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Comparison of Simulated annealing method with genetic algorithm to determine the optimal Self Compacting Concrete mix design

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ABSTRACT
Among the special properties of self-compacting concrete, high performance, no need to vibrate the concrete, reduced costs and manpower, and most importantly, accelerating the construction, can be noted. Such characteristics caused that day by day, the use this type of concrete becomes more, especially in components with high density of armature. Using a meta-heuristic algorithms is one of the most widely used methods of optimization. The trial and error method is used to find optimal solutions using these algorithms. The Simulated Annealing algorithm can be considered as one of the best meta-heuristic algorithms. This algorithm is derived from gradual freezing process of molten metal and their behavior during gradual freezing. Genetic algorithms can be considered as one of the most popular meta-heuristic algorithms, that's why its function includes a wide range of issues. The behavior of genetic algorithms inspired by the mechanism of evolution in nature. In this paper, with regard to 27 samples of self-compacting concrete mix design parameters as input, once the Simulated Annealing algorithm and again the Genetic Algorithm, were used to maximize the 7-day compressive strength of self-compacting concrete and to determine the optimal mix design. Then, the maximum compressive strength and optimal values determined by both algorithms have been compared with each other that the comparison shows that the results of both algorithms are identical.
Keywords*: self-compacting concrete, optimal mix design, maximum compressive strength, Simulated Annealing method, Genetic Algorithm.*

INTRODUCTION

Self-compacting concrete (SCC), for the first time was developed in Japan in 1987. This type of concrete does not require any vibration after pouring into the frame. This causes the economy and reduce construction time and thus increase in final efficiency. Self-compacting concrete with less than 30 years old, underlies solving many problems of concrete structures especially in sections with high density of bar. Other special features of this concrete include high performance, high strength against separation and accelerating the construction. Such characteristics caused that day by day, the use this type of concrete becomes more, especially in components with high density of armature. Despite some of the mentioned features, it contains the same ingredients of regular vibrated concrete, such as sand, gravel, cement, water and additives as well, but with different proportions. Despite researches were done on self-compacting concrete, no specific research has been conducted on the optimization of self-compacting concrete (resistance). Most research studies done on this type of concrete were reported in terms of its technology [1].

Simulated Annealing algorithm (SA) can be considered as one of the best meta-heuristic algorithms [2]. This algorithm was developed first by Kirk Patrick and colleagues. The algorithm in 1983, inspired by the gradual freezing of molten metal and studying their behavior during the freezing phase and has reached this stage with the help of Metro Police algorithms in Monte Carlo simulation. The basic idea of Simulated Annealing algorithm is the same Metro Police algorithm which simulates the microscopic behavior of a set of particles by Monte Carlo simulation model [2].

Genetic Algorithm (GA) can be considered as one of the most popular meta-heuristic algorithms, that's why its function includes a wide range of issues [2]. This algorithm is a model of machine teaching which its behavior has been inspired by the mechanism of evolution in nature. The Genetic Algorithms is implemented through creating a crowd of people which each are provided in the form of chromosomes. Then, the people in the population exposed to the process of evolution. An example of the broad application of genetic algorithms is in multi-dimensional optimization issues, that the various parameters which are considered to be optimized, are organized in the format of chromosomes string. This algorithm is often known as a method for optimizing functions which of course, the scope of application of this method is much broader[3].

In this paper an attempt is made to realize the maximum amount of the 7-day compressive strength of self-compacting concrete using the values of self-compacting concrete components that like ordinary concrete includes cement, sand, gravel, water and additives and through Simulated Annealing and Genetic algorithms, also the optimal values of the concrete components which cause that the 7-day compressive strength be maximum be determined by the two mentioned algorithms. In following, the effort is to compare the results of the optimization of Simulated Annealing with the results of the optimization of the Genetic Algorithm. To optimize through both algorithms and compare them with each other, 27 different concrete mix designs are applied. The input parameters for the algorithms contain cement, water, sand, gravel, stone powder and superplasticizer in kilograms per cubic meter. The value which must be maximized is the 7-day compressive strength of concrete in kilograms per square centimeter. To optimize, the software MATLAB 2014 and the relevant tool box have been used. It is necessary to cite that for optimization using Simulated Annealing and Genetic algorithms, an objective function is needed which the objective function of this study is obtained using multivariate linear regression and software MINITAB V16.

THE SIMULATED ANNEALING ALGORITHM

Each particle in materials has a surface energy, the lowest energy level for a matter is when none of the particles moves or in other words, the temperature of the particles reaches zero degrees Kelvin. Now, if solid materials congeal very slowly, their atoms are placed in the crystal lattice on a regular basis and the resulting solid material, will have a minimum level of energy. This method is called Simulated Annealing. In fact, the main idea of Simulated Annealing can be known derived from the motion of a well-rounded ball on the ground, namely if a safe ball is fallen on the ground, from the fall time to session time, the ball gradually loses its power and gradually becomes closer to a complete stop. When throwing the ball to the ground, if we push considerable amount of energy, we will see that the energy of the ball reduces gradually and finally, reaches the lowest place on its energy levels. Obviously, it is possible to use several balls in parallel (parallel mode of The Simulated Annealing method) instead of a single ball (standard form of Simulated Annealing method). In these mode, the optimization process normally starts from higher energy levels and then it randomly went into another place that this mode will be followed by a continuous decline in energy. This move is only acceptable when the new appeared mode has lower energy than its previous state and improves the aim, however, in minimization issues, this subject is addressed by reducing the value of the objective function for minimization [2].

GENETIC ALGORITHM

In the mid-twentieth century, some computer scientists began their work on evolutionary systems in the hope that use it as a mechanism for solving optimization problems. The Genetic Algorithm which is the pioneer of evolutionary methods, first was introduced by John Holland in 1975. Many current theories of mentioned algorithm are based on the basic principles proposed by Holland. The main goal of this computer scientist was not creating a new algorithm rather, he seeks to identify the exact way of accommodation in nature and to develop a way to use the natural accommodation process in computer systems. In this context, Holland activities created a general framework for genetic algorithms in order to provide for future advances. It is noteworthy that the genetic algorithm term has two general meanings. The first meaning, a narrow interpretation of this tool, was first proposed by Holland. In the second meaning, the genetic algorithm indicates each population-oriented models which use the selection and composition operators to create new instances of the search space [3].

Genetic algorithm repeatedly changes a collection of individual solutions for problem solving which these changes are called evolution. At each step of this evolution, two members of the population are randomly selected as parents and their children are considered as the next generation. Thus, the population evolves towards an optimal solution. Using this algorithm, it is possible to solve many optimization problems which cannot be solved by standard optimization algorithms. Among these issues, the issues can be cited that their objective function is discontinuous, indistinguishable, incidental or strongly nonlinear. GA uses

three basic rules to produce the next generation from the current generation: the first group is selection rules which using the rules, people who are used to produce the next generation will be selected. The second set is integration rules that these rules combine two parents and produce the next generation of children. The third group is mutation rules that imposed a random change on people and generate new population [3].

SAMPLES CHARACTERISTICS

In 27 samples, which come from research of Esmailnia and Faridi [1] and values of the components and the results of the 7-day compressive strength test are available on the mentioned research, for grading stone aggregate, the grading curves of sand and gravel which is placed between the gradation curves of Sweden (top) and Germany (Low). The curves are shown in Figure 1 and Figure 2. In these figures, the gradation curve is shown as solid. According to the research, the maximum coarse aggregate is 19 mm. The consuming sand is provided from Zana Beton Company located in the city of Sanandaj. The modified sand fineness modulus is 2.7 Also, Portland cement type-1produced by Bijar Factory with a specific weight of 3150 kilograms per cubic meter and Micro silica of Building Products Company containing 93.6% of SiO2, were used in mix designs. The consumed Super-plasticizer was in kind of Fabplast-20 and the product of Iranian Fiber Concrete Technology Corporation (ASTM-C494). It should be noted that in mix designs, Micro silica has been replaced to 15 % of cement weight. Table 1 and Table 2 show the chemical composition of cement and silica [1].

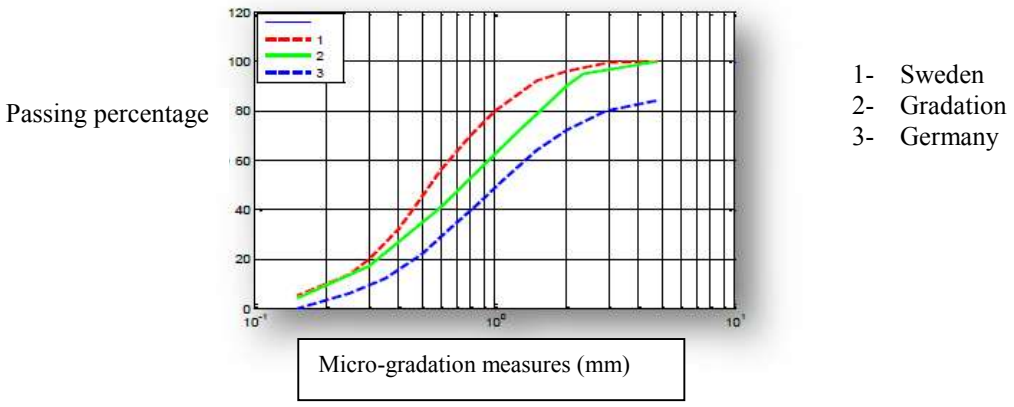

Figure 1: Sand gradation curve

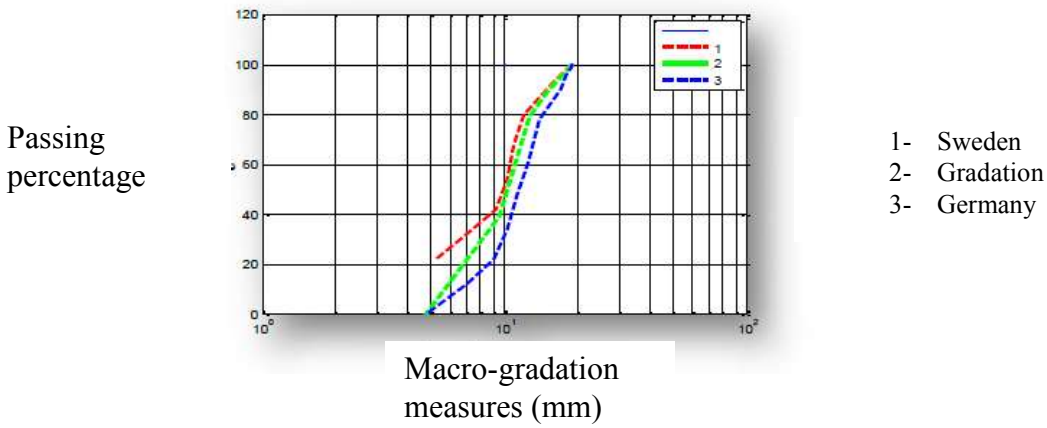

Figure 2: Gravel gradation curve

Table 1: Chemical composition of cement

MgO	SO3	CaO	Fe2O3	AL2O3	SiO2
3.9%	0	60.46%	2.72%	2.7%	22.43%
LOI	**P2O5**	**C**	**Sic**	**K2O**	**Na2O**

2.36%	0	0	0	0.62%	0.14%

Table 2: the chemical composition of micro silica

MgO	SO3	CaO	Fe2O3	AL2O3	SiO2
0.97%	0.1%	0.49%	0.3%	1.3%	93.6%
C	**P2O5**	**CL**	**Sic**	**K2O**	**Na2O**
0.3%	0.16%	0.04%	0.5%	1.01%	0.31%

5- The mix design of the concrete samples and the results of tests

Table 3 shows the mix design of concrete build by Esmailnia and Faridi [1]. The results of tests on samples that they have done, can be seen In Table 4.

Table 3: the mix design of built concrete samples

No	Water (Lit)	Cement (kg/m3)	Stone powder (kg/m3)	Superplasticizer (kg/m3)	Gravel (kg/m3)	Sand (kg/m)
1	200	464	103	8.5	736	861
2	200	464	111	7.5	736	861
3	200	464	110	8	736	861
4	190	442	103	8.5	736	878
5	190	442	111	7.5	736	878

Followed by Table 3: the mix design of built concrete samples

No	Water (Lit)	Cement (kg/m3)	Stone powder (kg/m3)	Superplasticizer (kg/m3)	Gravel (kg/m3)	Sand (kg/m)
6	190	442	110	8	736	878
7	197	438	103	8.5	736	832
8	197	438	111	7.5	736	832
9	197	438	110	8	736	832
10	190	438	103	7.5	718	861
11	190	438	111	8	718	861
12	190	438	110	8.5	718	861
13	197	464	103	7.5	718	878
14	197	464	111	8	718	878
15	197	464	110	8.5	718	878
16	200	442	103	7.5	718	832
17	200	442	111	8	718	832
18	200	442	110	8.5	718	832
19	197	442	103	8	770	861
20	197	442	111	8.5	770	861
21	197	442	110	7.5	770	861
22	200	438	103	8	770	878
23	200	438	111	8.5	770	878
24	200	438	110	7.5	770	878
25	190	464	103	8	770	832
26	190	464	111	8.5	770	832
27	190	464	110	7.5	770	832

Table4: The results obtained for the 7-day compressive strength of concrete samples

No	7-day compressive strength (kg/cm2)	No	7-day compressive strength (kg/cm2)	No	7-day compressive strength (kg/cm2)
1	422	2	415	3	404
4	396	5	412	6	419
7	405	8	392	9	399
10	412	11	400	12	406
13	421	14	433	15	428
16	417	17	439	18	446
19	413	20	409	21	395

Followed by Table 4: The results obtained for the 7 -day compressive strength of concrete samples

No	7-day compressive strength)kg/cm2(	No	7-day compressive strength)kg/cm2(	No	7-day compressive strength)kg/cm2(
22	393	23	390	24	402
25	447	26	451	27	453

Determining the optimal mix design of SA and GA algorithms and comparing the results of both algorithms to each other

Obtaining the objective function

For optimization through the toolbox of Simulated Annealing algorithm and the Genetic Algorithm toolbox in MATLAB, it is not possible to directly use the data of 27 mix designs and it needs to a function named the objective function which expresses the relationship between the values of the components in all mix designs and the 7-day compressive strength obtained for them. To obtain the objective function, in this study, the multivariate linear regression and MINITAB software were used. In following, first, the two-variable linear regression will be explained and then its difference with the multiple linear regression will be expressed as well.

In most statistical studies, it is needed to predict the approximate value of a dependent variable from the value of an independent variable. Such issues are called regression. Independent variable x and dependent variable Y are displayed together. In general, if we want to predict the value of the dependent variable through the independent variable, we need a relationship between two variables that this relation is a predictor equation which called the regression equation. Whenever a linear relationship exists between the independent variable x and the dependent variable Y, the equation called simple linear regression equation. The linear regression means that the mean Y is linearly in relation with x, which this line is called the regression line. Equation (1) shows the relation of this type of regression:

$$y = \alpha + \beta x \qquad (1)$$

Which A and β are the regression coefficients. These coefficients are unknown parameters that must be known. The least squares method is used to find the regression coefficients. The method of least squares is the sum of squared residuals are normally the sum of squared errors known around the regression line. To measure the dependence of two random variables of x and Y, a measure named the correlation coefficient (R) is used. This coefficient is between zero and one, that if be one, indicates that the correlation between two variables is complete and if it be zero, indicating no correlation between the two variables. The difference between two-variable linear regression and multivariate linear regression is that in multiple linear regression, rather than an independent variable x, several independent variables x1, x2, ..., and xn and instead of a regression coefficient β, some regression coefficients β1, β2, ... and βn exist [4].

After entering all the values of the components of the concrete mix designs and 7-day compressive strength values obtained by the software MINITAB, the software does the operations related to the regression and provided outputs it to the form if figure 3.

Regression Analysis: CS7 versus C, W, LP, SP, G, S

The regression equation is
CS7 = 472 + 0.997 C - 0.906 W + 0.284 LP + 3.78 SP - 0.053 G - 0.405 S

Predictor	Coef	SE Coef	T	P
Constant	472.0	236.9	1.99	0.060
C	0.9972	0.2283	4.37	0.000
W	-0.9058	0.6228	-1.45	0.161
LP	0.2836	0.7332	0.39	0.703
SP	3.778	6.392	0.59	0.561
G	-0.0533	0.1210	-0.44	0.665
S	-0.4053	0.1374	-2.95	0.008

S = 13.5586 R-Sq = 60.5% R-Sq(adj) = 48.6%

Figure 3: The obtained regression equation for compressive strength of concrete in MINITAB

At the top of the Figure 3, the regression equation of the relationship between the values of the 27 mix designs of concrete with the 7-day compressive strength are shown. Relation (2) shows this regression equation, which is obtained by the software:

$$CS7 = 472 + 0.997C - 0.906W + 0.284LP + 3.78SP - 0.053G - 0.405S \quad (2)$$

Where, C is cement content in kilograms per cubic meter, W the amount of water in liters, LP amount of powdered stone in kilograms per cubic meter, SP superplasticizer content in kilograms per cubic meter, G sand content in kilograms per cubic meter, S sand content in kilograms per cubic meter and CS7 is the 7 - day compressive strength of the concrete is in kilograms per square centimeter. At the bottom of the Figure 3 the correlation coefficient (R) shown as well. The value of this coefficient is equal to 0.605 that this value indicates that the obtained precision is a little higher than average.

Obtaining the optimal mix design and maximum 7-day compressive strength of the SA algorithm

The method of maximization through the software MATLAB: in the toolbox of optimization of Simulated Annealing algorithm in MATLAB Software, the attempt was to find the minimum value of the objective function. According to the book of Dr. Karamooz and co-workers [5], if it is needed to obtain the maximum value of the objective function and in fact, instead of immunization it was required that maximization operations be done, to do this, it is necessary to multiply all components of the objective function in a negative multiplier and then the minimization be performed on the objective function. In this article, first of all sentences of relation (2) are multiplied by a negative and then the equation was entered to the Software as well.

Setting of the algorithm in MATLAB software: about the setting of the algorithm in the software configuration, the only thing that should be mentioned is that no change is done in the configuration of Simulated Annealing algorithm in MATLAB software and all settings remained on default values.

Entering the objective function and the range of values of the variables into the Software and initiating the optimization operation: by entering the objective function and the range of values of the variables into the Software, the Software analyzed the data and presented the outputs as Figure 4.

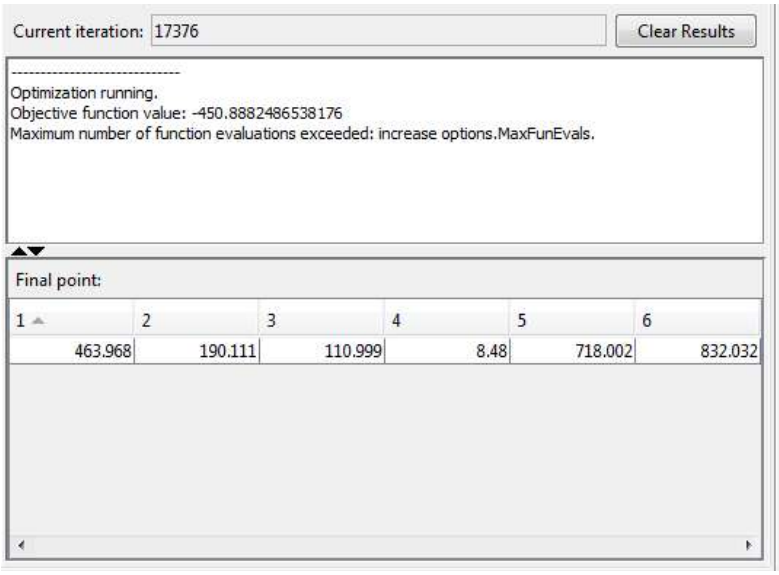

Figure 4: The performed analysis to maximize the compressive strength through the SA algorithm

Determining the maximum number of genetic algorithms duplications is one of its stopping requirements that in this condition, when the algorithm stops that the number of duplications reaches a certain number [3]. One of the requirements to stop the Simulated Annealing algorithm is also determining the maximum number of duplications. According to Figure 4, the Simulated Annealing after 17,376 iterations was stopped due to reaching the maximum number of iterations. After stopping algorithm, the optimal values of the 6 components of the concrete at the bottom of the toolbox were marked, which are shown in Figure 4. As can be seen, the optimal values are determined by the floating-point algorithm. That is why in this article to improve the determined results by the Simulated Annealing method, the Hybrid optimization function type Patternsearch, was used.

Hybrid optimization function and its variants are applied to improve the results of Simulated Annealing method [3]. In the software MATLAB, also a possibility was provided to take advantage of the optimization function and its variants. As was explained, it is intended to improve the results of Simulated Annealing method, the Hybrid optimization function to be used. For this purpose, first the Hybrid optimization function in the setting of the algorithm exited form the None mode and its type was specified. Then, the

software has been launched. By running the software, the analysis was done and outputs are provided as Figure 5. In Figure 5 it can be seen that the results are improved and the concrete's optimized components are obtained as integers. Also according to Figure 5, the maximum compressive strength is acquired to 451 kilograms per square centimeter. It is noteworthy that the negative sign of the number 451 is that's why to perform the maximization operation, all sentences of the objective function is multiplied by a negative that as a result, the maximum value is obtained as a negative number. Optimal mix design and maximum compressive strength of this mix are shown in table 5.

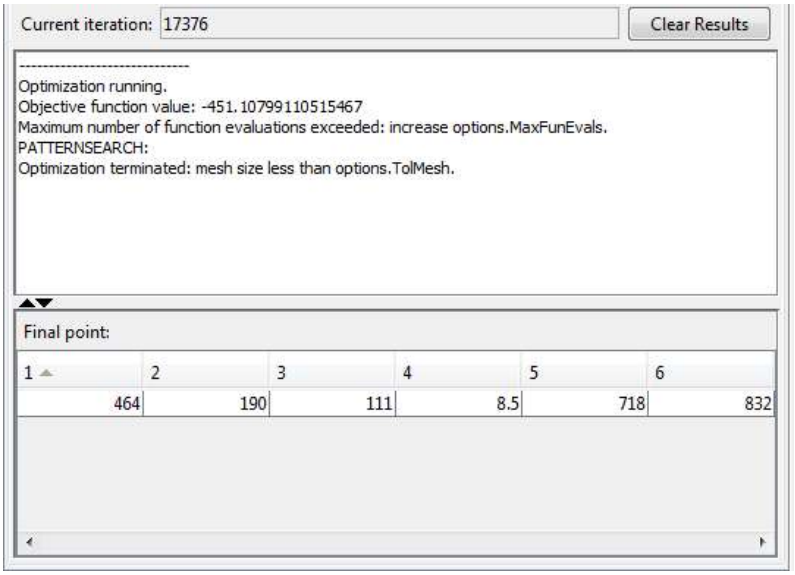

Figure 5: The results of analysis through the SA algorithm and function Hybrid to maximize compressive strength

Table 5: Optimal mix design and the maximum compressive strength determined by SA algorithm and the Hybrid function

7-day compressive strength (kg/cm2)	Superplasicizer (kg/m3)	Stone powder (kg/m3)	Cement (kg/m3)	Water (Lit)	Sand (kg/m3)	Grovel (kg/m)
451	8.5	111	464	190	832	718

Obtaining the optimal mix design and the maximum 7-day compressive strength by the GA algorithm

The genetic algorithm optimization toolbox also tries to find the minimum value of the objective function. Therefore, to maximize the genetic algorithm also, all sentences should be multiplied by a negative and then the minimization on the function be performed. In this paper, to maximize through the genetic algorithm, first of all sentences of equation (2) are multiplied by a negative and then the function has been entered in the software.

Setting of the algorithms in the software MATLAB: about the settings of the genetic algorithm in the software, it should be said that the only change in the configuration of the GA is that in the setting of Mutation part and in sub-division of the selection of the mutation function, the adaptive mutation function was selected and no change in other settings related to the genetic algorithm in MATLAB software has been created.

Entering the objective function and the range of values of the variables into the Software and initiating the optimization operation: by entering the objective function and the range of values of the variables into the Software, the Software analyzed the data and presented the outputs as Figure 6.

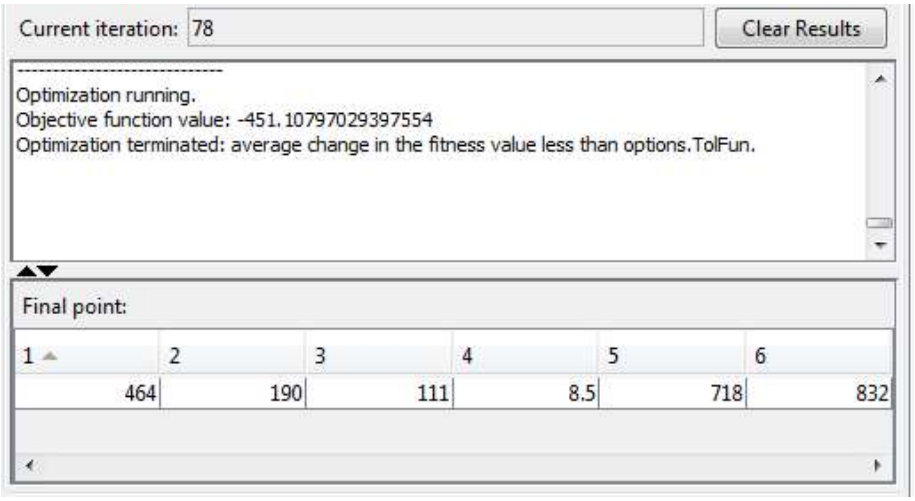

Figure 6: The results of performed analysis to maximize the compressive strength through the GA algorithm

Generation recession is one of requirements to stop the genetic algorithm. In accordance with the conditions, if any progress is not achieved in a certain number of generations, the algorithm is stopped [3]. With regard to the figure 6, the genetic algorithm after 78 generations is stopped because of the fulfillment of the stop condition of Generation recession. After stopping algorithm, the optimal values of the 6 components of the concrete at the bottom of the toolbox, are shown in Figure 6. The maximum compressive strength was obtained equal to 451 kilograms per square centimeter. Optimal mix design and maximum compressive strength of this mix are shown in table 6.

Table 6: The optimal mix design and the maximum compressive strength determined by the GA algorithm

7-day compressive strength (kg/cm2)	Superplasicizer (kg/m3)	Stone powder (kg/m3)	Cement (kg/m3)	Water (Lit)	Sand (kg/m3)	Grovel (kg/m)
451	8.5	111	464	190	832	718

Comparing the results of Simulated Annealing algorithm with the results of the GA algorithm

By comparing Tables 5 and 6 with each other, the result will be that the optimum amount of cement, water, sand, gravel, stone powder and super-plasticizer, determined by both algorithms, are identical. After comparing the optimal amounts of concrete components, it is turn to compare the values of maximum compressive strength. The maximum values of 7-day compressive strength determined by both algorithms, are identical. The only difference between the two algorithms is that the genetic algorithm without need to the Hybrid optimization function, determined the optimal values of the components of the concrete as integers but the Simulated Annealing algorithm determined the optimal values of the components of the concrete as integers by using the Hybrid optimization function.

CONCLUSIONS

In this paper the capability of Simulated Annealing and genetic algorithms were used to maximize the 7-day compressive strength of self-compacting concrete and to determine the optimal values of its components, which cause that the value of the 7-day compressive strength became maximum. A total of 27 different concrete mix designs and each with 6 components, were used in the optimization. These components which was the input parameters of the algorithm included cement, water, sand, gravel, superplasticizer and stone powder amounts in kilograms per cubic meter. The target was the 7-day compressive strength of self-compacting concrete in kilograms per square centimeter. The toolbox of Simulated Annealing and genetic algorithms was used for optimization in the MATLAB software. That's why for optimization through the toolbox of Simulated Annealing algorithm and the Genetic Algorithm toolbox in MATLAB, it is not possible to directly use the data of 27 mix designs and it needs to a function named the objective function which expresses the relationship between the values of the components in all mix designs and the 7-day compressive strength obtained for them. To obtain the objective function, in this study, the multivariate linear regression and MINITAB software were used. After determining the

maximum value of compressive strength and optimal values of 6 components of the concrete by both algorithms, the results of the Simulated Annealing algorithm were compared with the results of the genetic algorithm. The comparison showed that the results of both algorithms are identical.

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