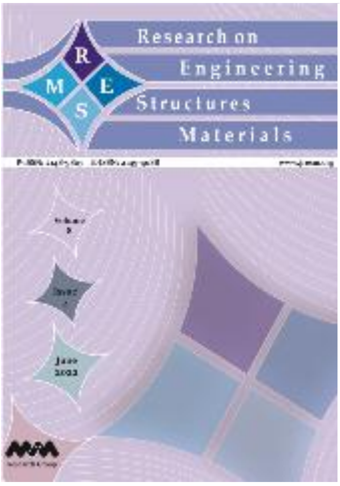
Research on Engineering Structures & Materials

journal homepage: http://www.jresm.org

Research Group



Optimized properties of concrete at various exposure conditions

Mahesh Patil, Shailendrakumar Dubey, Hiteshkumar Patil

Online Publication Date: 30 Jan 2023

URL: http://www.jresm.org/archive/resm2022.577ma1107.html

DOI: http://dx.doi.org/10.17515/resm2022.577ma1107

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article

Patil M, Dubey S, Patil H. Optimized properties of concrete at various exposure conditions. *Res. Eng. Struct. Mater.*, 2023; 9(2): 579-596.

Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org
Research Group

Research Article

Optimized properties of concrete at various exposure conditions

Mahesh Patil*[1,a], Shailendrakumar Dubey[2,b], Hiteshkumar Patil[3,c]

[1]*Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon-425001 (MS), India*
[2]*Civil Engineering Department at SSVPS BSD COE, Dhule (MS)-424005, India*
[3]*The Shirpur Education Society's, Shirpur R. C. Patel Institute of Technology, India, district Dhule- 425405 (MS) India*

Article Info

Article history:

Received 07 Nov 2022
Revised 18 Jan 2023
Accepted 23 Jan 2023

Keywords:

Exposure conditions; Water to cement ratio; Rheology; Compressive strength; Flexural Strength; Tensile Strength; PCA analysis; MLR Model; RSM Model

Abstract

This research explores the testing of M40 grade concrete results under various exposure scenarios. The characteristics of concrete are investigated at the plastic and hardening stages. The characteristics of concrete at both stages vary depending on the exposure circumstances. The rheological qualities of the concrete as well as its strength characteristics under various exposure situations are investigated. It has been noted that as exposure conditions deteriorate, cement content gradually rises while W/C and water content decrease. This research is more beneficial for predicting the diverse properties of concrete under various exposure conditions. This will also aid in reducing losses incurred during construction and structural decay. During the investigation, the correlation matrix and Principal Component Analysis (PCA) are used to evaluate the interrelationship of the experimental variables, which yields more accurate results and predictions of the various characteristics of concrete. A Multivariate Linear Regression (MLR) model developed for the prediction of concrete qualities in the plastic and hardens stages. The MLR model found to be best matched to experimental data, and its forecast is correct. The Response Surface Method (RSM) used to find the optimal properties of the concrete in all types of exposure scenarios.

Nomenclature

Cement	C	Compressive Strength (MPa)	CS
Sand	S	Split Tensile Strength	SPT
Water	W	Flexural Strength	FS
Water Cement Ratio	W/C	Compaction Factor	CF
Principle Component Analysis	PCA	Setting time test	ST
Multiple Linear Regression	MLR	Fine Aggregate	FA
Response Surface Regression Method	RSR	Coarse Aggregate	CA
Water Cement Ratio	W/C	Admixture	ADM

1. Introduction

Concrete serves as the most adaptable building material on the planet. It has the title of "biggest man-made substance" with an average per capita usage exceeding 2 kg[1,2]. Concrete is the preferred material for a wide range of uses including buildings, bridge, roadway pavement, industrial structures, liquid storage structures, retaining structures and so on. Concrete's well-known characteristics such as availability of ingredients, acceptable technical qualities for a wide range of structural applications, flexibility,

*Corresponding author: hitusp@gmail.com
[a] orcid.org/0000-0002-6948-7473; [b] orcid.org/0000-0002-5883-2585; [c] orcid.org/0000-0002-6850-2336
DOI: http://dx.doi.org/10.17515/resm2022.577ma1107

diversity, relative low cost and so on are credited with this feat. Furthermore, when compared to other building materials, concrete has an outstanding ecological characteristic. With the on-going increase in infrastructure and residential building, particularly in emerging Asia, Africa, and South America, the demand of cement and concrete is increasing and it is expected to rise further [3,4]. In recent times, the concrete building industry in India has grown significantly. Cement output in the country has more than doubled in the last 12 years, rising from 45.25 million tonnes in 1989-90 (the start of the decontrol era) to 215 million tonnes produced in 2019-20. India is now the second-biggest cement manufacturer behind China, which is a commendable feat [5, 6].

The exposed circumstances [7–10] determines the structure's durability requirements, choice of materials, proportion, design and construction. As a result, if the exposure class is chosen correctly, it will provide great durability of concrete buildings, reducing routine maintenance and costs. The durability of concrete is affected by factors such as relative humidity, quality of raw material, water to cement ratio, aggregate to cement ratio, coarse aggregate to fine aggregate ratio, concrete age, concrete compaction and temperature. As per IS 456:2000[11], various exposure circumstances are classified according to their impact as follows.

a) Mild exposure: Concrete surfaces protected from the elements or extreme conditions, with the exception of coastal areas.

b) Moderate exposure: Concrete exposed to condensation and rain, concrete submerged in water continually, concrete in contact with or buried beneath non-aggressive soil/ground water, and concrete surfaces shielded from saturated salt air in coastal locations.

c) Severe exposure: Concrete exposed to coastal region, concrete immersed completely in saltwater, concrete surfaces subjected to severe rain, alternating absorbing and drying or frequent freezing while wet.

d) Very Severe exposure: Concrete in touch with or buried in aggressive subsoil/ground water; wet concrete surfaces exposed to saltwater spray, toxic gasses, or high freezing weather.

e) Extreme exposure: Tidal zone surfaces; members in direct touch with liquid/solid hostile substances.

The testing of M40 grade concrete under various exposure situations is explored in this study. Investigations on the properties of concrete at the plastic and hardening stages are conducted. Based on the exposure conditions, concrete's properties change at both stages. It is researched how the concrete behaves rheologically and how strong it is in different exposure scenarios. It has been observed that cement content steadily increases while W/C and water content decrease when exposure circumstances intensify. This study is more useful for forecasting concrete's varied properties under various exposure scenarios. This will help to minimize damages from construction and structural deterioration. The research uses the correlation matrix and Principal Component Analysis (PCA) to assess how the experimental variables interact, producing more precise results and predictions of the different properties of concrete. For the purpose of predicting concrete properties during the plastic and hardening phases, a Multivariate Linear Regression (MLR) model is also being developed. The MLR model's prediction is accurate and it best matches the experimental data. In all kinds of exposure circumstances, the Response Surface Method (RSM) is also utilized to identify the concrete's ideal property because of its high coefficient of determination. The RSM provides the best match to experimental data and makes reliable predictions (R^2).

Main objectives of this research to scrutinize behaviour, rheological properties and strength characteristics of concrete under diverse environmental exposure conditions. Novelty of this experimental work is introduction of statistical tools Correlation Matrix, PCA, MLR and RSR for optimization purpose in construction industry.

2. Methodology

This research investigates the testing of M40 grade concrete under various exposure scenarios. It provides a good understanding on the influence of environmental exposure circumstances on concrete strength. Environmental exposure circumstances are unavoidable but its bad impact can be reduced. Research is done on the characteristics of concrete during its plastic and hardening stages. The characteristics of concrete alter at both stages depending on the exposure circumstances. This research may be helpful for the construction industry in future for optimization purpose. Research has been done on the rheological behaviour of concrete and its strength characteristics under various exposure conditions. When exposure conditions get worse, it has been observed that cement content progressively rises while W/C and water content fall. This study is more helpful for predicting the various properties of concrete under different exposure scenarios. It can be helpful in reduction of construction-related losses and structural deterioration damages. Figure 1 shows the research outline of the work carried out during the work. During the current experimental study, mathematical models like correlation, PCA, MLR and RSM established. These provide the most accurate predictions, best matched to the experimental data. The RSM models optimized the concrete properties in plastic and harden stage and also predict the accurate results.

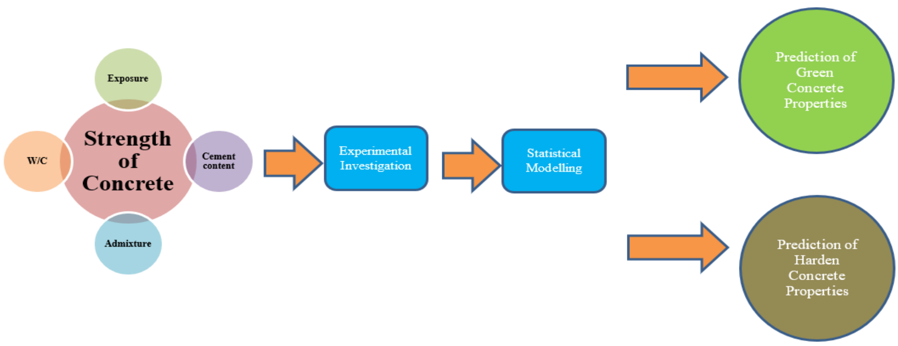


Fig. 1 Research Outline

3. Materials and Proportions

PPC cement manufactured by Ambuja Company in accordance with IS 1489-part 1:1991 [12] was used for the experiment. The detailed physical characteristics of the cement are shown in Table 1 (A). Table 1 (B) displays the characteristics of fine and coarse aggregates, which are in accordance with IS 383:2016[13]. Super plasticizer utilized to make the concrete more workable without compromising its strength or addition of excess water. The super plasticizers used was a high range water reducing Admixture sold by Fosroc under the trade name Auramix 200. Table 1 (C) displays characteristics of chemical Admixture (Superplasticizer) Auramix 200. Vibrating table utilized to compress freshly mixed concrete for one minute time period. 56 mix proportions by weight are taken into consideration for the investigation of various sorts of exposure conditions, proportions are listed in Table 1 (D).

Table 1. Materials Properties

Cement IS 1489 (Part1):1991		
Property	Results	IS code Specification
Fineness	6.5 %	< 10%
Setting Time (Initial)	36 min	> 30 min
Setting Time (Final)	290 min	< 600 min
Soundness	6.5mm	< 10mm
3 days compressive Strength	19.26 MPa	> 16 MPa
7 days compressive Strength	39.35 MPa	> 22 MPa
28 days compressive Strength	60.63 MPa	> 33 MPa

Aggregates, IS 383:2016		
Property	Fine Aggregate	Coarse Aggregate
Fineness Modulus	2.6	6.2
Specific Gravity	2.65	2.8
Water Absorption	0.5%	0.55%
Density	1440 kg/m^3	1910 kg/m^3

Properties of chemical Admixture (Superplasticizer) Auramix 200 by Fosroc
Specific Gravity: 1.05
pH = 6
Chloride Content: Nil
Alkali Content < 1g
Appearance: Yellowish to brownish Liquid

Mix Proportions designed as per IS 10262:2019 (5)														
Sr. No	C	FA	CA	W/C	Sr. No	C	FA	CA	W/C	Sr. No	C	FA	CA	W/C
1	1	1.21	2.46	0.3	21	1	2.46	4.22	0.5	41	1	1.48	2.65	0.45
2	1	1.57	3.03	0.36	22	1	0.8	1.62	0.3	42	1	1.48	2.65	0.45
3	1	1.83	3.41	0.4	23	1	1.06	2.04	0.36	43	1	1.21	2.46	0.3
4	1	2.16	3.85	0.45	24	1	1.25	2.32	0.4	44	1	1.57	3.03	0.36
5	1	2.46	4.22	0.5	25	1	1.48	2.65	0.45	45	1	1.83	3.41	0.4
6	1	2.52	4.15	0.5	26	1	1.73	2.96	0.5	46	1	1.83	3.41	0.4
7	1	2.52	4.15	0.5	27	1	1.73	2.96	0.5	47	1	1.83	3.41	0.4
8	1	0.8	1.62	0.3	28	1	1.73	2.96	0.5	48	1	1.83	3.41	0.4
9	1	1.06	2.04	0.36	29	1	1.21	2.46	0.3	49	1	1.83	3.41	0.4
10	1	1.25	2.32	0.4	30	1	1.57	3.03	0.36	50	1	0.8	1.62	0.3
11	1	1.48	2.65	0.45	31	1	1.83	3.41	0.4	51	1	1.06	2.04	0.36
12	1	1.73	2.96	0.5	32	1	2.16	3.85	0.45	52	1	1.25	2.32	0.4
13	1	1.99	3.27	0.55	33	1	2.16	3.85	0.45	53	1	1.25	2.32	0.4
14	1	1.99	3.27	0.55	34	1	2.16	3.85	0.45	54	1	1.25	2.32	0.4
15	1	1.21	2.46	0.3	35	1	2.16	3.85	0.45	55	1	1.25	2.32	0.4
16	1	1.57	3.03	0.36	36	1	0.8	1.62	0.3	56	1	1.25	2.32	0.4
17	1	1.83	3.41	0.4	37	1	1.06	2.04	0.36					
18	1	2.16	3.85	0.45	38	1	1.25	2.32	0.4					
19	1	2.46	4.22	0.5	39	1	1.48	2.65	0.45					

4. Result and Discussion

The rheological qualities of the M40 concrete as well as its strength characteristics under various exposure situations are examined during the investigation of the research. It has been noted that as exposure conditions deteriorate, cement content gradually rises while WC ratio and water content decrease. The graphical comparisons of the experimental results are shown in Figure 2. It has been found that the rheological and strength characteristics considerably affected as the exposure condition becomes critical. Table 2 demonstrates comparison of concrete's characteristics exposed to different environmental exposure conditions. For extreme environmental exposure condition, the maximum enhancements in slump, CF, CS, SPT, and FS are 10%, 0.99%, 1.89%, 4.3%, and 6.08%, respectively.

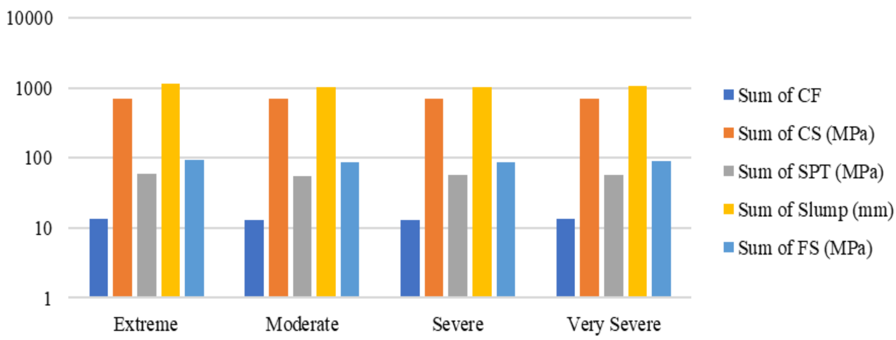


Fig. 2 Test Comparison (Compaction Factor (CF), Compressive strength (CS), Split Tensile Strength (SPT), Slump and Flexural Strength (FS)

Table 2. Percentage Increase for various exposures

Sr. No	Exposure Conditions	% Decrease in Slump	% Increase in CF	% Increase in CS	% Increase in SPT	% Increase in FS
1	Moderate	0	0	0	0	0
2	Sever	1.27	0.23	0.44	0.42	0.13
3	Very Sever	3.03	0.69	0.88	2.46	2.77
4	Extreme	10.05	0.99	1.89	4.3	6.08

In order to meet the requirements for the exposure condition, the strength and rheological qualities must rise as the harshness of the exposure condition increases [13]. Wons et.al [8], Mishra et.al [15] and Park et.al [9] noted same outcomes in their investigation. The experimental data thoroughly examined and evaluated in this part using statistical approaches such as correlation matrix, PCA, MLR, and RSM.

4.1 Correlation Matrix

The correlation study's input is shown in Figure 3. (A) displays the correlation matrix, which reveals interrelationship between experiments' variable. The correlation fluctuates between 1 and -1. Values close to 1 exhibit positive correlation, whereas values close to -1 exhibit negative correlation. Figure 3 illustrates how the relationship between concrete's characteristics and various exposures ranges from 0 to 0.1, additionally; it shows how different exposure conditions have a favorable effect on concrete's properties throughout both the plastic and hardening periods. Both Patil et al. [16], Endait et.al [17] and Baviskar et al. [18] reported the same kind of model results in their research.

4.2 Principal Component Analysis

A Scree plot of PCA's first three components reveals that this model has a variability close to 85.6%for dependent variables. This volatility is beneficial for prediction; shown in Figure 3 (B) (i). Similar to a Scree plot, the component plot of the PCA in Figure 3 (B) (ii) reveals that all of the study's variables are connected to one another. Concrete's compressive, flexural, and split tensile strengths are directly related to the cement content, CA, FA, and exposure circumstances. Unlike slump, this is directly correlated with Admixture quantity, exposure circumstances, cement content, CA and FA. However, the relationship between these characteristics and the water cement ratio and water content is inverse.

The loading plot in Figure 3 (B) (ii) illustrates the significance of the components for the study's variables. In order to predict the various properties of concrete, Patil et al. [19] and Lu et al. [20] employ correlation matrices; this plot also helps to condense a large number of unimportant variables.

4.3 Multiple Linear Regression (MLR)

A statistical method called multiple regression can be used to look at the relationship between a number of independent factors and one single dependent variable. Using available independent variables, multiple regression analysis seeks to estimate the value of a single dependent variable. Table 3 displays the MLR model's input parameters. Determining the connection between two or more variables is a common task in engineering. One statistical tool that has long captured the curiosity of researchers in this field is regression analysis. Regression modelling is widely believed of as the process of fitting models to data.

A special type of regression model called a linear regression model uses linear predictor functions to describe the data and estimates output parameters from the data. It is important to note that numerous input variables are often used in regression analysis applications, which results in the "multiple linear regression" function. In this instance, MLR analyses observed data and fits a linear equation to determine the correlation between two or more input variables. In multiple linear regression, data are summarized and the relationship between variables is examined. For prediction of concrete properties like slump, CF, CS, SPT and FS, MLR model gives the Equation 1, 2, 3, 4, and 5 respectively. The Charhate et al. [21] and Patil et al. [22] published results from a similar kind of model in their work.

$$\text{Loss in slump (mm)} = -480.93+0.63*W/C+0.63*C+0.35*FA+5.7E\text{-}02*CA-0.83*Admx-4.59*\text{Exposure-Extreme}+3.65*\text{Exposure-Modrate} + 3.55*\text{Exposure-Sever} \quad (1)$$

$$CF = 2.31-1.69E\text{-}02*W/C-5.39E\text{-}04*C-1.0E\text{-}03*FA-4.2E\text{-}04*CA+1.24E\text{-}2*Admx-6.6E\text{-}03*\text{Exposure-Extreme}+4.89E\text{-}03*\text{Exposure-Modrate}+1.14E\text{-}3*\text{Exposure-Sever} \quad (2)$$

$$CS\ (MPa) = 159.0-2.38*W/C-4.85E\text{-}02*C-8.5E\text{-}02*FA-2.9E\text{-}2*CA+0.86*Admx-0.145*\text{Exposure-Extreme}+0.43*\text{Exposure-Modrate}+0.18*\text{Exposure-Sever} \quad (3)$$

$$SPT\ (MPa) = 30.87-0.7*W/C-1.15E\text{-}2*C-1.8E\text{-}02*FA-8.86E\text{-}3*CA+0.24*Admx-5.15E\text{-}02*\text{Exposure-Extreme}+5.94E\text{-}02*\text{Exposure-Modrate}-0.010*\text{Exposure-Sever} \quad (4)$$

$$FS\ (MPa) = 53.78-0.80*W/C-2E\text{-}2*C-3.61E\text{-}02*FA-1.3E\text{-}02*CA+0.40*Admx-9.26E\text{-}02*\text{Exposure-Extreme}+0.18*\text{Exposure-Modrate}-1.2E\text{-}2*\text{Exposure-Sever} \quad (5)$$

Figure 4 (a) displays the prediction for slump loss and its corresponding means, Figure 4 (b) displays the prediction for CF and its corresponding means, Figure 4 (c) displays the prediction for CS and its corresponding means, Figure 4 (d) displays the prediction for SPT and its corresponding means, Figure 4 (e) displays the prediction for FS and its corresponding means, and Figure 4 (f) displays the performance of the MLR model. Since the values of R2 for slump loss, CF, CS, SPT, and FS are sequentially 0.903, 0.903, 0.952, 0.954, and 0.988, it can be concluded that the MLR model provides the best match to the empirical data and makes accurate predictions. A strong model is indicated by a reasonably high F-value. The MLR model predicts the flexural strength of concrete more precisely than it does the other parameters because the MLR model for FS has higher values for R2 and F. The changes in properties of the concrete is mainly due to meet the requirements for the exposure condition, the strength and rheological qualities must rise as the severity of the exposure condition increases. Several studies have confirmed such parallel sorts of outcomes [10,21,23–25].

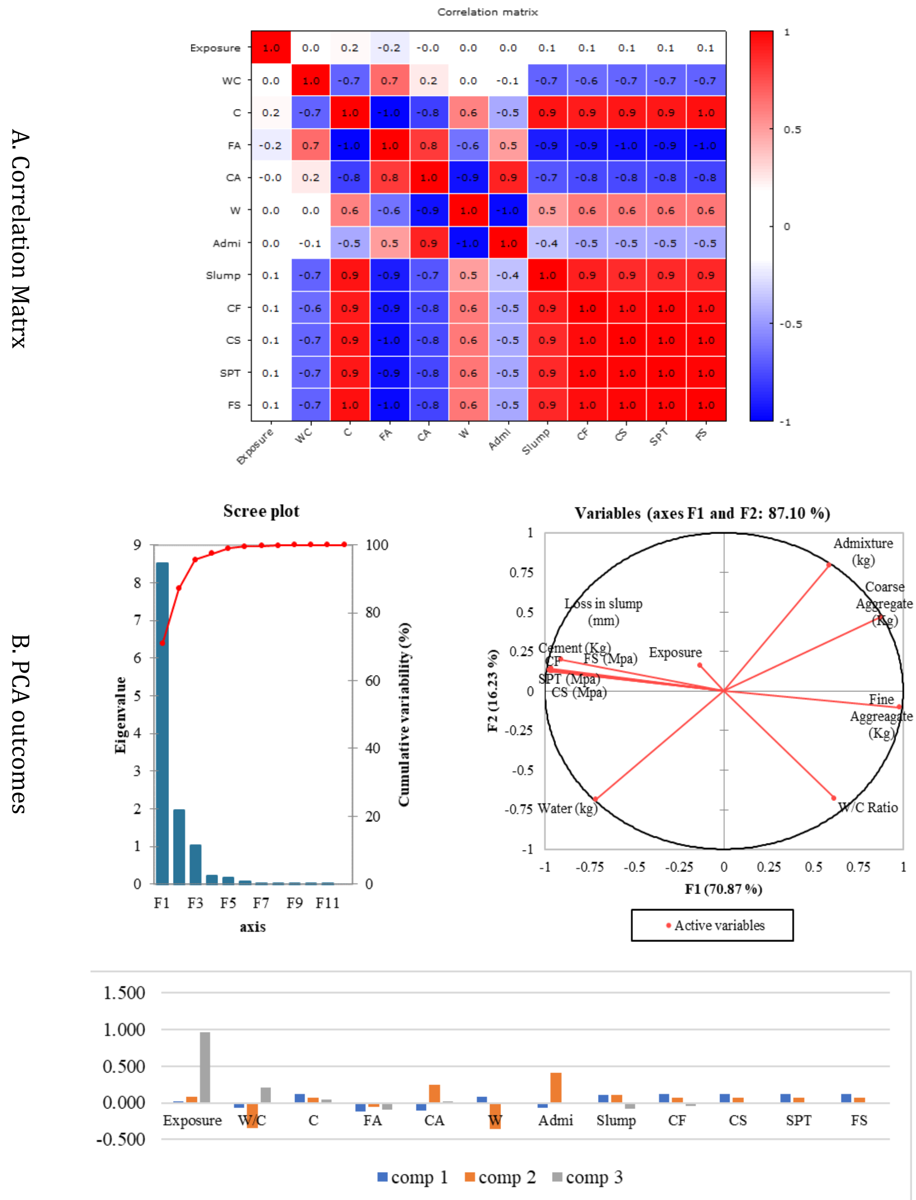


Fig. 3 (A) Correlation Matrix (B) PCA outcomes (i) Scree Plot (ii) Component Plot (iv) Loading Plot

Table 3. Experimental results

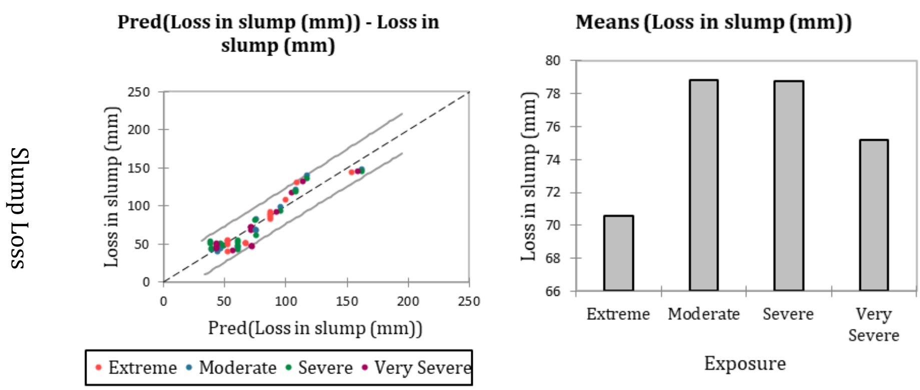
Sr No	Exposure	W/C Ratio	Cement (Kg)	FA (Kg)	CA (Kg)	Water (kg)	Adm (kg)	Slump (mm)	CF	CS (MPa)	SPT (MPa)	FS (MPa)
1	1	0.3	494	597.45	1215	148	4.94	122	0.99	52	4.65	7.56
2	1	0.36	412	645.95	1248	148	4.12	68	0.96	50	4.18	6.71
3	1	0.4	370	674.8	1260	148	3.7	47	0.92	49	3.83	6.12
4	1	0.45	329	707.54	1266	148	3.29	45	0.91	47	3.51	5.3
5	1	0.5	300	736.56	1264	148	3	43	0.9	46	3.37	4.82
6	1	0.55	300	754.97	1243	148	3	41	0.9	46	3.37	4.71
7	1	0.6	300	754.97	1243	148	3	44	0.9	46	3.31	4.7
8	1	0.3	639	508.98	1035	191.58	0	149	0.99	53	4.78	8.27
9	1	0.36	533	562.9	1087	191.58	0	141	0.99	53	4.69	7.85
10	1	0.4	479	594.24	1110	191.58	0	99	0.98	52	4.58	7.3
11	1	0.45	426	629.25	1126	191.58	0	83	0.97	51	4.39	6.96
12	1	0.5	384	661.12	1135	191.58	0	46	0.93	50	4.09	6.33
13	1	0.55	349	691.1	1138	191.58	0	49	0.91	47	3.55	5.6
14	1	0.6	349	691.1	1138	191.58	0	48	0.91	47	3.55	5.56
15	2	0.3	494	597.45	1215	148	4.94	119	0.99	52	4.65	7.44
16	2	0.36	412	645.95	1248	148	4.12	62	0.96	50	4.17	6.49
17	2	0.4	370	674.8	1260	148	3.7	52	0.92	49	3.82	6.08
18	2	0.45	329	707.54	1266	148	3.29	51	0.91	47	3.5	5.3
19	2	0.5	300	736.56	1264	148	3	51	0.9	46	3.29	4.52
20	2	0.55	300	736.56	1264	148	3	54	0.9	46	3.22	4.41
21	2	0.6	300	736.56	1264	148	3	45	0.9	46	3.22	4.33
22	2	0.3	639	508.98	1035	191.58	0	146	0.99	53	4.77	8.14
23	2	0.36	533	562.9	1087	191.58	0	136	0.99	53	4.69	7.78
24	2	0.4	479	594.24	1110	191.58	0	94	0.98	52	4.56	7.24
25	2	0.45	426	629.25	1126	191.58	0	82	0.97	51	4.34	6.8
26	2	0.5	384	661.12	1135	191.58	0	55	0.93	49	4.08	6.32
27	2	0.55	384	661.12	1135	191.58	0	43	0.93	49	3.94	6.2
28	2	0.6	384	661.12	1135	191.58	0	48	0.92	49	3.83	6.13
29	3	0.3	494	597.45	1215	148	4.94	118	0.98	52	4.62	7.38
30	3	0.36	412	645.95	1248	148	4.12	47	0.93	50	4.12	6.48
31	3	0.4	370	674.8	1260	148	3.7	42	0.92	48	3.77	5.87
32	3	0.45	329	707.54	1266	148	3.29	50	0.91	47	3.45	5.18
33	3	0.5	329	707.54	1266	148	3.29	44	0.91	46	3.44	5.16
34	3	0.55	329	707.54	1266	148	3.29	47	0.9	46	3.39	5.15
35	3	0.6	329	707.54	1266	148	3.29	51	0.9	46	3.38	4.99
36	3	0.3	639	508.98	1035	191.58	0	146	0.99	53	4.77	8.1
37	3	0.36	533	562.9	1087	191.58	0	133	0.99	52	4.66	7.63
38	3	0.4	479	594.24	1110	191.58	0	93	0.98	52	4.53	7.22
39	3	0.45	426	629.25	1126	191.58	0	72	0.96	51	4.31	6.79
40	3	0.5	426	629.25	1126	191.58	0	72	0.96	51	4.28	6.78
41	3	0.55	426	629.25	1126	191.58	0	72	0.96	51	4.26	6.76
42	3	0.6	426	629.25	1126	191.58	0	69	0.96	50	4.24	6.73
43	4	0.3	494	597.45	1215	148	4.94	108	0.98	52	4.6	7.35
44	4	0.36	412	645.95	1248	148	4.12	51	0.93	50	4.12	6.43
45	4	0.4	370	674.8	1260	148	3.7	41	0.91	48	3.64	5.77
46	4	0.45	370	674.8	1260	148	3.7	55	0.91	48	3.63	5.73
47	4	0.5	370	674.8	1260	148	3.7	54	0.91	48	3.58	5.7
48	4	0.55	370	674.8	1260	148	3.7	50	0.91	48	3.58	5.69
49	4	0.6	370	674.8	1260	148	3.7	55	0.91	48	3.56	5.67
50	4	0.3	639	508.98	1035	191.58	0	144	0.99	53	4.7	7.97
51	4	0.36	533	562.9	1087	191.58	0	131	0.99	52	4.66	7.6
52	4	0.4	479	594.24	1110	191.58	0	92	0.97	51	4.51	7.13
53	4	0.45	479	594.24	1110	191.58	0	90	0.97	51	4.44	7.06
54	4	0.5	479	594.24	1110	191.58	0	88	0.97	51	4.42	7.03
55	4	0.55	479	594.24	1110	191.58	0	86	0.97	51	4.41	7
56	4	0.6	479	594.24	1110	191.58	0	83	0.97	51	4.4	6.99

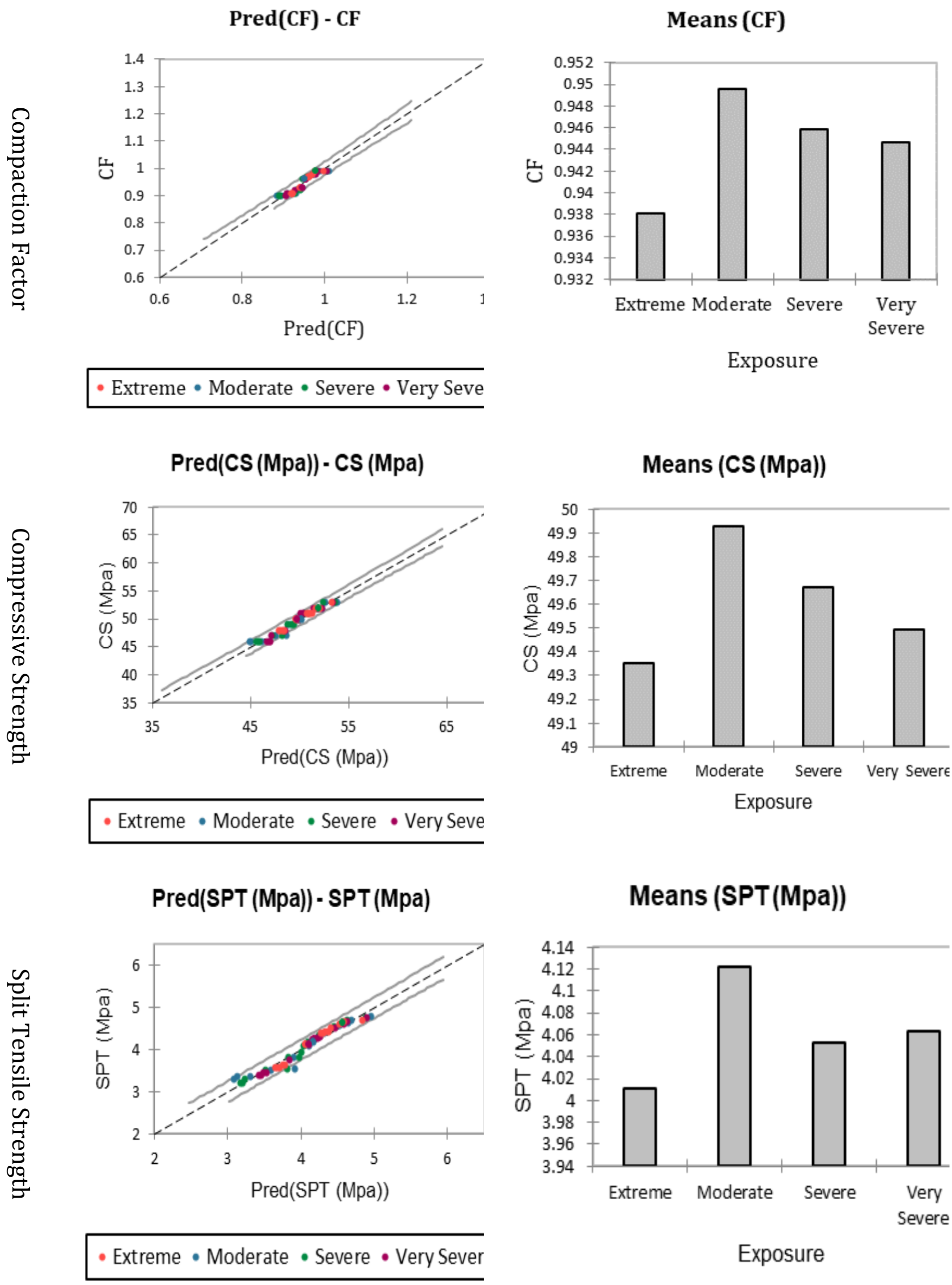
Where 1= Moderate exposure, 2= Severe Exposure, 3= Very Severe, 4= Extreme Exposure

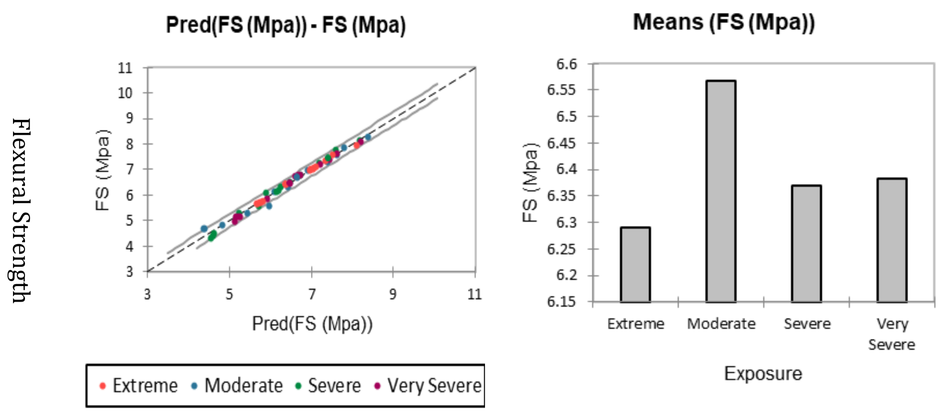
4.4 Response Surface Method

The relationship between a response variable and a group of experimental variables or factors is studied using RSM techniques. These procedures are often applied after selecting a few key controllable factors and identifying the factor settings that maximise the response. The RSM Model's input parameters are listed in Table 3. The variables are exposure, W/C, cement, FA, CA, water, and admixture. RSM chooses the variable combination that produces the best response for the dependent variables Slump, CF, CS, SPT, and FS. RSM approaches are used to investigate the association between a response variable and a collection of experimental variables or factors. Figure 5 displays the RSM model's output, which consists of two plots: a Pareto chart and a normal probability chart. Normal probability graphs display the effects of the factors or their interactions and can be employed to identify significant effects. Equations 6, 7, 8and 9 provide RSM predictions for slump at extreme, moderate, severeand very severe environmental exposure conditionsrespectively. These predictions provide the ideal slump value for each exposure. Equations 10, 11, 12, and 13 provide the optimal CF value for each exposure by providing RSM predictions for CF at extreme, moderate, severe, and very severe exposure conditions respectively.

Equations 14, 15, 16, and 17 provide RSM predictions for CS at extreme moderate, severe, and very severe levels, respectively, providing the ideal CS value for each exposure. Equations 18, 19, 20, and 21 provide RSM predictions for SPT at extreme, moderate, severe, and very severe levels, respectively, providing the ideal SPT value for each exposure. Equations 22, 23, 24, and 25 provide the optimal FS value for each exposure by providing RSM predictions for FS at extreme, moderate, severe, and very severe levels, respectively. The RSM model's pareto chart displays the independent variables in the experiment in descending order of importance. RSM calculates S (error estimate); the lower the value of S, the better the fit of the model to the data. Figure 5 (2) illustrates that the RSM model performs better for CF prediction than the Slump, CS, SPT, and FS models because the S value for the CF is lower than the S values for the Slump, CS, SPT, and FS models. The R^2 value, which represents how well the model matches the data, is used to assess the RSM model's performance. Figure 5 illustrates how well the RSM model fits Slump, CF, CS, SPT, and FS, with R^2 values of 0.986, 0.985, 0.987, 0.999, and 0.997, respectively. Similar results have been confirmed by numerous investigations[26-31].




Compaction Factor
Pred(CF) - CF
CF
Pred(CF)
Extreme
Moderate
Severe
Very Seve
Means (CF)
CF
Extreme
Moderate
Severe
Very Severe
Exposure
Compressive Strength
Pred(CS (Mpa)) - CS (Mpa)
CS (Mpa)
Pred(CS (Mpa))
Extreme
Moderate
Severe
Very Seve
Means (CS (Mpa))
CS (Mpa)
Extreme
Moderate
Severe
Very Severe
Exposure
Split Tensile Strength
Pred(SPT (Mpa)) - SPT (Mpa)
SPT (Mpa)
Pred(SPT (Mpa))
Extreme
Moderate
Severe
Very Sever
Means (SPT (Mpa))
SPT (Mpa)
Extreme
Moderate
Severe
Very Severe
Exposure



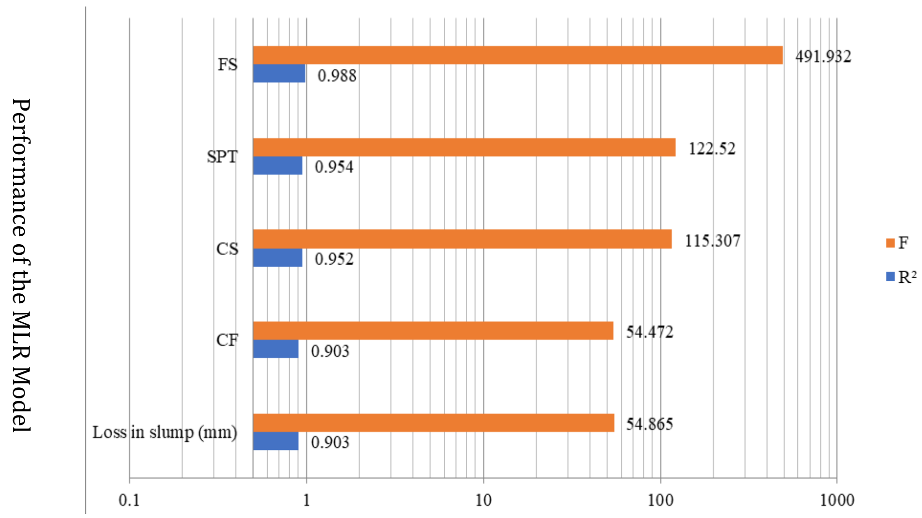


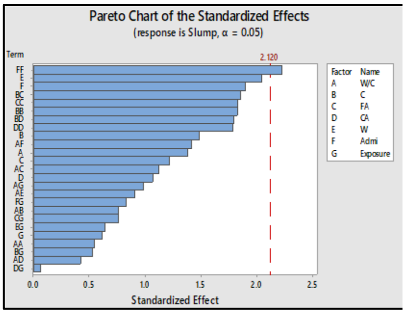
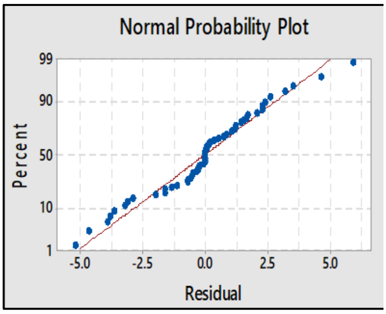
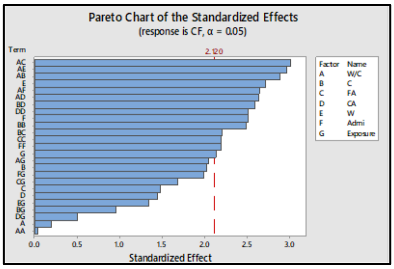
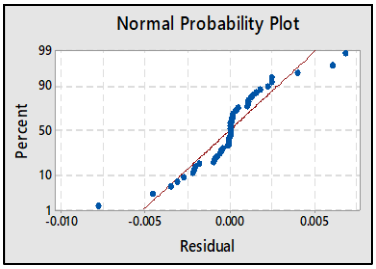
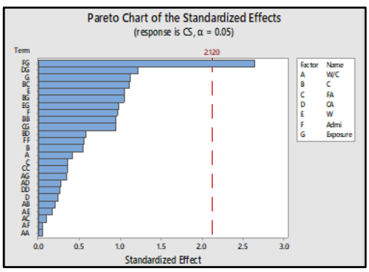
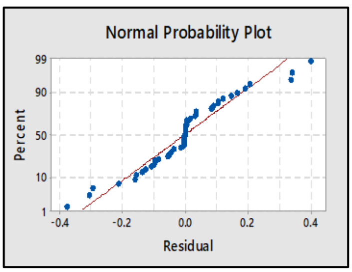
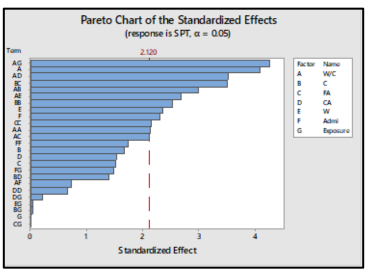
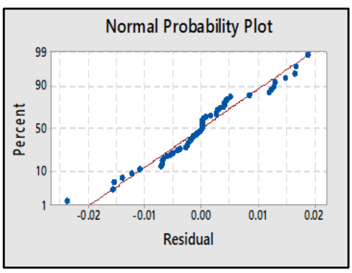
Fig. 4 Outcomes of the MLR Model for a) Slump Loss 2) CF 3) CS 4) SPT 5) FS 6) Performance of the Model

Test	Exposure	Test	
Slump	Extreme	Slump = 1377103 + 738422 W/C - 1909 C - 353 FA - 1639 CA - 297 W - 8837 Adm - 145 W/C*W/C + 0.599 C*C + 0.310 FA*FA + 0.538 CA*CA + 440 Adm*Adm- 253 W/C*C - 547 W/C*FA - 109 W/C*CA - 892 W/C*W - 1579 W/C*Adm + 0.595 C*FA + 1.022 C*CA	(6)
	Moderate	Slump =1441317 + 761663 W/C - 1931 C - 417 FA - 1645 CA - 388 W - 8923 Adm- 145 W/C*W/C + 0.599 C*C + 0.310 FA*FA + 0.538 CA*CA + 440 Adm*Adm- 253 W/C*C - 547 W/C*FA - 109 W/C*CA - 892 W/C*W - 1579 W/C*Adm + 0.595 C*FA + 1.022 C*CA	(7)
	Severe	Slump = 1419836 + 753743 W/C - 1924 C - 395 FA - 1644 CA - 357 W - 8884 Adm - 145 W/C*W/C + 0.599 C*C + 0.310 FA*FA	(8)

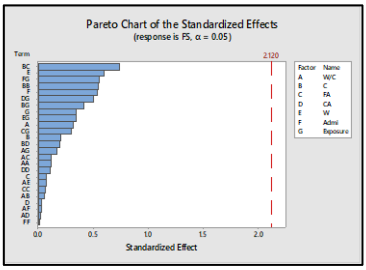
		+ 0.538 CA*CA + 440 Adm*Adm- 253 W/C*C - 547 W/C*FA - 109 W/C*CA - 892 W/C*W- 1579 W/C*Adm+ 0.595 C*FA + 1.022 C*CA	
	Very Severe	Slump = 1400693 + 745956 W/C - 1917 C - 374 FA - 1642 CA - 328 W - 8849 Adm - 145 W/C*W/C + 0.599 C*C + 0.310 FA*FA + 0.538 CA*CA + 440 Adm*Adm- 253 W/C*C - 547 W/C*FA - 109 W/C*CA - 892 W/C*W- 1579 W/C*Adm+ 0.595 C*FA + 1.022 C*CA	(9)
CF	Extreme	CF=1213 + 2670 W/C - 2.39 C - 0.065 FA - 2.125 CA + 0.361 W - 10.64 Adm- 0.011 W/C*W/C + 0.000825 C*C + 0.000377 FA*FA + 0.000766 CA*CA+ 0.437 Adm*Adm - 0.963 W/C*C - 1.474 W/C*FA - 0.691 W/C*CA - 2.948 W/C*W- 2.97 W/C*Adm + 0.000714 C*FA + 0.001491 C*CA	(10)
	Moderate	CF=1260 + 2706 W/C - 2.41 C - 0.145 FA - 2.115 CA + 0.270 W - 10.79 Adm- 0.011 W/C*W/C + 0.000825 C*C + 0.000377 FA*FA + 0.000766 CA*CA+ 0.437 Adm*Adm - 0.963 W/C*C - 1.474 W/C*FA - 0.691 W/C*CA - 2.948 W/C*W- 2.97 W/C*Adm + 0.000714 C*FA + 0.001491 C*CA	(11)
	Severe	CF=1222 + 2694 W/C - 2.40 C - 0.109 FA - 2.111 CA + 0.324 W - 10.73 Adm- 0.011 W/C*W/C + 0.000825 C*C + 0.000377 FA*FA + 0.000766 CA*CA+ 0.437 Adm*Adm - 0.963 W/C*C - 1.474 W/C*FA - 0.691 W/C*CA - 2.948 W/C*W- 2.97 W/C*Adm + 0.000714 C*FA + 0.001491 C*CA	(12)
	Very Severe	CF=1202 + 2681 W/C - 2.39 C - 0.080 FA - 2.113 CA + 0.359 W - 10.69 Adm- 0.011 W/C*W/C + 0.000825 C*C + 0.000377 FA*FA + 0.000766 CA*CA+ 0.437 Adm*Adm - 0.963 W/C*C - 1.474 W/C*FA - 0.691 W/C*CA - 2.948 W/C*W- 2.97 W/C*Adm + 0.000714 C*FA + 0.001491 C*CA	(13)
CS	Extreme	CS =-40337 + 11151 W/C + 59.0 C + 16.7 FA + 24.3 CA + 30.7 W + 276 Adm- 1.0 W/C*W/C - 0.0202 C*C - 0.0039 FA*FA - 0.0052 CA*CA - 7.2 Adm*Adm- 4.3 W/C*C - 3.2 W/C*FA - 4.6 W/C*CA - 10.7 W/C*W + 4.3 W/C*Adm- 0.0233 C*FA - 0.0217 C*CA	(14)
	Moderate	CS=-38792 + 11031 W/C + 58.4 C + 16.4 FA + 23.6 CA + 29.3 W + 278 Adm- 1.0 W/C*W/C - 0.0202 C*C - 0.0039 FA*FA - 0.0052 CA*CA - 7.2 Adm*Adm- 4.3 W/C*C - 3.2 W/C*FA - 4.6 W/C*CA - 10.7 W/C*W + 4.3 W/C*Adm- 0.0233 C*FA - 0.0217 C*CA	(15)
	Severe	CS=-37881 + 11070 W/C + 58.1 C + 15.9 FA + 23.3 CA + 28.3 W + 277 Adm- 1.0 W/C*W/C - 0.0202 C*C - 0.0039 FA*FA	(16)

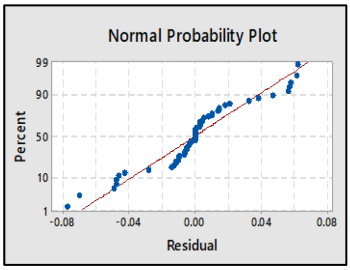
		- 0.0052 CA*CA - 7.2 Adm*Adm- 4.3 W/C*C - 3.2 W/C*FA - 4.6 W/C*CA - 10.7 W/C*W + 4.3 W/C*Adm- 0.0233 C*FA - 0.0217 C*CA	
	Very Severe	CS=-41033 + 11103 W/C + 59.3 C + 17.2 FA + 24.4 CA + 31.5 W + 279 Adm- 1.0 W/C*W/C - 0.0202 C*C - 0.0039 FA*FA - 0.0052 CA*CA - 7.2 Adm*Adm- 4.3 W/C*C - 3.2 W/C*FA - 4.6 W/C*CA - 10.7 W/C*W + 4.3 W/C*Adm- 0.0233 C*FA - 0.0217 C*CA	(17)
SPT	Extreme	SPT=-9990 + 10062 W/C + 10.67 C + 5.41 FA + 4.68 CA + 7.97 W + 42.6 Adm+ 2.18 W/C*W/C - 0.00322 C*C - 0.001415 FA*FA - 0.00077 CA*CA- 1.331 Adm*Adm - 3.81 W/C*C - 3.96 W/C*FA - 3.54 W/C*CA- 10.23 W/C*W- 3.17 W/C*Adm - 0.00435 C*FA - 0.00307 C*CA	(18)
	Moderate	SPT=-9944 + 10049 W/C + 10.66 C + 5.43 FA + 4.64 CA + 7.94 W + 42.8 Adm+ 2.18 W/C*W/C - 0.00322 C*C - 0.001415 FA*FA - 0.00077 CA*CA- 1.331 Adm*Adm - 3.81 W/C*C - 3.96 W/C*FA - 3.54 W/C*CA- 10.23 W/C*W- 3.17 W/C*Adm - 0.00435 C*FA - 0.00307 C*CA	(19)
	Severe	SPT=-9933 + 10051 W/C + 10.65 C + 5.42 FA + 4.64 CA + 7.93 W + 42.8 Adm+ 2.18 W/C*W/C - 0.00322 C*C - 0.001415 FA*FA - 0.00077 CA*CA- 1.331 Adm*Adm - 3.81 W/C*C - 3.96 W/C*FA - 3.54 W/C*CA- 10.23 W/C*W- 3.17 W/C*Adm - 0.00435 C*FA - 0.00307 C*CA	(20)
	Very Severe	SPT=-9925 + 10055 W/C + 10.65 C + 5.42 FA + 4.64 CA + 7.91 W + 42.8 Adm+ 2.18 W/C*W/C - 0.00322 C*C - 0.001415 FA*FA - 0.00077 CA*CA- 1.331 Adm*Adm - 3.81 W/C*C - 3.96 W/C*FA - 3.54 W/C*CA- 10.23 W/C*W- 3.17 W/C*Adm - 0.00435 C*FA - 0.00307 C*CA	(21)
	Extreme	FS=-2867 + 876 W/C + 6.1 C + 2.14 FA - 0.2 CA + 3.67 W + 28.1 Admi + 0.40 W/C*W/C - 0.00244 C*C - 0.00016 FA*FA + 0.00046 CA*CA + 0.03 Admi*Admi - 0.27 W/C*C - 0.77 W/C*FA - 0.09 W/C*CA - 1.0 W/C*W+ 0.5 W/C*Admi - 0.00321 C*FA - 0.00155 C*CA	(22)
	Moderate	FS =-2449 + 918 W/C + 6.0 C + 1.92 FA - 0.4 CA + 3.19 W + 28.0 Adm + 0.40 W/C*W/C - 0.00244 C*C - 0.00016 FA*FA + 0.00046 CA*CA + 0.03 Adm*Adm - 0.27 W/C*C - 0.77 W/C*FA - 0.09 W/C*CA - 1.0 W/C*W+ 0.5 W/C*Adm - 0.00321 C*FA - 0.00155 C*CA	(23)
	Severe	FS=-2425 + 903 W/C + 6.0 C + 1.93 FA - 0.4 CA + 3.18 W + 28.0 Adm + 0.40 W/C*W/C - 0.00244 C*C - 0.00016 FA*FA + 0.00046 CA*CA	(24)

	$+ 0.03\ Adm*Adm\ - 0.27\ W/C*C\ - 0.77\ W/C*FA\ - 0.09\ W/C*CA$ $- 1.0\ W/C*W + 0.5\ W/C*Adm - 0.00321\ C*FA - 0.00155\ C*CA$	
Very Severe	$FS = -2822\ + 890\ W/C\ + 6.1\ C\ + 2.12\ FA\ - 0.2\ CA\ + 3.60\ W$ $+ 28.3\ Adm$ $+ 0.40\ W/C*W/C\ - 0.00244\ C*C\ - 0.00016\ FA*FA$ $+ 0.00046\ CA*CA$ $+ 0.03\ Adm*Adm\ - 0.27\ W/C*C\ - 0.77\ W/C*FA\ - 0.09\ W/C*CA$ $- 1.0\ W/C*W + 0.5\ W/C*Adm - 0.00321\ C*FA - 0.00155\ C*CA$	(25)

Test	Pareto Chart	Normal Probability Plot	R^2	S
Slump			0.986	4.028
CF			0.985	0.0041
CS			0.987	0.26
SPT			0.999	0.016

FS





0.997

0.054

Fig. 5 RSM Model outcomes for (1) Slump (2) CF (3) CS (4) SPT (5) FS

5. Summary and Conclusion

A series of experiments have been conducted in this study to examine behaviour, rheological properties and strength characteristics of concrete under diverse environmental exposure conditions. IS 456:2000 [11] recommends, M40 be the minimum grade of concrete for extreme environmental exposure condition explored in this experimental work at both plastic and hardening stage.

Statistical tools such correlation matrices, PCA, MLR, and RSM were used to extensively analyze and assess the experimental data. The research uses correlation matrix and Principal Component Analysis (PCA) to produce precise results in order to assess interaction of experimental variables. Multivariate Linear Regression (MLR) model was developed to predict concrete properties during the plastic and hardening process. RSM techniques used to establish relationship between a response variable and a group of experimental variables.

The following inferences could be made in light of the experimental findings

- It had been observed that cement content steadily increases while W/C and water content decrease when exposure circumstances intensify.
- As the exposure condition worsens, rheological and strength parameters are significantly altered.
- Maximum enhancements in slump, CF, CS, SPT and FS for extreme environmental exposure conditions seem to be 10%, 0.99%, 1.89%, 4.3%, and 6.08%, respectively.
- Strength and rheological properties must improve as the exposure condition's abrasiveness rises in order to satisfy the exposure condition's demands.
- Correlations shows positive impact of various exposure conditions on properties of concrete throughout both the plastic and hardening periods as the relationship between concrete's features and different exposures varies from 0 to 0.1.
- According to a Scree plot of PCA's first three components, model has a variability of 85.6% for dependent variables. Compressive strength, flexural strength and split tensile strength are directly related to cement content, CA, FA and exposure circumstances. However, there is an inverse correlation between these traits and the water cement ratio.
- RSM model performs better for CF prediction than the Slump, CS, SPT, and FS models as "S" value for the CF is lower than the S values for the Slump, CS, SPT, and FS models. RSM model fits Slump, CF, CS, SPT, and FS, with R^2 values of 0.986, 0.985, 0.987, 0.999, and 0.997, respectively.
- It can be concluded that the MLR model provides the best match to the actual data and produces reliable prediction.

- In all kinds of exposure circumstances, the Response Surface Method (RSM) is also utilized to identify the concrete's ideal property. The RSM also matches experimental data the best because of its high coefficient of determination and its forecast is precise (R^2).

Declarations

- Conflict of Interest

The corresponding author confirms on behalf of all authors that no one's financial or personal interest conflict with the research described in this publication.

- **Author Contributions Statement**

  1) Experimental work was done by the first author.
  2) The manuscript's second and third authors each offer ideas, reviews, and additional effort.
  3) All authors reviewed the manuscript.

References

[1] Darban S, Tehrani HG, Karballaeezadeh N. Presentation a new method for determining of bridge condition index by using analytical hierarchy process. 2020 ;(March). https://doi.org/10.20944/preprints202003.0420.v1

[2] Pacheco-Torgal F, Miraldo S, Ding Y, Labrincha JA. Targeting HPC with the help of nanoparticles: An overview. Vol. 38, Construction and Building Materials. 2013. p. 365-70. https://doi.org/10.1016/j.conbuildmat.2012.08.013

[3] Tang F. Brief analysis on sampling and testing method of concrete specimen of building materials. MATEC Web Conf. 2018; 175. https://doi.org/10.1051/matecconf/201817501015

[4] Narmatha M, Felixkala DT. Meta kaolin -The Best Material for Replacement of Cement in Concrete. IOSR J Mech Civ Eng. 2016; 13(04):66-71. https://doi.org/10.9790/1684-1304016671

[5] Cavazos JS, González G, Kharissova O V, Ortega B, Peña L, Osorio M, et al. Effect of Nanoparticles on Mechanical Properties of Cement-Sand Mortar Applications. Adv Chem Eng Sci. 2017; 7:270-6. https://doi.org/10.4236/aces.2017.73020

[6] Jyothi Nikhila C, Chaitanya Kumar JD. Partial Replacement of Cement with Metakaolin in High Strength Concrete. Int J Engg Res Sci Tech [Internet]. 2015;4(4). Available from: http://www.ijerst.com/currentissue.php

[7] Ghadzali NS, Ibrahim MHW, Mohd Sani MSH, Jamaludin N, Desa MSM, Misri Z. Properties of concrete containing different type of waste materials as aggregate replacement exposed to elevated temperature - A review. IOP Conf Ser Earth Environ Sci. 2018; 140(1). https://doi.org/10.1088/1755-1315/140/1/012139

[8] Wons M, Camara L, Esteves I, Trentin PO, Medeiros-Junior RA. Evaluation of concrete self-healing with different fly ash contents and cracking ages by means of ultrasonic pulse velocity and compressive strength tests. J Build Pathol Rehabil [Internet]. 2021; 6(1):10. https://doi.org/10.1007/s41024-021-00104-7

[9] Park JK, Kim MO. The effect of different exposure conditions on the pull-off strength of various epoxy resins. J Build Eng [Internet]. 2021; 38:102223. https://doi.org/10.1016/j.jobe.2021.102223

[10] Eneowaji DO, Ucheowaji O. Effect of Exposure of Cement on the Compressive Strength of Concrete. J Eng Res Reports. 2021;20(6):24-32. https://doi.org/10.9734/jerr/2021/v20i617324

[11] Indian Code. IS:456 (2000) Plain and Reinforced Concrete Code of Practice. In: Bureau of Indian Standards, New Delhi. 2000.
[12] Indian Standard. IS: 1489 (Part 1):1991 Portland Pozzolona Cement Specification. In: Bureau of Indian Standards, New Delhi. THIRD. INDIA: Bureau of Indian Standards; 1991. p. 57.
[13] Indian Standard. IS 383 : 2016 Coarse and Fine Aggregate for Concrete - Specification. In: Bureau of Indian Standards, New Delhi. 2016.
[14] Indian Standard. IS 10262: 2019 Concrete Mix Proportioning- Guidelines. In: Bureau of Indian Standards (BIS). 2019. p. 1-40.
[15] Mishra RK, Ghosh P, Kulshreshtha M. Evaluation of strength of concrete on different initial exposure condition. Curr Mater Sci. 2020; 13.
[16] Patil HS, Dwivedi AK. Rheology of self-compacting concrete nanocomposites. Int J Recent Technol Eng. 2019; 8(2):554-7. https://doi.org/10.35940/ijrte.B1603.078219
[17] Endait M, Juneja A. New correlations between uniaxial compressive strength and point load strength of basalt. Int J Geotech Eng [Internet]. 2015; 9(4):348-53. https://doi.org/10.1179/1939787914Y.0000000073
[18] Baviskar S, Dwivedi A, Patil H. Analysis and development of the Composite Sustainable Condition Index for elevated service reservoir (ESR) by DER method. J Build Pathol Rehabil. 2022 Dec 16; 7(1):34. https://doi.org/10.1007/s41024-022-00177-y
[19] Patil H, Dwivedi A. Impact of nano ZnO particles on the characteristics of the cement mortar. Innov Infrastruct Solut [Internet]. 2021; 6(4). https://doi.org/10.1007/s41062-021-00588-9
[20] Lu K, Jin Y, Chen Y, Yang Y, Hou L, Zhang Z, et al. Review for order reduction based on proper orthogonal decomposition and outlooks of applications in mechanical systems. Mechanical Systems and Signal Processing. 2019. https://doi.org/10.1016/j.ymssp.2019.01.018
[21] Charhate S, Subhedar M, Adsul N. Prediction of Concrete Properties Using Multiple Linear Regression and Artificial Neural Network. J Soft Comput Civ Eng. 2018; 2(3):27-38.
[22] Patil H, Dwivedi A, Bidkar K. Prediction of upgraded properties of the concrete with the wash sand waste. J Build Pathol Rehabil [Internet]. 2022; 7(1):33. https://doi.org/10.1007/s41024-022-00171-4
[23] Alaneme George U, Mbadike Elvis M. Modelling of the mechanical properties of concrete with cement ratio partially replaced by aluminium waste and sawdust ash using artificial neural network. SN Appl Sci [Internet]. 2019; 1(11):1-18. https://doi.org/10.1007/s42452-019-1504-2
[24] Bidkar KL, Jadhao PD. Prediction of strength of remixed concrete by application of orthogonal decomposition, neural analysis and regression analysis. Open Eng. 2019; 9(1):434-43. https://doi.org/10.1515/eng-2019-0053
[25] Khademi F, Akbari M, Mohammadmehdi S, Nikoo M. Multiple linear regression, artificial neural network, and fuzzy logic prediction of 28 days compressive strength of concrete. Front Struct Civ Eng. 2017; 11(1):90-9. https://doi.org/10.1007/s11709-016-0363-9
[26] Patil H, Dwivedi A. Prediction of properties of the cement incorporated with nanoparticles by principal component analysis (PCA) and response surface regression (RSR). Mater Today Proc. 2021; 43:1358-67. https://doi.org/10.1016/j.matpr.2020.09.170
[27] Selvaraj S, Sivaraman S. Prediction model for optimized self-compacting concrete with fly ash using response surface method based on fuzzy classification. Neural Comput Appl [Internet]. 2019; 31(5):1365-73. https://doi.org/10.1007/s00521-018-3575-1
[28] Salem Alsanusi, Loubna Bentaher. Prediction of Compressive Strength of Concrete from Early Age Test Result Using Design of Experiments (RSM). Int J Civil, Environ Struct Constr Archit Eng. 2015;

[29] Gopalakrishnan R, Nithiyanantham S. Effect of ZnO Nanoparticles on Cement Mortar for Enhancing the Physico-Chemical, Mechanical and Related Properties. Adv Sci Eng Med. 2020; 12(3):348-55. https://doi.org/10.1166/asem.2020.2505

[30] Alyamac KE, Ghafari E, Ince R. Development of eco-efficient self-compacting concrete with waste marble powder using the response surface method. J Clean Prod. 2016; https://doi.org/10.1016/j.jclepro.2016.12.156

[31] Borucka-Lipska J. Acid Resistance, Water Permeability and Chloride Penetrability of Concrete Containing Crushed Basalt as Aggregates. Neural Comput Appl [Internet]. 2016 Apr; 31(2):137-50.