Optimization High-strenght concrete mixing design using meta-heuristic genetic algorithm

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Abstract
In addition to the mechanical properties and durability of concrete, its production cost can also affect the choice of materials. On the other hand, changing the quantity of materials in the concrete mixing design affects the properties of concrete, including compressive strength and cost of materials, and these two factors are very important factors in deciding to use more or less materials in terms of purchase price for manufacturers in the concrete industry. High strength concrete (HSC) is in the category of concretes that in addition to having high strength, has a low ratio of water to binder and a greater variety of materials, so in this type of concrete, choosing the exact amount of material to achieve a certain strength class, to have the lowest cost is difficult. In the present study, using meta-heuristic genetic algorithm, the data of a reference study related to a class of HSC were optimized in terms of compressive strength and fabrication price in addition to achieving the highest possible strength at the lowest cost, to achieve target strengths can also be minimized. The results showed that the meta-heuristic genetic algorithm acted intelligently to change the amount of materials in the mixing design and made the changes in such a way that in the process of obtaining the desired strengths, changes in the amount of materials used in the mixing design, with the least costs may be offered.

Keywords: High strength concrete mix design, Meta-heuristic genetic algorithm, Strength, Slump, Price.

1. Introduction
It is very desirable to use high-strength concrete in the construction industry. In general, strong concrete can be defined in terms of its strength and durability. Generally, by increasing the strength of concrete, its other properties are also improved. In North American construction workshops, concrete with a compressive strength of more than 42 MPa at the age of 28 days is usually called high-strength concrete [1]. This is while concrete with strength of more than 60 MPa is also called high strength concrete [2]. According to Mendes and Yang's recommendation, special attention should be paid to all aspects related to the production of this type of concrete, including materials, mix design, transportation and concreting [3].

Few researches have been done to optimize high-strength concrete mix design by algorithms, but all researchers have either used algorithms for part of the work, or they have only limited themselves to optimization by algorithms and finding a mix design. In this research, the experiments of Simon's report [4] were used as the basis of the work, and by using meta-heuristic genetic algorithm, the mixture design function was first calculated, and then this function was calculated in terms of the price of materials and by applying restrictions such as the limit of the ratio of water to cement materials and the permissible range. Slump was again optimized by genetic algorithm and the effect of changing the amount of each of the mixed design materials on the strength at the age of 28 days of concrete was investigated. The purpose of this research is to investigate the change in the amount of materials used for different strength categories at the age of 28 days, in order to minimize the finished price of concrete, and it answers the question of how to change the amount of materials in a way to While achieving the desired strength, taking into account the selection range for slump and the ratio of water to cement materials, the cost of materials used in concrete construction should be minimized.

2- Materials and methods
2-1- Materials and materials used in research
In this research, type 2 Portland cement from Karon Khuzestan factory and microsilica manufactured by Azna factory in Aligoderz city in Iran, and polycarboxylate ether based superlubricant and two types of broken aggregate produced in Khuzestan province were used.

2-2- Determining the optimal mix design using algorithm
In 1975, Holland presented an initial concept of genetic algorithm. In this algorithm, after the formation of the initial population, operators such as procreation or genetic mutation are responsible for the cyclical improvement of the population, and finally, the population of the next cycle is selected by a targeted random selection. Multiple generations in the next cycles improve the population and lead the people of the society to continuous improvement [5]. Chopra et al. used artificial network and genetic algorithm to predict strength development at 28, 56 and 91 days of age. In this research, 49 designs mixed with common materials and 27 designs with the addition of fly ash were examined in laboratory conditions. Investigations indicated the better performance of the neural network in predicting the growth of strength over time [6].

A: Introduction of meta-heuristic genetic algorithm

In the algorithm used, first the initial population was formed, then, in addition to the general operators of the genetic algorithm, some innovative methods were also used so that the search in the answer space would be more diverse and optimal for the algorithm. Then the process continues by selecting a new population based on random selection with the probability of selecting a better individual. For a better understanding of the topic, the operators were described in 8 steps in the text of the main article. For all the mentioned steps, it is programmed in MATLAB software and the answers are extracted from this process.

B: Solving the problem of functions using the algorithm

To solve the problem, according to the number of concrete components with high strength and the intended function, there are 28 unknowns, which are arranged in a string as shown in Figure 1. The algorithm is executed once for the unknowns of calculating the compressive strength function at the age of 28 days and again for the calculation of the unknowns of the slump function.

A_1	A_2	A_3	A_4	A_5	A_6	B_1	B_2	B_3	B_4	B_5	B_6	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{23}	C_{24}	C_{25}	C_{26}	C_{34}	C_{35}	C_{36}	C_{45}	C_{46}	C_{56}	K

Figure 1- Chromosome view of the problem in meta-heuristic genetic algorithm

C: Optimizing the mixed design function

The purpose of this research, in addition to finding a mixture design that is a balance between the strength and the price of its construction, is to provide specific target strength at the lowest possible price. To achieve this goal, the basis of the work will be the function of strength, and by applying the price of the materials, the necessary balance will be made. For this purpose, the strength function needs to be checked again, with the difference that this time the coefficients and powers (K, C_nm, B_n and A_n) are known and it is necessary that the volume ratios of the materials are such that the output strength of the function and the price of the materials ratios are economic. Considering having the strength function in hand, it is enough to enter the price of each design in its fitting function (the amount of input in the roulette cycle) and then select the next generation using the roulette cycle. Therefore, the random proportions of the materials are considered for the unknown variables of the function; these ratios must be within the accepted range for high strength concrete and it is better that they are very close to the selected range of laboratory designs. The use of slump function is also for the reason that samples with slump out of range are changed and re-referred to the algorithm cycle. Having the chromosome and the initial population, the algorithm process and operators are implemented. The process continues until no better answer is found or the changes are very minor.

D: Validation of meta-heuristic genetic algorithm

In order to find the amount of error of the function provided by the algorithm, first, several different mixed designs, whose details were previously taken from the algorithm in different strength categories, were made in the laboratory. After measuring the slump of fresh concrete according to ASTM C143 and determining the compressive strength at the age of 28 days according to ASTM C39, the results are compared with the output of the algorithm.

3- Results and discussion

In Simon's report as reference research, first 36 mixed designs were tested with specific scope for materials. He optimized the design of the mixture resulting from the experiments and determined the strength of 54.7 MPa as the optimal point of strength at the age of 28 days. To solve the problem, the data was the same as the data of the reference report. Based on the algorithm process, the output of coefficients and powers were obtained for strength at the age of 28 days and slump, and the least sum of squares was 280 and 7788, respectively.

The best answer in terms of the balance, between strength, price and the most economical mixture design for different characteristic strengths were calculated according to the price of local materials, and the corresponding answers are presented in the form of volume and weight in Tables 1 and 2. Mix design number 14 is the best answer of the algorithm based on the tested materials.

Table 1- Volume ratios of the design of optimal mixtures of meta-heuristic genetic algorithm (kg/m^3)

Mix code	comp str (MPa)	Water	Cement	Silica fume	SP	Coarse agg	Fine agg	slump (mm)	w/c	price (USD)
1	48	0.1579	0.12	0.012	0.00461	0.4364	0.2191	115	0.470	18.23
2	49	0.189	0.12	0.012	0.00461	0.411	0.2382	127	0.473	18.26
3	50	0.1892	0.12	0.012	0.00461	0.3984	0.2558	140	0.473	18.30
4	51	0.188	0.12	0.012	0.00461	0.3829	0.2729	145	0.470	18.34
5	52	0.181	0.12	0.012	0.00463	0.3813	0.2819	131	0.453	18.40
6	53	0.1725	0.12	0.012	0.00464	0.3823	0.2894	113	0.430	18.46
7	54	0.1639	0.12	0.012	0.00471	0.3875	0.2926	100	0.410	18.50
8	55	0.1612	0.12	0.012	0.0052	0.3898	0.2924	100	0.403	18.55
9	56	0.156	0.12	0.012	0.00552	0.3972	0.2901	100	0.390	18.56
10	57	0.1534	0.12	0.012	0.006	0.3993	0.2899	100	0.384	18.62
11	58	0.1507	0.12	0.012	0.00646	0.4017	0.2896	103	0.377	18.65
12	59	0.1504	0.12	0.012	0.00688	0.4015	0.2918	113	0.376	18.70

13	60	0.15	0.12	0.012	0.00735	0.4008	0.2927	123	0.375	18.72
14	60.35	0.15	0.12	0.012	0.0074	0.4008	0.293	134	0.375	18.73
15	61	0.15	0.143	0.0127	0.0074	0.3939	0.2929	86	0.317	20.80
16	62	0.15	0.15	0.0219	0.00739	0.3779	0.2928	80.5	0.291	24.78

Table 2- Weight ratios of optimal mixtures design of research genetic algorithm (kg/m^3)

Mix code	comp strength (MPa)	Water	Cement	Silica fume	SP	Coarse aggregates	Fine aggregates
1	48	187.9	374.4	25.56	4.84	1134.64	547.75
2	49	189	374.4	25.56	4.84	1082.12	595.5
3	50	189.2	374.4	25.56	4.84	1035.84	639.5
4	51	188	374.4	25.56	4.84	995.54	682.25
5	52	181	374.4	25.56	4.84	991.38	704.75
6	53	172	374.4	25.56	4.84	993.98	723.5
7	54	163.9	374.4	25.56	4.945	1007.5	731.5
8	55	161.2	374.4	25.56	5.46	1013.48	731
9	56	156	374.4	25.56	5.796	1032.7	725.25
10	57	153.4	374.4	25.56	6.3	1038.18	724.25
11	58	150.7	374.4	25.56	6.78	1043.62	725
12	59	150.4	374.4	25.56	7.224	1043.9	729.5
13	60	150	374.4	25.56	7.717	1042.08	731.75
14	60.35	150	374.4	25.56	7.77	1042.08	732.5
15	61	150	446.16	27.05	7.77	1042.14	732.25
16	62	150	468	46.647	7.759	982.54	732

The optimal response found by meta-heuristic genetic algorithm has 10.2% higher strength and 2.8% less cost compared to the response of the reference report. The comparison of the capability of the algorithm compared to the reference report shows that for the construction of concrete with the same strength as the response of the reference report, meta-heuristic genetic algorithm proposed a mixture plan with 9.2% less cost and for concrete construction with the cost of the reference report plan, in the mixture plan algorithm with 10.9% more strength can be achieved.

In order to validate, 4 mixed designs were made to compare the laboratory strength of the samples at the age of 28 days with the strength obtained from the output of the algorithm. The results of the work indicated the existence of 97% accuracy compared to the answers of the algorithm.

In Figure 2, which is taken from the information in Table 1, the outputs of the algorithm are drawn in the strength-price optimization chart. Based on this figure, according to the applied price of materials, three different slopes were obtained in the graph, the first slope is up to 54 MPa, the second slope is up to the optimal point of the graph, i.e. 60.3 MPa, and the third slope is up to the last possible output by applying the initial limit in view taken for materials means 62 MPa. From 54 to 60.3 MPa, the slope of the graph is very gentle and price changes are small compared to strength.

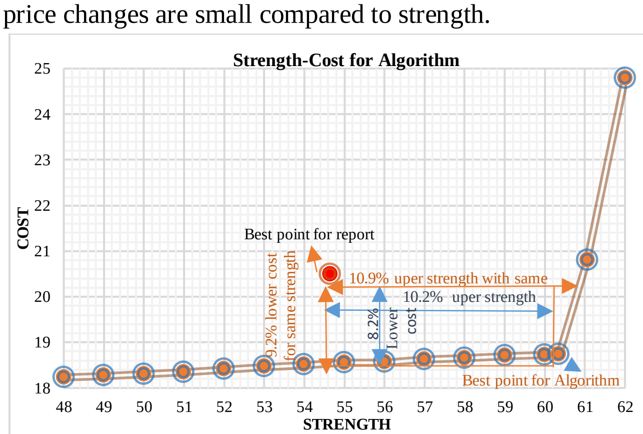

Figure 2

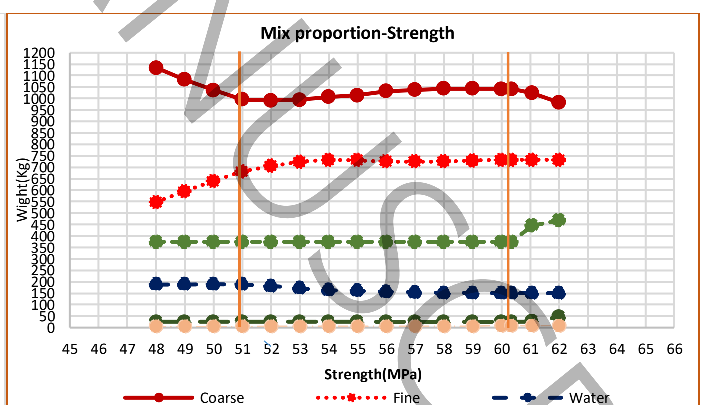

Figure 3

Figure 2- Variations in the cost-strength of the optimal responses of meta-heuristic genetic algorithm

Figure 3- Weight-strength varaitions of concrete ingredients at the age of 28 days for the mixed design of the optimal responses of the meta-heuristic genetic algorithm

3-7- Analyzing the selection of proportions in the design of HSC mix

Changing the ratio of materials in the mix plan affects the mechanical properties of concrete. Considering that in this research, the optimization between strength and price has been done, therefore, it is expected that the algorithm, taking into account the function of the mixture design and the price of materials, will be more cost-effective than the economic selection of materials to achieve the target strength, given in this section, while presenting the effect of changing the ratio of materials on the 28-day age strength of this type of concrete for laboratory data in which the selection of the amount of materials was experimental and discrete in terms of order, according to the answers listed in Table 2, the efficiency of the meta-heuristic genetic algorithm is also specified for the selection of materials according to Figure 3. Considering that the algorithm process is based on random selection and the algorithm suggests one of the optimal solutions, therefore, small changes in the upward or downward trend of the material selection chart can be expected.

4- Conclusions

1- The genetic algorithm of meta-engineering has a high capability in optimizing the design of concrete mix with high strength in terms of the price of materials. For this purpose, the algorithm first tried to meet the goal by changing the amount of cheaper materials, and in the next steps, increased the amount of more expensive materials. The best point with maximum strength and minimum cost was obtained for laboratory data of 60.3 MPa strength at a cost of 18.73 dollars and with a slump of 134 mm. Compared to the optimal design introduced in the reference report with a strength of 54.7 MPa at the age of 28 days, this design has 10.2% more strength and 2.8% less cost.

2- Since the construction of several mixed designs proposed by the algorithm was achieved with a high approximation of 97%, then the designs of the algorithm can be considered effective and to increase the strength of concrete by using a certain type of material, instead of trial-and-error method, The proposed process of this article was carried out to achieve the goal with the lowest cost.

3- In order to increase the strength in the lower grades, the algorithm has replaced coarse aggregates with fine aggregates, so up to the strength grade of 51 MPa, it has only suggested changing the size of aggregates from coarse to fine aggregates, which means that at a low cost, the strength can be increased.

4- To obtain more strength, the genetic algorithm considers reducing the amount of water as the best method, so to increase the strength at the age of 28 days from 51 to 60.3 MPa, which is the optimal point of strength-cost for this type of material, the amount of water in the mixture design has reduced it to increase the strength by reducing the ratio of water to cement materials and instead used coarse aggregates (the cheapest material after water); aggregate resistance also helps the design.

5- To achieve a strength greater than 60.3 MPa, it is necessary to increase cement and microsilica, and the algorithm has taken action by changing them and giving priority to increasing cement, because it is cheaper than microsilica; In order to comply with the quorum of the mix design, the amount of coarse aggregates that played the role of volume filler in the previous stage has been reduced.

6- In the designs in which the water was reduced, superplacticizer was added as an additive to maintain the fluidity of the concrete; in the plans where the amount of cement and microsilica were added, the algorithm also added the amount of superplacticizer.

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