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Modelling Of Self-Compacting Concrete With High Range Cement Content

Elizabeth George[1], A K Verma[2], Shalini R George[3]h P Upadhyay[4]
Associate Prof., Structural Engg dept., B.V.M. Engg College, V.V.Nagar, Anand, Gujarat, India-388120,
Prof.& Head of Structural EnggDept, B.V.M. Engg College, V.V.Nagar, Anand, Gujarat, India-388120,
UG Student, Civil Engg dept., ADIT Engg College, New V.V.Nagar, Anand, Gujarat, India-388120
PG Student, Structural Engg dept., B.V.M. Engg College, V.V.Nagar, Anand, Gujarat, India-388120
Corresponding Author; Elizabeth George

Abstract:*Prediction of optimal values of workability andhardenedproperties (compressive strengthat7,28,56daysandmodulusofelasticity) of SCC by selecting the appropriate values of the variables (cement,watertopowderratio,flyash)is still a point of research attributing to the fact that nowell-known explicitformulation is yet evolved. The best and viable approach could be the creation of statisticalmodels depicting the required situation which in turn can be manifested into predictive empirical models. The experiments are planned according to the Box-Benhen design. This work is intended to create empirical modelsusefultoreducethe testproceduresandtrialsneededfor theproportioningof self-compacting concrete.*
Key words: *SCC, cement,watertopowderratio,flyash,*

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I. Introduction

Non-availability of explicit mathematical relationships for predicting the workability and hardened properties of SCC is scuttling the effective utilization of properties of SCC for field applications, necessitating to model the influence of key mixture parameters namely cement, fly ash and water to powder ratio on hardened properties SCC. The responses of interest in the present study are compressive strength of seven, twenty eight and fifty six days as well as modulus of elasticity.

The formulations available to predict workability as well as final properties of SCC are not that explicit. Design of Experiments (DOE) could be effectively used for creating predictive models as a function of independent variables like cement, fly-ash, water-paste ratio, etc. Since experimentation need to be efficient a Box-Behnken design, rather than a full factorial could be used, taking cement, fly-ash, water-paste ratio as independent variables atthree levels and responses as compressive strength of 7 days, 28 days and 56 days apart from modulus of elasticity. This model enables us to effectively estimate the effect of all independent variables and their interactions. The adequacy of fitted models is tested by ANOVA [1-5].

Material Details

Ordinary Portlandcementof53grade, Fly Ash, Aggregates,Superplasticizer, Water, Viscosity Modifying Agent (VMA).

Objectives:

This investigation envisages the following: (i) To optimizethe mixtureproportions for high strength using cement of range 400-450 kg/m^3, (ii) Developmentofempiricalmodelfordesiredpropertiesofconcrete, compressivestrength at 7, 28 &56 days and modulus of elasticityas a function ofprocess variables, (iii) To investigate the influenceofprocess variables on responses.

5.4 Process Variables and Responses

The threeprocess parameters selected are cement,flyashand W/Pratio. Theresponsesurfacemethodology (Box-Behnken design) isusedtoinvestigatetheeffectofparameters onhardenedproperties.The responses considered are compressive strengthat7,28, 56daysand modulus of elasticity. Table 1 gives the process variables, their levels and values.

Table 1 Process Parameter and Responses

Sr. No.	Variable	Low (–)	Middle(0)	High (+)
1	Cement (kg/m^3)	400	425	450
2	Flyash (kg/m^3)	150	200	250
3	W/P ratio	1.1	1.2	1.3

II. Results and Analysis

Here,fresh and hardened propertiesofS C C are investigated, using cubical specimens, forthe responses compressivestrengths and modulusofelasticity.Thespecimens are tested after curingfor 7,28and56days.The derivedmodelsare validfor therangesofW/Pratioof1.1to1.3,cementcontentof400 to 450 kg/m^3, and fly-ash ranging 150 to 250 kg/m^3. Results of the investigation of fresh properties of SCC are given in Table 2

Table2 Fresh Properties of Concrete

Sr. No.	Cement	Fly ash	w/p Ratio	Fresh Properties				
				Slump-flow	T_{50}	T_0	T_5 min	L-Box Ratio
	Kg/m^3	Kg/m^3		mm	Sec	Sec	Sec	h2/h1
1	400	150	1.2	690	3.45	3.77	9	0.85
2	400	250	1.2	780	2.3	5.28	6	1.07
3	450	150	1.2	700	2.87	3.42	3.68	1
4	450	250	1.2	800	1.9	3.73	4.41	0.97
5	400	200	1.1	670	3.65	5.67	10.2	0.78
6	400	200	1.3	760	2.5	2.54	3.77	1
7	450	200	1.1	650	3.5	4.48	4.92	0.9
8	450	200	1.3	780	2.4	2.41	4.96	1
9	425	150	1.1	590	4.1	5.65	14.41	0.53
10	425	150	1.3	720	2.66	1.9	11.21	0.89
11	425	250	1.1	720	2.75	2.52	5.31	0.93
12	425	250	1.3	770	2.4	3.21	4.36	0.96
13	425	200	1.2	790	1.9	4.61	5.8	0.97
14	425	200	1.2	800	1.8	2.43	5.76	1
15	425	200	1.2	800	1.8	2.56	5.9	1

Results of the investigation of hardened properties of SCC are given in Table3

Table 3 Compressive Strength of SCC after 7, 28 and 56 days of curing

Sr. No	Process Parameters			Response - Comp. Strength, N/mm^2		
	Cement (A)	Fly ash (B)	w/p (C)	7-day	28-days	56-days
	Kg/m^3	Kg/m^3	Ratio			
1	400	150	1.2	22.88	29.19	48.11
2	400	250	1.2	28.45	35.64	50.61
3	450	150	1.2	24.64	30.95	45.91
4	450	250	1.2	30.8	37.28	51.04
5	400	200	1.1	33	38.43	49.87
6	400	200	1.3	22.44	26.55	43.83
7	450	200	1.1	28.75	33.44	46.05
8	450	200	1.3	25.37	28.45	44.29
9	425	150	1.2	26.99	32.71	47.67
10	425	150	1.3	22.15	26.40	47.52
11	425	250	1.1	28.6	34.61	48.1
12	425	250	1.3	23.03	27.57	43.12
13	425	200	1.2	29.04	32.27	47.23
14	425	200	1.2	28.45	33.59	48.53
15	425	200	1.2	28.31	32.56	46.78

Regression models are fitted for compressive strengths after curing for 7, 28, and 56 days as a function of the variables namely cement, flyash and W/P ratio.

Regression equation for 7-days compressive strength is given below:

CS-7 days = 28.60 + 0.349 A + 1.778 B - 3.044 C + 0.145 A*A - 2.053 B*B - 1.355 C*C+ 0.147 A*B + 1.795 A*C - 0.182 B*C 1

Ignoring the insignificant terms, the modified model in terms of significant parameters, the model is

CS-7 days = 28.60 + 1.778 B - 3.044 C 2

The ANOVA table depicting the details of 7-days compressive strength is given in table 4. Surfaces plots of 7-day Compressive Strength vs various factors are given in figures 1 and 2

Table 5.4 ANOVA of 7-days Compressive Strength

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	134.914	14.9904	4.62	0.053
Linear	3	100.364	33.4548	10.32	0.014
A	1	0.973	0.9730	0.3	0.607
B	1	25.276	25.2760	7.79	0.038
C	1	74.115	74.1153	22.85	0.005
Square	3	21.441	7.1470	2.2	0.206
A*A	1	0.078	0.0776	0.02	0.883
B*B	1	15.555	15.5548	4.8	0.080
C*C	1	6.779	6.7792	2.09	0.208
2-way Interaction	3	13.108	4.3694	1.35	0.359
A*B	1	0.087	0.0870	0.03	0.876
A*C	1	12.888	12.8881	3.97	0.103
B*C	1	0.133	0.1332	0.04	0.847
Error	5	16.216	3.2431		
Lack-of-fit	3	15.915	5.3051	35.34	0.028
Pure Error	2	0.300	0.1501		
Total	14	151.129			

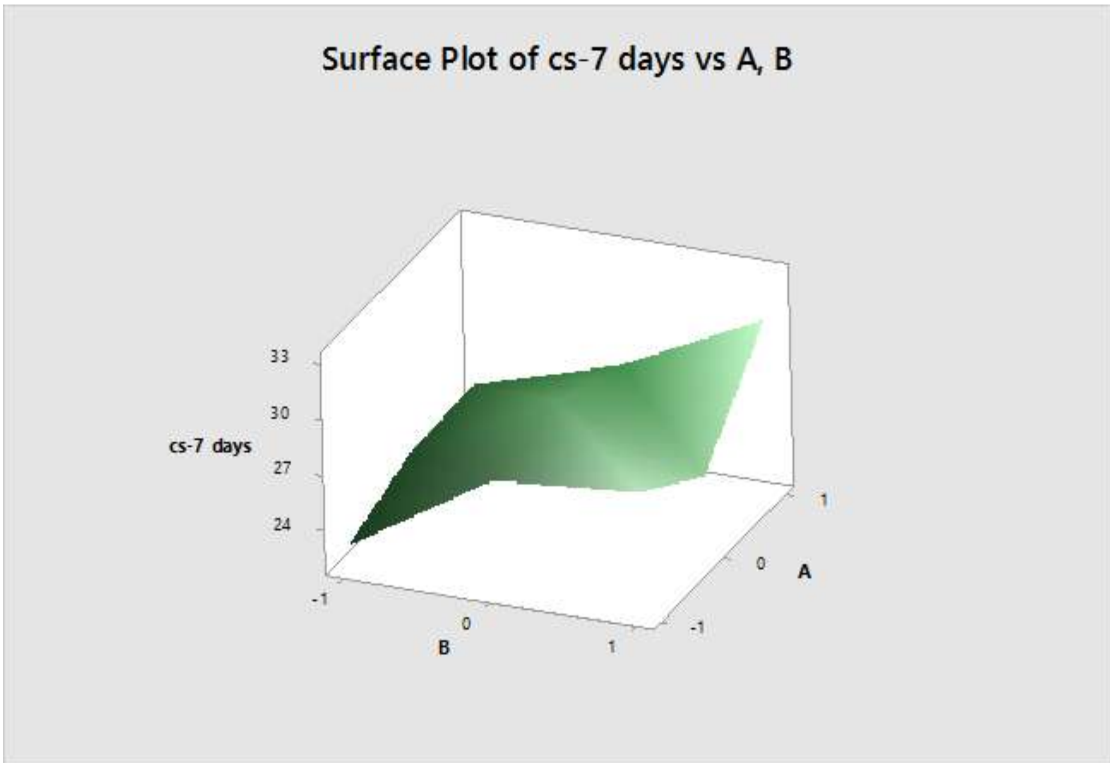

Figure 1

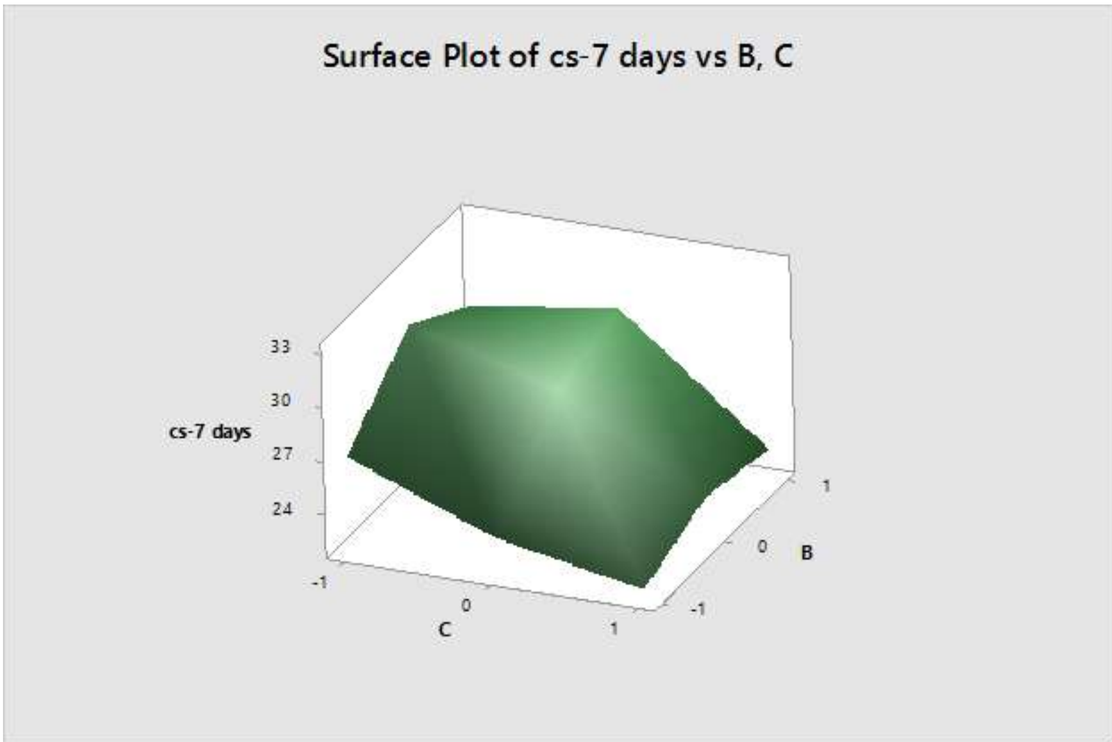

Figure 2

7days compressive strength ANOVA (95% confidence level) table brings out the following facts:

1. Linear terms of the model are adequate. Among the linear terms, the order of significance of the factors is w/p ratio & fly-ash.
2. It shows the influence of cement is insignificant.
3. The square terms are insignificant.
4. 2-way interactions terms are insignificant.
5. The fitted model is adequate.

Regression Equation for 28-days compressive strength is given below:

CS-28days = 32.81 + 0.039 A + 1.981 B - 3.778 C + 0.93 A*A - 0.47 B*B - 2.02 C*C - 0.030 A*B + 1.722 A*C - 0.182 B*C 3

Modified model in terms of significant parameters, leaving the insignificant ones gives:

CS-28 days = 32.81 + 1.981 B - 3.778 C 4

Table 5 gives the ANOVA of 28-days compressive strength

Table 5.5 ANOVA of 28-days compressive strength

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	177.495	19.722	5.04	0.045
Linear	3	145.571	48.524	12.40	0.090
A	1	0.012	0.012	0.00	0.958
B	1	31.403	31.403	8.03	0.037
C	1	114.156	114.156	29.18	0.003
Square	3	19.920	6.640	1.70	0.282
A*A	1	3.171	3.171	0.81	0.409
B*B	1	0.81	0.810	0.21	0.668
C*C	1	15.004	15.004	3.84	0.108
2-way Interaction	3	12.005	4.002	1.02	0.457
A*B	1	0.004	0.004	0.00	0.977
A*C	1	11.868	11.868	3.03	0.142
B*C	1	0.133	0.133	0.03	0.861
Error	5	19.562	3.912		
Lack-of-fit	3	18.599	6.200	12.88	0.073
Pure Error	2	0.962	0.481		
Total	14	197.057			

Surfaces plots of 28-day compressive strength vs various factors are given in figures 3 to 5

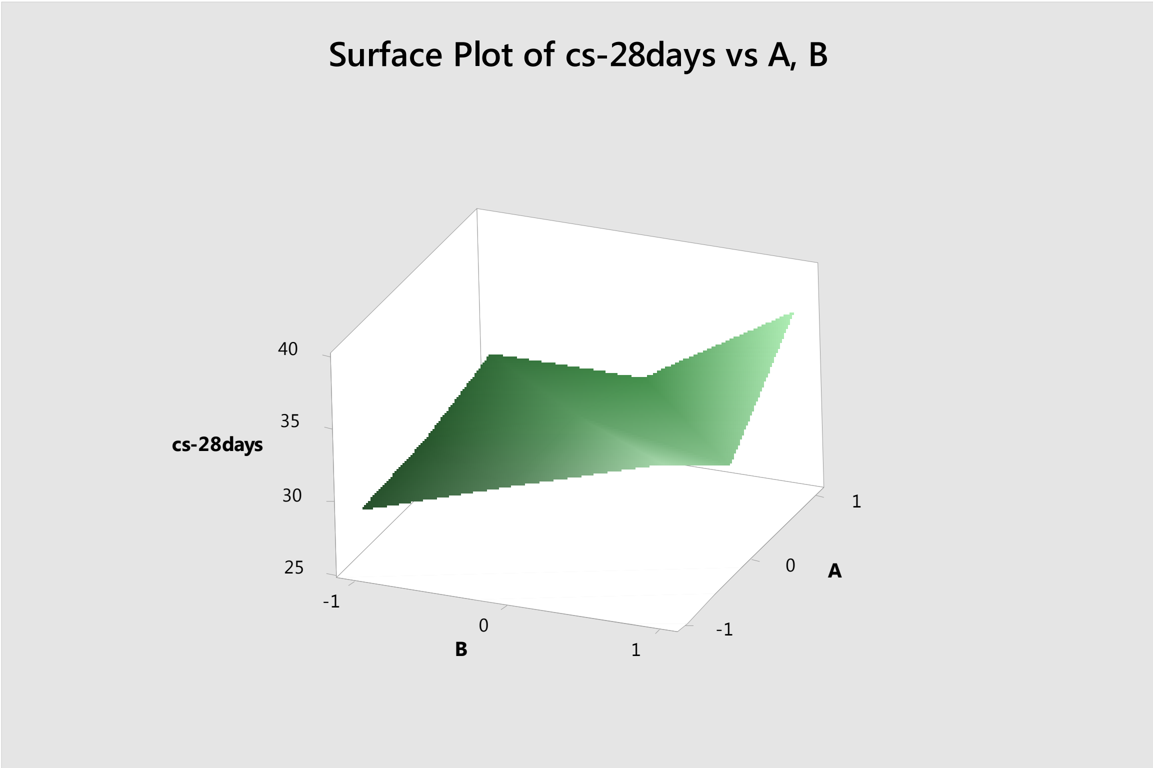

Figure 3

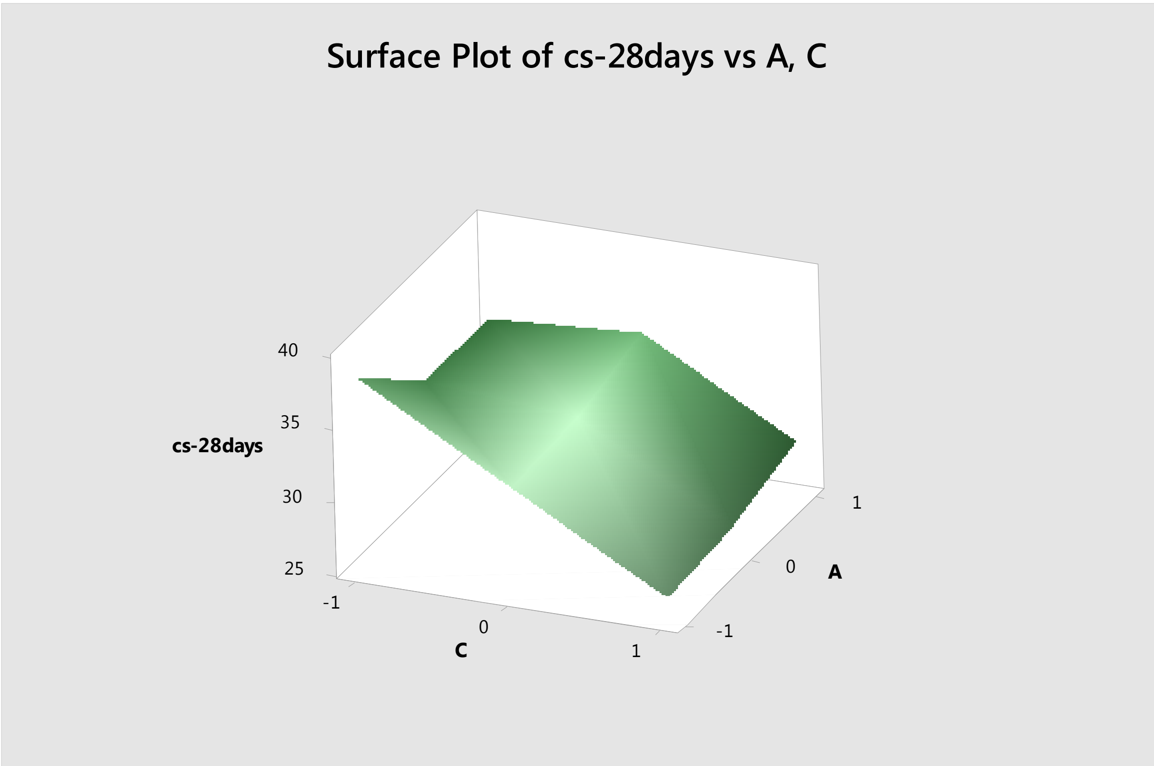

Figure 4

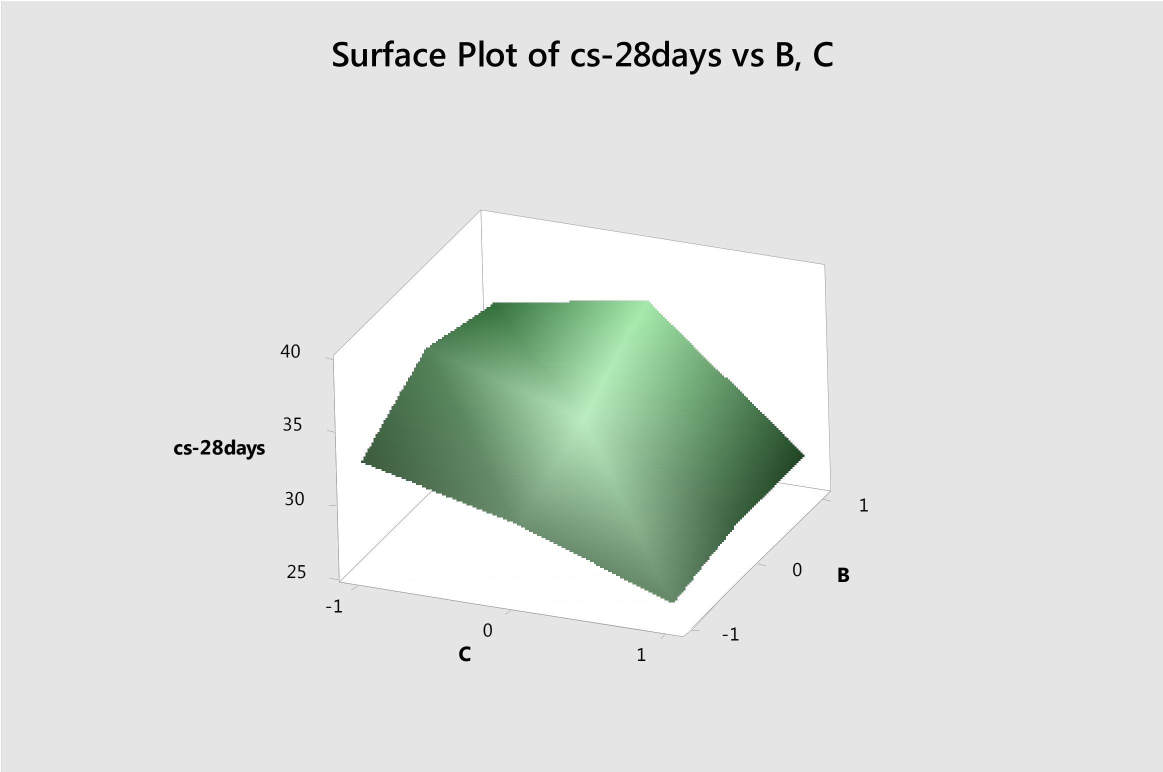

Figure 5

28-days compressive strength ANOVA (95% confidence level) table of SCC brings out the following facts:

1. Linear terms of the model are inadequate. Among the linear terms, the order of significance of the factors is w/p ratio & fly-ash.
2. The square terms are insignificant.
3. 2-way interactions are insignificant.
4. The fitted model is adequate.

Regression equation for 56- day's compressive strength is given below

CS-56days = 47.080 - 0.878 A + 0.895 B - 2.403 C + 1.206 A*A + 0.226 B*B - 1.984 C*C + 0.478 A*B + 1.363 A*C + 0.073 B*C 5

Modified model in terms of significant parameters

CS-56days = 47.080 - 0.878 A + 0.895 B - 2.403 C + 1.206 A*A - 1.984 C*C + 1.363 A*C 6

The ANOVA of 56-compressive strength is given in table 6

Table 6 ANOVA of 56-days compressive strength

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	88.7879	9.8653	12.94	0.006
Linear	3	58.7443	19.5814	25.68	0.002
A	1	6.1601	6.1601	8.08	0.036
B	1	6.4082	6.4082	8.4	0.034
C	1	46.1761	46.1761	60.56	0.001
Square	3	21.6849	7.2283	9.48	0.017
A*A	1	5.7325	5.3725	7.05	0.045
B*B	1	0.189	0.189	0.25	0.640
C*C	1	14.5302	14.5302	19.06	0.007
2-way Interaction	3	8.3587	2.7862	3.65	0.098
A*B	1	0.912	0.912	1.2	0.324
A*C	1	7.4256	7.4256	9.74	0.026
B*C	1	0.021	0.021	0.03	0.875
Error	5	3.8125	0.7625		
Lack-of-fit	3	3.6775	1.2258	18.16	0.053
Pure Error	2	0.135	0.0675		
Total	14	92.6004			

Figures 6 to 8 give the 56 days compressive strength surface plots.

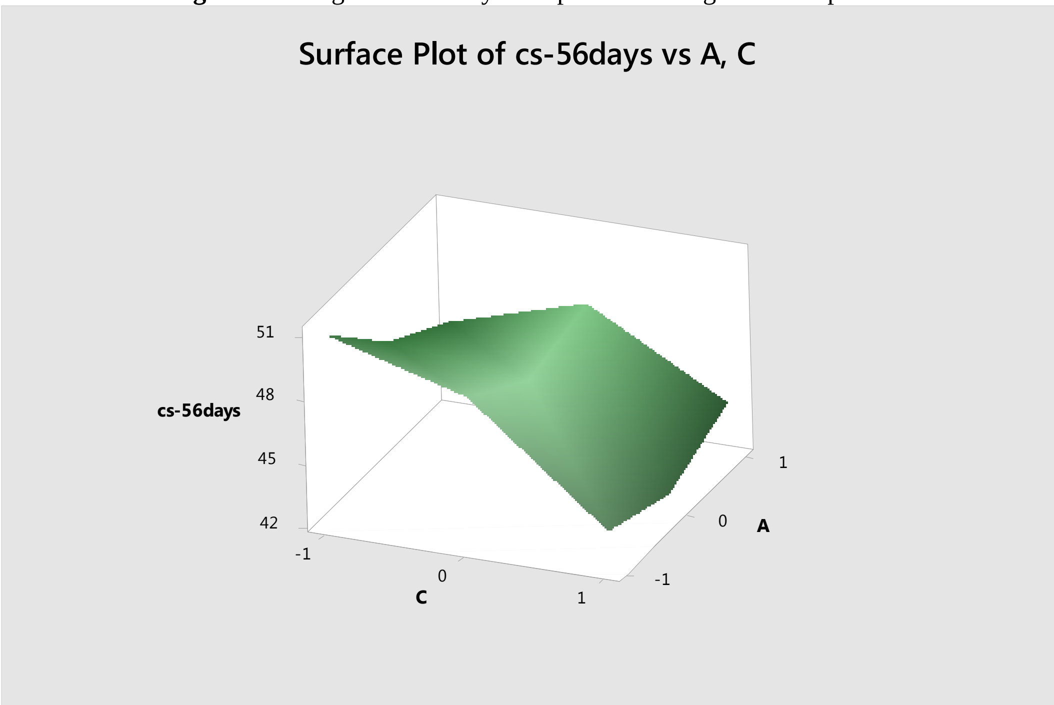

Figure 6

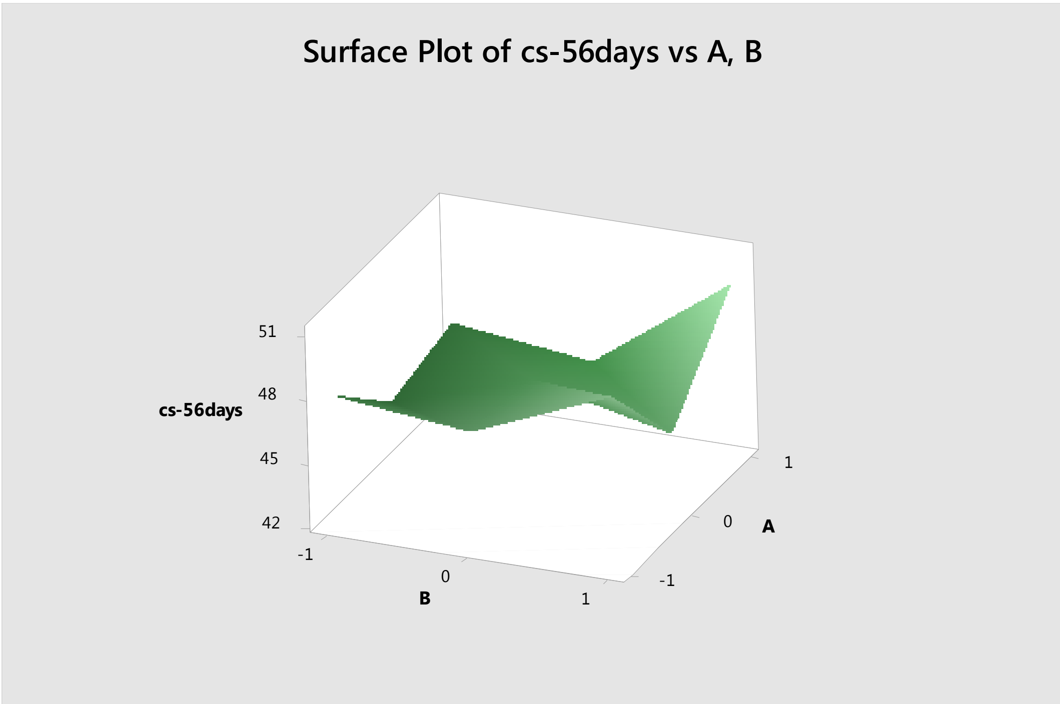

Figure 7

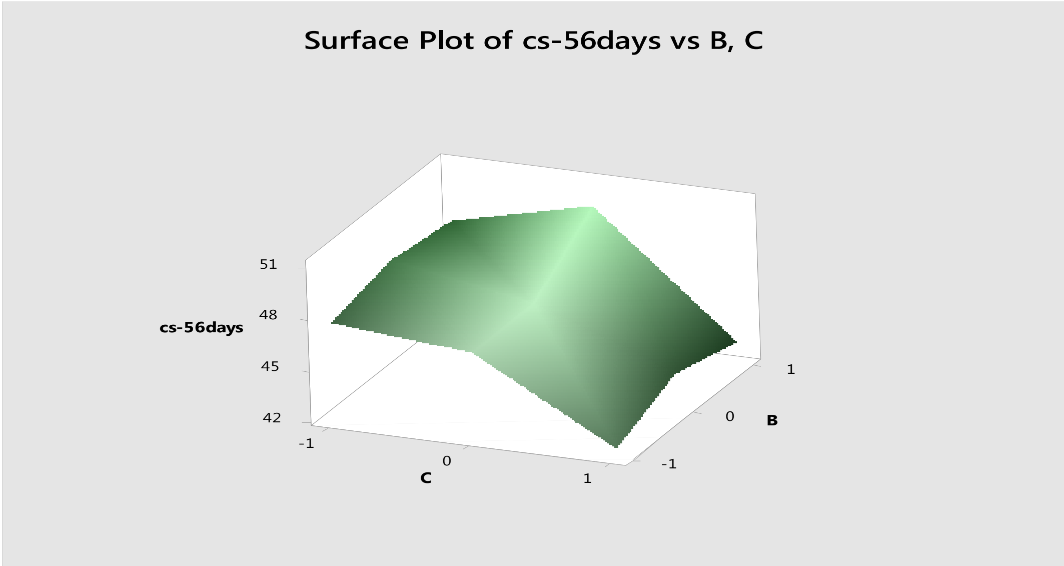

Figure 8

56-days compressive strength ANOVA (95% confidence level) table brings out the following facts:

1. Linear terms of the model are highly significant and the order of significance of the factors is w/p ratio, fly-ash, and cement.
2. The square terms are significant. Order of significance of square terms is w/p ratio & cement.
3. Two way interactions are inadequate. Among two way interactions order of significance cement and w/p interaction is significant.
4. The fitted model is adequate.

The design matrix and the elasticity values are given in table 7

Table 7 Design Matrix for Elasticity

Std. Order	Run Order	Pt Type	Blocks	A	B	C	Elasticity
23	1	2	1	1	0	1	20070
30	2	0	1	0	0	0	22183
10	3	2	1	0	1	-1	23998
19	4	2	1	1	1	0	22560
1	5	2	1	-1	-1	0	20749
2	6	2	1	1	-1	0	22635
8	7	2	1	1	0	1	19089
20	8	2	1	-1	0	-1	23169
22	9	2	1	-1	0	1	19844
28	10	0	1	0	0	0	23314
15	11	0	1	0	0	0	22258
5	12	2	1	-1	0	-1	23465
29	13	0	1	0	0	0	21126
25	14	2	1	0	1	-1	23013
18	15	2	1	-1	1	0	24920
16	16	2	1	-1	-1	0	21504
14	17	0	1	0	0	0	22862
21	18	2	1	1	0	-1	24295
4	19	2	1	1	1	0	23013
11	20	2	1	0	-1	1	19542
17	21	2	1	1	-1	0	23314
3	22	2	1	-1	1	0	22437
7	23	2	1	-1	0	1	18938
9	24	2	1	0	-1	-1	23088
27	25	2	1	0	1	1	20221
12	26	2	1	0	1	1	21126
6	27	2	1	1	0	-1	22334
13	28	0	1	0	0	0	23013
26	29	2	1	0	-1	1	20296
24	30	2	1	0	-1	-1	22638

Regression equation of modulus of elasticityof SCC after 28-days of curing is
Modulus of Elasticity = 22459 + 143 A + 470 B -1680 C - 79 A*A +261 B*B -980 C*C - 685 A*B + 48 A*C + 28 B*C 7
Regression equation, after removing the insignificant factors and interactions, is given by equation 8
Modulus of Elasticity = 22459 + 470 B -1680 C -980 C*C - 685 A*B 8
The surface plots of modulus of elasticity is given in figures 9 to 11
Table 8 gives the ANOVA of elasticity of SCC

Table 8 ANOVA of Elasticity

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	60717666	6746407	11.06	0.000
Linear	3	49000563	16333521	26.77	0.000
A	1	326041	326041	0.53	0.473
B	1	3536280	3536280	5.80	0.026
C	1	45138242	45138242	73.98	0.000
Square	3	7938790	2646263	4.34	0.017
A*A	1	45845	45845	0.08	0.787
B*B	1	502887	502887	0.82	0.375
C*C	1	7092788	7092788	11.62	0.003
2-way Interaction	3	3778312	1259437	2.06	0.137
A*B	1	3753800	3753800	6.15	0.022
A*C	1	18240	18240	0.03	0.864
B*C	1	6272	6272	0.01	0.920
Error	20	12203201	610160		
Lack-of-fit	3	1270303	423434	0.66	0.589
Pure Error	17	10932897	643112		
Total	29	72920867			

ANOVA (95% confidence level) of modulus of elasticity, after 28-days curing, of SCC brings out the following facts:

1. Overall model as well as Linear terms are adequate. Among the linear terms, the order of significance of the factors is W/P ratio and fly-ash.
2. The square terms are significant.
3. 2-way interactions are insignificant.
4. The fitted model is adequate.

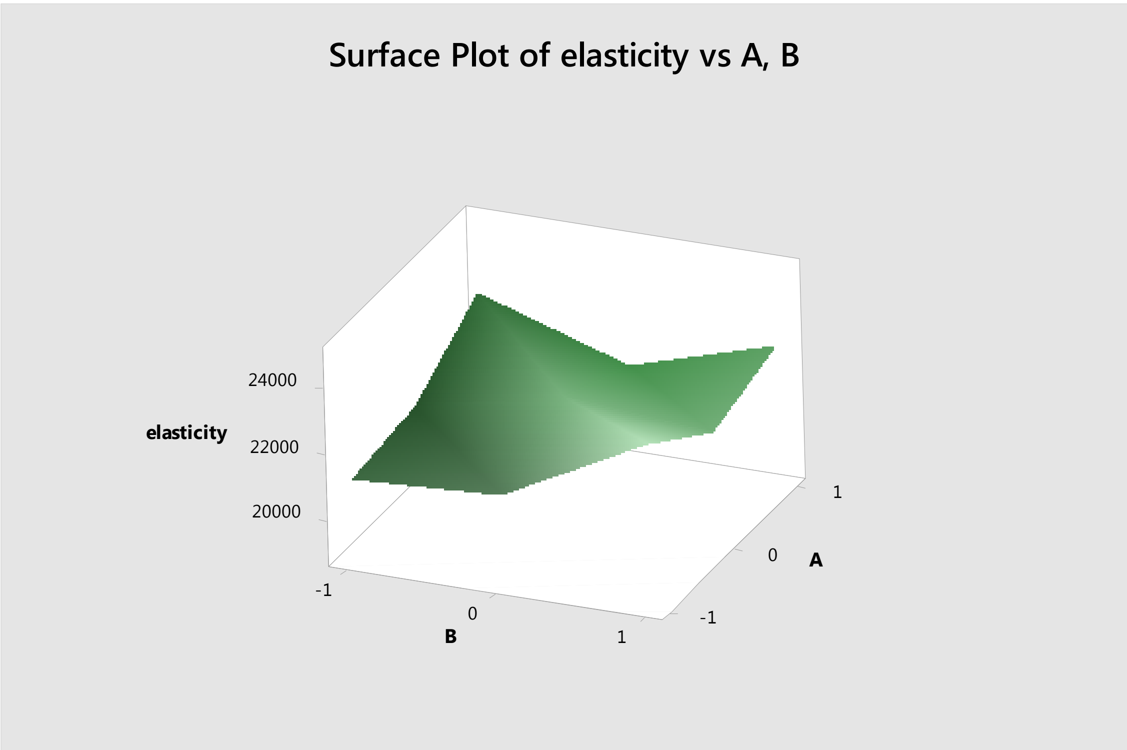

Figure 9

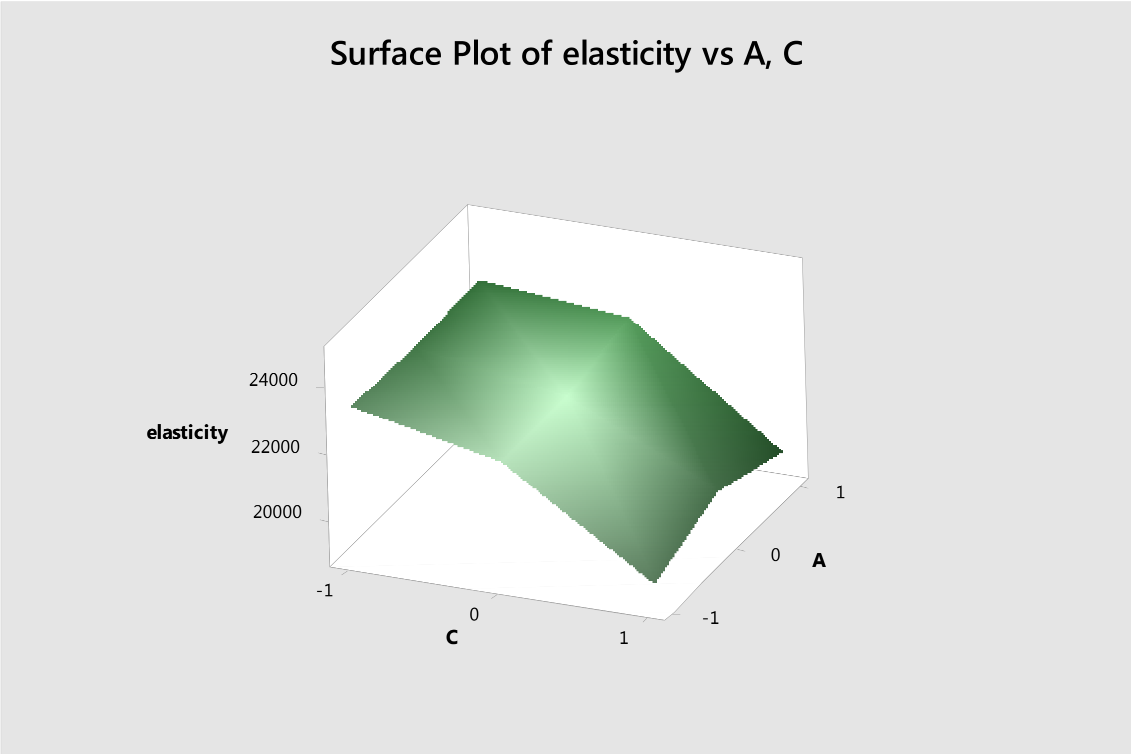

Figure 10

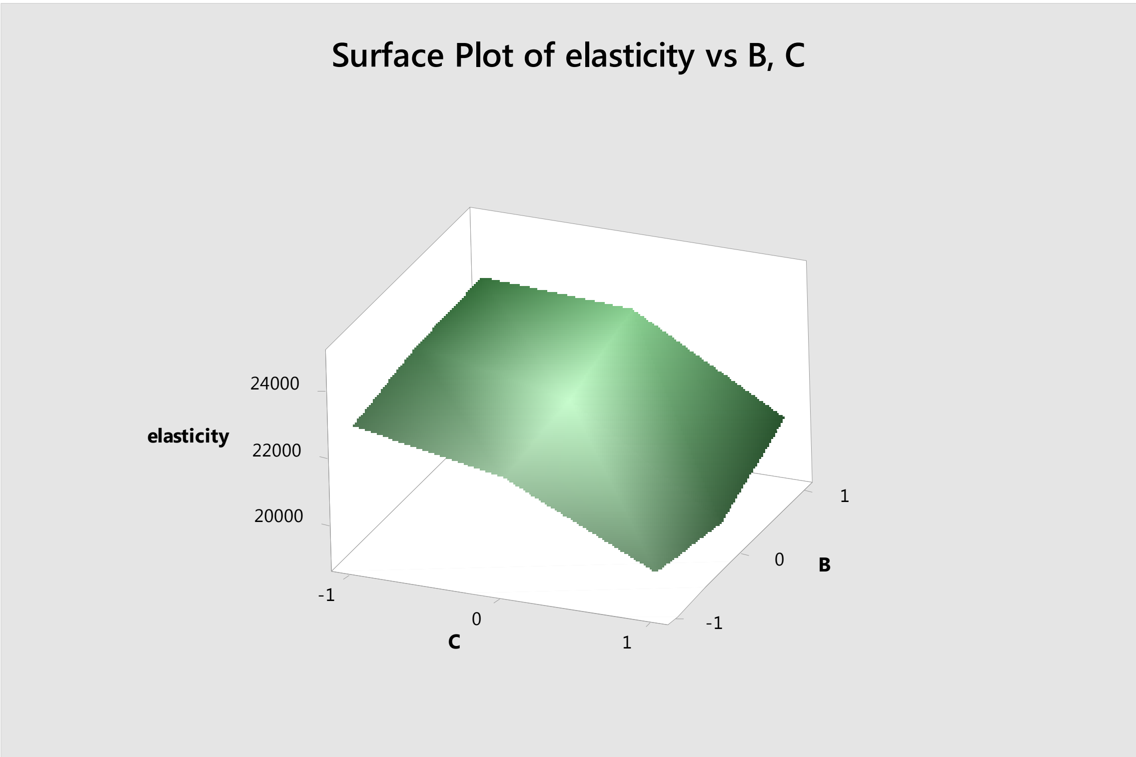

Figure 11

III. Conclusion

Compressive strength models fitted for 7-days, 28-days, and 56-days shows that the factors W/P ratio and fly-ash are significant influences. Moreover, interactions among the W/P ratio, flyash and cement are influencing the compressive strength.It has been observed that the use of flyash not only enhances the freshened properties but also increases the hardened property like compressive strength of the SCC after all the stages of curing.It can also be deduced that W/P ratio is a major factor regulating the hardened properties and is inversely proportional to the compressive strength of SCC.Modulus of elasticity is also found to be significantly influenced by W/P ratio and flyashapart from the interactions among the factors W/P ratio, cement, and flyash.

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