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Optimization of Self Consolidation Concrete

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ABSTRACT - Self-Consolidation concrete (SCC) is an engineered concrete, made to flow by its self-weight, without bleeding or segregation of concrete. Overutilization of concrete makes high impact on environment. Use of waste material as replacement of cement not only enhances the mechanical properties, but also adds to its sustainability. To minimize the overutilization of concrete materials, the optimization method is incorporated. Taguchi optimization method is proposed to reduce the number of mixes. L9 orthogonal array is used to identify the most optimum combination for the best results with minimum resources. Totally 9 mixes arrived by varying three different parameters were used in the study, eco sand (10%, 20%, 30%) as a partial replacement of fine aggregate; fly ash (5%, 10%, 15%) and Cement kiln dust (CKD) (25%, 30%, 35%) as a partial replacement of cement. Rheological properties of SCC were analysed by conducting Slump flow diameter, JRing flow time tests and confirmed with EFNARC guidelines. Compressive strength of casted cube specimens were tested after 7 days and 28 days. MINITAB v19.1.0 is used to find out the concrete mix which shows optimum results. Mix contains Eco Sand 10%, Fly Ash 10% and CKD 25% is found to be optimum for compression. CKD is found to be the most influencing parameter with 65.20% of contribution in strength of SCC. Regression equations are arrived to predict the strength of the concrete.

Keywords: Cementklindust, Eco-sand, Flyash, Mechanical strength, Master-sGlenium SKY 8233 super-plastizier.

I. INTRODUCTION

Self-compacting concrete (SCC) is a special type of concrete which can be placed and consolidated under its own weight without any vibration effort due to its excellent deformability, and which at the same time is cohesive enough to be handled without segregation or bleeding. The concept of SCC was first proposed by Okamura in 1986, and the prototype was first developed by Ozawa at the University of Tokyo in 1988 [1,2].Concrete mixture design is a selection of raw materials in optimum proportions to give concrete with required properties in fresh and hardened states for particular applications. Different from conventional concrete, a quality SCC should have three key properties: (1) filling ability – the ability to flow into the formwork and completely fill all spaces under its own weight; (2) passing ability – the ability to flow through and around confined spaces between steel reinforcing bars without segregation or blocking; (3) segregation resistance – the ability to remain homogeneous both during transporting, placing and after placing. In addition to good self-compact ability, designed SCC also should meet the requirements for rheological and hardened properties of concrete at the same time. Due to those obvious advantages, SCC has been a research focus for many years.

It has reported that factors including composition of raw materials, incorporation of chemical and mineral admixtures, aggregate, dose of super plasticizer and water to cement ratio (W/C) has significant effects on properties in terms of rheology, strength, shrinkage and durability of SCC. The increased paste volume could enhance the rheological properties of SCC. With the world moving toward to sustainable development, waste materials such as fly ash (FA) (5%, 10%, 15%), cement kiln dust (CKD) (25%, 30%, 35%), eco sand (ES) (10%, 20%, 30%) have been used in SCC. Unlike the use of single-objective optimization problem in traditional Taguchi method

II. MATERIALS

In present study, OPC Grade 53 was used. M sand and Eco sand are used as fine aggregate. The maximum and minimum size of coarse aggregate used in this study is 12.5mm and 10mm respectively. Both sand and coarse aggregate has a specific gravity of 2.65 and 2.7 respectively, while the polycarboxylate based superplasticiser (SP) Master Glenium Sky 8233 has a specific gravity of

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1.09 with pH 6.5. The superplasticiser was used to improve the workability of the fresh concrete Cement Kiln Dust used was collected from one of cement industry in Coimbatore. The substitution of sand with eco sand results in aggregate with a particle size distribution composed of variable dimensions. The chemical and physical characteristic of the cement and fly ash are shown in Table 1.

Table 1: Chemical and physical characteristic of OPC and flyash

Content %	OPC	Fly Ash
Chemical Analysis		
SiO_2	22.00	63.18
Al_2O_3	8.35	26.85
Fe_2O_3	3.92	4.39
CaO	58.93	1.4
K_2O	1.01	0.35
TiO_2	0.72	0.96
MgO	0.52	1.01
Na_2O	0.26	0.46
Physical Tests		
Specific Gravity	3.15	2.53
Bulk Density		1914 kg/m^3

III. MIX DESIGN

Mix Proportion

Orthogonal Array (often referred to Taguchi Method) are often employed in industrial experiments to study the effect of several control factor. An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. This experiments 3 variables at 3 different settings. A full factorial experiment would require 3^3 = 27 experiments. We conducted a Taguchi experiment with a L_0 (3^3) orthogonal array (9 tests, 3 variables, 3 levels). The experiment design is given in table 2, table 3 and table 4.

The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called signal-to noise (S/N) ratio [3]. It is the ratio of the mean (signal) to the standard deviation (Noise). The ratio relies on the quality characteristics of the product/process to be optimized. The standard S/N ratios commonly used Larger-the-Better (LB), Smaller-the-Better (SB) and Nominal-the-Best (NB) as given in Eqs.(1) – (3). The optimal setting is the parameter combination, which has the highest S/N ratio.

3.1 Larger – the – better (LB)

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

where n is number of replications and y is the observed data This is applied for problems where maximization of the performance characteristic of interest is desired. This is referred to as the larger-the-better type problem.

3.2 Smaller – the – better (SB)

$$\text{S/N ratio} = -\log_{10} = \left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

This is applied for problems where minimization of the performance characteristics is intended. This is termed as Smaller the Better type problem.

3.3 Nominal the Best

$$\text{S/N ratio} = -\log_{10} = \left(\frac{\mu^2}{\sigma^2}\right) \qquad (3)$$

Based on the S/N analysis, the S/N ratios for each level of process parameters are computed. Larger S/N ratio corresponds to better performance characteristics regardless of their category of performance. It means that the level of process parameters with the highest S/N ratio corresponds to the optimum level of process parameters. Taguchi recommends orthogonal array (OA) for conducting experiments as a result number of experiments are reduced significantly. These OAs are generalized Graeco-Latin squares. Finally, a confirmatory experiment is conducted to authenticate the optimal processing parameters obtained from the parameter design.

Table 2: L9 Orthogonal Array System (Taguchi method)

MIX ID	(A)	(B)	(C)
SCC1	1	1	1
SCC2	1	2	2
SCC3	1	3	3
SCC4	2	1	2
SCC5	2	2	3
SCC6	2	3	1
SCC7	3	1	3
SCC8	3	2	1
SCC9	3	3	2

Table 3: Array Level and Variables

Levels	Variables	1	2	3
A	FlyAsh	5%	10%	15%
B	Cement Kiln Dust	25%	30%	35%
C	Eco Sand	10%	20%	30%

Table 4: Array Distribution

MIX ID	FLY ASH (A)	CKD (B)	Eco Sand (C)
SCC1	5%	25%	10%
SCC2	5%	30%	20%
SCC3	5%	35%	30%
SCC4	10%	25%	20%
SCC5	10%	30%	30%
SCC6	10%	35%	10%
SCC7	15%	25%	30%
SCC8	15%	30%	10%
SCC9	15%	35%	20%

FRESH AND HARDENED PROPERTIES OF CONCRETE

In determining the fresh properties of the self-compacting concrete, the slump flow, V funnal, L Box, test were performed. These tests are important in order to ensure that the fresh state of concrete have the following properties; (1) passing ability, (2) filling ability and (3) segregation resistance. The procedure, conducting the test as described in Euro Standard. For each mixture, the compressive strength, split tensile strength and flexural strength of the concrete were determined at 7 and 28 days of water curing. The cube size of 100 mm is cast for the determination of compressive strength, cylinder of 100mm x 200mm and prism of 100mm x 100mmx x500mm are casted. The specimens were removed from the mould after 24 hour and cured in the water tank for 28 days.

IV. PROPOSED OPTIMIZATION METHODOLOGY

Traditional Taguchi approach is developed to solve single response optimization problems. It is then essential to transform these multiple objectives into an equivalent single objective function which can be treated as the representative index for multiple quality characteristics

Fig 1:compressive strength

Fig2:Splitting tensile strength

Fig 3:Flexural strength

Table 5: Properties of SCC

					28 Day Strength		
S No	**Mix Id**	**Slump Flow**	**V Funnal**	**L Box**	**Compressive Strength**	**Split Tensile Strength**	**Flexural Strength**
		mm	sec	mm	kN/mm^2	kN/mm^2	kN/mm^2
1	SCC1	660	11	0.91	41.4	2.23	3.52

2	SCC2	685	9	0.94	40.2	3.19	3.81
3	SCC3	670	10	0.95	37.1	2.54	3.31
4	SCC4	665	10.2	0.89	43.2	2.6	2.56
5	SCC5	695	8	0.92	37.0	2.06	2.39
6	SCC6	715	8.6	0.96	36.4	1.90	3.06
7	SCC7	610	9.5	0.92	35.7	2.69	6.17
8	SCC8	650	9.5	0.94	36.4	2.37	5.78
9	SCC9	655	10	0.90	35.9	2.38	4.90

V. REGRESSION EQUATION

Regression analysis was done to form the regression equation to predict the strength of the concrete such as compressive strength, he is following experimental relationship for predicting the compressive strength.

Compressive Strength = 48.4-0.166 (A) Cement Kiln Dust- 0.286 (B) Fly Ash+ 0.021(C) Eco Sand.

Split Tensile Strength = 4.036-0.0322 (A) Cement Kiln Dust- 0.0347 (B) Fly Ash+ 0.0046(C) Eco Sand.

Flexural Strength = 6.09-0.0262 (A) Cement Kiln Dust- 0.0436 (B) Fly Ash+ 0.0029(C) Eco Sand.

L9 ORTHOGONAL ARRAY

Regression Equation

RESPONSE = 46.6 + 0.060 ECO SAND - 1.280 CKD + 0.680 FLY ASH

Coefficients

Table 6Coefficients of regression equation

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	46.6	12.8	3.25	0.023	
CKD	-1.280	0.384	-1.66	0.157	1.00
ECO SAND	0.060	0.384	-0.27	0.797	1.00
FLY ASH	0.680	0.192	-0.32	0.765	1.00

Modal summary

Table 7 Model summary of regression equation

S	R-sq	R-sq.(adj)	R-sq.(pred)
5.81997	65.20%	44.32%	2.32%

Analysis of Variance

Table 8 Analysis of Variance for regression equation

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	317.28	105.760	3.12	0.12
ECO SAND	1	2.160	2.160	0.06	0.81
FLY ASH	1	69.36	69.36	2.05	0.21
CKD	1	245.76	245.76	7.26	0.04
Error	5	169.36	33.87		
Total	8	486.64			

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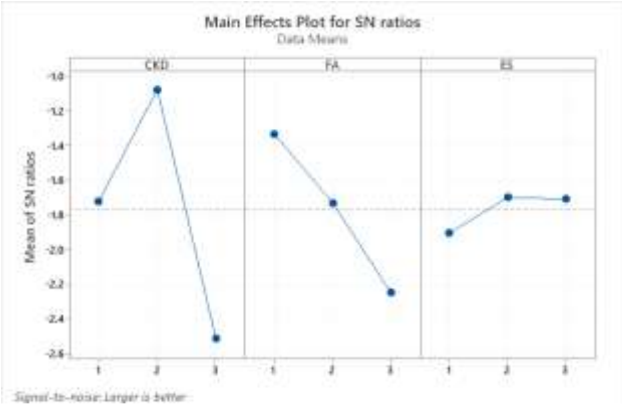

Fig 4 : Factorial Plot for S/N Ratio

VI. RESULTS AND DISCUSSION

Table 5 shows the parametric setting under which each experiment has been conducted and the measured responses such as Compressive Strength, Split Tensile Strength and Flexural Strength. In order to avoid biasness, experiments have been conducted in a random order. Experimental data from table 5 (responses) has been normalized as presented in table 6. LB (Larger – the - Better) criteria for all the responses using Eqs. (1). Principal component analysis (PCA) has been carried out on normalized responses using MINITAB 14 software.The corresponding S/N ratio for all experimental runs have been listed in table 8. The optimized (maximized) using Taguchi method. The predicted optimal setting becomes CKD_2, FA_1, ES_2(subscript represents optimal level of corresponding factors) as observed from figure 4

R-Sq value of 65.20% shows the efficiency of performing the experiments. InTaguchi method, the optimal setting was found to be CKD_2, FA_1, ES_2. The Cement Kiln Dust (CKD) is the most significant factor.

VII. CONCLUSION

The following conclusions may be drawn from the results of the experiments and study of the experimental data in connection with multi-response optimization with (1) Cement Kiln Dust (CKD) (2) Fly Ash (FA) and (3) Eco Sand (ES) as varying parameters in mix optimization of self-compacting concrete.

1. Optimum parameter setting can be evaluated by Taguchi method which proves its effectiveness in handling multi-response problems.
2. CKD is found to be the most significant factors from the analysis of variance.
3. This method can be recommended to solve other multi objective optimization problems.

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