. Due to the different specific gravities of metal and slag, separate from two liquids takes place. The liquefied ferrochrome slag slowly cools down in air forming a stable, dense, crystalline product having tremendous mechanical properties. The important constituents of ferrochrome slag are SiO_2, Al_2O_3 and MgO with minor traces of ferrous/ferric oxides and CaO.

1.3 Objective of work

- To find out the optimum solution about fly ash as a supplementary cementious material use in concrete mix design.
- To investigate mechanical property of concrete by replacing natural sand with ferro sand.

- This study is to optimize the mix design of concrete by using the Taguchi method through evaluation of its physical and mechanical properties.
- Three main control factors are utilized in the Taguchi method including water curing day, fly ash and ferro sand.

1.4 Definition of Taguchi Method

Taguchi has developed a new method of conducting the design of experiments which are situating on well defined guidelines. The Taguchi method uses a particular array called an orthogonal array. This standard array examines a minimalist experiment that gives information about all factors affecting performance parameter.

While there are many standard orthogonal arrays available, every one of the arrays is meant for a specific number of independent design variables and levels. Such as, if those who wants to do an experiment to understand the influence of 3 different independent variables with each variable having 3 set values (level values), and then an L9 orthogonal array might be the right choice in that experiment. The L9 orthogonal array is meant for understanding the effect of 3 independent factors each having 3 factor level values.

Table -1: Layout of L_9 orthogonal array.

Levels	Variable 1	Variable 2	Variable 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The Table 1 shows an L9 orthogonal array. There are totally 9 experiments to be conducted and each experiment is based on the combination of level values as shown in the table 1.

2. MATERIAL AND METHOD

2.1 Material

The Ordinary Portland Cement (O.P.C) of 53 grades was used in producing the concrete mixes and physical properties of cement shown in Table 2 by using IS 12269 (2013). Fly ash (F Class) captured from the chimneys of coal fired power plant. It has pozzolanic properties and its chemical composition is listed in Table 3 by using IS 3812 (2003). Fly ash is blended with cement for the reason and generated from the thermal power station at Eklahare Dist. Nashik and its physical properties shown in Table 4 by using IS 3812 (2003). Natural river sand was used as fine aggregate complying with the requirement of IS 383:2016 and its physical properties shown in Table 5. Ferro sand is waste product of the iron industry from Bhagvati Ferro Metal Pvt. Ltd. Sinnar is used as a replacement of natural fine aggregate. Chemical composition ferro sand is listed in Table 6 and also its physical properties of shown in Table 7 by using IS 383:2016. Coarse Aggregate is locally available natural aggregate were used to manufacture specimen for the design mix concrete. Coarse aggregate complying with the requirement of IS 383:2016. 12 mm and 20 mm crushed stones were used as course aggregates and its physical properties of shown in Table 8 by using IS 2386: Part III - (1963). Locally available potable water was used for mixing the concrete.

Table -2: Properties of cement

Sr. No	Properties of cement	Results
1	Fineness of cement	3.17%
2	Specific gravity of cement	3.15
3	Standard Consistency of Cement	31.5%
4	Initial setting time of cement	91 min
5	Final setting time of cement	321 min
6	Compressive strength of cement at 7 days and 28 days	37.5 Mpa and 54.2 Mpa

Table -3: Chemical composition of the Class F Fly Ash

Compound	Class F fly ash (%)
SiO_2	57.2
Al_2O_3	25.5
Fe_2O_3	6.01
$SiO_2 + Al_2O_3 + Fe_2O_3$	89.1
CaO	1.14
MgO	2.42
TiO_2	1.16
K_2O	4.6
Na_2O	0.42
SO_3	0.16
Cl	0.01
Loss on Ignition	1.12

Table -4: Physical Properties of Fly Ash

Sr. No	Physical Properties of Fly Ash	Results
1	Fineness	360 (m^2/Kg)
2	Specific gravity	2.4
3	Moisture content	0.80%

Table -5: Properties of fine aggregate (sand)

Sr. No	Properties of Fine Aggregate	Results
1	Particle Shape, size	Round, below 4.75 mm
2	Fineness modulus of fine aggregate (sand)	2.806
3	Zone as per IS 383-1970	II
4	Specific gravity of fine aggregate (sand)	2.65
5	Water absorption of fine aggregate (sand)	1.05%
6	Free (surface) moisture of fine aggregate (sand)	Nil

Table -6: Chemical composition of the ferro sand

Compound	Weight
Loss on Ignition at 900 ºC	5.20%
Silica (SiO_2)	44.25%
Alumina (Al_2O_3)	9.10%
Iron Oxide (Fe_2O_3)	24.10%
Calcium Oxide (CaO)	4.60%
Magnesium (MgO)	0.40%
Chromium Oxide (Cr_2O_3)	Nil
Total Alkalis (Na_2O + K_2O)	2.80%
Manganese Oxide (MnO)	8.10%
Phosphorus Pentoxide (P_2O_5)	0.32%

Table -7: Properties of Ferro Sand

Sr. No	Properties of Ferro Sand	Results
1	Particle Shape, size	Round, below 4.75 mm
2	Fineness modulus of Ferro Sand	2.87
3	Zone as per IS 383-1970	II
4	Specific gravity of Ferro Sand	3.0
5	Water absorption of Ferro Sand	1.32%

Table -8: Properties of Coarse Aggregate

Sr. No	Properties of Coarse Aggregate	Results
1	Particle Shape, size	Angular, Maximum 20 mm
2	Specific gravity of coarse aggregate	2.74
3	Water absorption of coarse aggregate	0.92%
4	Free (surface) moisture of coarse aggregate	Nil

2.1 Taguchi Method

By using steps of designing of experiment of Taguchi method, the following Table 9 shows number of factors and number of levels consider in this study. Base on the number of factors and number of levels the L_9 (3^3) orthogonal array taken in this study. Assigning the combination of factors and levels showed in Table 10 by using L_9 orthogonal array. Also shows the 9 experiment with combination of factors that is cement replace with fly ash and natural fine sand replace with ferro sand by weight percentage in the concrete mix design with given curing periods.

Table -9: Considered levels for each parameter in Taguchi design of experiment.

Levels	Factors		
	Fly Ash %	Ferro Sand (%)	Curing Days
1	10	15	3
2	20	30	7
3	30	50	28

Table -10: Taguchi Development Orthogonal Array L_9 (3^3)

Mix Design	Fly Ash %	Ferro Sand (%)	Curing Days
MD1	10	15	3
MD2	10	30	7
MD3	10	50	28
MD4	20	15	7
MD5	20	30	28
MD6	20	50	3
MD7	30	15	28
MD8	30	30	3
MD9	30	50	7

2.3 Preparation of specimens

M25 grade of concrete were used. Total 81 numbers of specimens were casted for the present experimental work including cubes, beams and cylinders. Three cubes mould of standard size 150 mm x 150 mm x 150 mm cast was used for the compressive strength test for each concrete mixture. Three beams mould of standard size 150 mm x 150 mm x 700 mm cast was used for the flexural strength test for each concrete mixture. Three standard size of cylindrical mould diameter of 150 mm and in length 300 mm cast were used for the split tensile strength test for each concrete mixture.

3. RESULTS AND DISCUSSION

3.1 Slump cone test

In order to consider the effect of replacement of cement with fly Ash and natural fine aggregate with ferro sand, the proportion of water cement ratio, method of curing and compaction are kept constant. The effect of fly ash and ferro sand on workability of concrete for various mixtures is given in Table 11.

Table -11: Slump cone test results

Mix Design	Fly Ash (%)	Ferro Sand (%)	Average Slump (mm)
MD1	10	15	81
MD2	10	30	90
MD3	10	50	96
MD4	20	15	74
MD5	20	30	84
MD6	20	50	92
MD7	30	15	55
MD8	30	30	66
MD9	30	50	72

The result of fresh concrete slump test showed that at 30 % fly ash and 15 % ferro sand gives the best result slump in 55 mm of concrete mix. Slump decreases as the percentage of replacement of ferro sand increases. Also slump increases with increase in percentage of fly ash increases.

3.2 Unit weight or Dry density test

The effect of fly ash and ferro sand on unit weight of concrete for various mixtures is given in Table 12

Table -12: Unit weight or dry density test result

Mix Design	Fly Ash %	Ferro Sand %	Average unit weight kg/m^3
MD1	10	15	2430.22
MD2	10	30	2512.88
MD3	10	50	2709.62
MD4	20	15	2452.14
MD5	20	30	2530.96
MD6	20	50	2671.11
MD7	30	15	2482.37
MD8	30	30	2551.7
MD9	30	50	2739.88

From the results it is noted that the unit weight or dry density increase with increase in percentage of fine aggregate replacement by ferro sand and unit weight or dry density decrease with increase in percentage of cement replace by fly ash. The increase in unit weight is due to the fact that density of ferro sand is much higher than other concrete constituents. The unit weight declined with increasing fly ash replacement rate from 10% to 30% of cement. The unit weight increase with increasing ferro sand replacement 15%, 30% and 50% of natural sand.

3.3 Mechanical strength for optimal proportion by Taguchi Method

In this study the best possible levels of mix properties were investigated for the maximization of compression strength, flexural strength, splitting tensile strength values by using Taguchi Method. The performance statistics for “the larger the better” situation are evaluated for maximization properties of fly ash and ferro sand.

A. Compressive strength test

Especially for concrete compressive strength is an important parameter to determine the performance of material during service conditions. Test was performed on 27 specimens (three specimens from each test group) casted. The effect of fly ash and ferro sand on compressive strength of concrete for various mixtures is given in Table 13 and is demonstrated in Figure 1.

Table -13: Average compressive strength of all different mix design

Mix Design	Fly Ash (%)	Ferro Sand (%)	Curing Days	Compressive Strengths in N/mm^2
MD1	10	15	3	13.568
MD2	10	30	7	18.796
MD3	10	50	28	27.591
MD4	20	15	7	16.345
MD5	20	30	28	25.257
MD6	20	50	3	11.068
MD7	30	15	28	20.789
MD8	30	30	3	10.306
MD9	30	50	7	14.856

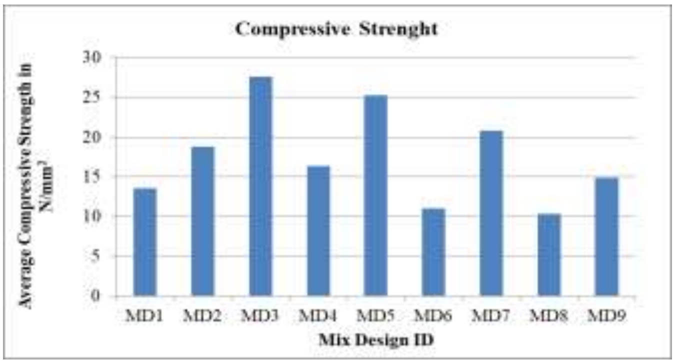

Fig -1: Average compressive strength of all test results shows graphically.

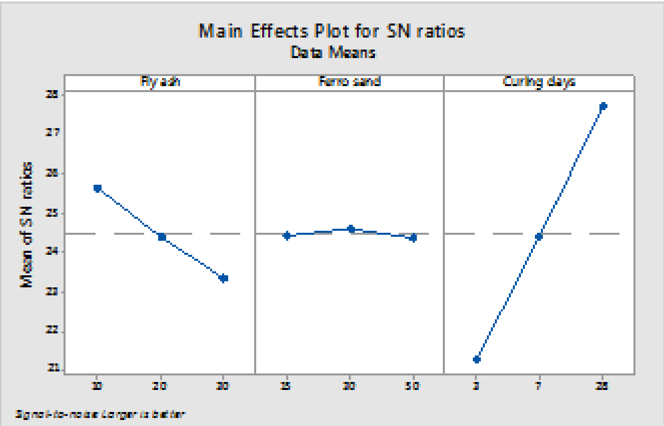

Fig -2: Effect of compressive strength on different parameter for mean S/N ratio.

Figure 2 shows main effect plot for SN ratio that is larger is better option taken for the result by using Taguchi method. The compressive strength indicates that increases with increases both fly ash and ferro sand percentage increases. The high in compressive strength for concrete mixture curing of 28 days over 7 days and 3 days strength due to its pozzolanic reactivity of fly ash. It can combine fly ash and ferro sand optimal w/c ratio control and increases the strength of all concrete mix. Figure 2 shows the concrete mix containing 10% fly ash, 30% ferro sand and 28 days curing age have shown the best performance in all mixture.

B. Flexural strength test

Flexural strength test is one measure of the tensile strength of concrete. The effect of fly ash and ferro sand on flexural strength of concrete for various mixtures is given in Table 14 and is demonstrated in Figure 3. Test was performed on 27 specimens (three specimens from each test group) for two point bending.

Table -14: Average flexural strength of all different mix design

Mix Design	Fly Ash (%)	Ferro Sand (%)	Curing Days	Flexural Strength in N/mm^2
MD1	10	15	3	1.825
MD2	10	30	7	3.54
MD3	10	50	28	4.435
MD4	20	15	7	3.045
MD5	20	30	28	4.65
MD6	20	50	3	1.698
MD7	30	15	28	3.92
MD8	30	30	3	1.125
MD9	30	50	7	2.651

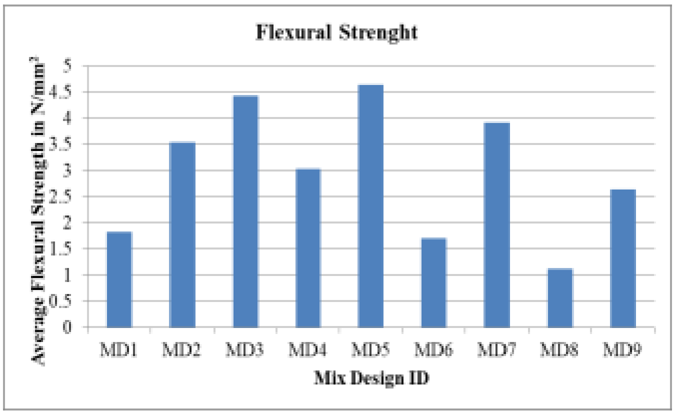

Fig -3: Average flexural strength of all test results shows graphically.

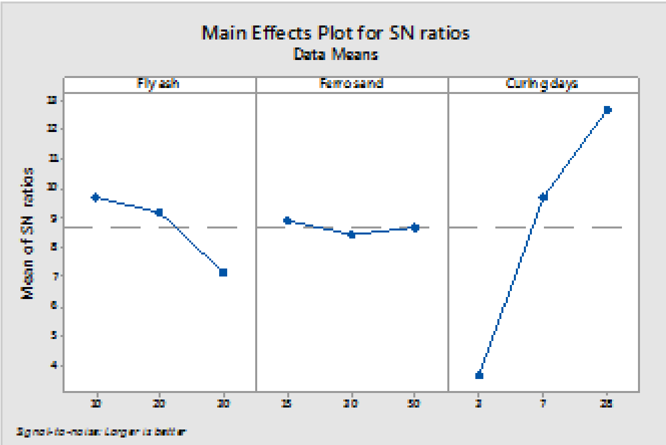

Fig -4: Effect of flexural strength on different parameter for mean S/N ratio.

The average result of flexural strength were reported in Table 14 and Figure 3 shows that the flexural strength of MD5 mixture was significantly more than the concrete with 30% fly ash and 50% ferro sand and 28 curing days. The flexural strength increases with fly ash and ferro sand percentage increases. Figure 4 shows main effect plot for SN ratio that is larger is better option taken for the result by using Taguchi method. The flexural strength of mix design mixture increase containing 10% fly ash when ferro sand added with 15%, 30%, and 50%. It can be seen from Figure 4 that 10% fly ash with 15% ferro sand concrete mixture with 28 curing days gives higher flexural strength.

C. Splitting tensile strength

Splitting tensile strength is used to determine the tensile strength of concrete in an indirect way. The effect of fly ash and ferro sand on splitting tensile strength of concrete for various mixtures is given in Table 15 and is demonstrated in Figure 5. Test was performed on 27 specimens (three specimens from each test group) by Taguchi method.

Table -15: Average split tensile strength of all different mix design

Mix Design	Fly Ash (%)	Ferro Sand (%)	Curing Days	Splitting Tensile Strength in N/mm²
MD1	10	15	3	1.566
MD2	10	30	7	2.684
MD3	10	50	28	3.126
MD4	20	15	7	2.269
MD5	20	30	28	2.697
MD6	20	50	3	1.324
MD7	30	15	28	3.375
MD8	30	30	3	1.111
MD9	30	50	7	1.577

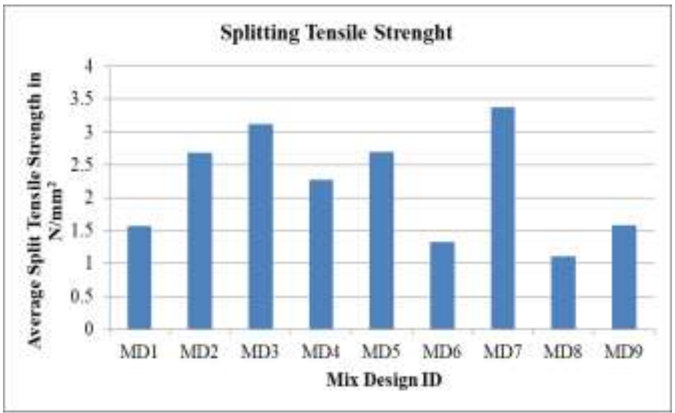

Fig -5: Average splitting tensile strength of all test results shows graphically.

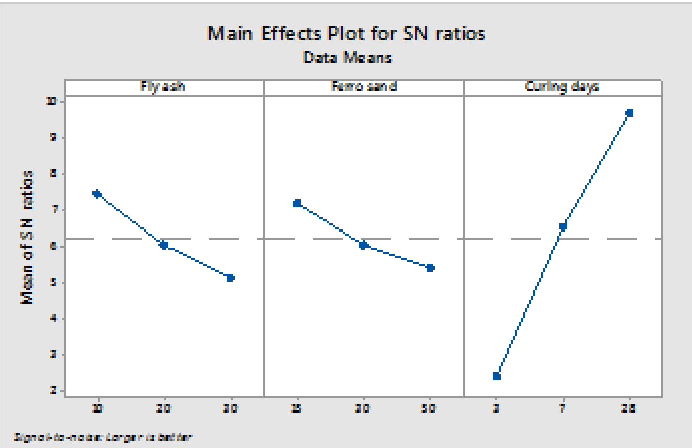

Fig -6: Effect of splitting tensile strength on different parameter for mean S/N ratio.

The Figure 5 illustrated that highest strength is related to MD7 specimen with control mix 30% fly ash, 15% ferro sand and 28 days curing age. The lowest strength is related to MD8 specimen with control mix 30% fly ash, 30% ferro sand and 3 days curing age. The splitting tensile strength result decrease in 3 day and 7 days with fly ash content increases. Figure 6 shows main effect plot for SN ratio that is larger is better option taken for the result by using Taguchi method. The split tensile strength at the age of 28 days curing of concrete mixture with 10% Fly ash and 15% ferro sand is gives high strength by using the Taguchi method.

4. CONCLUSIONS

- Workability of design mix concrete increases with increase in percentage of fly ash content as well as decreases with increases in percentage of ferro sand.
- Unit weight or dry density increase with increase in percentage of fine aggregate replace by ferro sand. Because the weight of ferro sand high as compared to natural fine sand. Unit weight or dry density decrease with increase in percentage of cement replace by fly ash.
- The higher in compressive strength for concrete mixture curing of 28 days over 7 days and 3 days strength due to its pozzolanic reactivity of fly ash.
- The concrete mix containing 10% fly ash, 30% ferro sand and 28 days curing age have shown the higher in compressive strength.
- The flexural strength of design mixture increase containing 10% fly ash with 15% ferro sand mixture gives higher flexural strength.
- The splitting tensile strength result decrease in 3 day and 7 days with fly ash content increases. The split tensile strength at the age of 28 days curing of concrete mixture with 10% fly ash and 15% ferro sand is higher value by using the Taguchi method.
- Taguchi method can simplify the best protocol required to optimize mix proportion of fly ash, ferro sand concrete by reducing the number of trial batches.

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