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Optimization of self compacting concrete with high volume fly ash: Response Surface Metodology (RSM) Approach

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Abstract
Concrete to move into very complicated forms or structures that have lots of reinforcing bars, it must be highly vibrated. The self-compacting concrete (SCC) is then used to resolve these defects. The SCC implementation provides significant advantages for increasing the efficiency of construction, reducing total expense and optimizing the workforce. This is a special kind of high performance concrete with excellent flowability, capacity to passing ability, and segregation resistance. The paper whuch is mainly concentrates on the several replacements of the high volume fly ash (HVFA). The replacements of the fly ash which is varies from 50%, 60%, 70% with the ordinay portland cement (OPC) and the water-cement ratio which is varies from 0.3 to 0.45. the valiadation whioch is done by the number of the mixes and casting of the specimens. The study described here aims to develop a statistical model that uses response surface methodology (RSM) for analysis of self-compacting concrete performance.

Keywords : Fly ash, Self compacting, RSM, optimization, compressive strength.

1. Introduction

Self compacting concrete is a concrete that can be placed and compacted in reinforced constructions with out any additional vibrations efforts[1]. Which can eaily filled with the around obstructions of reinforced structual members. Self-compacting concrete provides benefits, including shortened construction hours and operating costs, vibration denials, noise pollution reduction, high compressive strength, and dense structure[2]. SCC has very high flow rate and at the same time adequate cohesiveness to prevent bleeding or segregation. In the late 1980s in Japan, SCC was developed to mainly be used in seismic areas with highly congested enhanced structures. This concrete has recently been commonly used for various applications and structural configurations in many countries[3]. Hajime Okamura introduced in 1986 the idea of self-compacting concrete, but Ozawa (1989) at the University of Tokyo created the concept for the first time in 1988 in Japan[4]. This is commonly referred to as extremely elastic concrete, super workable concrete, non-vibrating concrete, etc[5].

India is an resourceful fly-ash country which produces more than 110 million tons per year, but the consumption remains less than 20% despite the quantum jump in the last 3 to 4 years. One of the major

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developments is that of High Volume Fly Ash (HVFA) which reduces cement consumption and eventually reduces CO2 emittance in order to produce one ton / metric tons of cement[6]. The use of fly ash as a partial cement substitute in cement is becoming very important today, especially as a consequence of the improvement in concrete's long-term durability and environmental benefits. The HVFA concrete is highly performing, has low hydration , sufficient early age strength and very high strength at a later age, a low shrinkage and excellent durable modern concrete structures[7]. The mechanical properties and toughness of concrete have been increased when used as cement substitute material as fly ash, and also Fly ash is a by-product of thermal power plants. Concrete which is having larger amount of fly ash consist are termed as high volume fly ash (HVFA).Fly ash is normally extracted in power stations and the fine fly-ash can be used for the production of blended cement or used as a separate ingredient in ready batching concrete plant according to the fine-fitness requirement of the ASTM C 618. In addition to this fine fly ash, there are large amounts of sub-standard (coarse) fly ash that can be used in the concrete industry[8].

By reducing vibration speculation, SCC can also create a better working environment. There are numerous advantages to SCC, especially when material costs are reduced. These include:Reducing the time and cost of construction, Eliminate vibration criteria of cocncret, Reduce noise pollution, increase the capacity for re-filling of structural members highly congested, faciliating constructiablity and ensure good structural efficiency[9].

Self-compacting cement (SCC) has been commonly used in recent years for placement in congested, hard casting concrete structures. New concrete must have a high degree of fluidity and cohesiveness for these applications[10]. The use of finest materials like fly ash will assure the unique properties required. An initial study results for the production and evaluation of SCCs with high fly ash volumes are presented and discussed[11].

Response Surface Methodology (RSM) which is most powerful experimental design technique used to model and analyze problems in which the response of interest is influenced by several variables. Although this method has been widely used for experimental process optimisation, it has had limited use in the concrete industry[12]. Central composite response surface to determine the effect of SCC mixture parameters on a variety of reactions, such as: slump speed, V-funnel flow time, and filling ability etc[13]. the RSM approach to optimize elevated-performance concrete mixtures at the same time for maximum compressive strength and minimum chloride permeability and cost[14]. An RSM-based analytical model to optimize reinforced steel fibre fracture parameters in order to achieve a more ductile response. A Central Composite Design (CCD) based on RSM has been implemented in the study mentioned here. A simultaneous multi-objective optimization approach was implemented to determine the optimum settings of the mixture variables resulting in a self-compacting mix with the highest flexibility in a certain region of concern. Finally, through contrast with selected experimental results, the accuracy of the model was verified[15].

This paper deals with the different levels of fly ash which are adeed and the number of trail mixes which are evaluated. The validation which is done by the casting of the different specimens. The specimens size are 150mm x150mm x150mm . The results which are obtained through the

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experimental and compare with the analytical data obatianed by the RSM.

2. Development of RSM Model

RSM was first introuduced by Box and wilson in tha year of 1951. The main aim of the RSM is used to optimize the performance of the products through adjusting the values of factors. RSM s a combination of a set of statistical techniques to create an anlytical model where in easch responses that number of a input variables that can effect it. This method is not only determine the relsation between parameeters and responses but it can also asses the effect of individual parameeters and the interactrion ofg parameeters on each of the response valiables.Three major steps are involved in tha anlysis of response surface : (1) The study of the response surface over the simple field. Conceiving a series of experiments to collect experimental interest response data; (2). The development and testing of a numerical model of the solution surface; and (3). Optimization of the proportion of the mixture constituent to satisfy the desirable variables specified.

RSM is an experimental design technique to evaluate optimum multi-level device factor rates. Although either the first or second-order model can be used, in RSM, the second-order model is more popular due to its simplicity and the easiness of calculating the optimum factor rates of the second-order model. Practical experiments show that second-order models can help to solve real word problems with multiple answers. Inadequate simulation of complex systems are the first-order models. Therefore, it is not very effective to optimize with first order models. However, modeling of the complex systems, including various material interaction, is effective in models secondary, including quadratic modeling.

Central Composite Design (CCD) is one of the most important second-order designs in RSM. With this method the independent mixture components are typically converted into different variables and two variables are combined.

A CCD is an effective experimental design that is used to create a quadratic model for each response in response surface methodologies. The CCD has several benefits, including the ability to estimate the quadratic effect (second order) for each response, the study of a surface response with relatively few trials, evaluating the inter-relationships between factors and finding the optimal response for each response. A CCD comprising a complete or fractional factor design with center points extended by star points, which increase the space of the variable and allow the quadratic terms to be calculated.

The experiment variables were coded according to Eq. (1):

$$X_j = (Z_j - Z_{oj})/\Delta_j \quad \text{--------------EQ(1)}$$

Where Xj is the independent variable code, Zj is the independent variable's real value and Z0j is the real central point value of the independent variable and Dj is the step change value.

The CCD variables A were used to estimate the Eq response. (2) in the form of a polynomial equation of the second degree:

$$Y = \beta 0 + \Sigma \beta i x i \ + \Sigma \beta i i x i^2 + \Sigma \beta i j x i x j \quad \text{-------- EQ (2)}$$

Where Y is the variable predicted , β0 is interception; βi is linear coefficients; βii is quadratic coefficients; βij is interaction coefficients; and Xi is the independent variables chosen by Xj

In table 1. The design matrix and their responses data which are shown in below.

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Table 1. Design matrix and Responses

S.NO	FLYASH	w/c	admixture dosage	L BOX	7Day CS	28Day CS	56 Day CS	Author
1	50	0.3	11.55	0.93	35.19	60.83	66.2	[7]
2	50	0.35	3.8	0.92	22.9	38.9	41.2	[3]
3	50	0.51	2.25	0.9	36.46	49.91	54.23	[6]
4	50	0.4	11.75	0.85	21.35	23.3	28.9	[16]
5	50	0.35	1.37	0.83	12.5	25.1	52.3	[10]
6	50	0.35	5.25	0.95	28.73	41.42	49.5	[17]
7	50	0.45	3.7	0.82	22.9	38.9	45.23	[14]
8	50	0.32	1.27	0.88	34.47	62.67	68.89	[8]
9	50	0.35	2.38	0.95	28.73	41.12	54.85	[18]
10	50	0.28	5.83	1	52.5	62.8	68.5	[19]
11	50	0.3	2.65	0.95	38.52	57.2	62.5	[11]
12	55	0.4	3.63	0.82	16.23	26.12	34.2	[5]
13	60	0.32	5.4	0.89	41.8	71.5	79.23	[1]
14	60	0.45	4.253	0.792	42.55	48.56	55.63	[4]
15	60	0.36	1.428	0.9	21.5	33.5	41.05	[20]
16	60	0.5	4.28	0.91	24.66	48.15	53.2	[9]
17	60	0.37	3.66	0.94	63.32	70.01	79.42	[21]
18	63	0.35	1.29	0.95	71.25	77.01	79.02	[22]
19	70	0.31	2.56	0.81	71.2	77.18	91.95	[23]

3. Results and discussions

A variance analysis (ANOVA) has been conducted using the program Design Expert, culminating in TableS, to investigate the validity of the model. All F and P-value were used to calculate the significance of the pattern. Regarding responses of the L-box, and compressive strngths were obtained the following F values 167.36, 4.59 and 3.48 indicating a large scale of the models.

There is only a probability of such a major F value of 0.01 percent.

Table 2.

Source	Sum of Squares	df	Mean Square	F- value	P-value	
Model	0.038905	9	0.004323	1.624739	0.240472	significant
A-FLY ASH	0.013529	1	0.013529	5.084797	0.050592	
B-W/C	0.002464	1	0.002464	0.926093	0.361022	
C-ADM DOSAGE	0.010511	1	0.010511	3.950599	0.078097	
AB	5.04E-06	1	5.04E-06	0.001893	0.96625	
AC	0.010703	1	0.010703	4.022648	0.075858	
BC	0.000257	1	0.000257	0.096778	0.762816	
AÂ²	0.007392	1	0.007392	2.778396	0.129893	
BÂ²	0.008673	1	0.008673	3.259807	0.104478	
CÂ²	0.004901	1	0.004901	1.842139	0.207757	
Residual	0.023945	9	0.002661			
Cor Total	0.06285	18				

Table 3.

Source	Sum of Squares	df	Mean Square	F- value	P-value	
Model	2647.31	3	882.44	4.59	0.018	significant
A-FLY ASH	1994.66	1	1994.66	10.37	0.0057	
B-W/C	583.42	1	583.42	3.03	0.102	
C-ADM DOSAGE	0.1035	1	0.1035	0.0005	0.9818	
Residual	2884.12	15	192.27			
Cor Total	5531.43	18				

Table 4.

Source	Sum of Squares	df	Mean Square	F- value	P-value	
Model	2218.75	3	739.58	3.48	0.0425	significant
A-FLY ASH	1329.29	1	1329.29	6.26	0.0244	
B-W/C	838.08	1	838.08	3.95	0.0655	
C-ADM DOSAGE	1.46	1	1.46	0.0069	0.935	
Residual	3184.57	15	212.3			
Cor Total	5403.32	18				

Table 5.

Source	Sum of Squares	df	Mean Square	F- value	P-value	
Model	2612.43	3	870.81	5.2	0.0116	significant
A-FLY ASH	1288.03	1	1288.03	7.7	0.0142	
B-W/C	1127.89	1	1127.89	6.74	0.0203	
C-ADM DOSAGE	60.44	1	60.44	0.3611	0.5568	
Residual	2510.43	15	167.36			
Cor Total	5122.86	18				

The actual equations of the responses of the data which is noted as below.

ACTUAL EAQUATIONS

L B0X = -1.37321+0.116969FLY ASH-6.15547 W/C+0.201775 ADM DOSAGE-0.002031 FLY ASH * W/C-0.003671 FLY ASH * ADM DOSAGE+0.032875 W/C * ADM DOSAGE-0.000939 FLY ASH^2+7.20914 W/C^2-0.002177 ADM DOSAGE^2--------EQ(3)

CS 7 = -28.66328+1.76491 FLY ASH-85.84974 W/C+0.026234 ADM DOSAGE -----EQ(4)

CS 28 =+9.93081+1.44078 FLY ASH-102.89404 W/C-0.098533 ADM DOSAGE----EQ(5)

CS 56 = +27.44488+1.41824 FLY ASH-119.36590 W/C-0.633977 ADM DOSAGE----EQ(6)

A research analysis was performed to verify that slumps and L boxes are slowed to confirm the optimum mixing ratio of RSM. Compression strength for 7 day, compressive strength for the 28th day, compressive strength for the 56 day could really be maximised, and the planned optimum mixing ratios could also reduce manufacturing costs.In approximate state,

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testing tests have been used. The findings demonstrate that the study effects are similar to the predicted outcomes shown in the table below. As proof of the validity of the predicted equations, the combined findings can be taken.

MODEL GRAPHS
FIG 1.

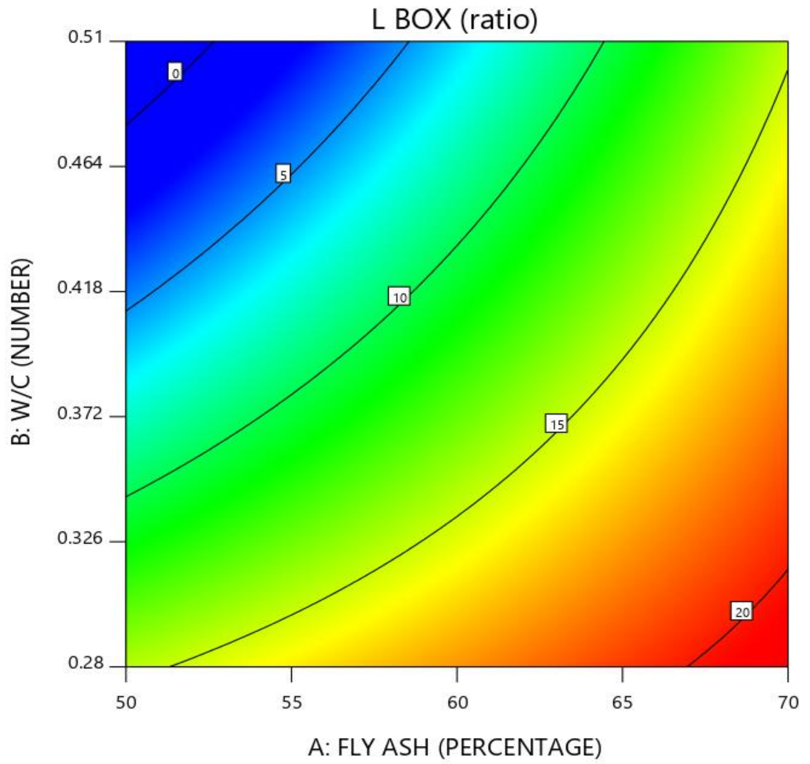


FIG 2.

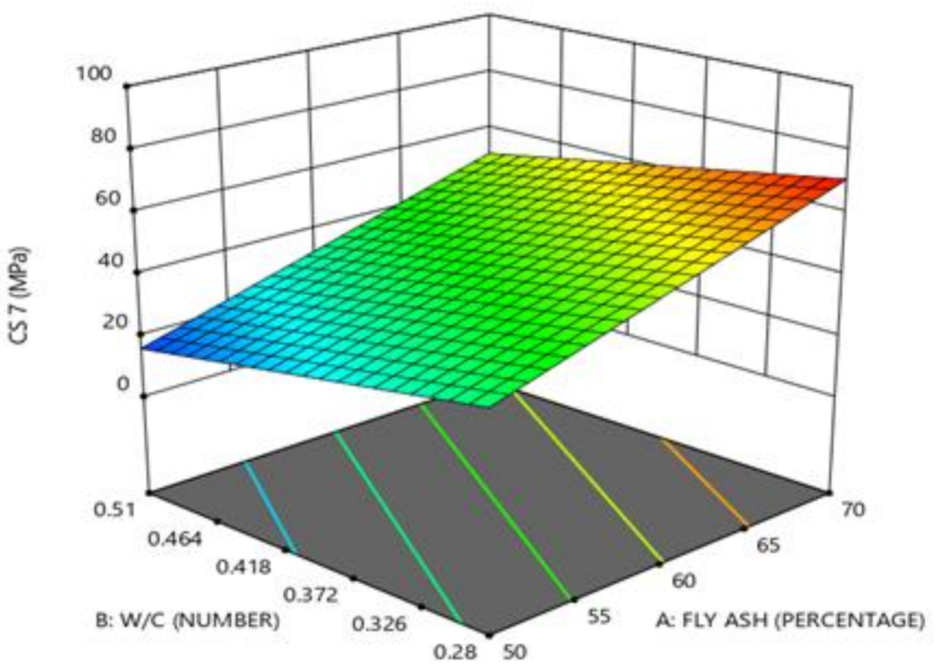


FIG 3.

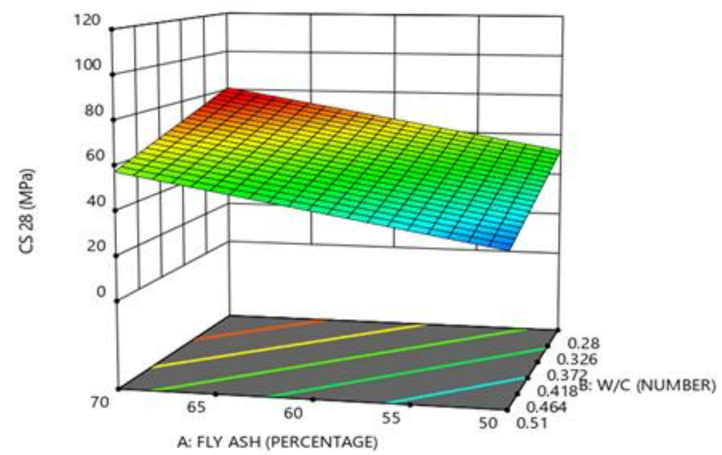


FIG 4.

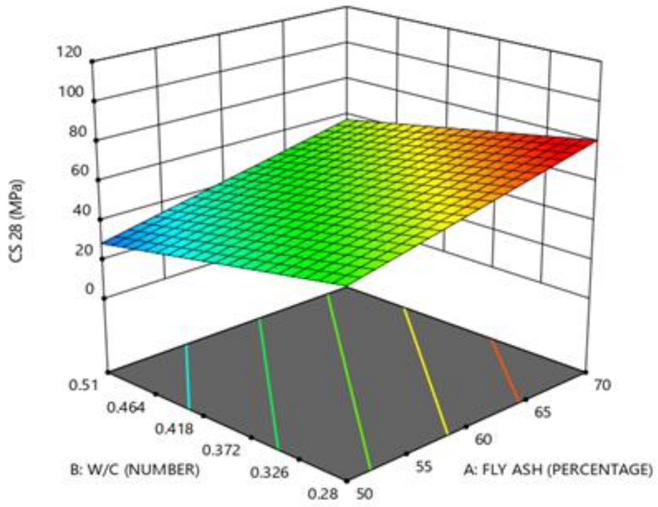
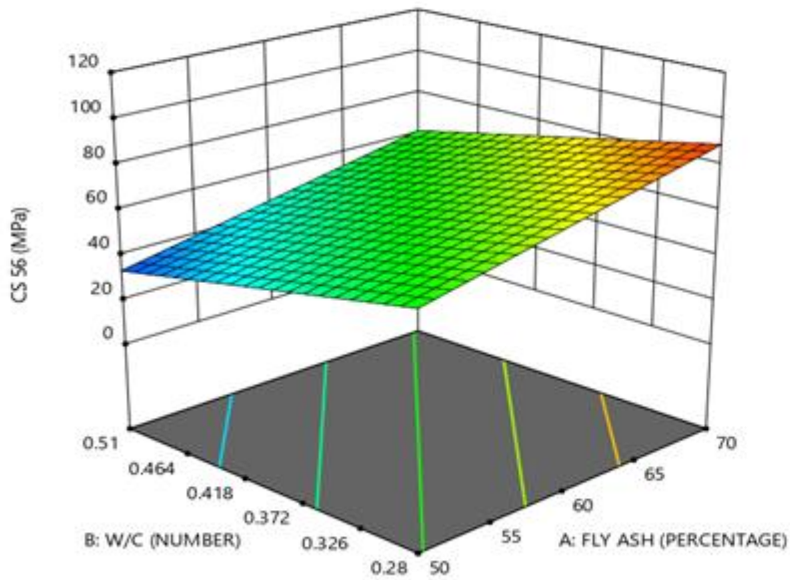


FIG 5.



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4. Validation

In the investigation, the following materials was used.

1) **Cemen**t: Specimen cement of (53 grade) with a particular specific graviyty of 3.12 confirms in line with IS: 12269:1987.
2) **Fine Aggregate**: Real sand of the river 2.66 asspecific gravity confirms in Zone III according to IS: 2386 (Part I).
3) **Coarse Aggregate**: Crashed coarse aggregate of 20 mm in size and with a specific gravity of 2.68.
4) **Water**: drinking water for mixing and cure of specimen.
5) **Fly Ash**: class Fly ash from the Chennai Ennore thermal power station, with a specific gravity of 2.21 compared to IS 1727:1967 6).
6) **Chemical admixture**: ploy carboxylic ether based super plasticizer is used.

Experimental results for different percentages of Fly ash
Table 6.

Validtion of Results							
S.No	**Varibles**			**Responces**			
	A	**B**	**C**	**L box**	**CS 7**	**CS 28**	**CS 56**
1	50	0.3	5.12	0.98	33.96	50.59	59.3
2	55	0.4	3.63	0.88	34.15	47.69	55.6
3	60	0.3	5.4	0.88	49.9	62.91	70.91
4	50	0.35	1.37	0.85	29.57	45.82	51.71
5	60	0.36	1.428	0.92	46.36	59.19	68.66
6	70	0.31	2.56	0.82	56.48	63.59	67.30
7	55	0.4	3.63	0.99	42.74	57.94	67.33
8	63	0.3	1.29	1	56.8	69.7	80.16
9	70	0.31	2.56	0.82	68.33	78.63	88.09

Predicted results for different percentages of Fly ash
Table 7.

Validtion of Results							
S.No	**Varibles**			**Responces**			
	A	**B**	**C**	**L box**	**CS 7**	**CS 28**	**CS 56**
1	50	0.3	5.12	0.93	35.19	60.83	66.2
2	55	0.4	3.63	0.82	16.23	26.12	34.2
3	60	0.32	5.4	0.89	41.8	71.5	79.23
4	50	0.35	1.37	0.83	12.5	25.1	52.3
5	60	0.36	1.428	0.9	21.5	33.5	41.05
6	70	0.31	2.56	0.81	71.2	77.18	91.95
7	55	0.4	3.63	0.82	16.23	26.12	34.2
8	63	0.35	1.29	0.95	71.25	77.01	79.02
9	70	0.31	2.56	0.81	71.2	77.18	91.95

5. Conclusions

A simultaneous optimization approach was introduced in this research, which implemented RSM (Respect surface method) in order to achieve self-compacting concrete efficiency.Three efficiency parameters were evaluated and used for the optimized mixture modeling process , L box package, compressive strength of 7 days, 28 day, 56 day. It highlights the following conclusions:

1. A thorough review of self-compacting concrete properties is carried out using the RSM regression model. The ANOVA results also verified the statistically significant inclusions of all model parameters based on very low P value.
2. In order to achieve a self-compacting combination with optimum compressive strength and at the same time minimal percentage of fly-ash material, a numerical analysis of several responses was also effectively conducted. The findings reveal that above Table 6 and Table 7 are the optimal values of concept variables
3. The similarity with the observations of the outcomes expected by the model leads us to conclude that the predictive approach can be used to correctly measure the properties of new mixes.
4. The results which are experimentally developed and comparison with the predicted results are verey nearly aproximatley same values.

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