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Optimization of Cement Kiln Dust incorporation and Development of Predictive Models for Strength and Durability of Self-compacting Concrete

Garba, I., Amartey, Y. D., Sulaiman, T. A., Yau, Y., Sabari, A. A., Abdullahi, M.
Department of Civil Engineering, Ahmadu Bello University, Zaria
*Corresponding Author's E-mail: isahgarba86@gmail.com

Abstract
Cement kiln dust (CKD is often viewed as waste and hazardous material, which has been disposed of in landfills at cement plants. This research employs response surface methodology to optimize and create predictive models for utilizing CKD as a partial replacement for cement in self-compacting concrete (SCC). The initial properties of the materials used and the rheological characteristics, including the L-box, V-funnel, flow, and T50 tests, were valuated to appraise the workability of the self-compacting concrete. The concrete was formulated with CKD at percentages of 0 (control), 5, 10, 15, and 20 % by weight of cement, and a water-cement ratio of 0.35 was used. The findings revealed that the established predictive models for the strengths and durability of the SCC had R^2 values of 98.11 %, 87.16 %, and 99.14 % for compressive, splitting tensile strength, and water absorption, respectively. Additionally, the difference between the adjusted and predicted R^2 values was under 0.2, suggesting a strong correlation. The optimized strength results showed 32.041 N/mm^2 and 3.455 N/mm^2 for compressive and split tensile strengths, respectively, at a CKD content of 10.683 %, while water absorption was measured at 2.916 % with a 20 % CKD substitution level and a curing period of 28 days. It is recommended to use 10 % CKD as a partial cement replacement in self-compacting concrete.

Keywords: Cement Kiln Dusts, Compressive Strength, Optimization, Self-Compacting Concrete, Split Tensile Strength, Water Absorption.

1. Introduction

Self-compacting concrete (SCC), commonly known as self-consolidating concrete, is an incredibly fluid, non-segregating type of concrete that effortlessly fills formwork, surrounds reinforcement, and self-levels without the need for external vibrations. It is made using standard concrete materials, and occasionally, a thickening agent is incorporated into the mixture. It has emerged as one of the significant advancements in the construction industry in previous years because of its remarkable rheological characteristics (Dinakar and Manu, 2014). An effective substitute for conventional concrete is self-compacting concrete. The primary goal of SCC is to simplify the handling and placement of concrete, resulting in more durable and efficient structural components by removing the need for concrete vibration (Shadkam *et al.,* 2017).

Self- compacting concrete (SCC) is an exceptional workable composite material, while retaining its homogeneity, can flow under its own weight over complicated form work geometries and congested steel sections (Vinutha *et al.,* 2016). It passes through congested reinforcement bars with sound resistance to segregation and can fully fill form works minus the need for vibration. It provides several advantages over traditional concrete, contributing to its growing popularity in the construction industry, including faster placement, reduced labor costs, enhanced consolidation, and improved rebar coverage (Celik *et al.,* 2015; Alexandra *et al.,* 2018). It development is a step in the right direction toward energy conservation and a decrease in CO_2 emissions in addition to reduction of construction costs.

Mineral additives are added into the Self-compacting concrete because it exhibits exceptional properties by preventing segregation and bleeding during filling and flowing processes. Excess water in self-compacting concrete can harm the microstructure of the interfacial transition area among the aggregate and the paste, and it can also enhance the capillary porousness of the set paste, both of which can affect characteristics linked to strength and durability (Gao *et al.,* 2014). To tackle this problem, a range of additives and supplementary cementing materials (SCMs) have been utilized. Supplementary cementitious materials enhance both the mechanical and durability characteristics of concrete, while also helping to decrease the CO2 emissions linked to cement manufacturing (Gartner and Sui, 2018).

The process of cement production negatively impacts the environscon due to its high intake of raw materials and the discharge of CO_2 into the atmosphere. To manufacture one ton of cement, approximately 1.5 to 1.85 tons of raw materials are utilized, resulting in the discharge of around 0.8 ton of CO_2, contributing to the greenhouse effect. To protect the environment and achieve sustainable development goals, it is essential to seek eco-friendly alternatives for cement to reduce the amount used. CKD is a spin-off produced during the cement manufacturing process, which can represent 3 to 4 % of the overall cement output, contingent upon the raw materials and production methods employed. Utilizing CKD as a substitute for cement holds promise for creating a unique type of SCC, especially in cases where high or ultra-high strength is not a key requirement.

Supplementary cementing material such as fly ash, ground granulated blast furnance (Zhao *et al.,* 2015) cement kiln dust (shoai *et al*., 2017) and agricultural by products such as rice husk ash (sua-iam *et al*., 2016, Ameri, *et al*., 2017) and sugarcane bagasse ash (Ameri *et al*., 2018) have been successfully used in concrete productions. Jae *et al*., (2019) examine the potentials of some Class C and F Pozzolans in workability retention of concrete and their effect on cement properties. Their findings shown the potential of Pozzolanic material in slump controlled concreting, which can be used in Slip form paving concrete with little or no admixture. Sulaiman *et al*., (2021) developed a Predictive Model for the Compressive Strength of Lightweight Concrete made with Nano-Silica as Admixture. According to study conducted by Garba et al., (2024) on ptimization and predictive models on strengths and durability of reinforced laterized concrete, and the developed models could be used for the predictions of desired strengths and durability of the reinforced laterized concrete. Sulaiman *et al.,* (2024) used of the agricultural wastes as partial replacement of cement in mortar and the findings indicated that 5 % to 10 % of Sesame husk ash (SHA) content can be used in the production of mortar.

Cement kiln dust is added to the manufacturing of self-compacting concrete to tackle challenges within the industry, as it contains high levels of alkalis that may cause alkali-silica reactions in concrete. This necessitates careful tracking of its amounts in the mixtures (Al-Bakri *et al*., 2022). Furthermore, the inconsistency of cement kiln dust affects its suitability as a cement substitute, making detailed analysis essential to improve its use. The costs associated with processing CKD for reuse might exceed those for traditional raw materials, but rising disposal fees are motivating more facilities to explore CKD recycling.

Najim *et al*., (2016) studied the application of cement kiln dust as a partial substitute for cement in the making of high-performance concrete. The CKD was used to exchange cement by weight at levels of 10 %, 20 %, and 30 %, while keeping all other components unchanged. Inclusion of CKD led to a cut-down in the dynamic modulus of elasticity. Addition of rice husk ash (RHA) blended with CKD enhanced the workability of fresh concrete and dcut-down the compressive strength of concrete (Sulaiman and Aliyu, 2020). Kadhim *et al*., (2020) examined the attributes of self-compacting mortar that includes nano-cement kiln dust. The results from their experiments demonstrated that the compressive strength, direct tensile strength, and flexural strength of the self-compacting mortar enhanced with a higher proportion of nanopowder. As the percentage of nanopowder increased, the dry density of the self-compacting mortar also rose. The uniformity of the microstructure and distribution of the nanopowder in the self-compacting mortar were illustrated using field emission scanning electron microscope (FESEM) images. Abukhashaba *et al*., (2014) investigated how incorporating polypropylene fiber reinforcement influences the mechanical, fresh, and stress-strain characteristics of self-compacting concrete (SCC). Although polypropylene fiber and cement kiln dust slightly affect workability and demand a higher amount of superplasticizer, it was found that they could be effectively used in self-compacting concrete production. The study concluded that the inclusion of polypropylene fiber helps to reduce the shrinkage of SCC. Additionally, this study optimized the amount of cement kiln dust at various curing ages to develop self-compacting concrete and utilized the response surface method to formulate mathematical prediction models.

2.0 Material and methods

2.1 Materials- second level heading.

2.1.1 Cement - The study utilized Portland limestone cement of grade 42.5R, sourced from a local retailer in Samaru, Zaria, Kaduna State. The tests for quality control and the physical characteristics of the cement were assessed. Table 1 displays the physical properties of the cement.

Table1: Physical Properties of the Cement

S/NO	Test	Average Values	Code Specification	Remark
1.	Consistency	29%	26% – 33%	Satisfactory
2.	Initial-setting time	89minutes	≥ 45 min	Satisfactory
3.	Final-setting time	172 minutes	≤ 600min	Satisfactory
4.	Soundness	4mm	≤ 10	Satisfactory

2.1.2 Aggregate - A locally sourced Sharp River sand was gathered from a river close to Nuhu Bamalli Polytechnic Zaria. It has a specific gravity of 2.63 and a water absorption rate of 4.17 %, with particle sizes that fall within Zone II of the aggregate distribution curve. A granite with a maximal nominal size of 20 mm was found from a quarry located along Jos Road in Zaria. The aggregate crushing value measured 23.1 %, the impact value was 20.34 %, and it has a specific gravity of 2.85.

2.1.3 Cement Kiln Dust (CKD) - The cement kiln dust examined in this study was sourced from landfills adjacent to cement manufacturing plants in Nigeria. It was acquired from Bua Company located in Kalambaina, Sokoto State. An XRF analysis was performed to identify the oxide makeup of the cement kiln dust. The material was initially received in a coarse texture and was subsequently ground into a finer, powdered state. Plate 1 illustrates the cement kiln dust utilized in this study.

Plate 1: Cement Kiln Dust

The CKD fine particles were passed through a 75µm sieve. Table 2 shows the oxide composition of the cement kiln dust and cement. It was observed that the sum of SiO_2, Fe_2O_3, and Al_2O_3 is 21.7 % which is less the minimum requirement of 70 % as specified by ASTM C 618 for pozzolana. However, it has a CaO content of 46.2 % which shows that it possesses some cementing characteristics and can be used to partially replace cement in concrete.

Table 2: Oxide Compositions of Cement Kiln Dust and Cement

Chemical compound	CKD (%)	Cement (%)
SiO_2	13.50	21.43
Fe_2O_3	2.50	2.77
Al_2O_3	5.70	2.83
MgO	1.14	1.05
CaO	46.2	68.03
Na_2O	0.20	0.18
SO_3	5.70	1.42
TiO_2	0.40	0.21
Loss of ignition	5.70	-

2.1.4 Water - The study utilized portable pipe-borne water provided by the Civil Engineering Department at Ahmadu Bello University, Zaria.

2.1.5 Superplasticizer - The superplasticizer employed is a polycarboxylic ether, a type of water-reducing additive acquired from Sabon Gari Market in Zaria.

2.2 Methods

2.2.1 Mix Design of Experiment - In this study, two independent variables are examined: curing ages and the inclusion of cement kiln dust, focusing on their effects on the compressive strength, split tensile strength, and water absorption of SCC. Each concrete mixture was prepared and cured at three different intervals (7, 14, and 28 days). Additionally, five different quantity of CKD were tested (0 % as the control, 5 %, 10 %, 15 %, and 20 %). Consequently, as stated in equation 1, this results in a total of fifteen runs within the response surface methodology (RSM) framework.

$$N = nr \tag{1}$$

In this equation, N stands for the total number of experimental points, n denotes the levels for the first factor (curing age), and r indicates the levels for the second factor (CKD). Utilizing a factorial design approach, a total of forty-five experimental sets were created for compressive and split tensile strength, with three replicates for each set. Additionally, regarding water absorption, curing time of 28 and 56 days were examined with CKD percentages of 0, 5, 10, 15, and 20 %. As a result, the necessary number of experimental points totals N = 15. Nevertheless, 45 and 30 experiments were conducted by incorporating three and two replicates, respectively, to meet the design power requirement of the DOE, which needs to be at least 80 %. The analysis and optimization were carried out using Design Expert software version 13 (2021).

2.2.2 Response Surface Methodology (RSM) - Revathi *et al*., (2018) describe RSM as a combination of mathematical and statistical methods utilized for process development and optimization. The response surface method utilizes exploratory data obtained from the scientific design of experiments to carry out regression analysis and establish a practical synergy between the identified factors and the response variable (Jo *et al*., 2007). The polynomial equation representing the relationship between the response variables and the independent variables can be formulated as follows (Montgomery, 2017).

$$Y = \beta_0 + \Sigma_{i=1}^{k}\beta_i X_i + \Sigma_{i=1}^{k}\beta_{ii} X_{ii}^2 + \Sigma_{j=2}^{k}\Sigma_{i\le i\le j}^{j=1}\beta_{ij} X_i X_j + \varepsilon \tag{2}$$

In this context, Y denotes the response variable, while xi and xj signify the independent variables (where i and j range from 1 to k). The constant coefficient is represented by βo, and the coefficients for linear, quadratic, and interaction effects are denoted as βi, βii, and βij, respectively, with ε indicating the error term. The coefficient of determination (R^2), which varies between 0 and 1, was utilized to assess the adequacy of the constructed model. A value of R^2 that approaches 1 indicates a high level of accuracy and significance for the model, as stated by Montgomery (2017).

3.0 Results and Discussions

3.1 Compressive Strength of SCC

The compressive strength results of SCC with various dosages of CKD are illustrated in Figure 1. The results for compressive strength indicate that concrete containing no cement kiln dust (0 %) achieves the highest compressive strength of 31.92 N/mm^2 after 28 days. The introduction of cement kiln dust leads to a decrease in strength; however, it was noted that at a 10 % replacement level and cured for 28 days, the compressive strength measures 31.1 N/mm^2, which is very close to the control sample. This decrease in strength may be the result of cutting down in C_3S and C_2S content, which contribute to the strength of cement, despite an increase in hydraulic modulus with the addition of CKD. Najim *et al.*, (2016) observed similar findings.

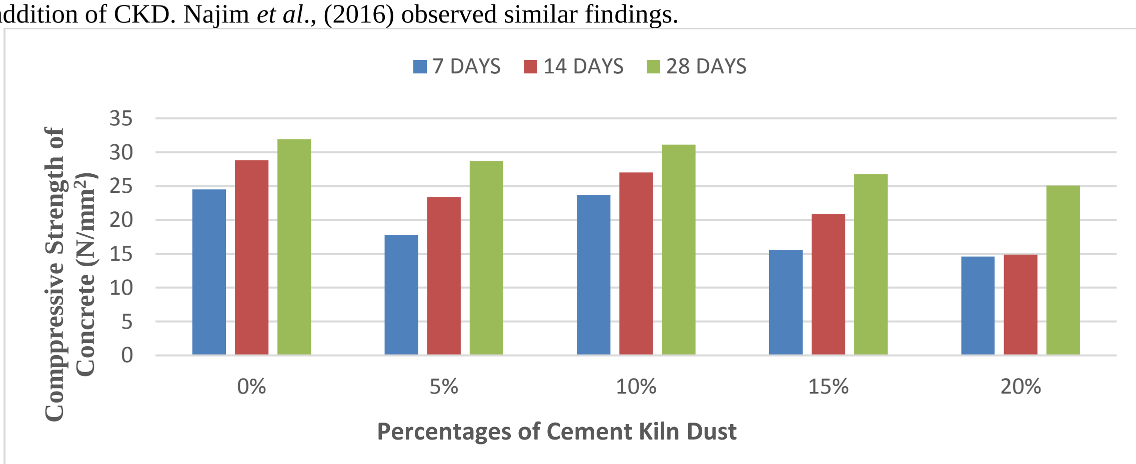


Figure 1: Compressive Strength SCC with Cement Kiln Dust Replacements.

3.2 Splitting Tensile Strength of SCC

The outcomes for the split tensile strength of SCC with different amounts of cement kiln dust are illustrated in Figure 2. From Figure 2, it can be noted that the split tensile strength of self-compacting concrete decreases as the percentage of cement replaced with CKD increases, except at the 0 % and 10 % replacement levels. The split tensile strength measured for the control mix at 28 days was recorded at 3.8 N/mm². Among the tested mixes, the one with a 10 % replacement showed a split tensile strength of 3.4 N/mm², which is the closest to that of the control. This decline in split tensile strength may be attributed to air voids acting as points for crack initiation during tensile loading; as a result, cracks develop more rapidly within the cement matrix, leading to quicker failure. Najim *et al.*, (2016) have documented similar observations.

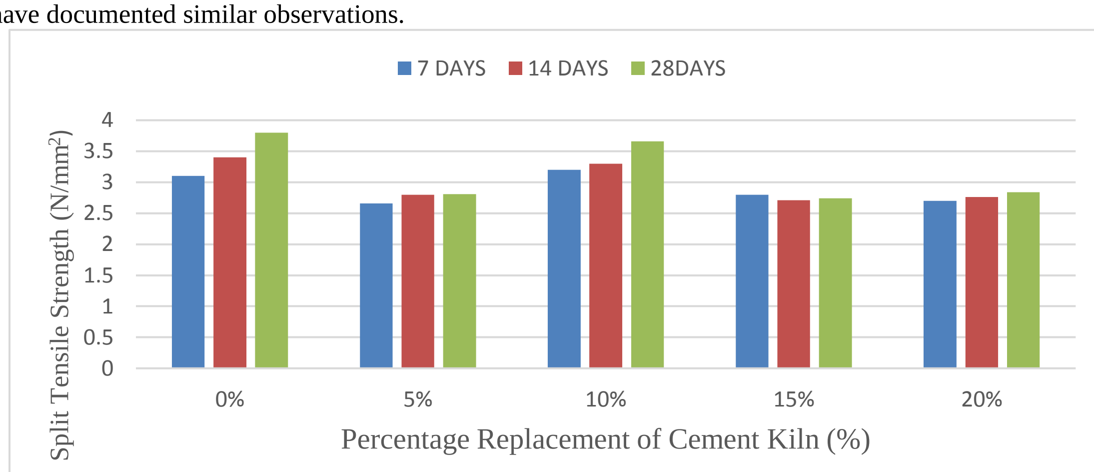


Figure 2: Split Tensile Strength with Cement Kiln Dust Replacements

3.3 Water Absorption of SCC

Figure 3 illustrates the water absorption characteristics of self-compacting concrete that has partially substituted cement with cement kiln dust. In Figure 3, it was noted that an increase in curing age along with rising levels of cement kiln dust results in higher water absorption in the concrete. This effect can be linked to the porous characteristics of cement kiln dust, which may cause increased moisture retention in the concrete matrix. This behaviour aligns with the findings of Al Bakri *et al*., (2022).

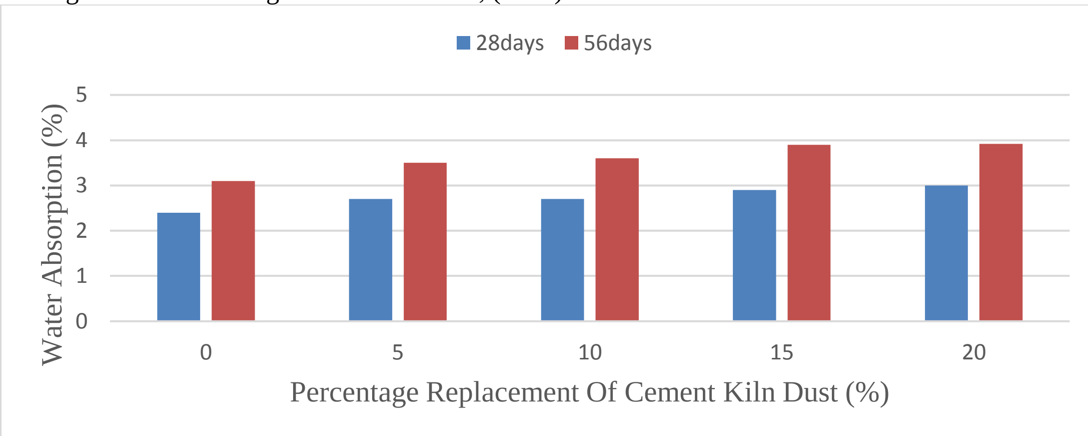


Figure 3: Water Absorption of Self-Compacting Concrete with Cement Kiln Dust

3.4 Analysis of Variance

One-way variance analysis (ANOVA) was employed to determine whether independent variables significantly affect dependent variables. In the Analysis of Variance, the impact of significant variables on the models is assessed based on a predetermined confidence level. The chosen confidence interval was set at 95 %, indicating that the P-value was under 5 % ($p < 0.05$). Additionally, the adequacy of the fit is examined at the significance level of the P-value. The model F-values of 158.83, 27.19, and 50.27 correspond to compressive strength, split tensile strength, and water absorption, respectively, suggesting that the model is significant. The chance of obtaining such a large F-value merely from random noise is only 0.01 %. Tables 3, 4, and 5 display the one-way analysis of variance for compressive strength, split tensile strength, and water absorption. Moreover, by reviewing the variance analysis tables for the three responses, it is evident that the independent variables include several significant terms within the developed model; therefore, this indicates a strong relationship of the model established, which can be utilized to improve the performance of self-compacting concrete that incorporates cement kiln dust as a partial substitute for cement.

Table 3: Analysis of Variance of Compressive Strength of SCC with CKD

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1490.52	12	124.21	158.83	< 0.0001	significant
A-cement kiln dust	698.90	1	698.90	893.69	< 0.0001	
B-curing age	478.27	2	239.14	305.79	< 0.0001	
AB	17.32	2	8.66	11.07	0.0002	
A^2	75.54	1	75.54	96.59	< 0.0001	
A^2B	33.80	2	16.90	21.61	< 0.0001	
A^3	67.86	1	67.86	86.77	< 0.0001	
A^3B	3.66	2	1.83	2.34	0.1127	
A^4	115.17	1	115.17	147.28	< 0.0001	
Residual	25.03	32	0.7820			
Lack of Fit	25.03	2	12.51			
Pure Error	0.0000	30	0.0000			
Cor Total	1515.55	44				

Table 4: Analysis of Variance of Split Tensile Strength of SCC with CKD

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	5.15	8	0.6442	27.19	< 0.0001	significant
A-cement kiln dust	1.89	1	1.89	79.87	< 0.0001	
B-curing age	0.8016	2	0.4008	16.92	< 0.0001	
AB	0.4162	2	0.2081	8.78	0.0008	
A^2	0.0052	1	0.0052	0.2198	0.6420	
A^3	0.1690	1	0.1690	7.13	0.0113	
A^4	1.87	1	1.87	78.91	< 0.0001	
Residual	0.8529	36	0.0237			
Lack of Fit	0.1131	6	0.0189	0.7647	0.6034	not significant
Pure Error	0.7398	30	0.0247			
Cor Total	6.01	44				

Table 5: Analysis of Variance of Water Absorption of SCC with CKD

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	8.44	6	1.41	50.27	< 0.0001	significant
A-cement kiln dust	0.0588	1	0.0588	2.10	0.1565	
B-curing age	6.23	1	6.23	222.54	< 0.0001	
AB	0.2832	1	0.2832	10.12	0.0032	
A^2	0.1305	1	0.1305	4.66	0.0382	
A^3	0.0396	1	0.0396	1.42	0.2426	
A^4	0.1653	1	0.1653	5.91	0.0207	
Residual	0.9231	33	0.0280			
Lack of Fit	0.0756	3	0.0252	0.8923	0.4565	not significant
Pure Error	0.8475	30	0.0283			
Cor Total	9.36	39				

3.5 Development of Mathematical Model

The models were formulated by examining compressive strength, split tensile strength, and water absorption, while accounting for the impact of the independent variable, which in this case is the curing age and the content of cement kiln dust. The responses were modeled using quartic equations, and through model reduction, all terms deemed insignificant with p values exceeding 0.05 were excluded from the analysis of variance tables. The compressive strength, split tensile strength, and water absorption of self-compacting concrete with varying amounts of cement kiln dust over different curing ages are presented in Equations 1, 2, and 3, respectively.

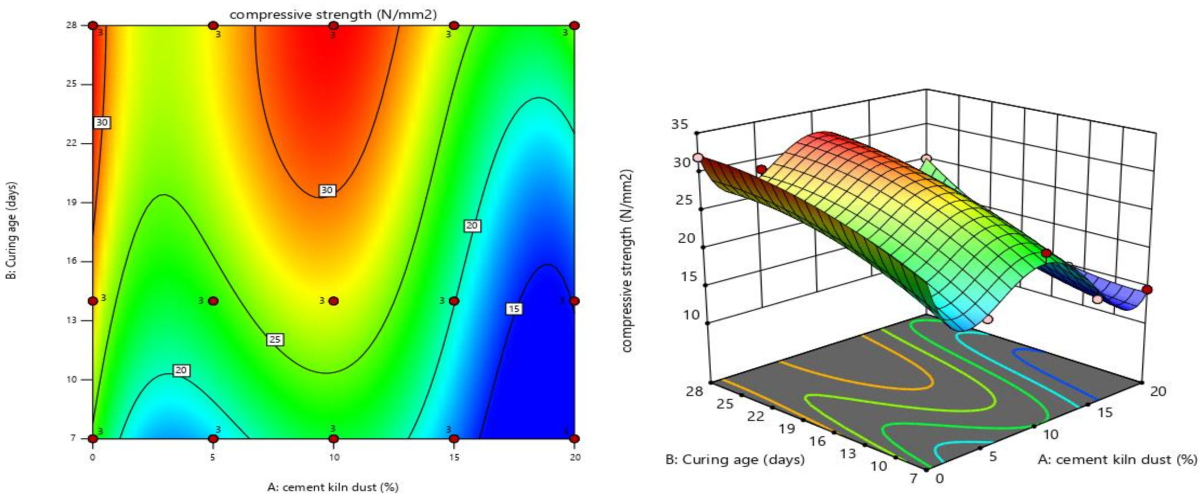
$$F_c = 27.20 - 0.6528A - 5.22B - 0.0749B^2 + 1.23AB - 0.4987AB^2 - 25.19A^2 - 2.55A^2 - 0.0343A^2B^2 - 5.79A^3 + 19.95A^4 \quad (3)$$

$$F_s = 3.35 - 0.0444A - 0.1407B - 0.0387B^2 + 0.1580AB + 0.0160AB^2 - 2.79A^2 - 0.2889A^3 + 2.54A^4 \quad (4)$$

$$W + 3.15 + 0.1629A + 0.3945B + 0.1190AB + 0.8004A^2 + 0.1483A^3 - 0.8017A^4 \quad (5)$$

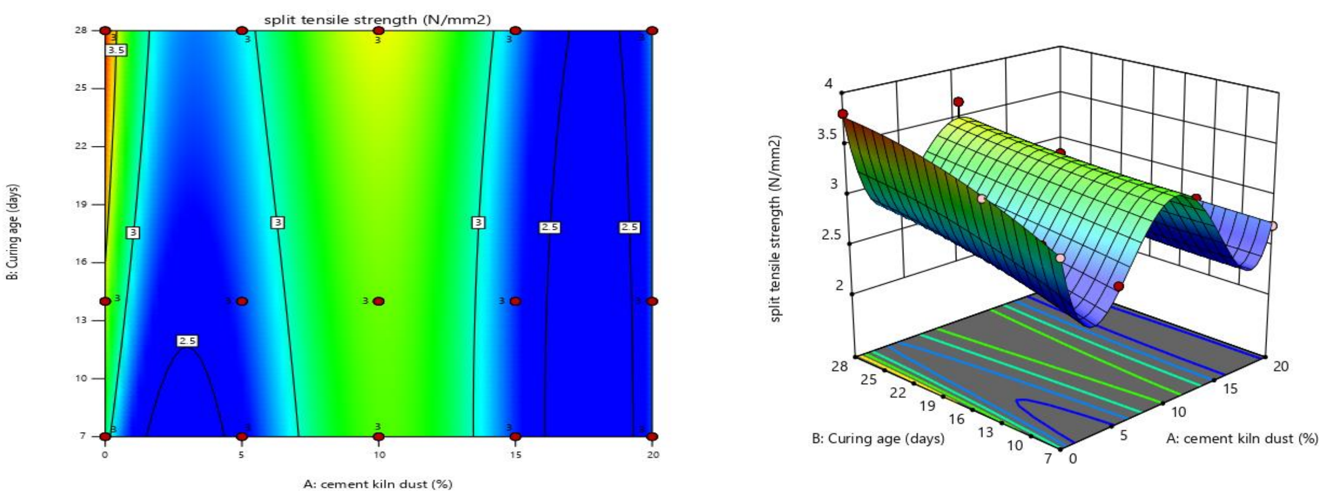
In this context, A refers to the cement kiln dust while B denotes the curing age of the concrete. The variables Fc, Fs, and W represent compressive strength, split tensile strength, and water absorption, respectively. The equations mentioned can be utilized to estimate the compressive strength, split tensile strength, and water absorption of self-compacting concrete, considering two independent factors: cement kiln dust and curing age.

The impact of various factors on the compressive strength, split tensile strength, and durability of self-compacting concrete (SCC) incorporating CKD is analyzed. As depicted in Figures 4, 5, and 6, the 2D and 3D representations illustrate the compressive and split tensile strengths, along with water absorption rates of SCC with partial CKD replacement. From the 2D graph, it is apparent that the compressive strength of SCC tends to vary; at 0 % and 10 % CKD replacement, an increase in the strength is noted, while at other levels of replacement, a decrease in strength is observed. The cut down in strength could be due to the lower presence of C_3S and C_2S, which are crucial for the strength of cement, despite the hydraulic modulus improving with the inclusion of cement kiln dust. This, in turn, enhances the amount of free lime (FCaO), which compromises the integrity of the cement intercellular substance due to the elevated calcium hydroxide (Ca(OH)) content. Similar conclusions were drawn by El-Aleem *et al*. (2005). Regarding split tensile strength, it enhanced with the curing duration, and as the percentage of cement kiln dust reduces—reflected by the transition from the blue area to the reddish area of the contour—strength improves. Furthermore, a rise in water absorption is observed with an increase in CKD replacement percentage, which may be caused by inadequate and weaker bond formation. El-Mohsen *et al*.. (2014) reported comparable findings when analyzing the partial replacement of cement with CKD in SCC. They discovered that the SCC mixture with a 20 % CKD replacement demonstrated superior mechanical strength relative to other SCC formulations.



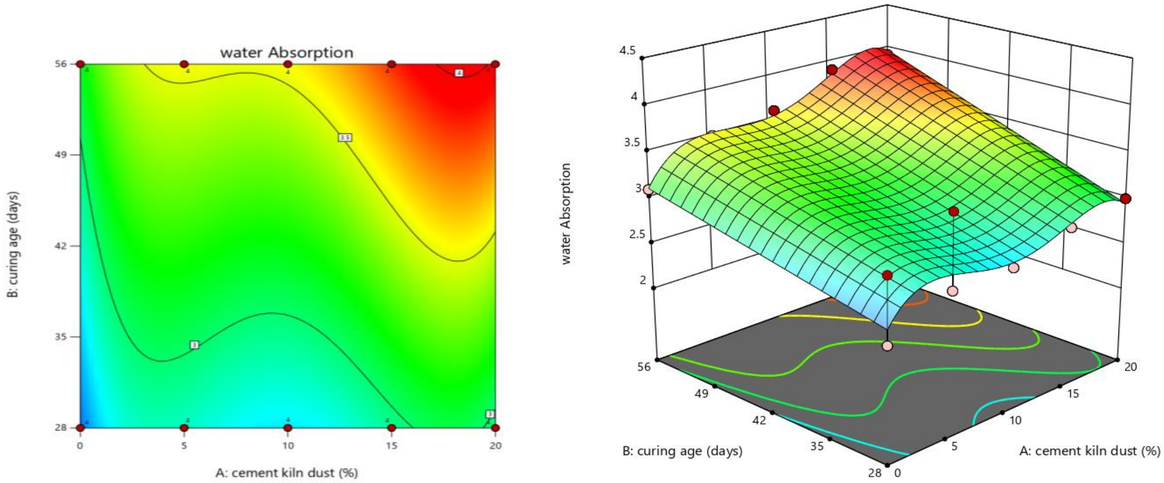
a **b**

Figure 4a and 4b: 2D and 3D Contour Plots for the Compressive Strengths of the SCC with CKD



a **b**

Figure 5a and 5b: 2D and 3D Contour Plots of the Split Tensile Strength of SCC with CKD



a **b**

Figure 6a and 6b: 2D and 3D Contour Plots for the Water Absorption of the SCC with CKD.

3.6 Coefficient of Determination of the Responses

Table 6 presents the coefficient of determination for the models, showing R^2 values of 98.11 %, 87.16 %, and 90.14 % for compressive strength, split tensile strength, and water absorption, respectively, all exceeding 80 %. This demonstrates a strong relationship in the established models.

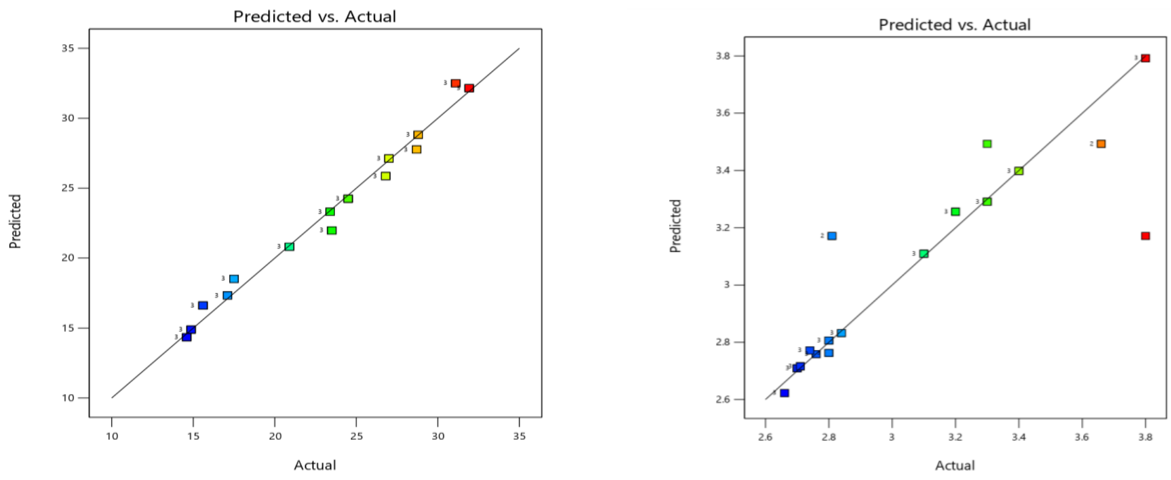
To ensure that the R^2 values of the models align well, the difference between the predicted and adjusted R^2 should be below 20 %. It is evident that all response variables met this criterion. Additionally, Table 6 lists the adequate precision (AP) values, which serve as an indicator of the signal-to-noise ratio and must exceed 4 to validate the desirability of the responses. Based on the AP values, all models exhibited good agreement.

Table 6: Coefficients of Determination for the Response Investigated.

Response	R^2	Adjusted R^2	Predicted R^2	Adequacy Precision AP
Compressive Strength F_c	0.9811	0.9775	0.9695	40.54
Split Tensile Strength, F_s	0.8716	0.8234	0.8230	14.01
Water absorption W	0.9014	0.8834	0.8538	20.17

3.7 Experimental against the Predicted Results

Figures 7a, 7b, and 8 illustrate the outcomes from both the experimental and predicted factorial design models. It is evident that the experimental results closely align with the predicted values, as nearly all points are positioned along a sloped straight line, indicating a robust correlation between the model.



a b

Figure 7a and 7b: Plot Predicted versus Actual of Compressive and Split Tensile Strength of SCC With CKD

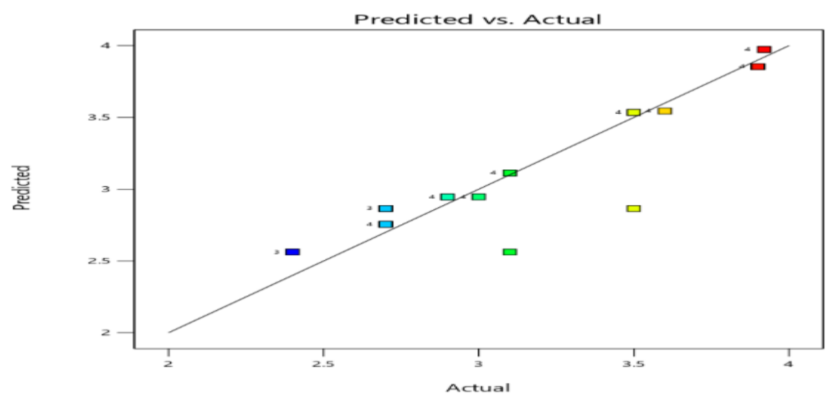


Figure 8c: Plot Predicted versus Actual of Water Absorption of SCC with CKD

3.8 Optimization Result of Self-Compacting with Cement kiln dust

Optimization entails the application of mathematical techniques, models, and algorithms to enhance a system or design to its fullest effectiveness. The objectives, constraints, and outcomes regarding compressive strength, split tensile strength, and water absorption are presented in Tables 7, 8, 9, and 10. The aim is to maximize the compressive strength, split tensile strength, and the content of cement kiln dust, while minimizing water absorption. The desirability value for both compressive and split tensile strengths is 0.720, whereas for water absorption it stands at 0.80. The findings indicate that the compressive strength and split tensile strength reach values of 32.362 N/mm2 and 3.455 N/mm2, respectively, with 10.683 % CKD content after 28 days of curing. In terms of water absorption, the optimized result is 2.946 % at 20 % CKD content after 28 days of curing.

Table 7: Optimization Goal and Constraint for Strength Properties

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Cement kiln dust	maximize	0	20	1	1	3
B: Curing age	is in range	7	28	1	1	3
Compressive Strength	maximize	14.6	31.92	1	1	3
Split tensile Strength Water Absorption	maximize	2.66	3.8	1	1	3

Table 8: Optimization Results for the Strength Properties

S/NO	Cement kiln Dust	Curing Age	Compressive Strength	Split tensile Strength	Desirability	
1	**10.683**	**28**	**32.362**	**3.455**	**0.720**	**Selected**
2	10.932	28	32.247	3.435	0.719	
3	10.639	14	26.956	3.279	0.591	
4	10.763	7	21.777	3.258	0.489	
5	10.513	7	21.872	3.261	0.488	
6	20.000	28	17.333	2.832	0.288	
7	0.790	14	25.669	3.035	0.203	
8	0.428	7	22.401	2.898	0.126	
9	20.000	14	14.891	2.758	0.113	

Table 9: Optimization Goal and Constraint for Water Absorption

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: cement kiln dust	maximize	0	20	1	1	3
B: curing age	is in range	28	56	1	1	3
Water absorption	minimize	2.4	3.92	1	1	3

Table 10: Optimization Results for Water absorption of SCC with CKD

Number	cement kiln dust	curing age	Water absorption	Desirability	
1	**20.000**	**28.000**	**2.946**	**0.800**	**Selected**
2	20.000	28.131	2.951	0.798	
3	20.000	28.292	2.957	0.796	
4	19.902	28.000	2.957	0.794	
5	20.000	28.689	2.972	0.790	
6	20.000	28.770	2.975	0.789	
7	20.000	29.112	2.987	0.783	
8	19.618	28.000	2.984	0.777	
9	16.759	28.000	3.029	0.701	
10	16.476	28.000	3.019	0.699	

4.0. Conclusions

The conclusion that can be drawn from the findings above is as follows:

i. The optimal values identified were 10.683 % CKD after 28 days of curing, yielding compressive and split tensile strengths of 32.326 N/mm^2 and 3.455 N/mm^2, respectively. Additionally, for water absorption, the optimal CKD content was determined to be 20 % at 28 days of curing, resulting in a value of 2.946 %.

ii. The created mathematical models for the responses are quartic and yield R^2 values of 98.11 %, 87.16 %, and 90.14 % for compressive strength, split tensile strength, and water absorption, respectively. Additionally, all other correlation values exceed 80 %, indicating a robust correlation.

5.0 Recommendation

It is recommended to use 10 % CKD content as a partial cement replacement in self-compacting concrete. For further study, effect of CKD admixed with high reactive pozzolana such as rice husk ash (RHA) and metakaolin (MK) should be in self-compacting concrete (SCC).

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