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Experimental analysis and modeling of steel fiber reinforced SCC using central composite design

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Abstract. The emerging technology of self compacting concrete, fiber reinforcement together reduces vibration and substitute conventional reinforcement which help in improving the economic efficiency of the construction. The objective of this work is to find the regression model to determine the response surface of mix proportioning Steel Fiber Reinforced Self Compacting Concrete (SFSCC) using statistical investigation. A total of 30 mixtures were designed and analyzed based on Design of Experiment (DOE). The fresh properties of SCC and mechanical properties of concrete were studied using Response Surface Methodology (RSM). The results were analyzed by limited proportion of fly ash, fiber, volume combination ratio of two steel fibers with aspect ratio of 50/35: 60/30 and super plasticizer (SP) dosage. The center composite designs (CCD) have selected to produce the response in quadratic equation. The model responses included in the primary stage were flowing ability, filling ability , passing ability and segregation index whereas in harden stage of concrete, compressive strength, split tensile strength and flexural strength at 28 days were tested. In this paper, the regression model and the response surface plots have been discussed, and optimal results were found for all the responses.

Keywords: steel fiber reinforced self compacting concrete, hybrid fiber; fly ash; statistical experimental design; response surface methodology

1. Introduction

Self Compacting Concrete (SCC) get placed due to its own weight without any vibration given and does not exhibit any segregation or bleeding. This is achieved by increasing the powder content of concrete and use of superplasticizer (SP). Sufficient yield and viscosity is achieved in fresh stage with the addition of mineral admixtures. When steel fiber are used as composite material in concrete, it tends to improve the flexural rigidity and has great potential for cracking control, the fiber resists the workability of SCC in fresh stage especially flowing ability and passing ability which is a basic property of SCC. Fiber aspect ratio plays an important role in dispersion of fiber in concrete, hence in mix proportion of SFSCC volume of mineral admixture, volume of steel fiber, aspect ratio of fiber and SP dosage play an important role. In recent year's

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concrete with high strength have been achieved, but such concrete have less ductility. Wafa and Ashour (1992); found the compromise between these two conflicting properties of concrete can be obtained by adding short fibers. Banthia and Trottier (1995); proved that short fiber arrest the micro cracks and form a bridge between cracks which prolong the crack. Barros and Figueiras (1999); reviled that Fiber reinforced concrete has high resistance to cyclic and dynamic loading. Shah (2005); carried out Research to make SCC more robust. The increase in tensile strength and toughness is an important feature of fiber reinforced cement composite. Other important feature is to increase the shear strength by fiber dispersion

Liberato *et al*. (2005); proposed some method which includes the fibers in the optimization of the solid skeleton through the concept of the "equivalent specific surface diameter". The model proved to be an efficient tool for designing fiber-reinforced concrete mixtures with selected fresh state properties, employing different ratio and types of steel fiber reinforcement. As a further prosecution of the work, the investigation on connections between fresh state properties, fiber dispersion and mechanical properties of fiber-reinforced cement composites is the major objective of the ongoing research.

Statistical experimental design model minimizes the trials. Using this design, the model describe the main influence and two way interaction of various parameter on a given properties can be established. Al Qadi *et al*. (2009); carried out statistical model to find the harden properties of SCC. The key parameters used in their research where cement, water/powder ratio, flyash and SP. They used CCD design to find the parameters that influence the mixture combination and found that all the response have high correlation coefficient, adjacent correlation coefficient, less level of significant and sum of square errors for the predicated model. Ammar *et al*. (2005); derived statistical model indicates that measured properties of mortar are highly influenced by the content of fly ash and lime stone. Ghezal *et al*. (2002)**;** derived statistical model, that can be used to facilitate test protocol needed to optimize SCC. Bayramov *et al*. (2004); optimizes the fracture parameter of steel fiber reinforced concrete and showed that model response were satisfactory. Almeida *et al*. (2010); used statistical study for harden properties of SCC and analyzed variables such as maximum size aggregate, paste and gravel content. Successful development of medium strength self-compacting concrete incorporating flyash. Ozbay *et al*. (2009); has carried out experimental results and analyzed by using the Taguchi experimental design methodology for mix proportion parameters of high strength self compacting concrete (HSSCC). Baris *et al*. (2013); applied Taguchi optimization method for mix proportioning HSSCC for ready mix concrete plant. Sandra *et al*. (2013); carried out CCD model for recycled ground glass material for SCC.

Murali *et al*. (2009); have also used derived statistical response surface methodology to develop cost efficient high performance self compacting concrete. Ammar *et al*. (2005); established model for mix proportioning SSC with lime stone filler and fly ash. Ghezal *et al*. (2002); also used statistical response model for mix proportioning high range water reducing admixture and lime stone filler. Farhad *et al*. (2013); have produced an analytical model for estimating the mechanical properties of SFRSCC

SFSCC is designed to satisfy the flowing ability, filling ability, passing ability and segregation index in fresh stage. The discussion and summarization of the test method of SCC and there limitation have been given in EFNARC. Particle size less than 12 Am of cement and filler are called powder. The SCC requires powder content of 500–600 kg/m3 of concrete to meet the three criteria in fresh state. A cementitious material of 350–450 kg/m3 is usually used in SCC. Further increases in cementitious materials cause increases in production cost, hence filler material of 100–200 kg/m^3 are required to satisfy the powder requirement. The uses of hybrid fiber (two or more type of fiber) prove to be more efficient than using single type of fiber. Hybrid fiber performance was better than single type of fiber.

2. Research significance

The mechanical and fresh properties of SFSCC is improved with four factors such as volume of fly ash, volume combination ratio of two steel fibers with aspect ratio of 50/35 and 60/30, SP dosage and volume of steel fiber needs optimum design . Using the experimental results, the flow ability, filling ability, passing ability and segregation index were under the limit of fresh test on SCC. Compressive strength, splitting tensile strength, and flexural strength were maximized simultaneously at the minimum of the above four factors, by using the above design parameters the model were found

3. Design of experiment

Design of Experiment is performed at early stage, to identify the design variables that have large effects for further investigation. DOE helps to find the pin point of the sensitive parts and sensitive areas in designs that cause problem. RSM is an important aspect of design of experiment. It was developed for model fitting of physical experiment and its main objective is to select point where response is evaluated. RSM is a mathematical and statistical technique representation to find existing relationship between variable(x_1, x_2, x_3….x_k) and response (y). RSM should have good fitting model. A model is a good fitting model only when F-value is significant, lack of fit F-value is insignificant, the “Pred R-Squared” value is in reasonable agreement with the “Adj R-Squared” of value and “Adeq Precision” Compares the range of predicted values at design points to the average prediction error. “Adeq Precision” ratio greater than 4 is desirable. Such model can be used to navigate the design space. Optimization is applicable to second- degree model. The Central Composite Design (CCD) is one of the most popular of all second order designs. This design consists of the following three portions:

Factorial Points: The two-level factorial part of the design consists of all possible combinations of the +1 and -1 levels of the factors. In two factor case, there are 4 design points:(-1, -1), (+1, -1), (-1, +1) (+1, +1).

Star or Axial Points: The star points have all of the factors set to 0, the midpoint, except one factor, which has the value +/- Alpha. For a two factor problem, the star points are:(-Alpha, 0) (+Alpha, 0) (0, -Alpha) (0, +Alpha). The value for Alpha is calculated in each design for both rotatability and orthogonality of blocks.

Center Points: As implied by the name Center points are points with all levels set to coded level 0 the midpoint of each factor range:(0, 0). Center points are usually repeated 4-6 times to get a good estimate of experimental error (pure error).

4. Modeling

Model specification involves several steps; a multiple regression analysis builds on a theory that describes the variables to be included in the study. Analysis of response surface over the simplex region involves the collection of experimental data, choosing a proper model that fits that data, and testing the adequacy of the fitted model. To optimize a process or to find the best-fitting function of experimental points, a model has to be found first and the optimization procedure is performed using the response surface of the model, which is the basis for finding the best solution. In order to build a model, it is necessary to have some experimental data.

4.1 Model building

Quadratic model associated with four independent variables A, B, C and D can be expressed as:

$$y_1 = b_0 + A + B + C + D + A^2 + AB + AC + AD + B^2 + BC + BD + C^2 + CD + D^2 + e \quad (1)$$

In Eq. 1 coefficient (bi) represent the contribution of independent variable on the response and ‘e’ is the effect of uncontrolled variable i.e. random error. The model constants are determined by multiple liner analysis. Only significant values are taken with 90 % confidence limit and are assumed to normally distributed error, so residual terms should exhibit similar properties. Analysis of variance show the significant of regression and t- test are performed to identify non- significant variables in model, which are eliminated from the model. The t-test value gives the significant of each variable on the response.

Variable exhibit significant effect only when t-test ratio associated with the variable is greater than student ($t\beta/2$, v) variable and the model is analyzed by stepwise selection method. The difference is that, variables already in the model do not necessarily stay there. After each variable is entered into the model, this method looks at all the variables already included in the model and deletes any variable that is not significant at the specified level. The process ends when none of the variables outside the model has a p-value less than the specified entry value and every variable in the model is significant at the specified stay value.

In this present work, it is aimed to develop a model for the average flow (SF) , v-funnel flow (VS), passing ratio (PR) , segregation index (SI) , compressive strength (f_{ck}), split tensile strength (f_{st}) and flexural strength (f_{flex}) at the minimum volume of fly ash, combination of two steel fiber with different aspect ratio, SP dosage and volume of steel fiber. Statistical and Mathematical methods of Experiment Design, regression analysis is to provide useful approaches to the problem development, improvement, or optimization. It provides a comprehensive, statistically based procedure for planning, executing and evaluating batch. A response surface can simultaneously represent two or more independent and one dependent variable when the mathematical relationship between the variables is known, or can be assumed. Experiment is performed to investigate the effect of four factors on fresh and harden properties of SFSCC. The four factors adopted are volume of fly ash (x_1), Volume of steel fiber (x_2), Volume combination ratio of two steel fiber with aspect ratio 50/35: 60/30 (x_3) and SP dosage (x_4).

Table 1 Fiber combination details

Sl.no	Volume steel fiber with aspect ratio 50/ 35(%)	Volume of steel fiber with aspect ratio60/30(%)	Volume combination ratio of two steel fiber (50/35:60/35) in %
1	0	100	0/100
2	25	75	25/75
3	50	50	50/50
4	75	25	75/25
5	100	0	100/0

Table 2 Process control parameters under limits

LIMITS	-2	-1	0	1	2
Fly-ash volume %(x_1) of cement Content	10	17.5	25	32.5	40
Steel fiber volume % (x_2) of total volume of concrete	0.5	0.75	1	1.25	1.50
Volume combination ration of two steel fiber with aspect ratio 50/35 : 60/30 (x_3)% of total volume of fiber	0 : 100	25 : 75	50 : 50	75 : 25	100 : 0
SP dosage% (x_4) of total powder content	1.5	1.875	2.25	2.625	3.00

Factor may be conveniently run at two levels. The full factorial design for four independent variable 24=16 factorial points, (2k) 2×4=8 and 6 center points. Full quadratic model for each response is obtained. The derived model are valid for a wide range of mixture with volume of fly ash (x_1) 10 to 40 % of cement content, steel fiber volume (x_2) 0.5 to 1.5 % of total volume of concrete, volume combination ratio of two steel fiber with aspect ratio 50/35 : 60/30 (x_3) is 0:100 % to 100:0%, Volume of fiber and volume of SP dosage (x_4) varies from 1.5 to 3 % by total powder content. Two steel fiber with aspect ratio 50/35 and 60/30 combinations in ratio of 0/100 to 100/0 were used in the mix design. In this study, the dependent variables are flow ability (SF), filling ability (VS), passing ability (PA), segregation index (SI), compressive strength (f_{ck}) at 28 days, split tensile strength (f_{st}) at 28 days, and flexural strength (f_{flex}) at 28 days were obtained. First priority test are proposed for European standardization as reference methods are Slump flow, V-funnel, L-box and Sieve stability test.

Thus the slump flow test was selected as the first priority test method for the flowing ability of SFSCC. Filling ability is obtained by V-funnel test. The passing ability of fresh SFSCC can be tested by L-box. The wet sieve segregation stability test was selected as the first priority test method for segregation index.

5. Experimental details;

5.1 Materials

A total of 30 concrete mixes were casted for this investigation. In all the mixes, the cement content was kept constant. Water to cement ratio adopted was 0.43 and water to fly ash ratio was 0.45. Ordinary Portland cement of 53 grade as per IS: 12269, obtained from a local cement manufacturing factory having a specific gravity of 3.15 were used. Locally available river sand confined to IS: 383-1970 having fineness modulus of 2.6 and specific gravity of 2.68 and locally available blue granite as per IS: 383-1970 passing through 16mm sieve with a specific gravity 2.6 and fineness modulus of 5.65 was used. Fly ash contains extremely fine amorphous particles of SiO2. The specific gravity and bulk density of fly ash used is 2.2 and 280 kg/m3.Steel fiber with aspect ratio of 50/35 and 60/30 was used. SP used in this research is in brown liquid based on sulphonated Napthalene formaldehyde condensates. It is a high range water reducing admixture for concrete and grouts conforming to IS: 9103-1999-ASTM-C-494 Type A & F. Specific gravity is 1.2+0.15 at 27^{o}C, Chloride content: Nil as per IS: 456 and BS: 5075 and air entrainment is less than 1 % additional air entrained.

5.2 Specimen preparation

Cement, fly ash, coarse aggregate and fine aggregate were blended first, then admixture and water were added to the mix. Steel fibers were to be mixed to get uniform distribution in concrete. Orientation of the fibers is generally random. In each mixture, slump flow, V-funnel, L-box test and wet sieve segregation were determined at 10 min after the first contact between cement and water. Fresh test of SCC were performed for each mix. Then specimens were cast in steel mould and all the specimens were demoulded after 24 hours and stored in water until 28 days. At least three specimens of each concrete mix were tested under each type of loading condition at the 28th day. Three cube specimen of 150×150×150 mm were used for compressive strength test, three cylinders of 150 mm height and 100 mm diameter were used for the split tensile strength test, and three beam specimens of 500×100×100 mm were used for flexure strength test were prepared as per standard.

5.3 Finding the limits of the process control variables

The coded forms of process control parameters were found by fixing the values for central parameter (0), maximum (+2) and minimum (-2) value of the variable. The coded values were calculated from the following relationships:

$$X_i = 2\frac{\left[2X - \left(X_{\max} + X_{\min}\right)\right]}{\left(X_{\max} - X_{\min}\right)} \tag{2}$$

where,

X_i = required coded values value of a variable X

X = any value of the variable form $X_{\min}$ to $X_{\max}$

5.4 Test on fresh concrete

According to specification and guidelines for SCC prepared by EFNARC (European Federation of Associations of Specialist Repair Contractors and Material Suppliers).

Fresh properties of SCC are flowing ability, filling ability, passing ability and segregation resistance:

1. Flowing ability: slump flow test is performed and its readings are indicated by SF in table - 3
2. Filling ability: V- funnel test is performed and their readings are indication by VS in table -3
3. Passing ability: L- box test is performed and their passing ratio values are found out and its readings are indicated by PR in table -3
4. Segregation resistance: wet sieve segregation test is performed and segregation index values

are found out and its readings are indicated by SI in table-3

A slump flow diameter ranging from 650 to 800 mm can be accepted for SCC. The V-funnel is filled with concrete and the bottom out let is opened, and the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom where observed from the top is noted down. According to EFNARC time ranging from 6 to 12 second is considered as adequate for a SCC. L-box is placed on level plane and the gate is closed between the horizontal and vertical section. The concrete is filled on the vertical section and the gate is opened, the concrete flows in the horizontal section. Then the difference with the height of the horizontal section of the box and the mean depth of the concrete is measured as H2. The same procedure is used to calculate the depth of concrete immediately behind the gate as H1 in mm. The passing ability ratio (PR) is calculated from the following equation PR = H2/H1 according to EFNARC. PR value should be more than 0.80. The segregation index is found by wet sieve segregation test. A 10 liters of concrete is placed in the container and it is left undisturbed for 15 min then it is allowed to be poured in sieve, then segregation index (SI) is found by the following Eq. (3)

$$SI = \frac{(W_{ps} - W_p)*100}{\mathrm{W_c}\%} \tag{3}$$

where, W_{ps} concrete that has passed into it from the receiver, weight of sieve W_p and the actual mass of concrete W_c. As per European Guidelines**,** $0<SI_1<15$, very good segregation resistance, $15<SI_2<30$ segregation resistance questionable; and in situ trial mixes recommended.

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6.1 Effect of variables on fresh concrete properties

When the volume of fly ash is increased from 10 to 40 % it tends to increase flowing ability by 23.25%, filling ability by 12.67%, segregation resistance by 14.48%, and passing ability by 1.57%.The increase of fiber volume from 0.5 to 1.5 % seem to have negative effect on filling effect, segregation resistance and passing ability by 10, 3.5 and 4.9 % respectively, but tends to increase flowing ability by 5.43%. Fiber combination ratio have improved the flowing ability, filling ability and segregation resistance by 5.41%, 4.9 %, 1.92% respectively and decreased passing ratio 2.7 %. With the increase in SP dosage, the flowing ability is increases by 7.6 %, filing ability by 3.1%, segregation resistance by 8.1 % and passing ability by 1.6 %.

6.2 Effect of variable on hardest concrete properties

When the volume of fly ash is increased from 10 to 40 % it tends to increase the compressive strength by 4.8 %, flexural strength by 3 %, and split tensile strength by 0.56 %. The increase in fiber volume showed more influence on split tensile strength of concrete it has increased about 14.34 %. It has increased the compressive strength by 7.3 % and flexural strength by 9.9 %. Fiber combination ratio has influenced the compressive strength by 1.08 %. It has also have improved the flexural strength and split tensile strength by 0.69 % and 2.3 % resp. The increase in SP dosage increases the compressive strength by 1.71 %, flexural strength 7.08 % and split tensile strength by 6.14 %.

Table 3: Design matrix in coded form and observed values of the response

Sl No.	x_1	x_2	x_3	x_4	SF (mm)	VS (Sec)	SI	PR	Compressive strength (f_{ck}) MPa	Flexural strength (f_{flex}) MPa	Split tensile strength (f_{st}) MPa
1	-1	-1	-1	-1	691.0	8.2	14.2	0.9	66.85	8.25	5.55
2	1	-1	-1	-1	732.5	6.8	12.2	0.94	60.30	7.43	4.35
3	-1	1	-1	-1	730.5	8.3	12.5	0.95	72.00	8.20	4.35
4	1	1	-1	-1	721.0	7.0	15.0	0.94	75.25	8.41	4.57
5	-1	-1	1	-1	709.0	6.1	8.7	0.91	81.90	9.01	4.85
6	1	-1	1	-1	804.5	6.2	15.2	0.97	77.50	7.57	4.35
7	-1	1	1	-1	740.0	6.1	8.8	0.88	75.50	7.10	4.54
8	1	1	1	-1	787.5	5.4	11.5	0.9	77.90	7.25	4.30
9	-1	-1	-1	1	778.0	6.0	10.3	0.91	73.75	7.83	4.55
10	1	1	-1	1	845.5	5.4	9.3	0.94	73.50	7.70	4.39
11	-1	1	-1	1	785.5	6.1	11.2	0.92	77.65	7.60	4.25
12	1	1	-1	1	812.5	5.9	11.0	0.92	82.11	8.50	4.86
13	-1	-1	1	1	730.0	6.7	11.8	0.9	78.90	8.20	4.67
14	1	-1	1	1	755.0	8.1	15.0	0.95	74.60	8.29	4.31
15	-1	1	1	1	737.0	6.2	11.4	0.87	74.40	8.34	4.35
16	1	1	1	1	760.0	6.5	14.0	0.85	74.40	8.40	4.90
17	-2	0	0	0	637.0	6.2	12.4	0.95	77.80	8.40	4.41
18	2	0	0	0	830.0	7.1	14.5	0.96	81.77	8.66	4.44
19	0	-2	0	0	844.0	7.1	14.5	0.97	70.69	6.81	4.09
20	0	2	0	0	892.5	6.5	14.0	0.92	76.29	7.57	4.78
21	0	0	-2	0	786.0	6.0	12.8	0.95	71.43	7.83	4.54
22	0	0	2	0	831.0	6.3	13.0	0.93	72.21	7.88	4.65
23	0	0	0	-2	630.5	6.3	12.2	0.92	75.42	8.01	4.51
24	0	0	0	2	682.5	6.5	13.3	0.94	76.73	8.62	4.80
25	0	0	0	0	706.5	7.6	15.2	0.85	75.42	6.65	5.45
26	0	0	0	0	708.0	7.7	15.3	0.84	74.60	6.00	5.30
27	0	0	0	0	673.0	7.5	15.0	0.84	76.00	7.30	5.40
28	0	0	0	0	654.0	7.5	15.6	0.85	74.00	7.34	5.20
29	0	0	0	0	664.0	7.4	15.2	0.84	75.00	7.30	5.56
30	0	0	0	0	663.0	7.6	15.0	0.83	76.00	6.20	5.30

7. Regression analysis

An appropriate model of each response is chosen and the each response of SFSCC is analyzed individually by examining summary plots of the data, fitting a full quadratic model using ANOVA, Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as “variation” among and between groups), validating the model by examining the residuals for trends and outliers, and interpreting the model graphically. A full quadratic model is simplified by using a backward stepwise technique. Only significant terms are included in this model. Thus experimental data were fitted to a polynomial type of mathematical model by adjusting parameters until calculated values were in close agreement with the experimental values.

The Regression equations obtained from analysis are as follows

$$SF = 1350 - 9.1x_1 - 1527x_2 - 1.38x_3 + 131.92x_4 - 1.9x_3x_4 + 0.26x_1^2 + 775.11x_2^2 + 0.05x_3^2 \tag{4}$$

$$VS = 6.8 + 0.03x_1 + 6.4x_2 + 0.06x_3 + 0.23x_4 + 1.56x_1x_3 + 0.07x_1x_4 - 0.04x_2x_3 + 0.05x_3x_4 - 3.6x_1^2 - 2.78x_2^2 - 5.25x_3^2 - 1.12x_4^2 \tag{5}$$

$$SI = -5.1 + 0.42x_1 + 18.36x_2 - 0.13x_3 + 7.9x_4 + 5.4x_1x_3 - 0.08x_2x_3 + 0.10x_3x_4 - 0.01x_1^2 - 7.2x_2^2 - 1.27x_3^2 - 3.32x_4^2 \tag{6}$$

$$PR = 1.5 - 0.01x_1 - 0.41x_2 - 0.27x_4 - 0.32x_2^2 - 0.06x_4^2 \tag{7}$$

$$f_{ck} = 48 - 1.55x_1 + 2.6x_2 + 1x_3 + 12.39x_4 + 0.9x_2\ x_3 - 0.4x_2x_3 - 0.20x_3x_4 + 0.01x_1^2 - 1.2x_3^2 \tag{8}$$

$$\mathrm{f}_{\mathrm{flex}} = 24 - 0.55x_1 - 3x_2 - 0.02x_3 - 7.9x_4 + 0.11x_1x_2 + 0.05x_1x_4 - 0.03x_2x_3 + 1.02x_2x_4 + 0.01x_3x_4 + 1.3x_4^2 \tag{9}$$

$$\mathrm{f}_{\mathrm{st}} = 1.08 + 0.03x_1 + 3.7x_2 + 0.03x_3 + 1.35x_4 + 0.01x_1x_2 + 0.03x_1x_4 + 0.7x_2x_4 - 3.79x_2^2 - 0.73x_4^2 \tag{10}$$

These values are established using coded values for the investigation factor. A minus sign indicated that the response decreases with the increases in variable factor, while a positive sign indicated that the response increases with the increases in variable factor.

8. Optimization

The regression model is built with relationship between mix design variable and response is expressed in Eqs. (4) - (10). The optimization finds the “best setting” that maximizes the response. A numerical optimization technique using desirability functions (dj), which are defined for each response, can be used to optimize the responses simultaneously Derringer and Suich (1980**)**. A desirability function (dj) varies over the range of 0≤1. By using the single composite response (D) given in Eq.11, which is the geometric mean of the individual desirability functions, the multi objective optimization problem is solved.

$$D = (d_1 \times d_2 \times d_3 \times .... \times d_n)^{1/n} \tag{11}$$

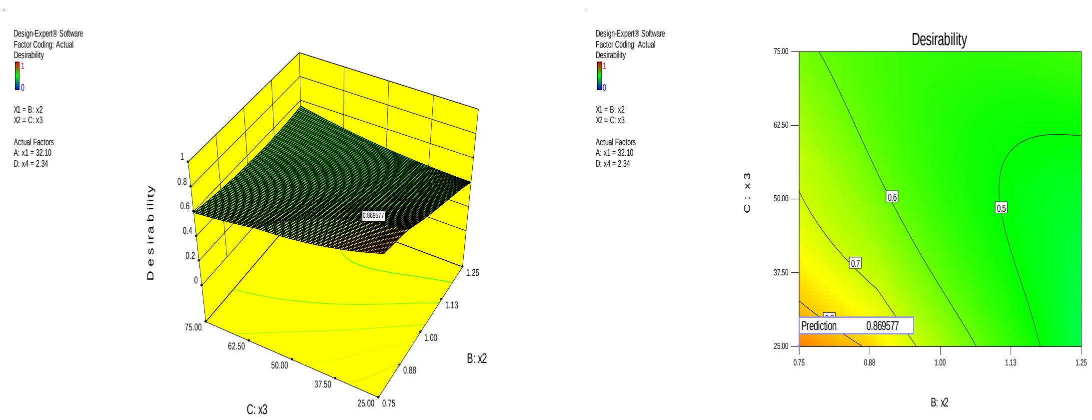
where, n = the number of responses included in the optimization. If any of the responses or factors falls outside their desirability range, the overall function becomes zero. For building the regression model and optimization, a commercially available (Design-Expert) software package was used.

SFSCC with high workability SF should be between 660 to 850 mm, VS should be less than 8 sec, PR should have value more than 0.8 and SI should be less than 20, and for harden concrete with the highest compressive strength (f_{ck}), split tensile strength (f_{st}), and flexural strength (f_{flex}) is to be obtained, so it is necessary to maximize f_{ck}, f_{st} and f_{flex} simultaneously.

The optimal values of the design variable are X_1=25 %, X_2= 0.84 %, X 3= 32 % and X_4=1.8 %.The predicted response values and associated uncertainties (at 95% confidence level) are SF=665±20 mm, VS=7.5±2 sec, PR=0.84±0.2, SI=15 ±2, f_{ck} =75±5 MPa, f_{st}=7 ±2 MPa and f_{flex}=8.16±2 MPa.

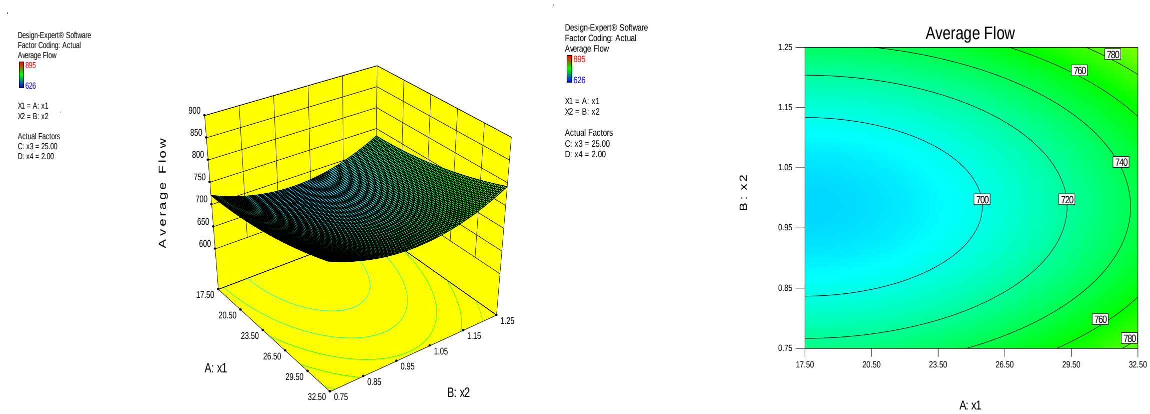
9. Model fitting and validation;

Fitted Models has to be verified for adequacy. Model (linear, quadratic, etc.), with higher order of R- squared and F- Statistic values is generally chosen. Significance of this value is judged from probability of F- value. If this probability is less than 0.05, the terms are significant.



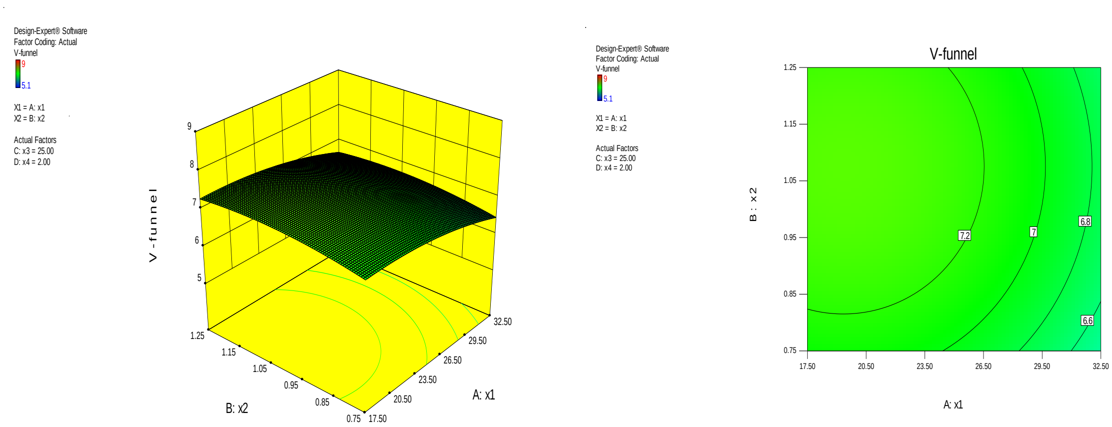
(a) Desirability (b) Desirability Contour

Fig. 1Response surface plot of the composite desirability (D) when are f_{ck}, f_{st} and f_{flex} maximized simultaneously.



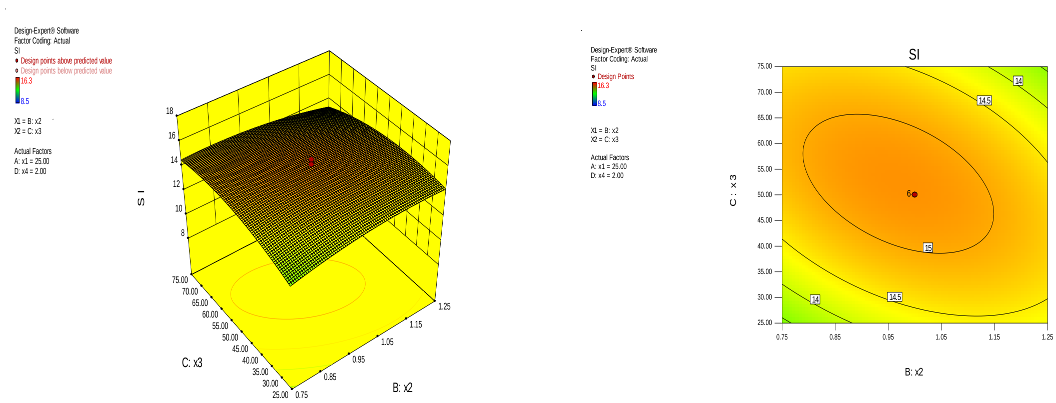
(a) Average flow (b) Contour diagram

Fig. 2 Average flow 3D Surface graph and contour diagram



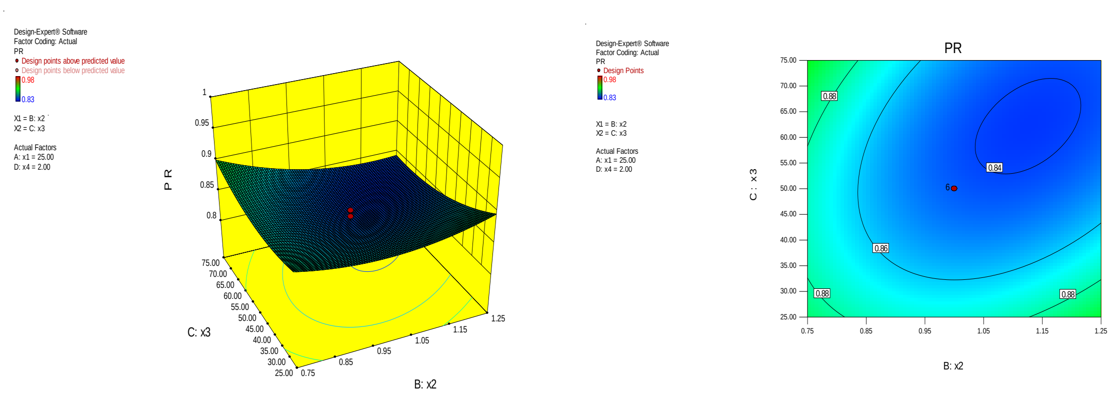
(a) V – funnel flow (b) Contour diagram

Fig. 3 V – funnel flow 3D Surface graph and contour diagram



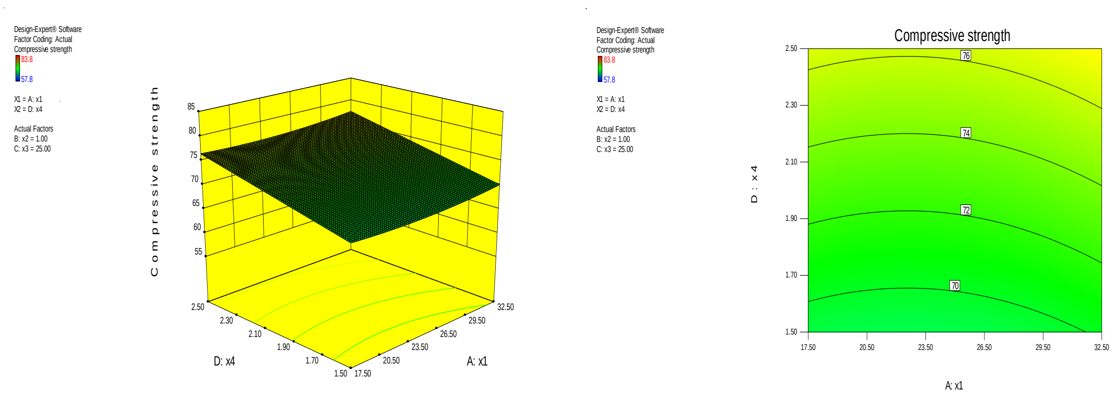
(a) Segregation resistance (b) Contour diagram

Fig. 4 Segregation resistance 3D Surface graph and contour diagram



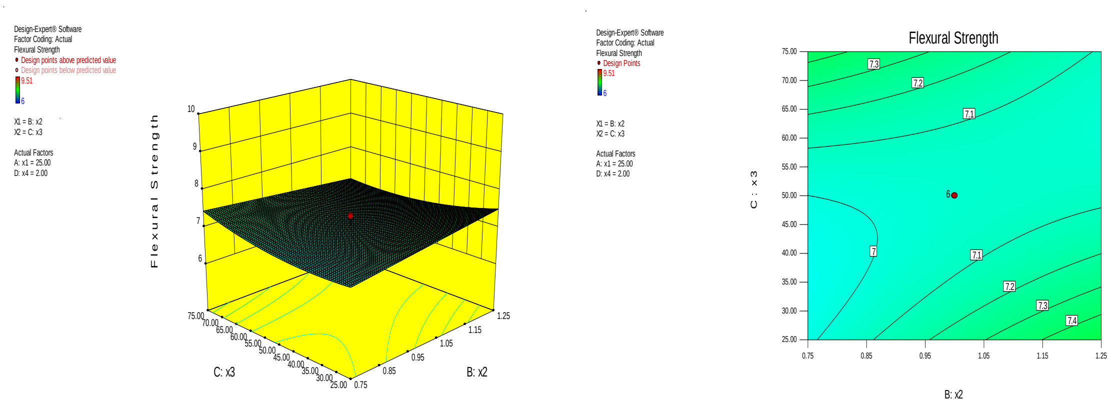
(a) Passing ratio (b) Contour diagram

Fig. 5 Passing ratio 3D Surface graph and contour diagram



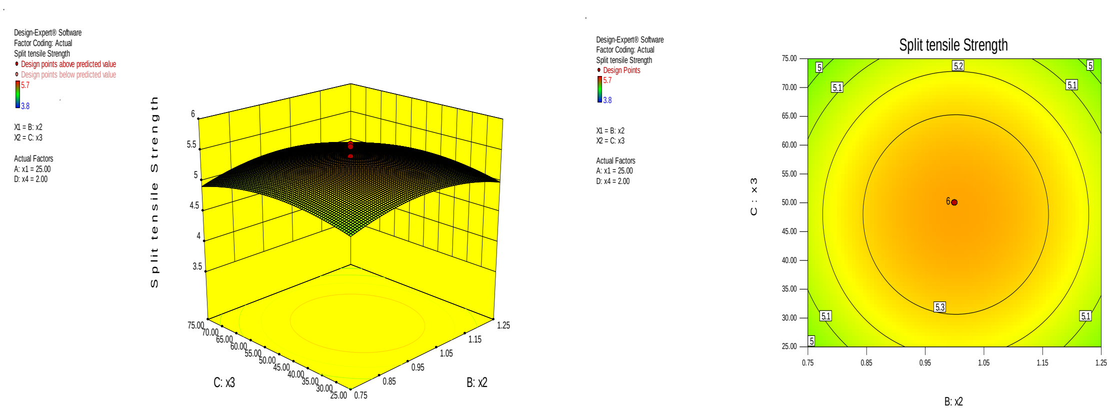
(a) Compressive strength (b) Contour diagram

Fig. 6 Compressive strength 3D Surface graph and contour diagram



(a) Flexure strengt (b) Contour diagram

Fig. 7 Flexure strength 3D Surface graph and contour diagram



(a) Split tensile strength (b) Contour diagram

Fig. 8 Split tensile strength 3D Surface graph and contour diagram

Table 3 Compassion between models (linear, 2FI, Quadratic and cubic)

Model Summary Statistics								
	Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	F- value	P- Value
Average Flow	Linear	66.18	0.2127	0.1484	0.0502	2.59E+05	3.31	0.0177
	2FI	66.83	0.2955	0.1316	0.055	2.58E+05	0.84	0.5445
	Quadratic	37.18	0.8023	0.7313	0.6113	1.06E+05	24.99	< 0.0001
	Cubic	34.97	0.8609	0.7623	0.5452	1.24E+05	1.63	0.1554
V- Funnel	Linear	0.87	0.0439	-0.0341	-0.1609	45.04	0.56	0.6908
	2FI	0.6	0.6052	0.5134	0.4076	22.98	10.19	< 0.0001
	Quadratic	0.48	0.7638	0.679	0.5302	18.23	6.54	0.0004
	Cubic	0.42	0.8565	0.7547	0.5144	18.84	2.50	0.0317
SI	Linear	2.24	0.1129	0.0405	-0.0739	298.59	1.56	0.2000
	2FI	1.84	0.4743	0.3521	0.1631	232.7	4.93	0.0006
	Quadratic	1.61	0.6377	0.5076	0.2784	200.64	4.39	0.0050
	Cubic	1.65	0.6952	0.479	-0.0367	288.25	0.73	0.6625
PR	Linear	0.039	0.1744	0.107	0.0431	0.086	2.59	0.0482
	2FI	0.037	0.3399	0.1864	0.132	0.078	1.80	0.1224
	Quadratic	0.025	0.7191	0.6183	0.4435	0.05	13.16	< 0.0001
	Cubic	0.027	0.7515	0.5751	0.1646	0.075	0.50	0.8439
compressive strength	Linear	4.41	0.24	0.1779	0.0586	1182.67	3.87	0.0083
	2FI	3.17	0.656	0.576	0.426	721.12	8.67	< 0.0001
	Quadratic	2.95	0.7299	0.6329	0.4635	674.02	2.67	0.0464
	Cubic	2.59	0.8346	0.7172	0.4426	700.19	2.45	0.0349
Flexure Strength	Linear	0.68	0.0327	-0.0462	-0.1348	26.8	0.41	0.7973
	2FI	0.63	0.2827	0.1159	0.0444	22.57	2.50	0.0367
	Quadratic	0.41	0.7264	0.6282	0.501	11.79	15.81	< 0.0001
	Cubic	0.38	0.8148	0.6834	0.5333	11.02	1.85	0.1052
Split tensile strength	Linear	0.44	0.0235	-0.0562	-0.137	11.17	0.29	0.8801
	2FI	0.42	0.2176	0.0356	-0.0894	10.7	1.78	0.1265
	Quadratic	0.31	0.6299	0.497	0.2693	7.18	10.86	< 0.0001
	Cubic	0.26	0.7853	0.6329	0.2932	6.94	2.80	0.0184

10. Conclusion

On the basis of experiment investigation the following conclusion was drawn

- Statistical experimental design helps us to investigate the selected range of combination of variables for the desired characteristics.
- The mathematical models found in the investigation can be used to predicate the proportion of various constitutes of concrete, by substituting the values in coded form, of respective factor.
- The result shows that productiveness of the polynomial regression model is satisfactory.
- From the model predicted it is seen that volumes of fly ash and SP dosage play a major role in workability of SFSCC while fiber volume and fiber combination play their major role in harden properties of SFSCC.
- The increases in fiber volume from 0.5 to 1.5 % have negative effect on flow performance but positive effect on harden properties on concrete.
- The hybrid fiber combination (32:68) of fiber with aspect ratio 50/35 and 60/30 resulted in better performance in fresh and harden concrete properties.
- When the mechanical properties are maximized (f_{ck}, f_{st} and f_{flex}), the optimal values of the design variables are X_1 =25% , X_2 =0.84%, X_3 = 32% and X_4 =1.8%

References

Almeida Filho, F.M., Barragán, B.E., Casas J.R. and El Debs, A.L.H.C.. (2010), "Hardened properties of self-Compacting concrete – A statistical approach", *Constr. Build. Mater.*, **24**(9), 1608-1615.

Ammar Yahia, Makoto Tanimura and Kamal H.Khayat (2005), "Experiment design to evaluate the effect of mixture parameters on rheological properties of self-consolidating concrete equivalent mortar", First International Symposium on Design, Performance and Use of a Self-Consolidating Concrete SCC. China, May.

Arabi N.S. Al Qadi, Kamal Nasharuddin Bin Mustapha, Hashem Al-Mattarneh and Qahir N.S. AL-Kadi (2009), "Statistical models for hardened properties of self-compacting concrete", *Am. J. Eng. Appl. Sci.*,**2(4)**, *764-770*.

Aslani, F. and Natoori, M. (2013), "Stress-strain relationships for steel fiber reinforced self- compacting concrete", *Struct. Eng. Mech.*, **46**(2), 295-322.

Balaguru, P. and Shah, S.P. (1992), "Fiber-reinforced cement composite", McGraw-Hill, New York, USA.

Banthia, N. and Trottier, J.F. (1995),"Concrete reinforced with deformed steel fibres. Part II: Toughness characterization", *ACI Mater. J*, **92**(2), 146-154.

Barros, J.A.O. and Figueiras, J.A. (1999), "Flexural behaviour of SFRC: Testing and modeling", *J. Mater. Civil Eng*, **11**(4), 331-339.

Bayramov, F. and Tasdemir, C. and Tasdemir, M.A. (2004), "Optimisation of steel fibre reinforced concrete by means of statistical response surface method", *Cement Concrete Compos.*, **26**, 665-675.

BS 5075: Part 1: 1982 Specification for accelerating admixtures, retarding admixtures and water reducing admixtures, India.

BS 5075: Part 3: 1985 Specification for superplasticizing admixtures, India.

Derringer, G. and Suich, R. (1980), "Simultaneous optimization of several response variables", *J. Quality Tech.*, **12**(4), 214-219.

EFNARC (2002), "Specification and guidelines for self-compacting concrete, English edition".

European Federation for Specialist Construction Chemicals and Concrete Systems. Norfolk, UK .

Ferrara, L., Park, Y.D. and Shah, S.P. (2007), "A method for mix-design of fiber-reinforcedself-compacting concrete", *Cement Concret Res*, **37**, 957-971.

Ghezal, A. and Kamal H.K. (2002), "Optimizing self – consolidating concrete with limestone filler byusing statistical factorial design methods", *ACI Mater. J.*, **99**(3), 264-272.

IS 12269 is the Indian standard code for 53 grade cement, India.

IS 383-1970 is the Indian standard code for fine and coarse aggregate, India.

IS 9103 -1999 is Indian standard code for Specification foe concrete admixture, India.

IS 456 is Indian standard code for plain and reinforced concrete, India.

Kurihara, N., Kunieda, M., Kamada, T., Uchida,Y. and Rokugo, K. (2000), "Tension softeningdiagrams and evaluation of properties of steel fibre reinforced concrete", *Eng. Fract. Mech.*, **65**, 235-245.

Mobasher, B., Stang, H. and Shah, S.P. (1990), "Microcracking in fiber-reinforced concrete", *Cement Concrete Res*, **20,** 665-676.

Murali, T.M. and Kandasamy, S. (2009), "Mix proportioning of high performance of self- compacting concrete using response surface methodology", *J. Civil Eng*, **32**(2), 91-98.

Nawy, E.G. (2001), "Fundamentals of high-performance concrete", John Wiley & Sons, New York, USA.

Ozbay, E., Oztas, A., Baykasoglu, A. and Ozbebek, H. (2009), "Investigating mix proportions of high strength self compacting concrete by using Taguchi method", *Constr. Build. Mater.*, **23**(2), 694-702.

Qian, C.X. and Stroeven, P. (2000), "Development of hybrid polypropylene-steel fibre reinforced concrete", *Cement Concrete Res.*, 63-69.

Sahmaran, M. and Chrisiano, H.A. (2006), "The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars", *Cement Concrete Compos.*, **28**(5), 432-440.

Sandra Nunes, Ana Mafalda Matos, Tiago Duarte, Helena Figueiras and Joana Sousa-Coutinho, (2013), "Mixture design of self- compacting glass mortar", *Cement Concrete Compos.*, **43,** 1-11.

Shah, S.P. (1991), "Do fibers increase the tensile strength of cement-based matrixes?", *ACI Mater J*, **88**(6), 595-602.

SimSek, B., Tansel Ic, Y. and Simsek, E.H. (2013), "A TOPSIS-based taguchi optimization to determine optimal mixture proportions of the high strength self-compacting concrete", *Chem. Intell. Lab. Sys.*, **125**(15), 18-32.

Song, P.S., Wu, J.C., Hwang, S. and Sheu, B.C. (2005), "Statistical analysis of Impact strength and strength Reliability of steel-polypropylene hybrid fibre reinforced concrete", *Constr. Build. Mater.*, **19**, 1-9.

Su, W. and Chen, H. (2001)," The effect of hybrid fibres and expansive agent on the shrinkage and permeability of high-performance concrete", *Cement Concrete Res.*, **31**(4), 595-601.

Takada, K. and Tangtermsirikul, S. (2000), *Testing of Fresh Concrete: State-of-the-Art Report of RILEM Technical Committee Report*, 174-SCC, RILEM Report, vol. 23, S.A.R.L., RILEM, Bagneux, France.

Wafa, F.F. and Ashour, S.A. (1992), "Mechanical properties of high-strength fibre reinforced concrete", *ACI Mater J.*, **89**(5), 449-455.

Yao,W., Li, J. and Wu, K. (2003), "Mechanical properties of hybrid fibre-reinforced concrete at low fibre volume fraction", *Cement Concrete Res,* **33**, 27-30.

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