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Statistical Modeling of Fiber Reinforced High Performance Concrete

D.Maruthachalam*, R.K.Rajalaxmi*, B. G. Vishnuram**

Abstract— This paper employed statistical tools to test different properties of Fibre Reinforced High Performance Concrete (FRHPC) using Polyolefin Macro-Monofilament Fibre (PMM fibre).PMM fibre serves to effectively anchor the fibres into concrete thus resisting matrix pullout and enhancing the concrete's performance even after it has developed stress cracks. These fibres are non-corrosive and can be considered, in many applications, as an alternative to both steel fabrics and steel fibres. Generalized coded equations were established with the raw materials used and mix design was conducted using absolute volume method. An experimental work was conducted using different trial mixes. Statistical analysis was done at 95% confidence interval. Test result shows that a simple linear model is adequate to predict the mechanical and durability properties of FRHPC. The terms considered in the models were significant with p-values less than 0.05. The analysis of variance (ANOVA) showed that the developed models adequately fit the experimental data with a p-value for the regression less than 0.05. Out of 34 models developed, 31 models recorded co-efficient of determination values (R^2) ranges from 0.843 to 0.997 and other three models ranges from 0.792 to 0.812 . This statistical analysis assures reasonable response prediction. Statistical approach has proved to be a useful tool for of Fibre Reinforced High Performance concrete to predict different properties

Index Terms— Statistical modeling, Fiber Reinforced High Performance Concrete, Mechanical properties, Durability studies, Fiber Volume Fraction, SPSS software, Simple linear regression model, Analysis of Variance

1 INTRODUCTION

The new type of concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes is called High-Performance concrete (HPC). This concrete is expected to provide either substantially improved resistance to environmental influences (durability in service) or substantially increased structural capacity while maintaining adequate durability. Metakoline becomes a necessary ingredient to increases strength above to 65 MPa. The best quality fly ash may be used for other nominal benefits. In spite of the fact that these pozzolanic materials increase the water demand, their benefits will outweigh the disadvantages. The crux of whole problem lies in using very low w/ c ratio, consistent with high workability at the time of placing and compacting. FRHPC results from the addition of either short discrete fibers or continuous long fibers to the cement based matrix. In this composite material, short discrete fibers are randomly distributed throughout the concrete mass. Fiber Reinforced High Performance Concrete (FRHPC) represents potential alternative for providing more cost-effective ductile beam–column joints for structures constructed in active seismic zones. Modeling is a process of establishing a mathematical relationship between two or more variables to describe their influence on the output results; a model is a representation of construction and working of some system of interest. One purpose of a model is to enable the analyst to predict the effect of changes in the variables to the system. A model should be as close as possible to the real system and should incorporate most of its salient features. Model validation techniques include simulating the model under known input conditions and comparing model output with experimental values.

2 INVESTIGATION PROGRAMME

The experimental data of mechanical properties and durability studies on Fibre Reinforced High Performance Concrete were statistically analyzed to get the best fit model to describe the properties of Fibre Reinforced High Performance concrete.

2.1 Materials used

The materials used in the study and their properties are presented in Table 1.

Table 1: Material Properties

SI. No	Material	I.S.Code Provision	Physical Properties		
			Size	Specific gravity	Fineness
1.	OPC-53 grade	IS12269-2004[7]	12 μm	3.15	7.5
2.	Fine aggregate	IS 383-1970 [8]	Finer than 4.75 mm	2.67	2.25
3.	Coarse aggregate	IS 383-1970[8]	12.5 mm	2.60	5.96
4.	Metakaolin	ASTM C-618[3]	1 μm	2.54	-
5.	Fly ash	IS 3812-1999[6]	powder	2.15	-
6.	Super plasticizer	IS 9103-1999[5]	Semi solid	1.23	-
7.	Fiber	ASTM C-94[2]	45 mm	0.91	-

2.2 Mix Proportions

Selecting proportions for high - strength concrete using Portland cement and other Cementitious materials (ACI 211.4R-08)[2]. The factors used for modeling are fibre by mortar composite. The mortar composites are formed by adding cement, flyash, metakaolin, fine aggregate, water and superplasticizer.

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The present study was carried out based on the Modeling factors adopted by Abdullah.M, Al-Mattarneh.H.M.A, Mohammed B.S (2009)[1]. From mix proportions the coded values have been arrived. The uncoded values are converted to coded values as shown in Table 2 using equation 1.

$$X_{coded} = (X_{uncoded} – X_{avg})/(X_{maxi} - X_{avg}) \quad (1)$$

$$X_{avg} = (X_{maxi} + X_{min})/2$$

Where, X_{coded} is the coded values, X_{min} is the uncoded minimum values, X_{maxi} is the uncoded maximum values, $X_{uncoded}$ is the uncoded value to be translated to coded value, X_{avg} is the average value of maximum and minimum uncoded values.

Table 2: Mixes and coded values

Mix	F/M	F/M (coded)
CM	0	-1
HPC00	0	-1
HPC01	0.000711249	-0.336094958
HPC02	0.00142545	0.330565977
HPC03	0.002142622	1

Table 3: Measured Responses (Experimental)

Mix	**Compressive strength (MPa)**			**F/M (coded)**
	28 days	**56 days**	**90 days**	
CM	66.3	72.9	74.1	-1
HPC00	66.1	72.5	73.6	-1
HPC01	69.6	75.9	77.0	-0.336094958
HPC02	71.3	77.7	78.6	0.330565977
HPC03	72.6	79.1	80.5	1

Where CM refers to control mix, HPC00 refers to High Performance concrete without fibre. HPC01, HPC02 and HPC03 refers to High Performance concrete with fibre content of 0.1, 0.2 and 0.3 %, respectively. The measured responses are shown in Table 3 and the above procedure is followed for the remaining thirty one models

2.3 Details of Experimental Investigation

The fibre reinforced high performance concrete specimens having shapes like cube (100 x 100 x 100 mm), cylinder (150 mm (diameter) x 300 mm (height)) and prism (100 x 100 x 500 mm) were cast and tested after different periods (28, 56 and 90 days) of curing. For mechanical properties totally 105 specimens were tested and results were recorded. Similarly, for durability studies, totally 321 specimens were cast and each having different shapes like cube (100 x 100 x 100 mm), disc (150 mm (diameter) x 63.5 mm (height)), cylinder (100 mm (diameter) x 200 mm (height)) and prism (285 x 75 x 75 mm). Then the specimens were tested after different periods (28, 56 and 90 days) of curing and results were recorded. Modeling was developed using these experimental results.

2.4 Methods

Different methods by which the experimental results are analyzed are explained here.

2.4.1 Regression Analysis

Regression is the measure of the average relationship between two or more variables in terms of original units of the data. Regression helps to estimate one variable or the dependant variable from the other variable or the independent variables. In other words the methods can estimate the value of one variable, provided the variables of other variable given. The statistical method which helps us to estimate the unknown value of one variable from the known variables of the related variables is called as regression.

2.4.2 Simple Linear Regression

Regression equation is an algebraic method. It is an algebraic expression of the regression line. It can be classified into regression equation, regression coefficient, individual observation and group distribution. As there are two regression lines, there are two regression equations for the two variables X and Y there are two regression equations. They are regression equation of X on Y and regression equation of Y on X.

$$\mathbf{Y = aX + b} \quad (2)$$

Where ‘a’ and ‘b’ are the two unknown constants at the parameters of the line, determine the position of the line. The constants ‘a’ show the level of the fitted line. It is the distance between the point of origin and the point where the regression line touches the y axis. By the least square method, we can find out the values of ‘a’ and ‘b’ and determine the regression line, which is known as the best fit. The formulae are

$$\mathbf{X = na + by} \quad (3)$$

$$\mathbf{Xy = ay + by^2} \quad (4)$$

Where n is the number observed pairs of value x, y, xy, y^2 are the tools and they are computed from the value of two variables X and Y. Thus we can fit the least square line.

3 MODELING

Statistical tools were employed to analyses the test results and to develop the models to describe mechanical properties and durability studies of Fiber Reinforced High Performance Concrete. The details are given below.

3.1 Model Developed

- *Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, India, E-Mail: dmaruthachalam@gmail.com, PH- +91 9843169584
- *Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, India, ,E-Mail: aashacivilengg@gmail.com, PH - +91 9677561461
- ** Principal, EASA College of Engineering and Technology, Coimbatore, India.

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A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical equation is termed as mathematical modelling. Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures. In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics. In many cases, the quality of a scientific work depends on how well the mathematical models developed on the theoretical side agree with results of repeatable experiments. Lack of agreement between theoretical mathematical models and experimental measurements often leads to development of better theories are developed. Based on statistical approach reported by Ghezal A. and Kamal H. Khayat (2002) [4] and Padmanaban.I. , Kandasamy.S and Natesan S.C (2009)[9], process control parameters were identified models were developed for the mechanical properties and durability properties at the ages of 28, 56, and 90. The response function representing any of the recorded response can be expressed as

$$Y = f(F/M) \quad (5)$$

The relationship selected is a single degree response surface expressed as follows

$$Y = a_0 + a_1[F/M] \quad (6)$$

Where, F refers Fiber, M refers Mortar composite (Cement, metakaolin, flyash, water, super plasticizer and fine aggregate), a_0 refers Intercept and a_1 refers Variable co-efficients. Probable models were established by identifying the terms in the model that are significant using a t-test and carrying out an analysis of variance (ANOVA) to determine the adequacy of the model to fit to the experimental data. Using simple linear regression, model has been developed for strength and durability properties of Fiber Reinforced High Performance Concrete. Regression model were developed by using Statistical Package for the Social Sciences (SPSS) and the same have been shown in the Table 4 and Table 5.

Table 4: Statistical Models and coefficients of the terms

Mechanical properties	Days	Statistical Models
Compressive strength	28	66.842 + 3.291F/M
	56	76.280 + 3.283 F/M
	90	77.432+ 3.340 F/M
Splitting tensile strength	28	6.210 + 0.649 F/M
Modulus of rupture	28	6.493 + 1.345 F/M
Modulus of elasticity	28	38910.766 + 704.931 F/M
Poisson's ratio	28	0.184 + 0.012 F/M

Table 5: Statistical Models and coefficients of the terms

Durability studies	Days	Statistical Models
Voids permeability	28	4.12 – 2.62 F/M
	56	3.281 – 2.581 F/M
	90	2.565 – 2.462 F/M
Water absorption	28	2.250 – 0.346 F/M
	56	1.005 – 0.431 F/M
	90	0.644 – 0.160 F/M
Permeability	28	4.959 – 0.214 F/M
	56	4.038 – 0.316 F/M
	90	3.178 – 0.316 F/M
RCPT	28	2186.95 – 1122.05 F/M
	56	1011.832 – 800.222 F/M
	90	671.56 – 595.89 F/M
Impact resistance	28	296.545 + 63.526 F/M
	56	400.153 + 63.098F/M
	90	415.589 + 59.847 F/M
Corrosion	28	4.67 – 2.11 F/M
	56	3.19 – 1.06 F/M
	90	2.015 – 0.880 F/M
Drying shrinkage	28	-0.019 + 0.021 F/M
	56	-0.046 + 0.032 F/M
	90	-0.056 + 0.034 F/M
Acid resistance(H_2SO_4)	28	2457.99 – 47.784 F/M
	56	2432.99 – 47.784 F/M
	90	2454.907 – 71.071 F/M
Acid resistance (HCl)	28	2340.017 – 49.641 F/M
	56	2415.02 – 49.64 F/M
	90	2453.381 – 67.721 F/M

4 RESULTS AND DISCUSSION

The models developed were validated with experimental results and the findings are reported here.

4.1 Validation

The Linear regression model indicated that out of the explanatory variables under study, variables namely,X_1 have significantly contributing to strength and durability properties. The analysis of variance of linear regression model for strength and durability properties indicates the overall significance of the model fitted. The coefficient of determination R^2 value showed that these variables put together explained the variations of strength and durability properties to the range extent of 79.2 to 99.7 %. The significant levels of strength properties and durability studies are ranging from 0.5 to 4.8%. Hence all the models are adequate. The significant of the entire models have been presented in the Table 6 & Table 7.

Table 6: Significance of the models

Mechanical Properties	Days	F	t	Standard Error Estimate	Significance (%)
Compressive Strength	28	68.433	218.673 8.272	0.691	3
	56	88.257	271.942 9.395	0.607	2
	90	126.821	325.195 11.261	0.515	1
Splitting Tensile Strength	28	260.262	192.372 16.133	0.070	1

Modulus of Rupture	28	53.705	44.064 7.328	0.319	1
Modulus of Elasticity	28	11.407	232.228 3.377	362.715	4
Poisson's Ratio	28	83.231	175.778 9.123	0.002	2

Table 7: Significance of the models

Durability studies	Days	F	t	Standard Error Estimate	Significant %
Voids permeability	28	42.58	12.772 6.525	0.698	1
	56	47.264	10.885 6.875	0.652	0.6
	90	36.943	7.888 6.078	0.704	0.9
Water absorption	28	1114.083	270.02 33.378	0.018	0.9
	56	22.380	13.761 4.731	0.158	1.8
	90	372.039	96.563 19.288	0.014	0.9
Permeability	28	17.806	121.551 4.220	0.088	2.4
	56	48.583	110.946 6.970	0.079	1
	90	48.583	87.320 6.970	0.079	1
RCPT	28	57.12	18.349 7.551	258	0.9
	56	12.976	5.673 3.602	386.056	3.7
	90	9.60	4.351 3.099	334.16	4.8
Impact resistance	28	22.253	29.483 4.717	24.832	0.5
	56	16.189	34.163 4.024	28.918	1
	90	16.20	37.212 4.003	27.572	1
Corrosion	28	7.64	7.605 2.764	1.330	4
	56	35.66	22.438 5.972	0.307	1
	90	14.551	10.876 3.815	0.401	3.2
Drying shrinkage	28	7.752	3.278 2.784	0.014	3.9
	56	16.805	7.962 4.099	0.014	0.9
	90	18.972	9.501 4.356	0.015	0.7
Acid resistance (H_2SO_4)	28	19.060	197.021 4.366	26.956	2.2
	56	54.73	110.946 6.970	0.079	1
	90	48.583	87.320 6.970	0.079	1
Acid resistance (HCl)	28	14.703	164.991 3.835	32.210	3.1
	56	53.10	462.176 7.287	11.396	1
	90	53.099	462.176 7.287	11.396	1

Notes
F (statistic) = mean square (Regression)/mean square (Residual),t (statistic) = Signifacnt ranges from 0 to 0.05,
Standard estimate error = square root of mean square for the residual, Significance Percentage is <0.05 or 5%

4.2 Application of the models

The models are applicable for the concrete with mineral admixtures fly ash and metakaolin, 12.5 mm size of coarse aggregates and PMM fiber type. The compressive strength of PMMFRHPC can be estimated with good accuracy based on the derived model. Model can be used to estimate the Mechanical properties and durability studies of the PMMFRHPC mixtures. The models of PMMFRHPC properties would be useful to assess the performance and thus to facilitate the usage of PMMFRHPC. The ability of models and variation in the range of models were discussed in validity of the PMMFRHPC models section. The following Figure 1 and figure 2 shows the linear coefficient of determination between predicated and measured values (at the age of 28, 56 and 90 days) of strength and durability properties.

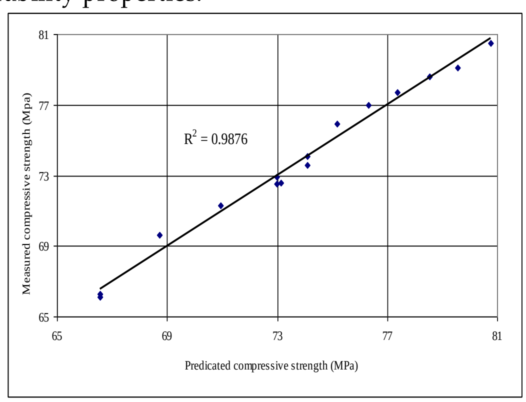

Figure 1: Predicated and measured compressive strength of concrete

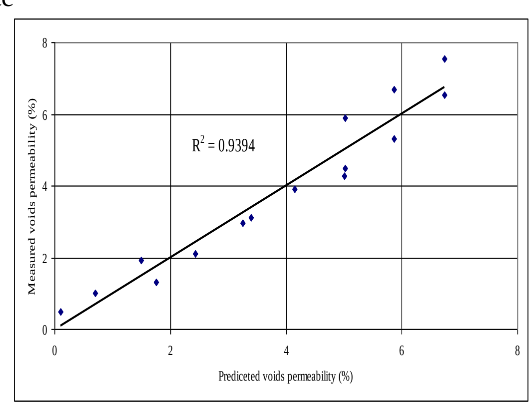

Figure 2: Predicated and measured voids permeability of concrete

5 Conclusions

Statistical models made up of parameters fiber dosage and mortar composites have been used to describe the effect of concrete mix ingredients on the mechanical properties and durability studies of a Fiber Reinforced High performance concrete using Polyolefin Macro-Monofilament Fibers. These fibers are non-corrosive and can be considered, in many applications, as an alternative to both steel fabrics and steel fibers.

The regressions models of mechanical properties are developed based on the variables given in equation (6).Models are developed for 28, 56 and 90 days as presented in the Table 4. The coefficient of determination (R^2) ranges from 0.792 to 0.989. The regression models of durability studies are developed based on the variables given in equation (6).Models are developed for 28, 56 and 90 days as presented in the Table 5. The coefficient of determination (R^2) ranges from 0.812 to 0.997.

A model is said to be significant p- values for less than 0.05. Thus the results of present investigation are found to be significant. The analysis of variance (ANOVA) showed that the developed models adequately fit the experimental data with a p-value for the regression less than 0.05. Statistical approach has proved to be a useful tool for modeling of Fiber Reinforced High Performance concrete.

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Authors Biography

D. Maruthachalam is working as Assistant Professor / Civil Engineering and R.K.Rajalaxmi, doing ME Structural Engineering in Sri Krishna College of Technology, Coimbatore. Dr. B.G. Vishnuram, Principal, EASA College of Engineering and Technology, Coimbatore, he is a Fellow member in IEI, and published more than 50 papers in Journals and Conferences and guiding five PhD scholars.

First Author: D. Maruthachalam

Second Author, R.K.Rajalaxmi

Third Author Dr. B.G. Vishnuram