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Strength Prediction and Optimization of Saw Dust Ash-Eggshell Cement Blends Using Response Surface Methodology

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Abstract: The necessity to overcome the challenge of cumbersome and time-wasting technique of strength determination of cement blends. Several avenues are been exploited in prediction of the mortar compressive strength of ternary cement blended comprising saw dust ash (SDA) and eggshell powder (ESP). The strength gains of the cement blends were determined and monitored based on factors like saw dust ash content, curing age and replacement level. The purpose of this research was to evaluate on the influence of saw dust ash with eggshell powder content, replacement level and curing age on the mortar strength using Box & Behnken (BBD), Central Composite (CCD) and Three Level Factorial (3FD) designs. Comparison of the various models was be conducted to ascertain the model with the best strength prediction. Optimization of the process conditions were also evaluated to obtain the optimal strength of the cement blends using response surface methodology. Analysis of variance (ANOVA) results showed that the experimental data satisfied second order polynomial regression model for all three models. An increase in SDA/SDA-ESP ratio and curing age both independently or simultaneously led to an increase in the mortar strength of various cement blends using 3FD and BBD models with the exception of CCD model which experienced a variation in the mortar strength due to an increase in SDA/SDA-ESP ratio and curing age. The curing age indicated the most significant influence compared with SDA/SDA-ESP ratio for CCD and 3FD models respectively. There was an agreement between experimental data and the predicted values evident by regression values of 0.9568, 0.9696 and 0.9923, for 3FD, CCD and BBD respectively. It was also observed that mortar strength via 3FD model produced a better model compared to CCD and BBD according to the ANOVA. The ANOVA revealed that the predicted regression value (R^2_{pred}) and Regression value (R^2) for 3FD model was very close compared with the other models and thus most suitable to describe the mortar strength of the SDA-ESP cement blends with R^2_{pred} =0.9091 and had R^2_{pred} = 0.8843 and R^2_{pred} =0.5050 for CCD and BBD respectively. Optimization of the strength prediction for the ternary cement blends was conducted and the optimal condition desirability of 0.997 at SDA/SDA-ESP ratio of 0.2, replacement level 6.05 wt.% and curing age of 60 days with a mortar strength of 44.02 N/mm^2 respectively.

Keywords: Strength Prediction, Optimization, Saw Dust Ash, Eggshell Powder, Replacement Level

1. Introduction

Saw dust ash is obtained by calcination of saw dust which can be employed as a material to replace cement [1]. Culminating from enormous release of such agricultural wastes stemming from disposal issues and health hazards, thus providing opportunities for them to be deplored as a pozzolanic material or filler in the construction sector [2]. Bansal & Chugh [3] investigated the effect of SDA on the concrete properties between 5- 20% at 5% interval and concluded that both 5 and 10% cement replacement with SDA produced improved 7- and 28-day strengths compared with control by 7.55 - 4.89 and 16.69 – 8.71% respectively while beyond 10% resulted in lower strengths. Many researchers have explored several industrial by-products such as rice hull ash [4, 5], bottom ash [6-9], coal fly ash [9, 10] Corn cob ash [11, 12], as a ternary cement blend. Previous work by Olubajo [12] investigated the impact on their cement properties by replacing cement with sawdust ash and eggshell powder. The need to employ several predictive models such as artificial neural network (ANN), response surface methodology (RSM), regression analysis etc due their cumbersome nature and time taken procedures in determining their strengths.

De Weerdt *et al.* [8] conducted optimization of strength prediction using a singular variation of factors. However, this work will involve interaction of different variables such as SDA/SDA-ESP ratio, curing time and replacement level as a function of the blended cement mortar strength. The combination of these factors and its interactions influence the desired response. The application of RSM has been considered as one of the effective methods of optimization compared to the conventional method which requires a long span of time along with its cumbersome nature in production of mortars. RSM is an efficient technique in which the combination of several factors along with their interactions influence the desired responses, for optimization of a process [13]. RSM employs the principle of experimental design which includes the use of Central composite design (CCD) via least squares method to describe the process [14]. Box-Behnken design provides maximum efficiency for experiment comprising of more than two factors and levels respectively with fewer experiments to be conducted in comparison with central composite design [15]. RSM was performed in mortar strength prediction of SDA-ESP cement blends as well as determination of the optimal conditions. The mortar strength of the cement blend (response) was considered as a function of independent variables such as curing time, SDA/SDA-ESP ratio and replacement level. It also enables to quantify the interaction and quadratic effects, thereby, providing a glimpse of the shape of the response surface studied [15]. The design of experiment and randomization of the runs were achieved with Design expert software. The ANOVA significance is to ascertain the adequacy of the model proposed. The responses surface graph further assists in elucidating the dependency/sensitivity of the response on the factors and to locate the optimum conditions.

This research paper considers the investigation of the effects of SDA and ESP on the mortar strength of blended cements as well as employing CCD, BBD and 3FD models to obtain the prediction of the mortar strength in terms of curing time, SDA/SDA-ESP ratio and replacement level. The comparison of the prediction of the mortar strengths via BBD, CCD and 3FD models to ascertain the best predictive model were conducted. This also involves optimization of the process condition of the determination of the mortar strength of SDA-ESP cement blends.

2. Experimental Design

The design summary for responses are the mortar strengths via CCD, BBD and 3FD models with SDA/SDA-ESP ratio, replacement level and curing age as factors. The range of parameters for the independent variables were selected as SDA/SDA-ESP ratio are 0.20, 0.50 and 0.8; SDA+ ESP content are 2.5 wt.%, 7.5 wt.% and 12.5 wt.%; and the curing age are 3, 28 and 60 days respectively. Face centred composite design (FCCD) comprises of three factors and three levels resulting in fifteen runs. For the lower level of the factors implies SDA/SDA-ESP ratio of 0.2, replacement level of 2.5 wt.%, curing age of 3 days; the middle level implies SDA/SDA-ESP ratio of 0.5, replacement level of 7.5 wt.%, curing age of 28 days; for the high level implies SDA/SDA-ESP ratio of 0.8, replacement level of 12.5 wt.%, curing age of 60 days. were employed to investigate the effect of the above factors on the responses. A model was fitted to the response surface generated by the experiment.

$$S_k = f\left(\frac{SDA}{SDA-ESP} ratio, Replacement\ level, Curing\ age\right) \quad (1)$$

Design Expert 6.0.8 software was employed to provide a model that best fits the experimental data and to evaluate the optimum conditions for the various factors. RSM technique was used to determine the optimum factors in order to obtain the maximum mortar strengths for various models: CCD, BBD and 3FD respectively as well as the interaction between the factors were determined. 15, 17 and 32 runs were conducted to fit equation (1) for CCD, BBD & 3FD respectively followed by obtaining the optimum SDA/SDA-ESP ratio, curing age and replacement level for the maximum mortar strength of the cement blend.

$$S_i = \beta_o + \sum_{i=1}^{k}(\beta_i A_i) + \sum_{i=1}^{k}(\beta_{ii} A_i^2) + \sum_{i\,f=1(i\neq j)}^{k}(\beta_{ij} A_i A_j) \quad (2)$$

Where S_i denotes the mortar strengths of various SDA-ESP cement blends. β_o, β_i, β_{ii} and β_{ij} represents the coefficient constant, linear coefficient, quadratic coefficient effect and interaction coefficient effect respectively. A_i and A_j stand for the coded values of variables *i* and *j* respectively. S_1, S_2, S_3 denotes mortar strength via CCD, BBD and 3FD respectively with A_1 A_2 and A_3 as SDA/SDA-ESP ratio which is dimensionless, replacement level in wt.% and curing age in days.

3. Results and Discussion

3.1. Statistical Analysis for Mortar Strengths for SDA-ESP Cement Blends

The experimental data obtained from the mortar strength of cement blends via RSM for CCD, BBD and 3FD are tabulated in Table 1 to investigate SDA/SDA-ESP ratio, replacement level and curing age effects on the mortar strength of cement blends respectively.

The statistical analysis of the results was conducted using ANOVA to evaluate the model and its parameters were tabulated in Table 2. The F-test of the experimental result was determined to establish the statistical significance. In order to obtain the predictive model for the mortar strength of cement blends, some of the model terms were selected or rejected based on the probability value with 95% confidence level. This is followed by plotting of the response surface contour and 3D graphs generated to visualize the individual and interactive effects of the variables. CCD, BBD and 3FD were employed and the factors include SDA/SDA-ESP ratio (A_1), replacement level (A_2) and curing age (A_3) with the responses; mortar strength for CCD, BBD and 3FD S_1, S_2, and S_3 respectively. The investigation of the effect of independent and dependent variables were conducted employing Design Expert. Quadratic equations describe the results obtained for the mortar strengths for CCD, BBD and 3FD respectively:

Table 1. *Experimental Design and Results for CCD (S_1), BBD (S_2) and 3FD (S_3).*

Run	SDA/SDA-ESP ratio A_1	Replacement level wt.%, A_2	Curing age Days, A_3	Mortar strength N/mm² S_1	Mortar strength N/mm² S_2	Mortar strength N/mm² S_3
1	0.2	7.5	60	-	42.70	42.70
2	0.2	12.5	60	44.20	-	44.20
3	0.2	2.5	60	41.10	-	41.10
4	0.2	2.5	28	-	39.40	39.40
5	0.2	7.5	28	34.80	-	34.80
6	0.2	12.5	3	13.60	-	13.60
7	0.2	7.5	3	-	12.30	12.30
8	0.2	12.5	28	-	33.90	33.90
9	0.2	2.5	3	13.30	-	13.30
10	0.5	7.5	28	28.00	28.00	28.00
11	0.5	7.5	3	12.70	-	12.70
12	0.5	7.5	28	-	27.71	27.71
13	0.5	7.5	28	-	28.15	28.15
14	0.5	7.5	28	-	-	27.71
15	0.5	2.5	28	23.20	-	23.20
16	0.5	7.5	28	-	28.00	28.00
17	0.5	12.5	28	26.40	-	26.40
18	0.5	12.5	60	-	28.00	28.00
19	0.5	12.5	3	-	11.20	11.20
20	0.5	7.5	28	-	27.71	27.71
21	0.5	2.5	3	-	11.60	11.60
22	0.5	2.5	60	-	33.10	33.10
23	0.5	7.5	60	37.90	-	37.90
24	0.8	2.5	60	32.50	-	32.50
25	0.8	2.5	28	-	30.00	30.00
26	0.8	12.5	3	13.80	-	13.80
27	0.8	2.5	3	12.20	-	12.20
28	0.8	12.5	60	30.50	-	30.50
29	0.8	7.5	3	-	14.20	14.20
30	0.8	7.5	60	-	36.10	36.10
31	0.8	12.5	28	-	27.50	27.50
32	0.8	7.5	28	26.20	-	26.20

Equations (3) - (5) denote the quantitative effect of the independent variables such as SDA content (SDA/SDA-ESP ratio, replacement level and curing age (A_1, A_2, A_3) and their interactions on the dependent variable; mortar strengths from CCD, BBD and 3FD S_1, S_2 and S_3 respectively.

$$S_1 = 10.34 - 29.24A_1 + 2.084A_2 + 0.894A_3 + 30.494A_1^2 - 0.118A_2^2 - 0.0049A_3^2 - 0.317A_1A_2 - 0.308A_1A_3 - 0.0009A_2A_3) \quad (3)$$

$$S_2 = 23.91 - 61.85A_1 - 0.183A_2 + 1.204A_3 + 56.31A_1^2 - 0.0113A_2^2 - 0.01A_3^2 + 0.5A_1A_2 - 0.227A_1A_3 - 0.0079A_2A_3 \quad (4)$$

$$S_3 = 17.082 - 47.175A_1 + 0.809A_2 + 1.11A_3 + 46.37A_1^2 - 0.0518A_2^2 - 0.009A_3^2 - 0.044A_1A_2 - 0.282A_1A_3 - 0.0030A_1A_3 \quad (5)$$

The factors: A_1, A_2 and A_3 were inserted into the equations to determine the theoretical responses; S_1 S_2 and S_3 respectively. The mortar strength prediction via the three models significantly satisfied quadratic models in relation to the experimental design and interaction of the independent variables.

Table 2 shows the ANOVA for mortar strengths from CCD, BBD and 3FD with all producing F values for lack of fit was 0, 381.39 and 211.4 respectively. Table 3 indicates the model summary statistics for the 3 models employed for mortar strength predictions of SDA-ESP cement blends. The Predicted R^2 value (R_{pred}^2 = 0.9018) and Adjusted R^2 value (R_{adj}^2 =0.9392) for the 3FD model was very close compared with the other models and found to be the most suitable model to describe the mortar strength of SDA-ESP-cement blends. All three models gave adequate precision ratios which were greater than four indicating a desirable signal [16]. Table 4 also indicates that the models F values for (S_1, S_2, S_3) CCD, BBD and 3FD were significant, thus there is 0.01% probability of the large model F value of 71.33, 24.77 and 54.17 could occur due to noise respectively.

Chauhan and Gupta [17], Ikara *et al*. [18], Olubajo *et al*. [19] and Olubajo & Aderemi [20] suggested that a fitted model was considered acceptable if R^2 is greater than 80% and not less than 75% respectively and the predicted values for developed models should possess significantly closer relationship in comparison with experimental data. Based on this, 3FD was found to be most suitable. In this study R^2 and R^2_{adj} values for CCD, BBD and 3FD were 0.9923 and 0.9759; 0.9696 and 0.9304; 0.9450 and 0.9392 implying the efficiency of the model in prediction of indicating appropriateness of the developed model in predicting SDA- ESP cement blends mortar strength for three independent variables with R^2 and R^2_{adj} value near 1.

Table 2. *ANOVA for Mortare Strength of cement blended with SDA and ESP via CCD, BBD and 3FD models.*

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model S_1	1671.03	9	185.67	71.33	< 0.0001	Significant
A_1	105.2	1	105.2	40.42	0.0014	Significant
A_2	3.8	1	3.8	1.46	0.2809	
A_3	1454.44	1	1454.44	558.76	< 0.0001	Significant
A_1^2	19.37	1	19.37	7.44	0.0414	Significant
A_2^2	22.46	1	22.46	8.63	0.0323	Significant
A_3^2	39.7	1	39.7	15.25	0.0114	Significant
A_1A_2	1.8	1	1.8	0.69	0.4429	
A_1A_3	55.61	1	55.61	21.37	0.0057	Significant
A_2A_3	0.13	1	0.13	0.052	0.8289	
Residual	13.01	5	2.6			
Lack of Fit						
Model S_2	1405.5	9	156.12	24.77	0.0002	Significant
A_1	57.10	1	57.10	9.06	0.0197	Significant
A_2	24.51	1	24.51	3.89	0.0893	
A_3	1026.05	1	1026.05	162.77	< 0.0001	Significant
A_1^2	108.15	1	108.15	17.16	0.0043	Significant
A_2^2	0.33	1	0.33	0.053	0.8243	
A_3^2	270.56	1	270.56	42.92	0.0003	Significant
A_1A_2	2.25	1	2.25	0.36	0.5690	
A_1A_3	15.17	1	15.17	2.41	0.1648	
A_2A_3	5.13	1	5.13	0.81	0.3970	
Residual	44.12	7	6.30			
Lack of Fit	43.97	3	14.66	381.39	< 0.0001	Significant
Model S_3	3004.95	9	333.88	54.17	< 0.0001	Significant
A_1	162.04	1	162.04	26.29	< 0.0001	Significant
A_2	3.22	1	3.22	0.52	0.4777	
A_3	2478.08	1	2478.08	402.04	< 0.0001	Significant
A_1^2	124.58	1	124.58	20.21	0.0002	Significant
A_2^2	11.97	1	11.97	1.94	0.1773	
A_3^2	330.56	1	330.56	53.63	< 0.0001	Significant
A_1A_2	0.053	1	0.053	0.00865	0.9267	
A_1A_3	69.95	1	69.95	11.35	0.0028	Significant
A_2A_3	2.25	1	2.25	0.37	0.5519	
Residual	135.6	22	6.16			
Lack of Fit	135.41	17	7.97	211.4	< 0.0001	Significant

Table 3. *Model Summary for CCD, BBD and 3FD for mortar strengths for SDA-ESP cement blends.*

Source	CCD	BBD	3FD
Sum of Squares	86.20	362.60	*420.57*
DF	3	3	*3*
Mean square	28.73	120.87	*140.19*
F value	11.04	19.17	*22.74*
Prob> F	0.0121	<0.0009	*< 0.0001*
$Std_{Dev.}$	1.61	2.51	*2.48*
R^2	0.9923	0.9696	*0.9568*
R^2_{adj}	0.9784	0.9304	*0.9392*
R^2_{pred}	0.8843	0.5050	*0.9018*
PRESS	194.79	717.31	*308.39*
			Suggested

Table 4. *Diagnostic Statistics for mortar strength for various cement blends for CCD, BBD & 3FD models.*

Standard Order	SDA/SDA-ESP ratio	Replacement level wt.%	Curing age Days	Actual Value N/mm^2	Predicted Value N/mm^2 CCD	Predicted Value N/mm^2 BBD	Predicted Value N/mm^2 3FD
1	0.2	2.5	3	13.30	12.47	-	14.25
2	0.2	7.5	3	12.30	-	14.35	15.62
3	0.2	12.5	3	13.60	14.91	-	14.40
4	0.2	2.5	28	39.40	-	37.51	33.85
5	0.2	7.5	28	34.80	33.47	-	34.84
6	0.2	12.5	28	33.90	-	32.78	33.24
7	0.2	2.5	60	41.10	42.11	-	43.39
8	0.2	7.5	60	42.70	-	41.18	43.90
9	0.2	12.5	60	44.20	44.04	-	41.82
10	0.5	2.5	3	11.60	-	8.89	9.54
11	0.5	7.5	3	12.70	13.29	-	10.85
12	0.5	12.5	3	11.20	-	10.41	9.56
13	0.5	2.5	28	23.20	24.22	-	27.03
14	0.5	7.5	28	28.00	27.80	-	27.96
15	0.5	12.5	28	26.40	25.48	-	26.29
16	0.5	2.5	60	33.10	-	34.10	33.88
17	0.5	7.5	60	37.90	37.41	-	34.31
18	0.5	12.5	60	28.00	-	30.5	32.16
19	0.5	7.5	28	27.71	27.80	27.91	27.96
20	0.5	7.5	28	27.71	-	27.91	27.96
21	0.5	7.5	28	27.71	-	27.91	27.96
22	0.5	7.5	28	28.15	-	27.91	27.96
23	0.5	7.5	28	28.00	-	27.91	27.96
24	0.8	2.5	3	12.20	12.19	-	13.19
25	0.8	7.5	3	14.20	-	15.65	14.42
26	0.8	12.5	3	13.80	12.74	-	13.07
27	0.8	2.5	28	30.00	-	31.12	28.57
28	0.8	7.5	28	26.20	27.63	-	29.42
29	0.8	12.5	28	27.50	-	26.91	27.69
30	0.8	2.5	60	32.50	31.31	-	32.70
31	0.8	7.5	60	36.10	-	34.12	33.07
32	0.8	12.5	60	30.50	31.33	-	30.86

In a bid to obtain the most suitable empirical model which fit the experimental data, Zaibunnisa et al. [21] and Arsenovic *et al*. [22] stated that a model is said to be adequate if R^2 value is near 1 but felt that a significantly high R^2 value do not necessarily implies the adequacy of the model. Zaibunnisa *et al*. [21] also buttressed on the fact that R^2_{adj} values greater than 90% was a strong indication of the model's appropriateness to evaluate the model adequacy on the response for CCD, BBD and 3FD respectively which were closer to unity.

ANOVA indicates whether the factors and their interactions on the responses were significant. From Table 4, the model terms for mortar strength prediction for SDA-ESP cement blend via CCD include: A_1, A_3, A_1^2, A_2^2, A_3^2, A_2A_3 and A_1A_3 were significant whereas, BBD indicated A_1, A_3, A_1^2 and A_3^2 are significant with no interactions considered significant. Similarly, ANOVA results for 3FD indicated that linear, quadratic terms for replacement level A_2 were all insignificant with A_1, A_3, A_1^2, A_3^2, A_1A_3 terms found to be significant.

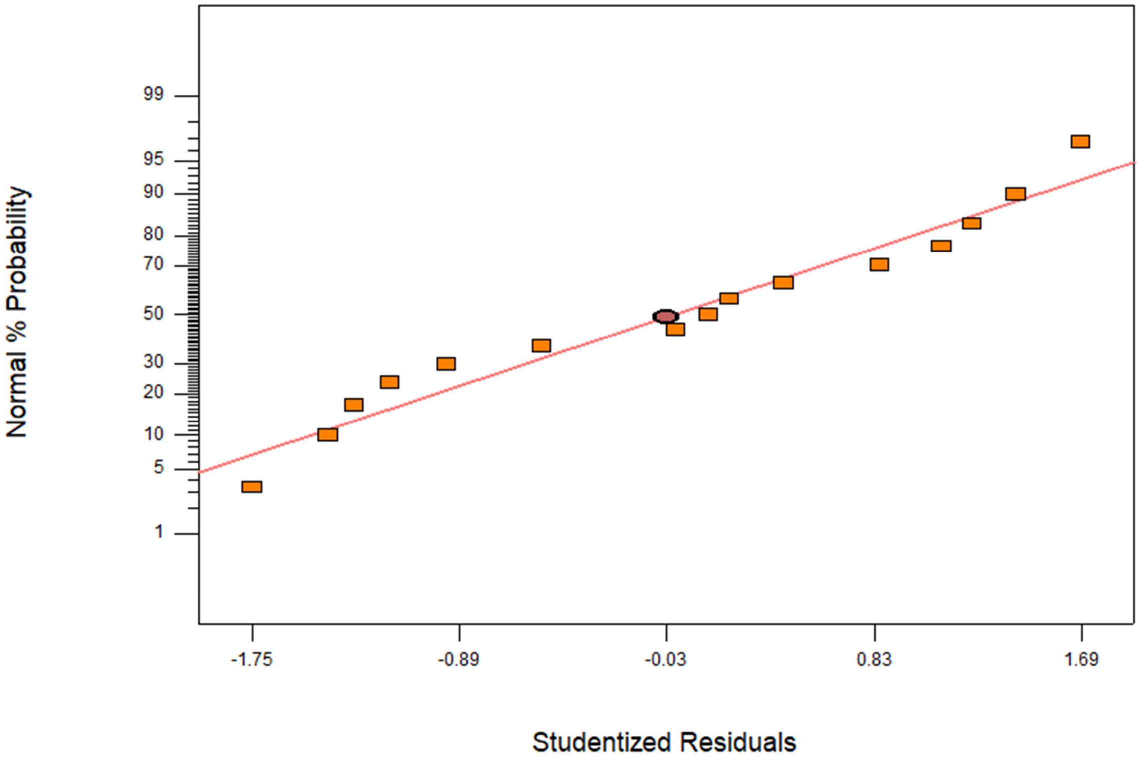
The SDA/SDA-ESP ratio (A_1) had F values of 40.42, 9.06 and 26.29, while the curing age (A_3) produced a F value of 558.76, 162.77, and 402.04, whereas, replacement level (A_2) had F value of 1.46, 3.89 and 0.52, for mortar strengths via CCD, BBD and 3FD models respectively. The curing age was observed to have a significant impact on the mortar strengths in comparison with the other factors which was evident by significantly higher F values for all the models. The F values for the quadratic term of the SDA/SDA-ESP ratio were 7.44, 17.16 and 20.21 for CCD, BBD & 3FD models with their p values ranging between $p< 0.05$ or $p < 0.10$ respectively while the replacement level quadratic term F values of 8.63, 0.053 and 1.94 for CCD, BBD & 3FD models with only BBD's p values ranging between $p< 0.05$ or $p < 0.10$ respectively. Whereas the quadratic terms of curing age F values of 15.25, 42.92 and 53.63 for CCD, BBD & 3FD models with all p values ranging between $p< 0.05$ or $p < 0.10$ respectively. Low F values were obtained for quadratic terms of interaction between SDA/SDA-ESP ratio and replacement level and the interaction between replacement level and curing age, confirming the fact that the above interactions are insignificant for responses for CCD, BBD and 3FD models respectively. It was observed from the ANOVA that both terms A_3 & A_3^2 strongly influenced the mortar strengths of the three models.

The ANOVA of the experimental results from the mortar strengths of cement blends showed that the regression is statistically significant p<0.0001) and quadratic models were suitable for the three responses. However, the lack of fit was statistically insignificant at 99% confidence level, implying that the models' residual variance was insignificant which was in accordance with Dutta *et al*. [23] and Sivaramu *et al*. [24] works. ANOVA indicated significant effect of the curing age;

quadratic term of the curing age; interaction between curing age and SDA/SDA-ESP ratio on the response for CCD and 3FD while only the curing age and quadratic term of the curing age were significantly influenced the response for BBD.

3.2. Predicted vs Actual and Normal Probability Graphs

Figures 1(a), 2(a) and 3(a) depicted that there is a strong correlation between the experimental and the predicted values for mortar strength with CCD, BBD and 3FD respectively.



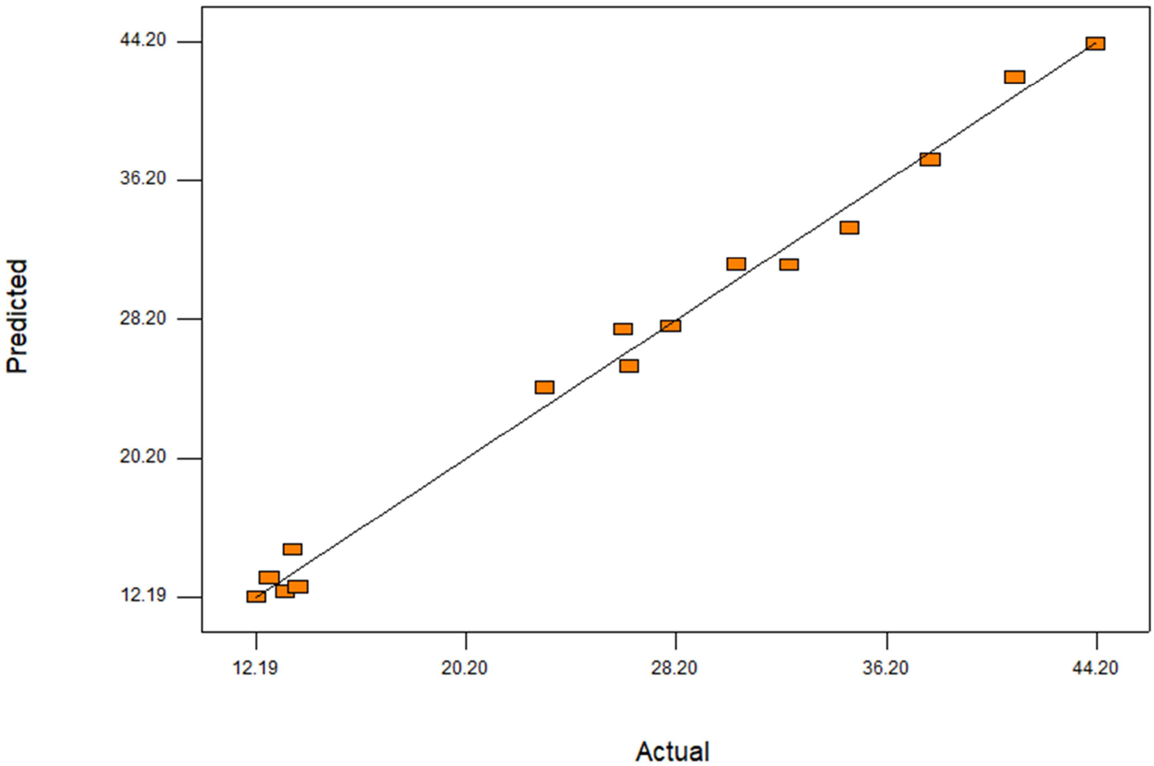


Figure 1. *(a) Predicted vs Actual graph of the model developed for mortar strengths with CCD (b) Normal probability graph of residuals indicating significance of the model developed for mortar compressive with CCD model.*

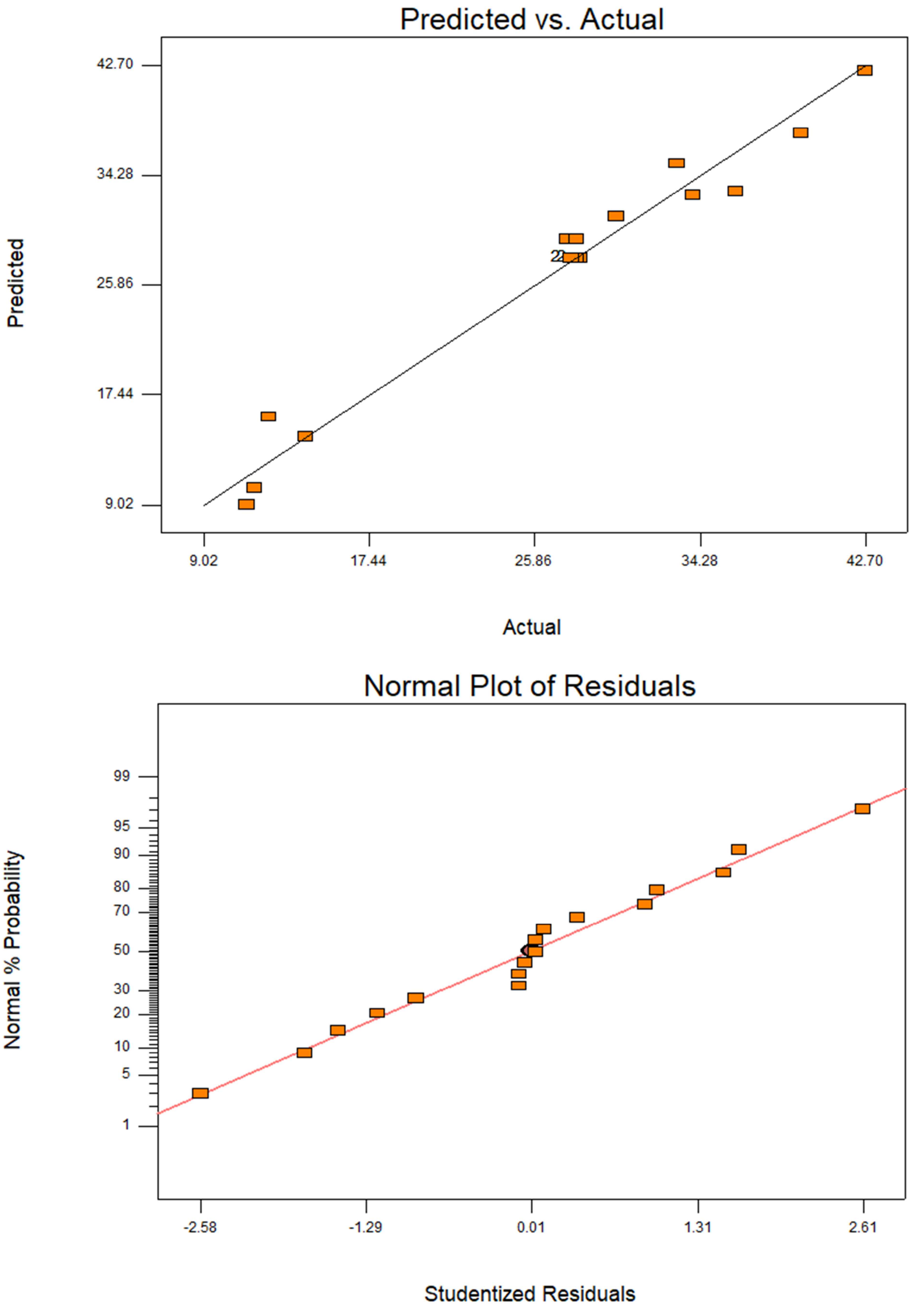


Figure 2. *(a) Predicted vs Actual graph of the model developed for mortar compressive with BBD and (b) Normal probability graph of residuals indicating significance of the model developed for mortar compressive with BBD model.*

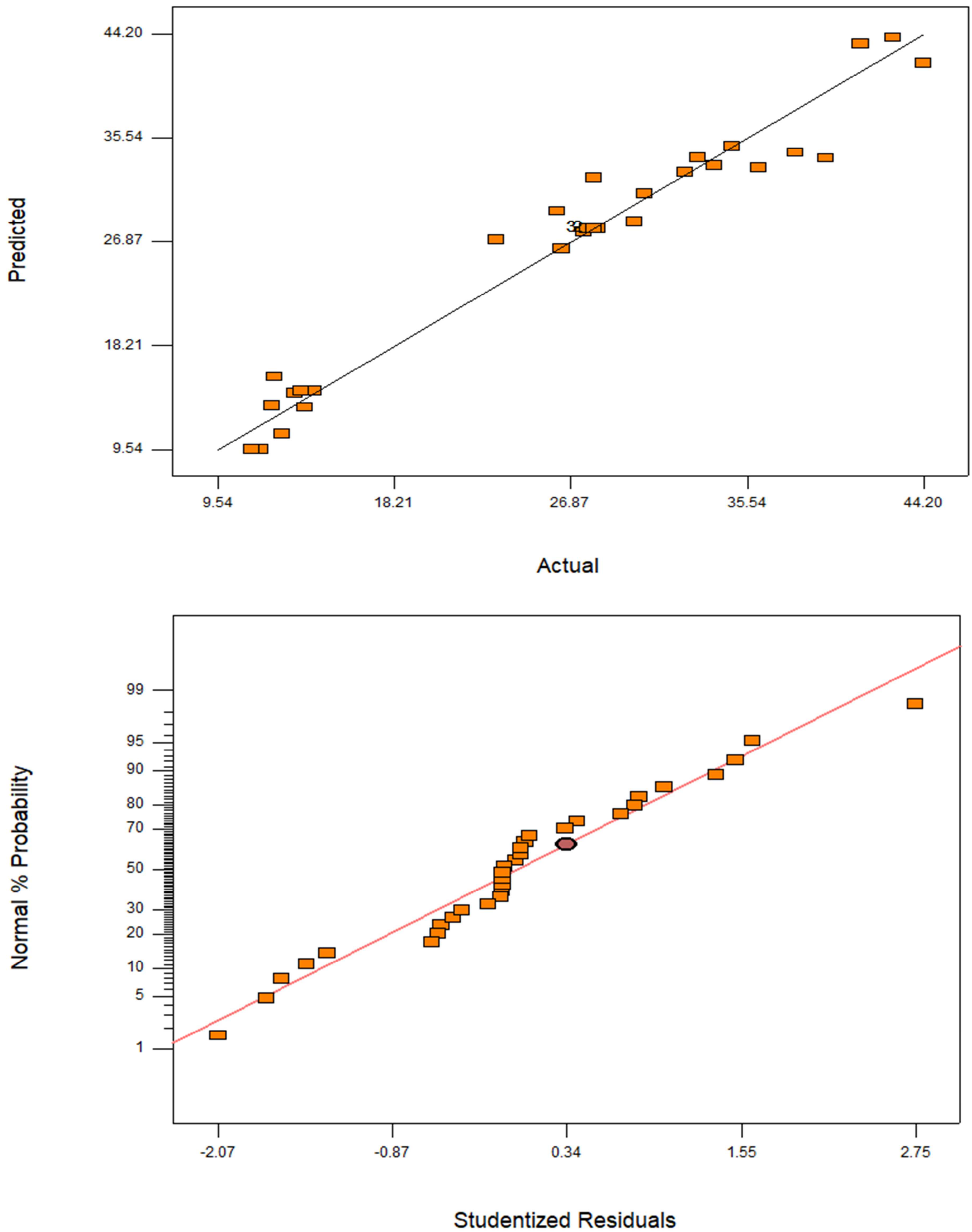


Figure 3. *(a) Predicted vs Actual graph of the model developed for mortar strength with 3FD and (b) Normal probability graph of residuals indicating significance of the model developed for mortar strength with 3FD model.*

It can be deduced via Design Expert that the predicted model was significantly satisfactorily in mortar strength prediction of cement blended with SDA and ESP with 3FD and CCD respectively. The correlation between the predicted and the actual values of the mortar strength of SDA-ESP cement blends for CCD, BBD and 3FD models presented in Table 4.

The 3-Dimensional and contour graphs elucidate the correlation between the dependent variable (responses) and the independent variables (factors). Figures 4-6 depicts the diagnostic graphs required to evaluate if the regression model is satisfactory which illustrates the 3 dimensional and contour graphs for SDA/SDA-ESP ratio A_1, replacement level A_2 and curing age A_3 influences on the mortar strength of cement blends via CCD S_1, mortar strength of cement blends via BBD

S_2 and mortar strength of cement blends via 3FD S_3. The 3D curves illustrate the correlation between the several factors as well as determination of the optimum conditions for maximum strengths. The parabolic behavior seen in the contour graphs suggests strong correlations between factors [25] as shown in Figures 4-6.

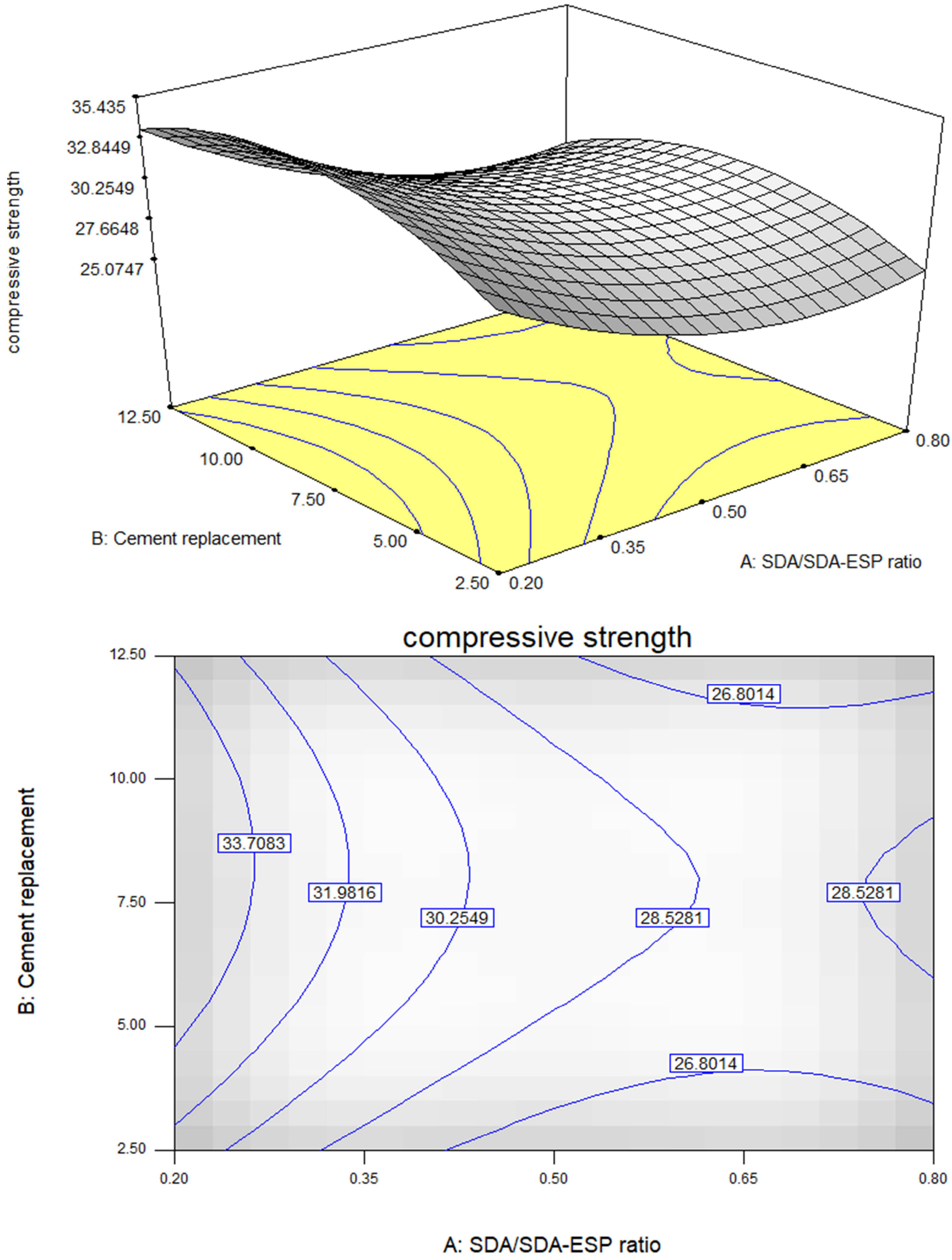


Figure 4. *3 Dimensional and Contour graphs indicating the influence of the factors (A_1: SDA/SDA-ESP ratio, A_2: replacement level, A_3: curing age) for mortar strength of cement blends for CCD.*

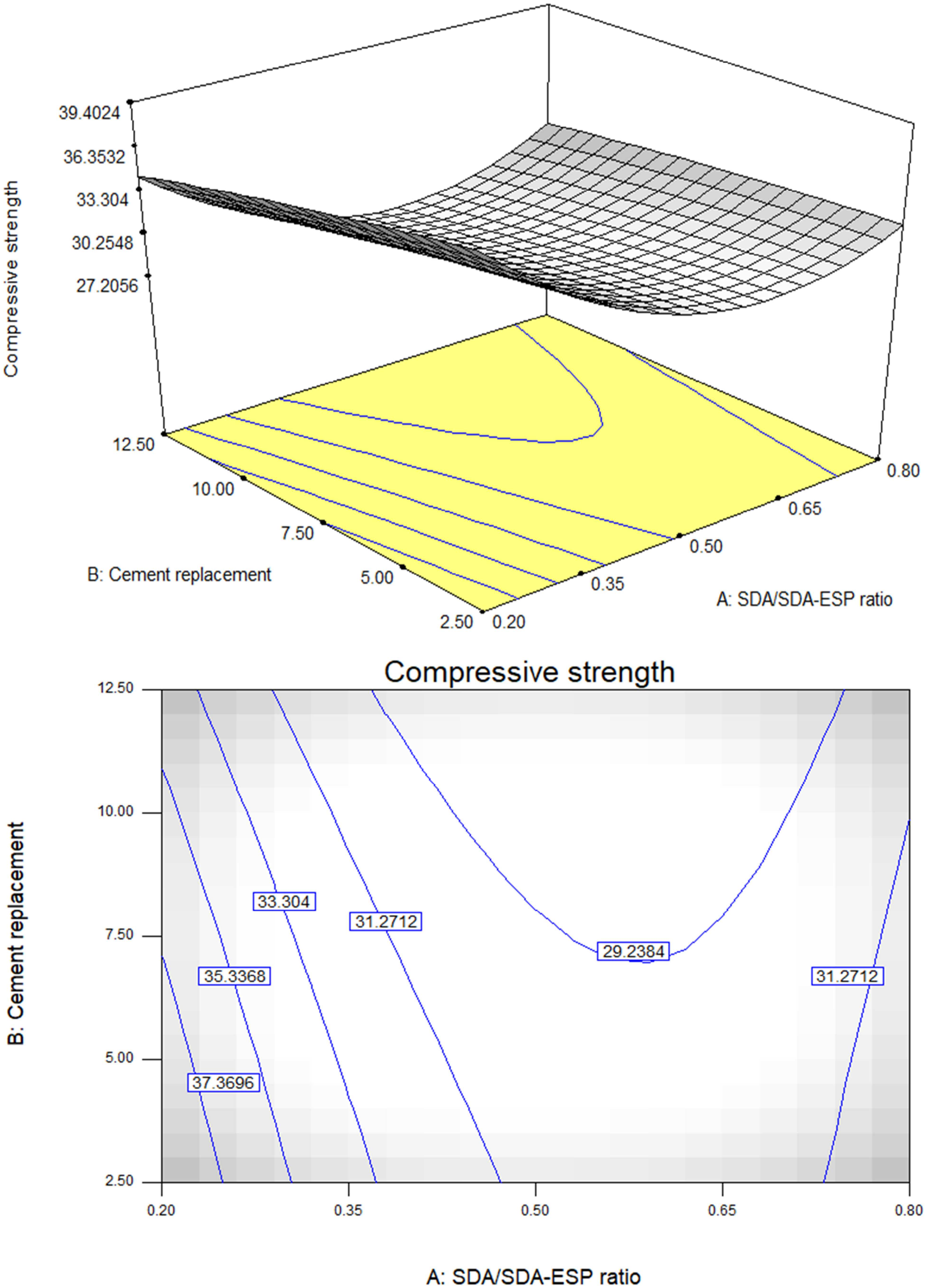


Figure 5. *3 Dimensional and Contour graph indicating the influence of the factors (A_1: SDA/SDA-ESP ratio, A_2: replacement level, A_3: curing age) for mortar strength of cement blends for BBD.*

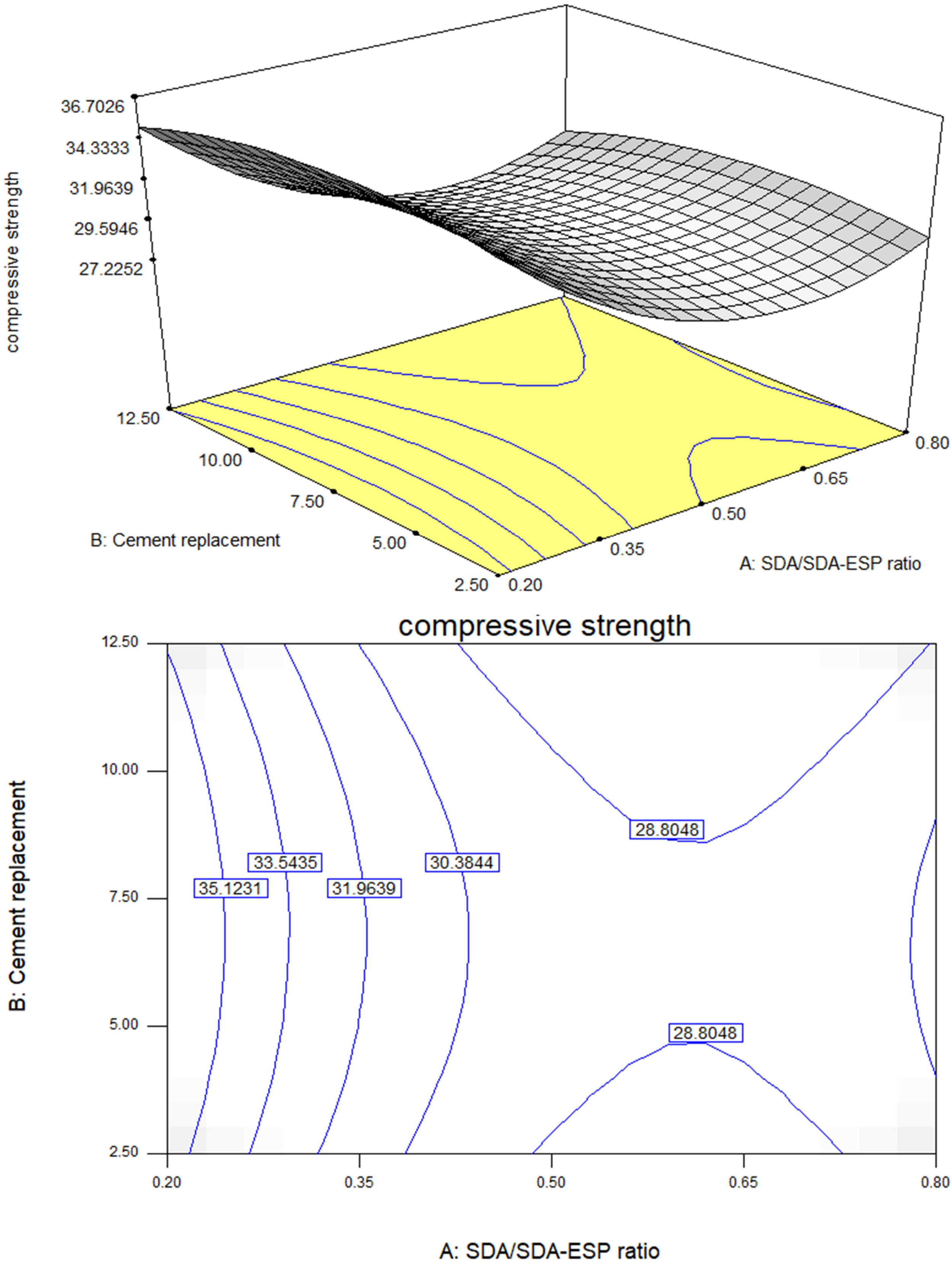


Figure 6. *3 Dimensional and Contour graph indicating the influence of the factors (A_1: SDA/SDA-ESP ratio, A_2: replacement level, A_3: curing age) for mortar strength of cement blends for 3FD.*

Figure 6 indicated by 3D surface graphs experienced and increase in the mortar strength of the cement blends as SDA/SDA-ESP ratio and curing age were increased from lower to the higher level. The various models showed an increase in the mortar strength of the cement blend increased as the curing age progressed between 3 to 60 days at constant SDA/SDA-ESP ratios of 0.2, 0.4, 0.5, 0.6 and 0.8 respectively. It could also be seen that the mortar strength of the cement blends experienced increments as curing days progressed. The mortar strength of the blended cements for CCD experienced a variation with increase in the SDA/SDA-ESP ratio whereas the mortar strength of cement blends via BBD experienced an increase with an increase in curing days and SDA/SDA-ESP ratio.

Similarly, from the model for 3FD, an increase in the mortar strength of the cement blends was observed as the curing days progressed from 3 to 60 days at a given SDA/SDA-ESP ratio and a given replacement level (since the replacement level in the model was insignificant). Whereas a decrease followed by an increase in the mortar strengths were observed as the SDA/SDA-ESP ratio was increased from 0.2 to 0.8 for all curing days except for 60 days in which led to a decrease in the mortar strength of the cement blends as seen in Figure 7.

An increase in the SDA/SDA-ESP ratio and curing age simultaneously resulted in an increase in the mortar strengths of SDA-ESP cement blend as illustrated in Figure 8. Similarly, it could also be observed from the ANOVA results that the curing age of the cement blends produced a high F value signifying significantly influence in the mortar strength of the cement blend for all 3 models employed. This significant increase in the mortar strength of SDA- ESP cement blends could be attributed to the fact that as the curing age progressed hydration reactions occurs coupled with slow pozzolanic reaction between the excess lime presence with silica present in the SDA producing more CSH as the curing age is lengthened, thus, enhancing the strength of the cement blends.

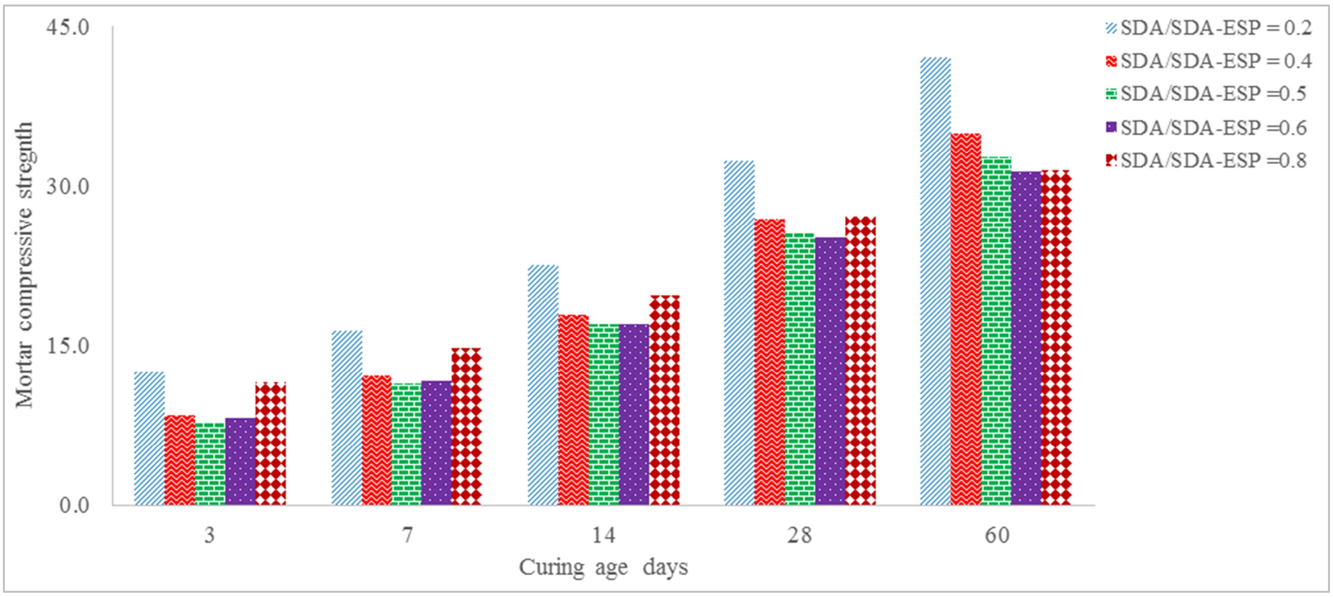


Figure 7. *Effect of curing age and SDA/SDA-ESP ratio on the mortar strengths of cement blends via 3FD.*

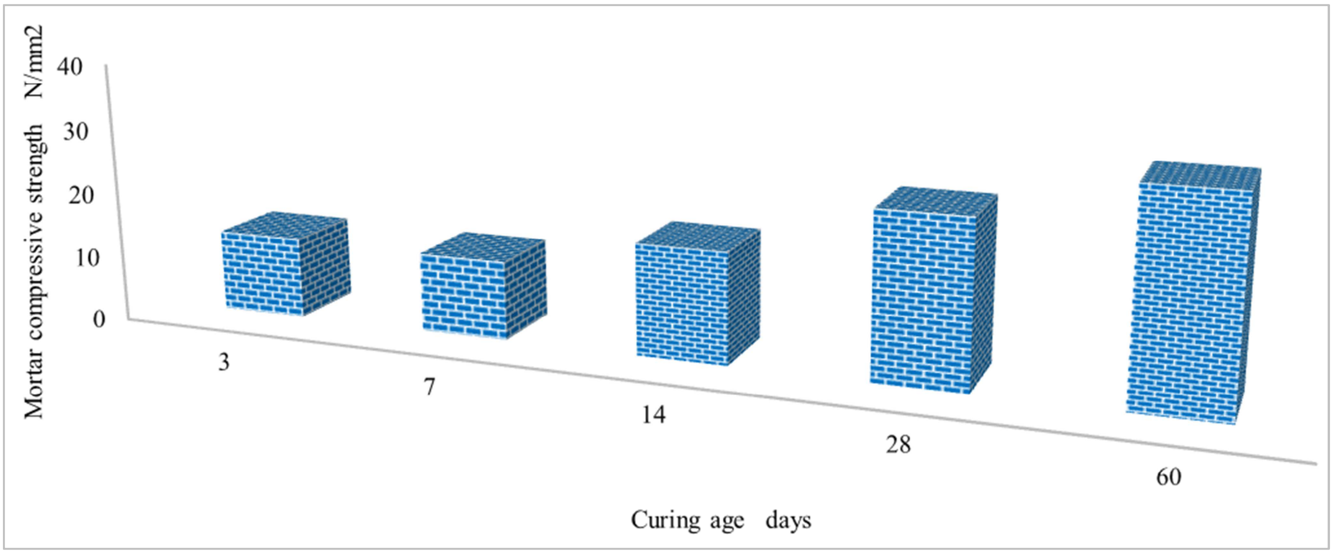


Figure 8. *Interaction between SDA/SDA-ESP ratio and curing age on the mortar strength of SDA-ESP cement blend for 3FD model.*

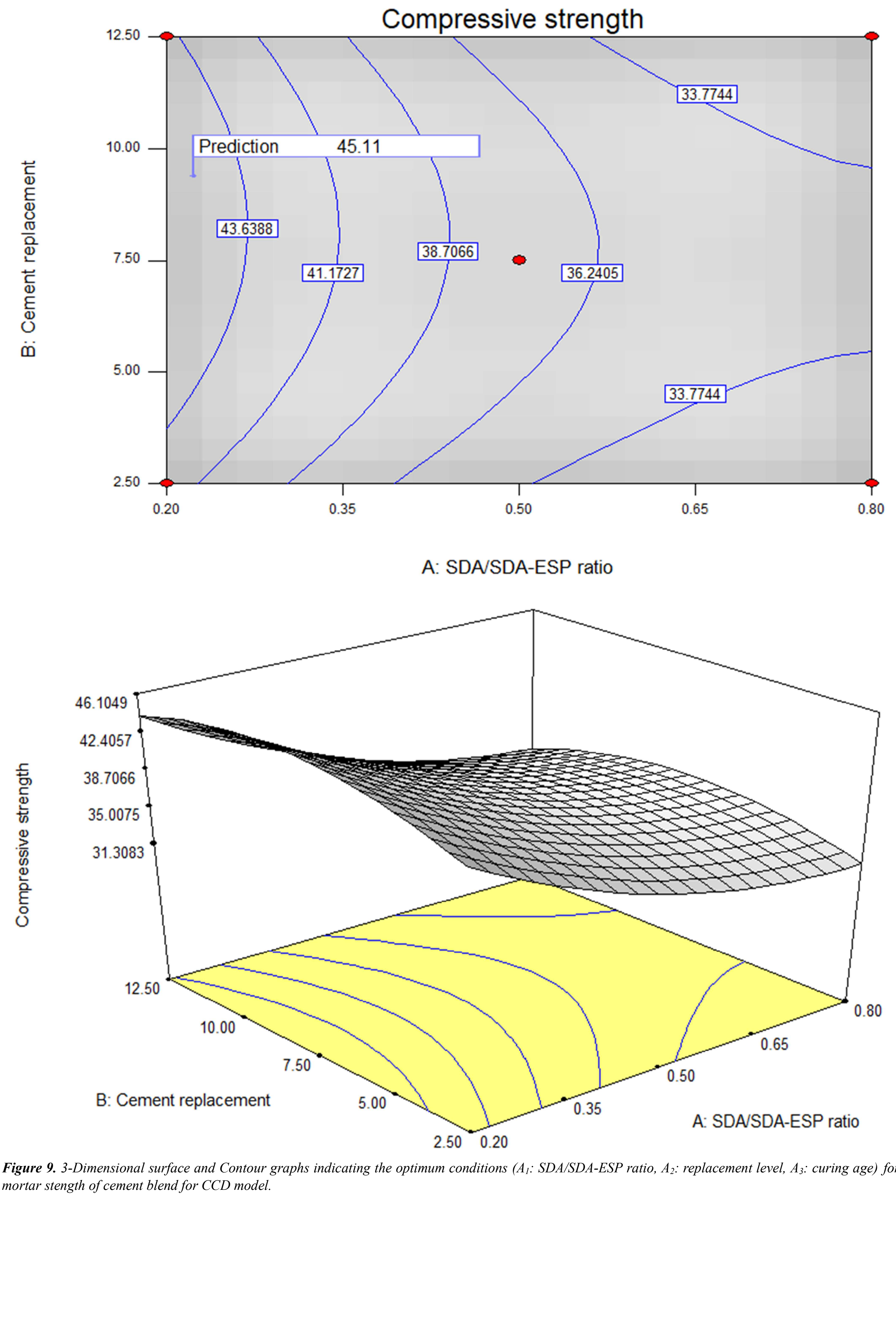


Figure 9. *3-Dimensional surface and Contour graphs indicating the optimum conditions (A_1: SDA/SDA-ESP ratio, A_2: replacement level, A_3: curing age) for mortar stength of cement blend for CCD model.*

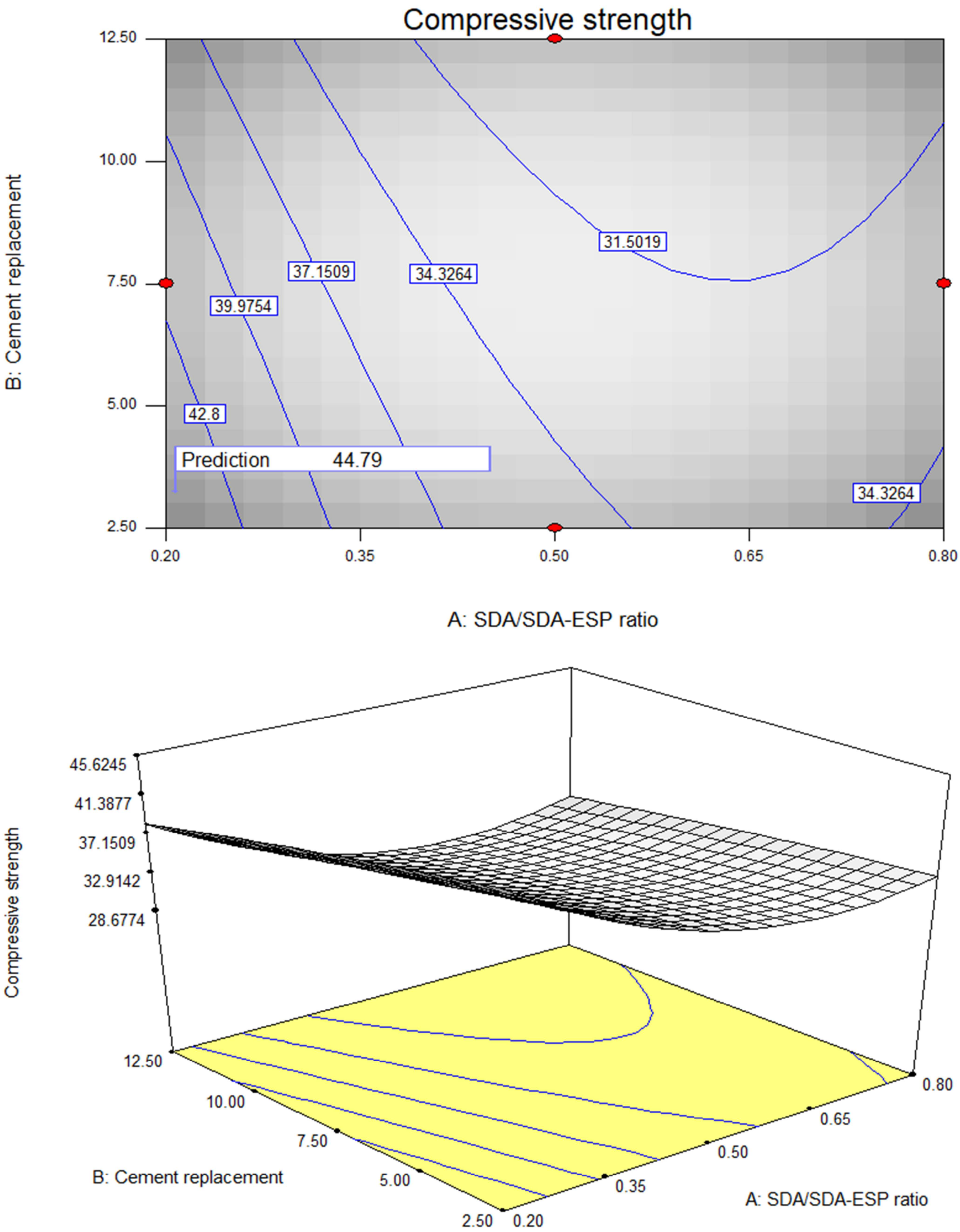


Figure 10. *3-Dimensional surface and Contour graphs indicating the optimum conditions (A_1: SDA/SDA-ESP ratio, A_2: replacement level, A_3: curing age) for mortar stength of cement blend for BBD model.*

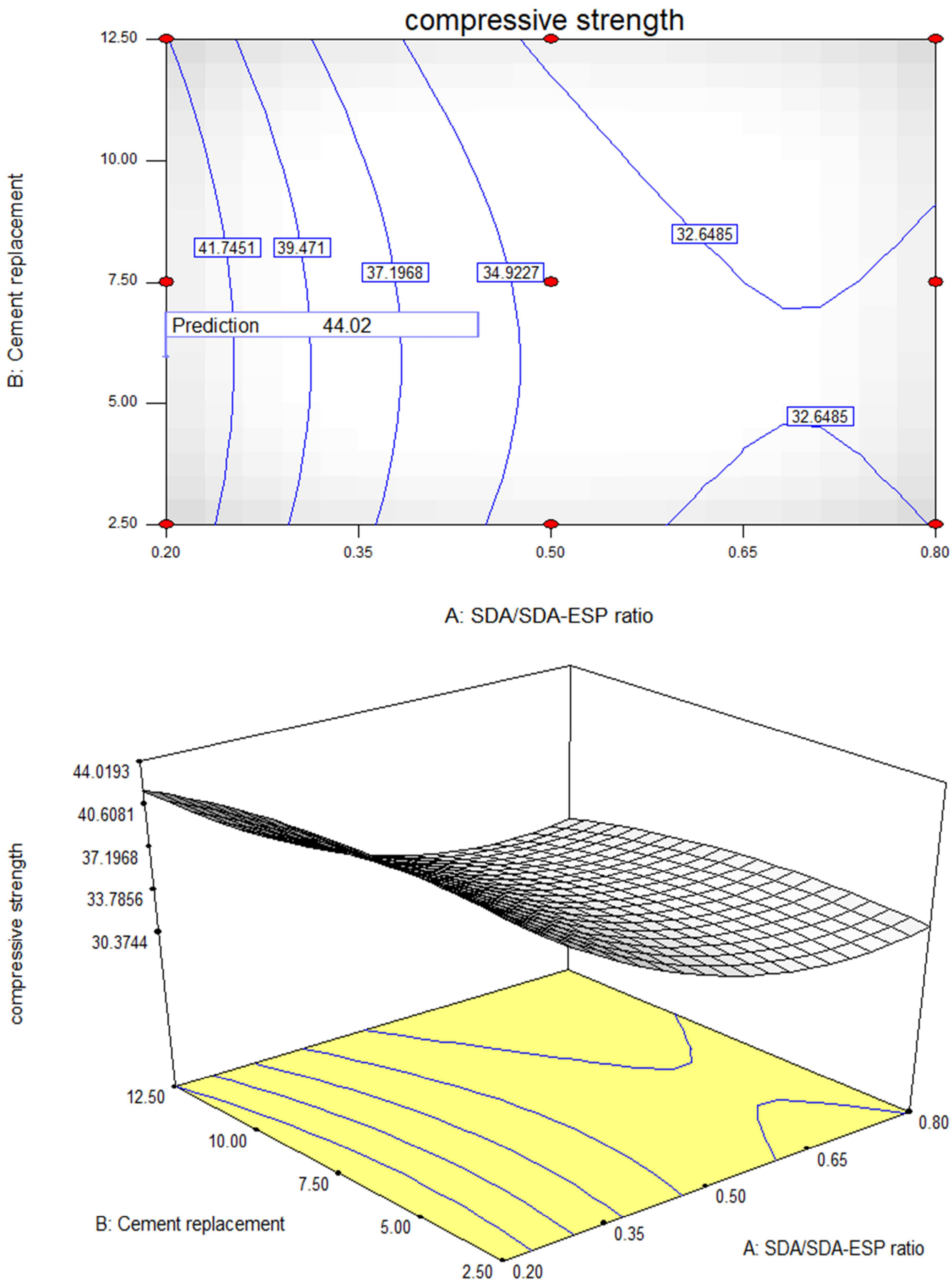


Figure 11. *3-Dimensional surface and Contour graphs indicating the optimal conditions (A_1: SDA/SDA-ESP ratio, A_2: CM content, A_3: curing age) for mortar stength of cement blend for 3FD model.*

3.3. Optimization of Mortar Strength of SDA-ESP Cement Blends

Optimization of the mortar strength of SDA-ESP cement blends were carried out and the optimal condition with desirability of 0.997 at SDA/SDA-ESP ratio of 0.2, replacement level 6.05 wt.% and curing age of 60 days with a mortar strength of 44.02 N/mm^2 for 3FD while for CCD and BBD optimal conditions of desirability of 1.000 and 1.000, SDA/SDA-ESP ratio of 0.22 and 0.21, replacement level of 9.38 and 3.24 wt.%, curing age of 60 and 60 days and mortar strength of 45.11 and 44.79 N/mm^2 respectively.

Figures 9-11 indicated similar pattern with increase in mortar strengths of SDA-ESP cement blend as the curing day progressed.

4. Conclusion

Increasing the curing time from 3 – 60 days and SDA/SDA-ESP ratio from 0.2 – 0.8 culminated in an increase in the mortar strength gain of SDA-ESP cement blends. Experimental results obtained by varying the factors such as curing time, SDA/SDA-ESP ratio and replacement level on the mortar strengths of SDA-ESP cement blends found all models best suited with quadratic models respectively. Amongst the 3 models, 3FD was found to be most suitable in predicting the mortar strength which was evident by the closeness of the R_{pred}^2 with R_{adj}^2 values. The ANOVA of the experimental results from the mortar strength of cement blends indicated that quadratic models were suitable for the responses from the 3 models. however, the lack of fit is statistically insignificant at 0.99 confidence level, thus the residual variance for the models were insignificant. The curing age produced a strong influence on the mortar strength compared with SDA/SDA-ESP ratio for CCD, BBD and 3FD models respectively. The ANOVA clearly showed that the mortar strength prediction via 3FD model gave a better model compared to CCD and BBD. An empirical relationship was obtained to establish a relationship between the mortar strength of SDA-ESP cement blend and independent variable such as replacement level, SDA/SDA-ESP ratio and curing age via 3D response and contour graphs. The mortar strength of 44.02, 45.11 and 44.79 N/mm^2 via 3FD, CCD and BBD of 0.997, 1.00 and 1.00 were obtained under optimal value of SDA/SDA-ESP ratio of 0.20, 0.22, 0.21 and replacement level of 6.05, 9.38 and 3.24 wt.% respectively.

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References

[1] Elinwa, A. U., Ejeh, S. P. and Mamuda, A. M. (2008). Assessing of the fresh concrete properties of self-compacting concrete containing sawdust ash. Construction and Building Materials, 22 (6), 1178-1182.

[2] Antiohos, S., Maganari, K., Tsimas, S. (2005). Evaluation of blends of high and low calcium fly ashes for use as supplementary cementing materials. Cement & Concrete Composites, 27, 349-356.

[3] Chugh S. and Bansal R Study on Saw dust ash as partial replacement with cement. International Journal of Engineering Technology Science and Research IJETSR 3 (4), 126-130.

[4] Osha O. A, Olubajo O. O. and B. Gutti (2015). Investigation of cementitious material produced from rice husk ash and lime waste. *Nigerian Journal of Tropical Engineering*, 8 (1&2), 73-80.

[5] Olubajo, O. O, Isa Y. M., Ayeni S., Menta S. and Nwuhu W. (2020). A Study on Ordinary Portland cement blended with Rice Husk Ash and Metakaolin *Path of Science*, 6 (1), 3001-3019.

[6] Olubajo, O. O. Osha A. O., El- Nafaty, U. A. and Adamu H. A (2017). A study on Coal bottom ash and limestone effects on the hydration and physico-mechanical properties of ternary cement blends. Ph.D. Thesis. Abubakar Tafawa Balewa University, Bauchi, Nigeria.

[7] Olubajo, O. O. and O. A. Osha. (2013). Influence of bottom ash and limestone powder on the properties of ternary cement and mortar". *International Journal of Engineering Research and Technology*, 12 (7), 1201-1212.

[8] De Weerdt, K., Kjellsen, K. O., Sellevold, E. and Justnes, H. (2011). Synergy between fly ash and limestone powder in ternary cements, *Cement and Concrete Composites*, *33* (1), 30-38.

[9] Georgescu, M. and Saca, N. (2009). Properties of blended cements with limestone filler and fly ash content. *Scientific Bulletin*, Series B, *71* (3), 13-16.

[10] Kaya A. (2010) A study on blended bottom ash cements. Masters in Science. Thesis, Middle East Technical University. 1-73.

[11] Mujedu K. A., Adebara S. A., & Lamidi I. O. (2014). The use of corn cob ash and saw dust ash as cement replacement in concrete works. *The International Journal of Engineering and Science (IJES)* 3 (4), 22 – 28.

[12] Olubajo O. O. (2020). The effect of eggshell powder and saw dust ash on the physicomechnical properties of blended cement, American Journal of Construction and Building Materials, 4 (2), 78-88.

[13] Montgomery D. C., Runger G. C., and Hubele N. F., *Engineering Statistics*, John Wiley and Sons Inc., Hoboken, NJ, 2001.

[14] Vining G. G., *Statistical Methods for Engineers*, Duxburg Press, An International Thomason Publishing, Europe, London 1V7AA, 2003.

[15] Sivakumar D., Manohar M., Joseph J., and Selvaraj T., (2013) Application of Box Behnken design to optimize the parameters for turning Inconel 718 using coated carbide tools International Journal of Scientific & Engineering Research IJSER, 4, 4, 620-642.

[16] Koocheki A., Taherian A. R., Razavi S. M. A., and Bostan A. (2009). Response surface methodology for optimization of extraction yield, viscosity, and hue and emulsion stability of mucilage extracted from Lepidiumperfoliatum seed. *Food Hydrocolloids* 23, 2369–2379, 2009.

[17] Chauhan B. and Gupta R., (2004). Application of statistical experimental design for optimization of alkaline protease production from bacillus species RGR-14", *Process Biochem*., 39, 2115-2122.

[18] Ikara I. A., Kundiri A. M. and Mohammed A. (2019). Predicting CBR values of black cotton soil stabilized with cement and waste glass admixture using regression model. *American Journal of Traffic and Transportation Engineering* 4 (1), 31-36.

[19] Olubajo O. O., Isa Y. M. and Osha O. A. (2019), Prediction of loss on ignition of ternary cement containing coal bottom ash and limestone using central composite design. *Path of Science*, 5 (8), 2010-2019.

[20] Olubajo O. O. and Aderemi B. O. (2018). Optimization of the decomposition of aluminum sulfate derived from kaolin clay using response surface methodology *Proceeding of National Conference 2018.*

[21] Zaibunnisa A. H., Norasikin S., Mamot S., and Osman H. (2009). An experimental design approach for the extraction of volatile compounds from turmeric leaves (Curcuma domestica) using Pressurized Liquid Extraction (PLE). *Journal of Food Science and Technology* 42, 233-238.

[22] Arsenovic M., Pezo L. and Radojević Z., (2012). Response surface method as a tool for heavy clay firing process optimization: roofing tiles*. Processing and Application of Ceramics* 6 (4), 209–214.

[23] Dutta S., Ghosh A., Moi S. C., and Saha R., (2015). Application of response surface methodology for optimization of reactive azo dye degradation process by Fenton's oxidation, *International Journal of Environmental Science and Development,* 6, 111-116.

[24] Sivaramu V., Sumithra A., Sundar M. S. (2015). Performance analysis of mustard and pongamia methyl ester blends with diesel in CI engine, *Journal of Chemical and Pharmaceutical Science* 4 (4), 974-2115.

[25] Dockery G., (2017). The effect of temperature on activation energy 24th April, 2017. Retrieved www. sciencing.com/effect-temperature-activation-energy-5641227. html.