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APPLYING SIMPLEX LATTICE IN OPTIMIZING SELF-COMPACTION CONCRETE COMPRESSIVE STRENGTH

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ABSTRACT

Due to its convenience, speed, and quality of implementation, overusing of self-consolidating concrete necessitates adopting new methods to optimize its designs. This study focuses on effective parameters in determining the decision variables related to the objective function of optimization concrete and introduces a set of optimization techniques; finally, based on the simplex method, the study presents the highly optimized mixing amounts of each self-consolidating concrete component such as cement, water, coarse and fine aggregates, superplasticizer, and powder, according to the strength standards.

The results demonstrate that the optimization method selection depends on the objective function, decision variables, and constraints and has a significant impact on the calculation of concrete mix design.

Besides, the component's value parameter poses a large influence on the compressive strength of concrete.

Keywords: Self-compaction concrete; optimization; mix design; objective function.

1. INTRODUCTION

One of the fundamental features of concrete is compressive strength, by which I would determine many properties of concrete or estimated [1], strength has achieved in the process of hydration and hardening in concrete that rely on many factors [2]. Due to requirements of using concrete with the high armature, many methodical activities have performed for offering suitable solution, finally, for producing concrete with high performance; the self-compaction concrete has introduced by Okamura in the early 80s in the Japan and during of research and quickly accelerates its usage in the world. In 1998, he introduced concrete, which could flow into frame and filled out in the natural process and moved through of bars and other barriers. Current and condensation under the own weight concrete’s, called self-

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compaction concrete [3]. Some of the research institutes in identifying materials and advanced systems in concrete, the different additional has used so that find a solution for decrease of this component have a great impact on economy, so given that cement and high-range water reducer (HRWR) cause to increasing costs, but mineral compounds such fly ash powder (PFA), ground granulated blast furnace slag (GGBS) or limestone powder (LSP) given to arise in the fluidity concrete, without many costs, it can be considered as minimizing value of cement and extra-plasticizer for optimization economy. Adding PFA or GGBS or LSP reduces the needs of extra-plasticizer [4]. The cost production reduced designing [5]. The concept of optimization for designing concrete is considered to minimize cost by making suitable features [6]. Different method in order to design of multi-parameters function for concrete mix design such as factorial [7], computer numerical methods [8], and using of sample with different ratios of components[9], simplex design method [10], linear distribution function [11], two-stage factorial [12], experimental method[13], numerical method [14], Ukamora method for production of self-compaction concrete with high value of powder materials and less than 0.3 water-cement ratio [15], forecasting method such as neural network [16], Tauguchi method [17] and Box Behenken [18] in the problem of optimum design mixture with different component has been interested in current research [19]. Research and studies on concrete mix design optimization have analyzed and introduced concrete strength function by linear and non-linear methods based on decision variables to bulk ratio, weight of concrete components to bulk, or total weight concrete. In this study, by choosing the simplex lattice model for self-compaction concrete with six mix component and by utilizing the suitable effective decision variables on the compressive strength has offered this model with regulations and executive constraints.

2. RESEARCH METHOD

To discuss strategies of compressive strength (F_c) optimization can be effectively assisted to create the appropriate safety factor in calculations and structure design and also using of maximum strength capacity of concrete structure, especially self-compaction concrete that in which an expensive adding used in production will cause to save costs and sources. Optimization of self-compaction concrete’s strength would be performed by constituent parameters and effective strength in F_c and by determining simplex network model for objective function of F_c with results processing and determining of relations constraints.

3. OPTIMIZATION METHODS

The optimization involves various mathematical methods, which dealing with linear, nonlinear, geometry, topology, and dynamic and from optimization so that each of these methods depended on the application issue, and objective function model can be used [20].

4. THE CONCRETE MIX DESIGN METHODS:

4.1 Mathematical

Mathematical-based methods such as Taguchi, Factorial, simplex with linear or non-linear function like Scheffe function has introduced for determine concrete mix design. Firstly, a mathematical model is selected for compressive strength, which functions are frequently used in related objective function as follows:

$$Y = \sum b_i * X_i + e \tag{1}$$

$$Y = \sum b_i * X_i + \sum b_{ij} * X_i * X_j + \sum b_{ii} * X_i^{\,2} + e \tag{2}$$

Where that Y denotes the objective function or compressive strength, b_i denotes the fixed coefficients, X_i denotes the decision variables and e denotes the percentage of probable error in relationship.

4.2 Standard

It's necessary to providing concrete, by initially investigating of the types of material in the place, their properties specified by exactly tests and to be determined according to existing standards like ABA, ACI, DIN and BS, and then mix design or values of weight or bulk of concrete components calculated by standard methods. Considering the regulations assumptions about materials and conditions of the project plays a significant role in this method. Fig. 1 illustrates standard of stone materials and their grain size for regulations of Iran. It should be noted that each regulation to achieve its considered aims at design constraints in kerbs, provided charts that should be considered in this method [21-25].

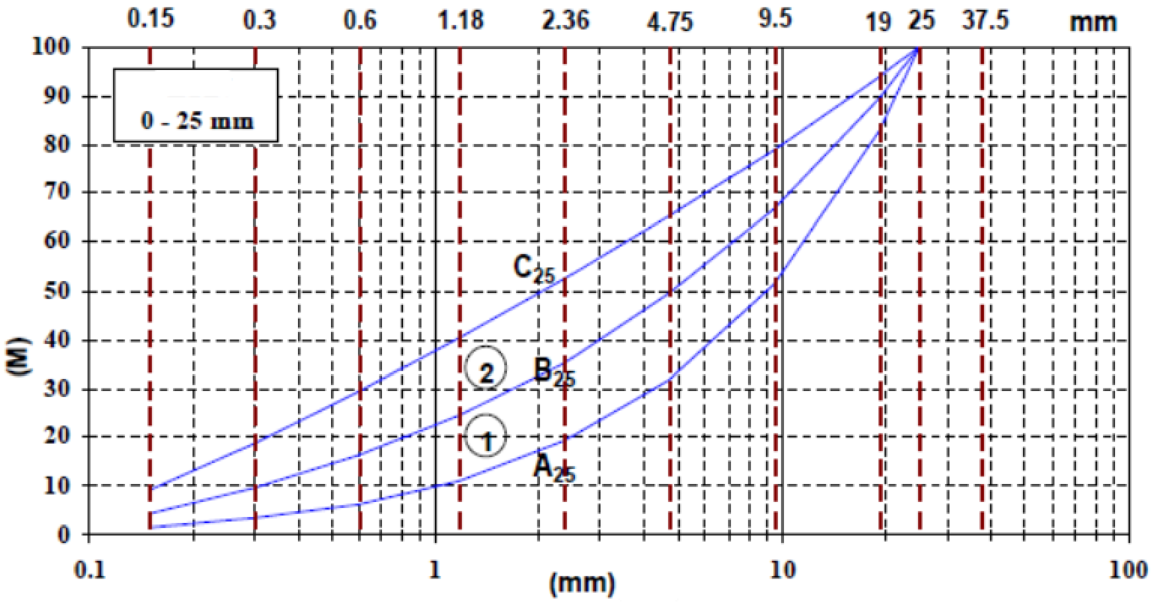

Figure 1. Fine and coarse aggregate gradation curve for maximum size = 25mm

5. SIMPLEX

One of the proposed methods of the mix design in mathematical method is the simplex lattice, the structural model of lines simplex lattice, which connect the components of a mixture is the same as concrete components. With respect to constructor concrete's components, it can be used the mix components' simplex lattice as a multi-dimensional equatorial, that the number of vertices would depend on the number of parameters. Plural mixed component according to Scheffe theory is equal. 1:

$$\sum_{i=1}^{q} Xi = 1 \tag{3}$$

where that q denotes the number of components and X_i is the ith component ratio. Simplex network (q,n) that introduced by Scheffe in 1958, it has illustrated the result of desired properties equation such as compressive strength of concrete. Polynomial is determined by using of that model was presented with equation (1) or (2). Polynomial function of degree n with q variable $X_1 \ldots . X_2$ in the following from has shown where b_i is a constant coefficient.

$$Y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + \cdots + \sum b_{i\ldots n} X_i \ \ldots \ X_n \tag{4}$$

$$1 \le i \le q \,, 1 \le i \le j \le q \,, 1 \le i \le \cdots \le n \le q$$

By developing Eq. (4) for six mix components, achieves Eq. (5).

$$\begin{aligned} Y = b_0 + \ & b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_{12}X_1X_2 + b_{13}X_1X_3 \\ & + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{16}X_1X_6 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 \\ & + b_{26}X_2X_6 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{36}X_3X_6 + b_{45}X_4X_5 + b_{46}X_4X_6 \\ & + b_{56}X_5X_6 + b_{11}{X_1}^2 + b_{22}{X_2}^2 + b_{33}{X_3}^2 + b_{44}{X_4}^2 + b_{55}{X_5}^2 \\ & + b_{66}{X_6}^2 \end{aligned} \tag{5}$$

Also due to Eq. (3), satisfy:

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 + b_0X_6 = b_0 \tag{6}$$

$$\begin{aligned} {X_1}^2 &= X_1 - X_1X_2 - X_1X_3 - X_1X_4 - X_1X_5 - X_1X_6 \\ {X_2}^2 &= X_2 - X_2X_1 - X_2X_3 - X_2X_4 - X_2X_5 - X_2X_6 \\ {X_3}^2 &= X_3 - X_3X_1 - X_3X_2 - X_3X_4 - X_3X_5 - X_3X_6 \\ {X_4}^2 &= X_4 - X_4X_1 - X_4X_2 - X_4X_3 - X_4X_5 - X_4X_6 \\ {X_5}^2 &= X_5 - X_5X_1 - X_5X_2 - X_5X_3 - X_5X_4 - X_5X_6 \\ {X_6}^2 &= X_6 - X_6X_1 - X_6X_2 - X_6X_3 - X_6X_4 - X_6X_5 \end{aligned} \tag{7}$$

By replacing Eqs. (6 and 7) into Eq. (5), Eq. (8) will be achieved:

$$Y = \sum_{1\le i\le q}^{6} a_i X_i + \sum_{1\le i\le j\le q}^{6} a_{ij} X_i X_j$$
$$a_i = b_0 + b_i + b_{ii} \tag{8}$$
$$a_{ij} = b_{ij} - b_{ii} - b_{ij}$$

The typical mix ratio's like 1:2:4 or 1:3:6 cannot use in this method, whereas prerequisite of simplex method is that to be plural of total components equal one. Thus, it is necessary to alternate (shift) main components to virtual components. The main components investigate to mix ratios X_1 to X_6 by simplex polyhedral network. The Z is used for real components and X for virtual components. Therefore, by a transformation matrix, Z and X can be expreesed by $Z=AX$, $X=BZ$ where A is transformation matrix virtual component to real and B is the inverse of A. The real components transformed by Eq. (5) for measurement value of water (Z_1), cement (Z_2), coarse aggregate (Z_3), fine aggregate (Z_4), PFA (Z_5) and micro silica (Z_6) at the ratios related to them for testing concrete cube strength. Also it has considered HRWR value in all mix designs the same. The table 1 has illustrated the real and virtual value which examined decision variables. A six-vertex can simulate the mentioned simplex lattice and vertices represent bounding values per decision.

Table 1: Real and virtual values of concrete content

	Real value of content						Virtual value of content					
NU	Water	Cement	CA	FA	PFA	Micro silica	Water	Cement	CA	FA	PFA	Micro silica
1	207	260	832	900	177	18	1	0	0	0	0	0
2	199	280	832	878	169	14.5	0	1	0	0	0	0
3	188	320	844	894	158	20	0	0	1	0	0	0
4	190	340	834	913	156	23.5	0	0	0	1	0	0
5	191	420	836	925	136	39	0	0	0	0	1	0
6	189	440	854	915	131	44	0	0	0	0	0	1
7	203	270	832	889	173	12.6	.5	.5	0	0	0	0
8	197	290	838	897	167	15.4	.5	0	.5	0	0	0
9	198	300	833	906	166	17.1	.5	0	0	.5	0	0
10	199	340	834	912	156	24.9	.5	0	0	0	.5	0
11	198	350	843	907	154	27.4	.5	0	0	0	0	.5
12	193	300	838	886	163	17.2	0	.5	.5	0	0	0
13	194	310	833	895	162	19	0	.5	0	.5	0	0
14	195	350	834	901	152	16.7	0	.5	0	0	.5	0

15	194	360	843	896	150	29.2	0	.5	0	0	0	.5
16	189	330	839	903	157	21.7	0	0	.5	.5	0	0
17	189	370	840	909	147	29.5	0	0	.5	0	.5	0
18	188	380	849	904	144	32	0	0	.5	0	0	.5
19	190	380	835	919	146	31.2	0	0	0	.5	.5	0
20	189	390	844	914	143	33.7	0	0	0	.5	0	.5
21	190	430	845	920	133	41.5	0	0	0	0	.5	.5

CA=Coarse aggregate, FA= Fine aggregate

6. OPTIMIZATION

6.1 Decision variables

The value of six mix components have considered as decision variables. These values used as optimization of decision variables consisting water (X_1), cement (X_2), coarse aggregate (X_3), fine aggregate (X_4), PFA (X_5), micro silica (X_6) which all of these values divided on total weight up to total decision variables are equal one.

6.2 Objective function

Considering modified Scheffe model for mix design of self-compaction concrete with the mentioned six-components, the objective function is expresse as following:

$$Y = \sum_{1\le i\le q}^{6} a_i X_i + \sum_{1\le i\le j\le q}^{6} a_{ij} X_i X_j \tag{9}$$

6.3 Laboratory program

Making specimen and processing results and determining the coefficients of objective function by making specimen, the test of compressive strength was performed on block samples (15*15*15 cm) during 28 days, which put in water tank and was tested by a compressive testing device. Regarding the laboratory results, achieving compressive strength, and real slump samples, responses and mix ratios, which used for making specimen, placed on objective function and obtained constant coefficients by solving the 21 equations and 21 unknowns of first degree.

$$S = \sqrt{\sum \frac{\left(y_{act} - y_{pre}\right)^2}{(n - p)}} \tag{10}$$

where that y_{act} and y_{pre} denotes the compressive strength obtained by equation and laboratory and n denotes the number of mix designs and p denotes of decision variables.

6.4 Constraint relations of objective function

Based on the recommendations of the different regulations and local and workshop's restrictive conditions the related constraint of each parameter would determine as a mathematical equation. Here, some of the mentioned constraint has extracted and discussed and regulated by analyzing and other exist a constraint.

6.5 Rewriting of objective function and constraints

$$\begin{aligned} Y = & -1.7986X_1 - .1466X_2 + .1612X_3 - .2426X_4 + .9128X_5 \\ & + 4.7291X_6 +. .0017X_1X_2 + .0011X_1X_3 - .0006X_1X_4 + .008X_1X_5 \\ & - .0031X_1X_6 - .0004X_2X_3 + .0001X_2X_4 + .0046X_2X_5 - .0017X_2X_6 \\ & + .0003X_3X_4 - .0024X_3X_5 - .0021X_3X_6 - .0006X_4X_5 + .0005X_4X_6 \\ & - .0296X_5X_6 \end{aligned} \tag{11}$$

s.t.:

$$161 \le X_1 \le 250$$

$$230 \le X_2 \le 550$$

$$2.7 \le \frac{(X_3 + X_4)}{(X_2 + X_6)} \le 6.4$$

$$.52 \le \frac{(X_4)}{(X_3 + X_4)} \le .4$$

$$.25 \le \frac{(X_5)}{(X_2 + X_6)} \le .55$$

$$.35 \le \frac{(X_1)}{(X_2 + X_6)} \le .55$$

$$.3 \le \frac{(X_1)}{(X_2 + X_6 + X_5)} \le .45$$

$$\begin{aligned} & -1.7986X_1 - .1466X_2 + .1612X_3 - .2426X_4 + .9128X_5 + 4.7291X_6 +. .0017X_1X_2 \\ & + .0011X_1X_3 - .0006X_1X_4 + .008X_1X_5 - .0031X_1X_6 - .0004X_2X_3 \\ & + .0001X_2X_4 + .0046X_2X_5 - .0017X_2X_6 + .0003X_3X_4 - .0024X_3X_5 \\ & - .0021X_3X_6 - .0006X_4X_5 + .0005X_4X_6 - .0296X_5X_6 = Strength \end{aligned}$$

At the recent equation, strength denotes the desired resistance for design (F_C). By using of different numerical methods can optimize this problem and obtain optimize value which are compared by experimental and illustraed in Table 2.

Table 2: Comparison compressive strength (MPa) results of objective function with real

Number	Strength design	Experimental strength y_{act}	Relation strength y_{pre}
1	30	26.2	32
2	30	28	32.53
3	30	31.5	35
4	35	33.5	30
5	35	36	37
6	35	37.5	37.34
7	30	26.2	39

8	30	28.7	36
9	30	29.5	41
10	30	31.5	38
11	35	34.2	46
12	35	29.3	31
13	35	30.4	33
14	35	33.9	42
15	35	35.6	41
16	35	32.1	33
17	40	36.6	35
18	40	37.5	49
19	40	36.4	45
20	40	37.7	42
21	40	40.1	35

7. ANALYSIS OF DATA

According to the results of experiments and review the obtained results from the equation for mathematical model of simplex network, by using mentioned model different mix design with desired compressive strength can design and results for each decision variable and effect of change in this variable can examine.

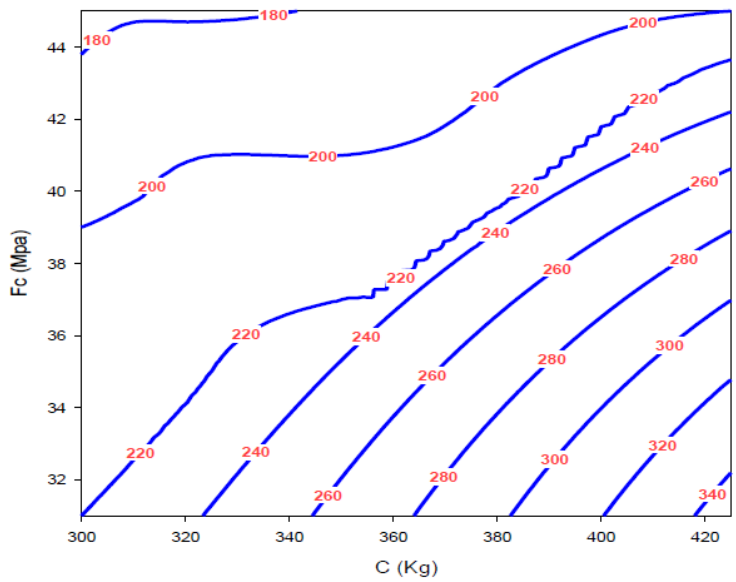

Figure 2. Contour of water with the compressive strength and the cement obtained from Eq. (11)

As seen in Fig. 2, when cement value goes up and other values stay stable, resistance ascends in various conditions. These variations in water value depend on water-cement ratio and compressive strength variation from Eq. (11) at constant conditions; have the reverse ratio with the water-cement ratio.

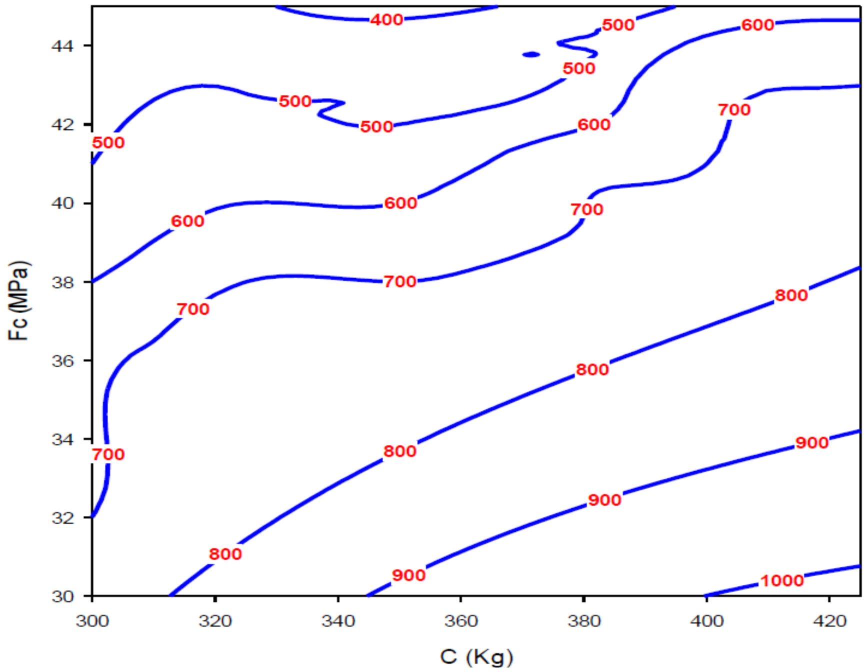

Figure 3. Contour of fine aggregate with F_c (MPa) vs. Cement (Kg) value from Eq. (11)

Fig. 3 has illustrated that, resistance would drop when fine grained stone material goes up, these changes depend on fine grained-cement ratio, and it has discovered an inverse relationship between the obtained compressive strength from Eq. (11) and fine grained-cement ratio.

The Fig. 4 has shown that an increase in resistance and fixed state of ratios leading an increase in coarse grain value. These changes depend on coarse grain-cement ratio and at constant conditions at other ratios of change, obtained compressive strength from Eq. (11) have a direct ratio. Moreover, due to the Fig. 3 and Fig. 4, strength value has reverse relationship with the fine aggregate-coarse aggregate ratio.

Fig. 5 represents an increase of micro silica strength value at constant conditions raise other ratios , this changes at micro silica value depend on micro silica-cement ratio and by using of obtained results from Eq. (11), increasing micro silica value and cement value into total powder materials cause to increase compressive strength of self-compaction concrete. By using of the obtained results Eq. (11), can compare various values hybrid components of self-compaction concrete with various ratios and according to define aims for making this concrete like strength and slump and other require properties provided objective optimize the design for production concrete and used.

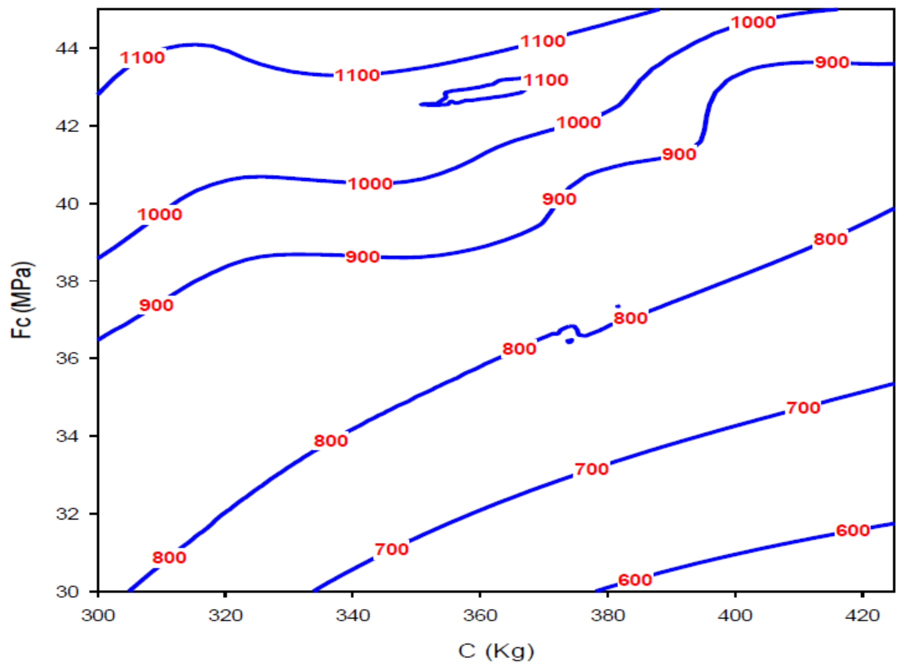

Figure 4. Contour of coarse aggregate with F_c (MPa) vs. Cement (Kg) value from Eq. (11)

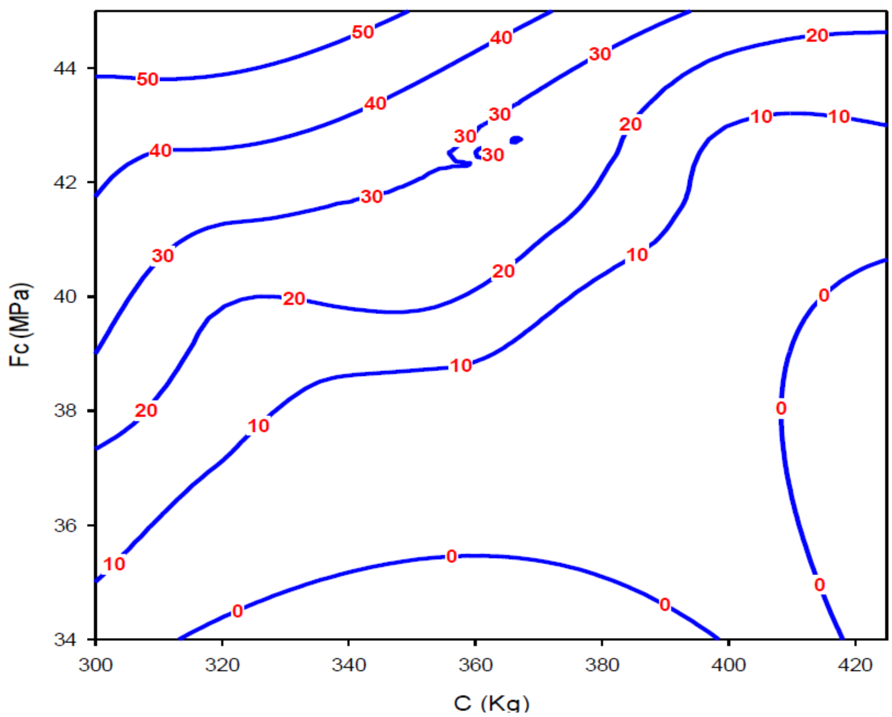

Figure 5. Contour of micro silica (Kg) with F_c (MPa) vs. Cement (Kg) value from Eq. (11)

8. ANALYSIS AND DISCUSSION

In linear planning has been determined that decision variables X_6 and X_4 and X_3 have linear relationship with positive dip with compressive strength It means that by increasing value of water-cement ratio and cohesive-water ratio and micro silica-cohesive material ratio linearly causes to compressive strength value of concrete with various dips increased.

The functions that have been reported in previous studies based on bulk ratio and weight of component's fundamental concrete to their total since statistical functions are relevant to this context like Scheffe, the equality of the selected parameters for function is the main condition and by choosing above ratios, this condition is satisfied, while identifying decision variables according to bulk ratio or weight of component's fundamental concrete to their total, it may not be properly expressed objective function equation with strength, because each of ratios and in other words, shifter per component, fundamental concrete has not been direct related with strength, but the decision variables at linear function in this study has used that with objective function means compressive strength have direct related and effect strength, the probability of similarity of the obtained result with actual results will discuss further.

Effect of water-cement ratio and water-cohesive ratio on strength is excessive while percentage of plasticizer does not have direct effect on strength, also by increasing value stone powder-cement material ratio; strength has been influenced and decreased. By using of micro silica cause to strength go up, but cause to increasing water-cement value, increasing strength, but the efficiency is very low and sometimes not usable concrete. For creating efficiency the plasticizer would use. Using of plasticizer cause to increasing production costs. In making concrete with high strength, although the use of additives leads to increase making cost, the use of high-strength concrete would justify this.

Effect of the introduced components values on the concrete strength is high, while percentage of extra-plasticizer has not direct effect on strength, strength have been influenced and decreased by increasing value of stone-powder-cement material ratio as well. Using of micro silica can help to ascend strength, but causing an increase in the cost of production one cube meter concrete too. By decreasing water-cement value, strength increase, but efficiency become very low and sometimes become not applicable concrete, extra-plasticizer cause to raise production cost.

The using conditions of self-compaction concrete often requires round aggregates to achieve better efficiency, but this is rely on DIN standard leading to decreasing concrete strength, in the cement with strength 52.5 MPa, by using round aggregate into broken aggregate decrease strength in water-cement ratio 35% about 20%, therefore for obtaining higher strength at the same water-cement condition, it can be use broken aggregate material by provided suitable condition for efficiency and slump current like using of extra-plasticizer and powder material.

Assessment of the real strength and those which represented by objective function relation shows that represented relation with suitable reliability can be calculated compressive strength of mix design.

9. CONCLUSION

Due to the time-consuming and costly mix design calculations of self-compaction concrete with regulation methods; applying a mathematical model for determine hybrid component of this concrete could be useful solution for decrease computation cost of design.

For calculating this relation from experimental samples and determining compressive strength samples have influenced by processing these results. The obtained function can be calculated by entry main data of concrete strength. By using suitable variables for a choice model make similar results to the experimental real results. To achieve this, it can be clearly seen that those variables have chosen in which the linear model has linearly the relationship with concrete strength and in non-linearly the model has similar relationship with compressive strength concrete.

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