# Response Surface Methodology (RSM) Models for prediction of steel fibre reinforced concrete strength by using 5 independent pie terms

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**Abstract:**

The object of the present research paper is to develop Response surface methodology (RSM) Models from five independent pi terms. (Aspect ratio, aggregate-cement ratio, water-cement ratio, percentage of fibre and control strength for prediction of SFRC strength. The output of this RSM model can be evaluated by comparing it with experimental strength and the predicted RSM model strength. The study becomes more fruitful when my using same model three SFRC strength were predicted that is compressive strength, flexural strength and split tensile strength.

**Keywords:** RSM model; 5 independent π Terms: predicted SFRC strength

## 1.Introduction:

To arrive at mathematical model, the course of action started with development of some foundation mathematical relations and then arriving at some single generalized equations. Mathematical models are developed to predict the strength of SFRC for different grade of concrete, for different Aspect ratio and different percentage of steel [5-8] [9-13] Shende .A.M et.al [7-10] studied the investigation for 1) Grade of concreteM20, M30 and M40 2) Aspect Ratio 50, 60 and 67 3) Percentage of steel fibres 0%, 1%, 2% and 3%.The mathematical modeling to calculate predicted compressive strength, flexural strength and split tensile strength of SFRC are studied by shende [4]in 2013.In this paper an effort is made to extend the work by developing RSM model by using five independent π terms that is control strength ,percentage of steel fibre, Aspect ratio, water cement ratio and Aggregate cement ratio for the prediction of steel fibre reinforced concrete compressive strength ,flexural And split tensile strength.

### 1.1 Response Surface Methodology (RSM) Models

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the aim is to optimize this response.

The objective of Response Surface Methodology is:

•How is a particular response affected by a given set of input variables over some specified region of interest?

•What values of the inputs will yield a maximum (or minimum) for a specific response?

•What is the relationship response-factors like close to this maximum (or minimum)?

For instance, suppose we wish to find the levels of two factors x1, x2 that maximize the response variable y of a process:

$y = f(x1, x2) + \varepsilon$ (Noise)

The surface represented by $\eta = f(x1, x2)$ is called a response surface, graphically represented as a solid surface in a three-dimensional space. In the contour plot, lines of constant response are drawn in the x1, x2 plane, which help visualize the shape of the response surface. Each contour corresponds to a particular height of the response surface. Such a plot is helpful in studying the levels of x1 and x2 that result in changes in the shape or height of the response surface.

As an important subject in the statistical design of experiments, the Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery 2005). As per the dimensional analysis, following $\pi$ terms are developed. These $\pi$ terms are dimensionless hence it is very easily possible to convert into three groups. These groups are converted into 3 dimensions in space to develop response surface[1] [3]

1.2 Steps in Response Surface Methodology

•To find a suitable approximation for the true functional relationship between y and the set of independent variables (usually, a low-order polynomial in some region of the independent variables: first-order model, or second-order model if there is curvature in the system).

•To estimate the parameters in the approximating polynomials (to find the maximum response, for instance).

•To do the response surface analysis in terms of the fitted surface. If the fitted surface is an adequate approximation of the true response function, then analysis of the fitted surface will be approximately equivalent to analysis of the actual system.

1.3 Response Surface Design

As per the dimensional analysis, six π terms are developed. These π terms are dimensionless hence it is very easily possible to convert into three groups. These three groups are converted into 3 dimensions in space to develop response surface. Hence,

X= Pi1 x Pi2 x Pi3

Y= Pi4 x Pi5

Z= Pi01

The ranges of input X, Y and output Z are more variant. Hence by using scaling principle, the above X, Y and Z values are scaled as follows:

x = X / max (X), y = Y / max (Y), and z = Z / max (Z)

1.4 RSM Model Development

The experimental data are collected, with the process parameter levels set as given in observation table to study the effect of process parameters over the output parameters.

The experiments are designed and conducted by employing response surface methodology (RSM). The selection of appropriate model and the development of response surface models have been carried out by using statistical software, "MATLAB R2009a". The best fit regression equations for the selected model are obtained for the response characteristics, viz., prediction of SFRC Strength. The response surface equations are developed using the field data and are plotted (figure to) to investigate the effect of process variables on various response characteristics. Table shows sample calculations for RSM model.

Table 1: Performance analysis of RSM Model and Comparison of Experimental and predicted strength (out of 495 reading first 15 are reported here) [4]

| Sr NO | X=Π2*Π3*Π5 | Y=Π1*Π4 | Predeicted strength by RSM model Π01 | Experimental strength | % Error |
|---|---|---|---|---|---|
| 1 | 91.35 | 35.9 | 38.5987 | 7.52 | 16 |
| 2 | 137.025 | 39.06 | 39.2254 | 0.42 | 17 |
| 3 | 182.7 | 39.74 | 39.1644 | 1.45 | 18 |
| 4 | 68.5125 | 39.6 | 37.3213 | 5.75 | 19 |
| 5 | 45.675 | 35.3 | 34.3013 | 2.83 | 20 |
| 6 | 102.76875 | 42 | 38.9383 | 7.29 | 21 |
| 7 | 68.5125 | 36.83 | 37.3213 | 1.33 | 22 |
| 8 | 137.025 | 42.74 | 39.2254 | 8.22 | 23 |
| 9 | 91.35 | 37.21 | 38.5987 | 3.73 | 24 |
| 10 | 45.675 | 34.9 | 34.3013 | 1.72 | 25 |
| 11 | 64.05 | 38.43 | 27.745 | 27.80 | 26 |
| 12 | 96.075 | 37.4 | 28.8231 | 22.93 | 27 |
| 13 | 128.1 | 37.5 | 30.2178 | 19.42 | 28 |
| 14 | 102.375 | 45.47 | 34.9614 | 23.11 | 29 |
| 15 | 153.5625 | 47.54 | 38.7512 | 18.49 | 30 |

Table 2: Performance analysis of RSM Model and Comparison of Experimental and predicted strength (out of 495 reading Last 15 are reported here) [4]

| **Sr No** | **X=Π2*Π3*Π5** | **Y=Π1*Π4** | **Predeicted strength by RSM model Π01** | **Experimental strength** | **% Error** |
|---|---|---|---|---|---|
| 480 | 33.8625 | 21.5 | 3.33 | **2.628019** | 21.08 |
| 481 | 38.2725 | 25.8 | 3.4 | **3.026657** | 10.98 |
| 482 | 36.0675 | 25.8 | 2.97 | **2.855499** | 3.86 |
| 483 | 33.8625 | 25.8 | 3.14 | **2.684142** | 14.52 |
| 484 | 38.2725 | 28.81 | 3.18 | **3.065614** | 3.60 |
| 485 | 36.0675 | 28.81 | 2.83 | **2.892254** | 2.20 |
| 486 | 33.8625 | 28.81 | 3.04 | **2.718691** | 10.57 |
| 487 | 41.7051 | 17.5 | 4.25 | **3.77511** | 11.17 |
| 488 | 43.7166 | 17.5 | 4.39 | **3.953649** | 9.94 |
| 489 | 37.9503 | 21 | 4.25 | **3.514886** | 17.30 |
| 490 | 41.7051 | 21 | 4.1 | **3.855731** | 5.96 |
| 491 | 43.7166 | 21 | 4.39 | **4.038083** | 8.02 |
| 492 | 37.9503 | 23.45 | 3.82 | **3.560128** | 6.80 |
| 493 | 41.7051 | 23.45 | 4.25 | **3.90536** | 8.11 |
| 494 | 43.7166 | 23.45 | 4.53 | 4.068083 | 9.71 |
| 495 | 33.8625 | 21.5 | 3.33 | **2.628019** | 21.08 |

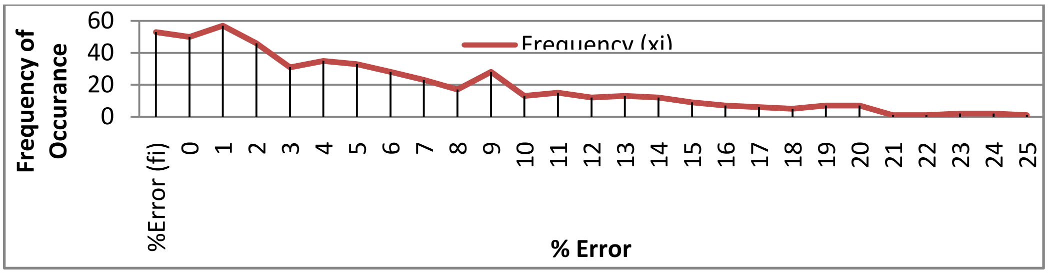


**Figure No 1 %Error vs Frequency graph for Pi01: predicted SFRC Strength**

**Linear model Poly55:**

f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3 + p40*x^4 + p31*x^3*y + p22*x^2*y^2 + p13*x*y^3 + p04*y^4 + p50*x^5 + p41*x^4*y + p32*x^3*y^2 + p23*x^2*y^3 + p14*x*y^4 + p05*y^5

| |
|---|
| Pridected SFRC Strength by using RSM =20.93 + 38.43*x -0.9203*y + 7.285*x^2 -7.838*x*y -2.23*y^2 -31.62*x^3 -7.281*x^2*y + 0.7373*x*y^2 + 0.6571*y^3 14.18*x^4 + 6.735*x^3*y + 0.351*x^2*y^2 + 2.28*x*y^3 + 0.09493*y^4 -1.862*x^5 -1.247*x^4*y + 0.04662*x^3*y^2 -0.6144*x^2*y^3 -0.5488 *x*y^4 + 0.1536*y^5 |

Where x is normalized by mean 28.09 and std 32.7 and where y is normalized by mean 62 and std 13.14 Coefficients (with 95% confidence bounds):

**Goodness of fit:**

**SSE: 4.941e+04 R-square: 0.6901 Adjusted R-square: 0.6775**

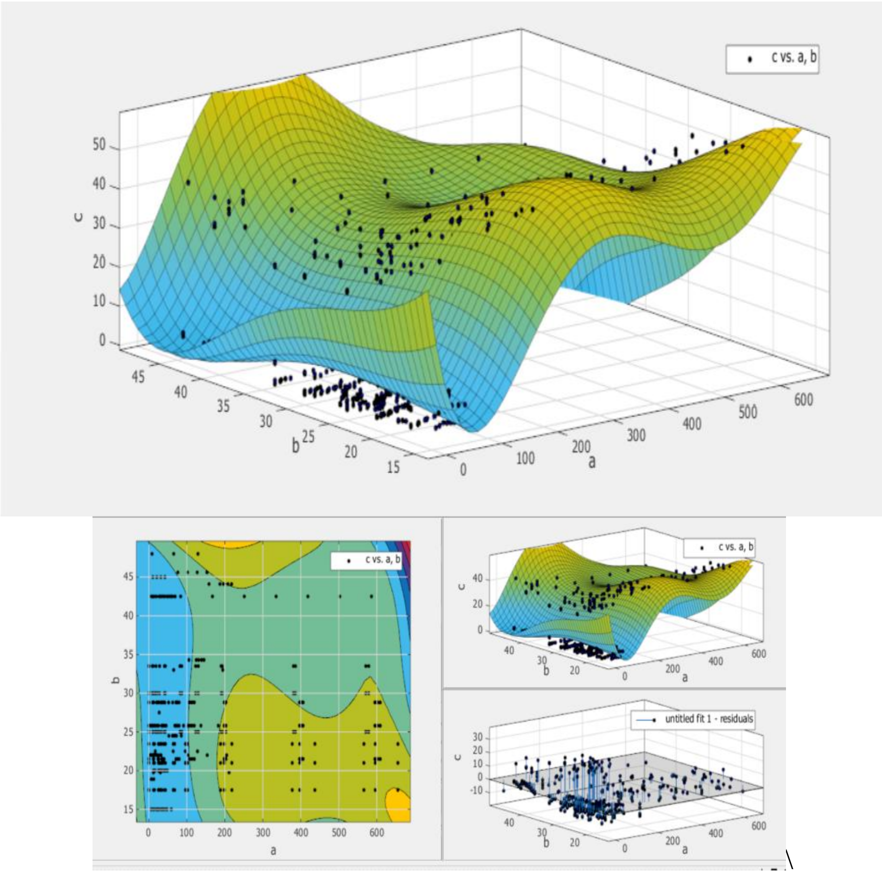


Figure No 2 3D graph showing predicted SFRC strength

2 DISCUSSIONS OF 3D GRAPHS

It is possible to evaluate the behavior of any model through graphical presentation in order to justify how the real

Phenomena work on account of appropriate interaction of independent terms. An attempt has been made for the prediction of steel fibre reinforced concrete strength.

In this model there are five independent terms and one dependent term. It is very difficult to plot a 3D graph.

To obtain the exact 3D graph dependent terms is taken on Z-axis where as from five independent terms, three are combined and a product is obtained which is presented on X-axis. The remaining two independent p terms are

Combined by taking product and represented on Y-axis.

On X axis X= 2 *3*5 On Y axis Y =1 *4, on Z axis = 01 (predicted SFRC strength

## 3 CONCLUSIONS

RSM model developed for predicting strength of SFRC, using strength of controlled concrete, percentage of fibres, aspect ratio, aggregate cement ratio and water cement ratio can very well be used in prediction of compressive strength, flexural strength and split tensile strength of SFRC using the five parameters listed above. The significance of this model can very well be seen from the data presented in column experimental strength and the predicted RSM strength . The significance of this model can very well be seen from %Error vs Frequency graph for predicted SFRC Strength

RSM model developed for prediction of compressive strength, Flexural strength and split tensile strength when compared with own observed experimental strength it is observed that predicted strengths and observed experimental strength are close to each other and are found to be within 90% of confidence limit It clearly indicates the reliability of RSM models developed to calculate predicted strength.The best fit regression equations for the selected model are obtained for the response characteristics

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