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Effects of Drying Temperature and Aggregate Shape on the Concrete Compressive Strength: Experiments and Data Mining Techniques

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ABSTRACT

The main purpose of this paper is to assess the impact of the geometry and size of the aggregate, as well as the drying temperature on the compressive strength of the ordinary concrete. To this end, two aggregates with sharp and round corners were prepared in three different aggregate sizes. After preparing concrete samples, the drying operations were carried out in the vicinity of room temperature, cold wind, and hot wind. Next, the linear relationship between the concrete strength and the studied parameters was estimated using Multiple Linear Regression (MLR) method. Finally, the Taguchi Sensitivity Analysis (TSA) and Decision Tree Analysis (DTA) were applied in order to determine the importance of the parameters on the compressive strength of concrete. As a result, it is obtained that the aggregate size has the greatest influence on the compressive strength of the ordinary concrete followed by drying temperature as stated by method TSA and DTA. In addition, the influence percentages reported for each parameter by Taguchi approach and decision tree method are matched. The prediction of the strength obtained by Taguchi method and second-order regression with the experimental data are in a good agreement. It was concluded that the impact of drying temperature on the concrete strength is several times greater than the effect of the aggregate geometry. Finally, the main conclusion of this research is related to the application of cold wind for drying operation, which leads to an increase of the compressive strength by 8.67% and 11.55% for ordinary concrete containing a constant aggregate size of 20 and aggregate geometries of round and sharp corners, respectively.

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1. INTRODUCTION

Concrete as one of the most famous building materials is widely applied due to its easy operation, low cost, and responsiveness to the requirements. Today, ordinary concrete is not used in construction of a new building. In addition, civil engineers are attempted to use reinforced concrete to increase the strength of the building. However, there are many old buildings in the world that require their ordinary concrete to be partially repaired. Therefore, researchers are still looking for different methods to improve the strength of ordinary concrete and finding various techniques to predict concrete strength based on the composition of the raw material and changes in its manufacturing process. Besides, the knowledge of concrete compressive strength is major factor in assessing the strength and lifetime of structures and buildings. It is obvious that the strength of concrete is mainly dependent on the aggregate's sizes and geometries as a raw material. In addition, another parameter that greatly affects the concrete strength is its drying temperature. However, finding a general concept of the relationship between these parameters with concrete strength is still problematic. Therefore, one of the main tasks that plays important role is to determine the aggregate's size and type as well as the drying temperature.

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In this regard, recently, much research has been performed on both ordinary and reinforced concrete using different statistical analysis methods.

Study performed by Benidir et al. [1] on the aggregate size influence on the core compressive strength of concrete has shown the increase of compressive strength by increasing the drilled core diameter. It was also found that as the aggregate size increases the concrete compressive strength increases.

Ogundipe et al. have studied the impact of different aggregate sizes (coarse and fine) on the compressive strength of concrete [2]. They stated that increase in aggregate size increases the compressive strength. The authors claimed that application of very big aggregate sizes in normal concrete do not produce the desired result, which is related to the difficulty in compacting the concrete to a dense state, unworkable concrete mix, and the greater voids that is created in the mix. Kilic et al. have presented a new model for compressive strength assessment of ordinary concrete based on the physico-mechanical properties of aggregate rock [3]. In this study, nine different materials for aggregates (different mechanical and physical properties) are used to fabricate concrete samples. The authors concluded that increase in unit weight of the aggregate rock, compressive strength of rock, and young's modulus of aggregate rock lead to an increase in concrete compressive strength. Li et al. have studied how the specimens' shape and size affect the concrete behavior under static and dynamic loading conditions [4]. They found that the influence of specimen shape on the results of static compressive tests is trivial. In addition, as the aspect ratio of the specimen decreases the concrete strength increases. Moreover, the experimental results showed that the size and shape impacts on the static compressive strength are independent of the concrete grades. Also, the different effective parameters of pipe cooling system have been analyzed on the temperature regime and the thermal stress state during construction massive concrete [5]. Dmitry has studied the deformation of concrete modified by adding chemical and fine mineral elements under shrinkage phenomenon [6]. Zinevich has presented a new numerical modelling in order to design technology, heat and concrete solidification in monolithic structures [7]. Darayani et al. have studied the effect of the application of styrofoam artificial lightweight aggregate in the self-compacting concrete on the compressive strength, modulus of elasticity, and its workability [8]. The authors stated that as the amount of artificial lightweight aggregate increases the compressive strength and workability for both conventional and self-compacting concrete decrease. In addition, the elasticity modulus of concrete decreases as the styrofoam artificial lightweight aggregate replacement increases. Buller et al. have investigated the influence of 12-hours fire on the reinforced concrete beams (made by using 50% replacement of natural coarse aggregates with recyclable concrete aggregates from demolished concrete) [9]. The authors claimed that, as a result, the deflection increases, whereas the pick load decreases for all studied beams. It was also concluded that dominant failure pattern in all beams is shear failure with shear cracks.

Moreover, ANN and MLR techniques have been used to estimate the static strength of the 28-day concrete [10]. In this study, the parameters such as the largest size of aggregate, the content of cement and sand, the modulus of fitness, the ratio of water-cement, and gravel were used as input parameters. It was shown that the MLR techniques should be used for designing the preliminary mix of concrete and the ANN model should be used in order to get to the optimum mode. Also, Self Organization Feature Map (SOFM) has been optimized by the genetic algorithm and utilized to predict the concrete strength [11]. The obtained results by ANN and regression technique were compared, and then importance of the parameters was determined using this technique. They have listed the parameters in order of degree of importance as follows: 1- slump; 2- water-cement ratio; 3- the gravel maximum size; 4- cement content; 5- Sand. Nikoo et al. applied the ANN to estimate the concrete strength [12]. They investigated four optimal network structures (different learning algorithms, transfer function, number of hidden layers, and number of hidden neurons) based on the proposed by genetic algorithm. Eventually, the best network structure which has special capability in nonlinear mapping is introduced. Besides these methods, the fuzzy logic method has been applied in order to determine how the concrete raw material affect the compressive strength [13]. The results showed that the ANN technique could predict concrete strength more accurately than fuzzy logic approach in terms of R^2. Young et al. have estimated the concrete strength by knowing the mixture proportions and using machine learning methods [14]. They also reported the most optimal mixture for concrete considering the cost analysis. Moreover, the discrepancy between the predicted compressive strength of concrete using this proposed model and the experimental results is less than 10%. Moreover, Rastegarian and Sharifi have proposed equations while studying the relationship between inter-story drift and structural performance objectives of reinforced concrete intermediate moment frame [15]. By means of the proposed equations, the inter-story drift at performance levels with a bit of story information can be predicted. The effect of application of recycled aggregates on concrete strength has been reviewed by Silva et al. [16]. The laboratory data of the compressive strength of 28-day concrete in terms of coarse and fine recycled aggregate contents, age, additional material (fly ash), and oven-dried density was collected. In addition, in order to predict the recycled concrete strength under static axial compression load, the

Deep Learning (DL) technique was used [17]. Nouri and Guneyisi have presented a new strength assessment model based on the genetic algorithm [18], by means of which the compressive strength of recycled aggregate concrete-filled steel tube columns was obtained. Moreover, Kazemi et al. employed the Schmidt rebound hammer and core testing to assess the compressive strength of recycled aggregate concrete [19]. The results demonstrated an increase in compressive strength of recycled aggregate concrete by raising the curing days.

Anwar has studied the impact of nano-clay, nano-silica, and hybrid nanoparticles on the concrete strength in vitro [20]. The findings of this research revealed that the nano-silica in wet conditions and nano-clay in dry conditions have remarkable improvement on the compressive strength. Also, the optimum value for replacement of cement with nanoparticles is 0.75 and 3% for nano-silica and nano-clay, respectively. Moreover, the wet mix for nano-clay is more efficient than dry mix with approximately 24% improvement in compressive strength. The effect of adding nanoparticles such as titanium dioxide has been investigated on the strength of cementitious concrete [21]. The compressive strength of high-performance concrete, which contains nano-silica and copper slag has been investigated by Chithra et al. [22]. For this purpose, they have used various statistical techniques including regression and ANN. The authors used the following parameters as input variables in their statistical models: parameters of cement content, nano-silica content, fine aggregate content, copper slag content, age of specimen, and super plasticizer dosage. In addition, the coarse aggregate content and water content are constant in all the concrete mixes. Recently, a modified firefly algorithm-artificial neural network has been presented for predicting strength of high-performance concrete [23]. In addition to that, in order to study the strength of self-compacting concrete, the Adaptive Neuro Fuzzy Inference System (ANFIS) has been applied [24].

In summary, all studies conducted on the improvement of concrete compressive strength classify into two categories. The first group focuses on adding nanoparticles and finally recommend to use reinforced concrete. Therefore, the concrete strength based on the characteristics and the adding particles amount has been predicted by applying some different algorithm. The impact of raw materials of concrete on the compressive strength was examined by the second group, and the most optimal combination was suggested in order to increase the strength. The brief review presented here shows that predicting the concrete strength under different conditions (raw material rates, production process, and material additives) is a quite serious problem. In the present paper, for the first time, the effects of drying temperature and the aggregate shape on the concrete compressive strength were investigated. To this end, different data mining techniques including Taguchi approach, multiple linear regression, and decision tree analysis were used. Finally, the main aims of this paper are related to the following issues:

-To investigate experimentally the impact of aggregate geometry (round and sharp corners) and its size on the concrete compressive strength.

-To determine the effects of cold and hot air-dried on the concrete strength in vitro.

-To provide the decision tree to select the most optimal mode for adjusting various parameters in order to increase the concrete strength.

-To develop a new mathematical equation based on multiple linear regression method in order to assess the compressive strength of the concrete.

-To detect the greatest and least important factors on the concrete compressive strength using Taguchi approach.

2. METHODS

In the present research, the American Concrete Institute recommendations (ACI-211.1-91) was considered to select the proportions of concrete elements [25]. Moreover, water/cement ratio was considered to 0.5 and finally superplasticizer was added to the mix (2% of total weight of cement). River stone as aggregate with different types of geometrical shapes (sharp and round corners) were used as the objective of this study. Also, each type of aggregate was prepared in three different sizes. To this end, the results of particle size distribution for the aggregates using different sieve sizes (2.36, 4.75, 10, 12.5, 20, 25, and 32) are shown in Figure 1.

The 28-days concrete samples were developed in the cubic shape (with a height of 150 mm and a square cross-section of 50×50 mm) based on the ISO-1920-3 standard [26]. Totally, 54 specimens were prepared in 18 different groups according to the Taguchi design (each group consists of three specimens). The characteristics and raw

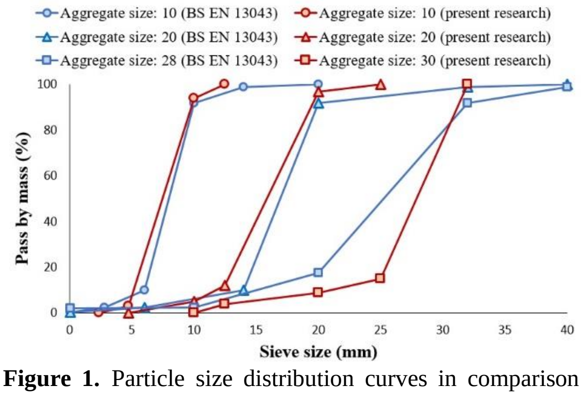


Figure 1. Particle size distribution curves in comparison with BS EN 13043 standard for aggregate

material proportions are presented in Table 1. For drying operations, the specimens were air-dried at different temperatures (temperature of 10 °C as cold wind, temperature of 20 °C as room temperature, and temperature of 30 °C as hot wind). Eventually, Figure 2 shows the working flowchart to clarify the research methodology in this study.

3. EXPERIMENTAL PROCEDURE

Firstly, different types of concrete specimens were classified using below designing code. For example, the sample code of R1020 represents the concrete which is made of aggregate with round corner geometry and size of 10 with a drying temperature of 20 °C.

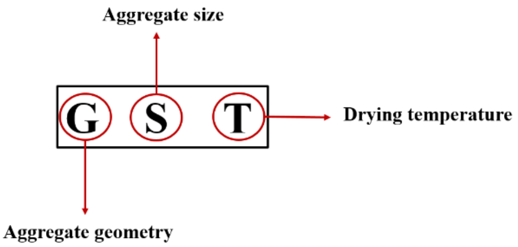


TABLE 1. The characteristics and raw material proportions

Parameters	Unit	Value
Slump	mm	50
Water-cement ratio	-------	0.5
Cement	Kg/m^3	238
Sand 3/8	Kg/m^3	2411
Sand ¾	Kg/m^3	1224

The hydraulic universal compression testing machine (Amsler brand made in USA) with a capacity of 60 tons was employed in order to perform the tests and report the concrete compressive strength. In accordance with ISO-1920-4 standard [27], a constant rate of loading equal to 1000 N/sec (0.4 Mpa/sec) was applied continuously and without shock. All tests were carried out at room temperature. Moreover, the authors repeated each test three times in order to ensure the accuracy of the experimental results and then the mean value was reported as sample strength.

4. FRACTURE SURFACE ANALYSIS

Different failure modes of cubic concrete are shown in Figure 3. When the stress reaches 75-90 % of ultimate failure load, the cracks are initiated in the mortar through the concrete samples. In ideal state, under pure uniaxial compression loading, the cracks are approximately parallel to the load direction. In practice, due to the Poisson’s effect, concrete cube tends to lateral expansion, but rigid plates on both sides of sample have not any movement. In other words, the degree of two sides plates restrain on the concrete is related to surface friction [28].

Three failure modes were observed in the tests (Figure 4). It means that the air temperature had a significant effect on the concrete bonding by considering the same conditions (proper mortar and mix design).

5. STATISTICAL ANALYSIS

In order to get the linear relationship between dependent and several independent variables, the MLR method is mostly used in various industries and academic researches [10, 22, 29]. However, the order of the

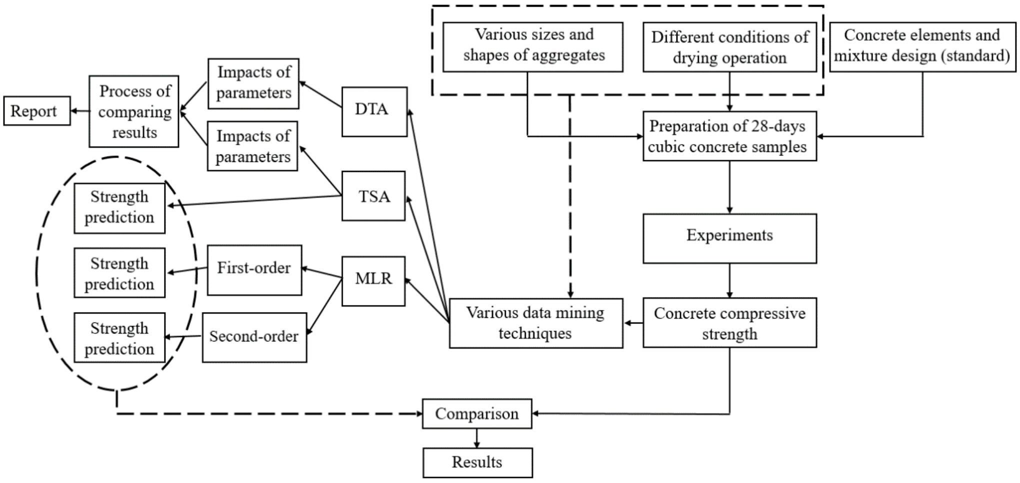
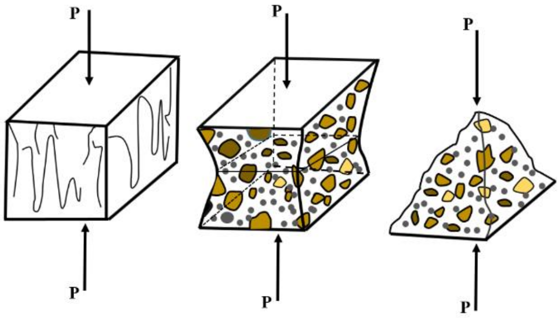


Figure 2. The working flowchart used in this research.



a) Non-explosive b) Semi-explosive c) Explosive

Figure 3. Different failure modes of cubic concrete [27]

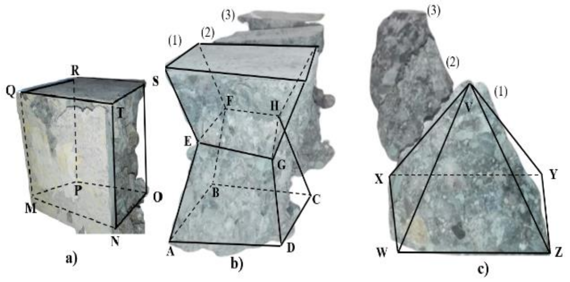


Figure 4. a) fracture surface of a rejected case in the GS30 samples, b) fracture surfaces in the GS20 samples, and c) fracture surfaces in the GS10 samples.

equation and interaction with the input parameters affect the accuracy of the response. Nevertheless, generally, using such relationships is very cost-effective in comparison with the high cost of mechanical tests.

In this study, the authors have presented separate relationships for each of the aggregate geometries with sharp and round corners to predict the compressive strength in terms of aggregate size and drying temperature. This is because there are two quantitative variables (the size of the aggregate and drying temperature) and one qualitative variable (aggregate geometry) and it is impossible to consider the impact of the qualitative parameter in such relationships. In addition, the Minitab software was applied to get the first-order and the second-order of linear regression equations, by means of which the influence of order condition on response accuracy was investigated and compared to experimental data.

Next, application of TA made it possible to determine the impact of aggregate geometry, aggregate size, and drying temperature on the compressive strength of the concrete. This section mainly aims at determination of the most important factor and prediction of the concrete compressive strength under different conditions without tests. This method uses the minimum number of samples needed for sensitivity analysis in comparison with the other methods of Design of Experiments (DOE) [29]. Figure 5 illustrates the applied algorithm in this study, which includes the input and output variables. Three different levels were considered for each aggregate size and drying temperature parameters. Also, the aggregate geometry is qualitatively coded so that the numbers 1 and 2 represent the sharp and the round aggregate, respectively. Variables and their levels considered as input data are presented in Table 2.

The main goal of this research focuses on the increase of the concrete compressive strength. Hence, the equation "the larger is the better" is used (Equation (1)) [30]:

$$\frac{S}{N} = -10\,log\left[\frac{1}{n}\left(\frac{1}{y_1^2}+\frac{1}{y_2^2}+...+\frac{1}{y_n^2}\right)\right] \qquad (1)$$

where y1, y2, and y_n demonstrate the bent angles measured during bending process. It should be mentioned that the authors repeated n time each bending condition.

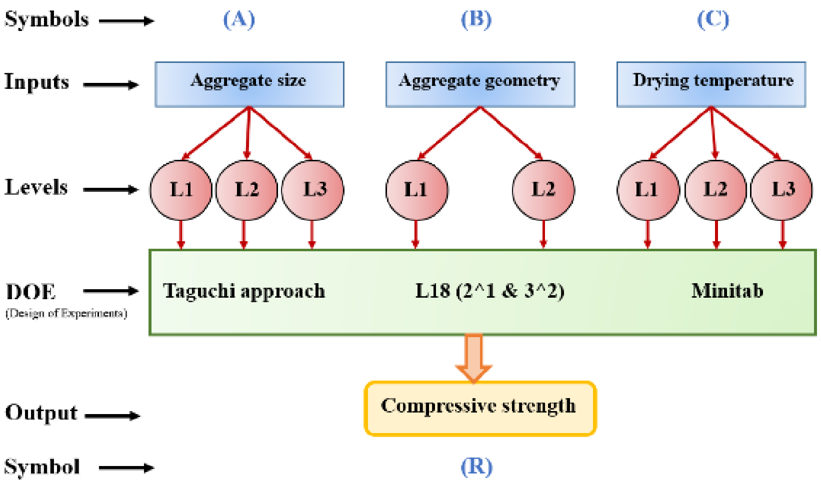


Figure 5. Design of experiments based on the Taguchi method

TABLE 2. Variables and their levels used as input data in the Taguchi-based DOE

Parameter	Symbol	Level		
		L1	L2	L3
Aggregate size	A	10	20	30
Aggregate geometry	B	1	2	-------
Drying temperature	C	10	20	30

In addition, the compressive strength of the concrete was considered as positive values. Because it is not possible to enter negative values in Taguchi sensitivity analysis [31]. In this research, a mixed-mode design of Taguchi (2^1 & 3^2) consist of 18 tests was used. The Taguchi orthogonal matrix including different test conditions is presented in Table 3.

Moreover, DTA is a widely used classifier in machine learning. This method has a tree structure that splits the input data into groups to explain the variation of a single response which may be numeric and/or categorical [32]. The features are represented by nodes and the values of the nodes are also represented by branches. A decision tree is described graphically which makes it easy to explore and understand. This method is also easy to interpret and able to handle missing values in both response and explanatory variables [33]. A decision tree forest evaluates the parameters sensitivity or parameter combinations. Random forest consisting of many decision trees is a classifier that evolves from decision trees. Each classifier in decision tree represents a “weak” classifier but in ensemble, they form a strong classifier. In random forest approach, each decision tree depends on the random vector values, which are sampled independently. Moreover, the important parameters determined by the algorithm through branching of inputs.

TABLE 3. The orthogonal matrix extracted from the mixed-mode design of Taguchi for L18

Run No.	A	B	C
1	L1	L1	L1
2	L1	L1	L2
3	L1	L1	L3
4	L2	L1	L1
5	L2	L1	L2
6	L2	L1	L3
7	L3	L1	L1
8	L3	L1	L2
9	L3	L1	L3
10	L1	L2	L1
11	L1	L2	L2
12	L1	L2	L3
13	L2	L2	L1
14	L2	L2	L2
15	L2	L2	L3
16	L3	L2	L1
17	L3	L2	L2
18	L3	L2	L3

A decision tree forest is an ensemble of single decision trees formed by various methods, by different subsamples of observations over one and the same phenomenon, by applying different characteristics. Finally, the predictions are combined to make the overall prediction for the forest as it is shown in Figure 6.

In decision tree forest, the improvement of a large number of independent trees and laws of the researched phenomenon grow in parallel, and problem consideration makes it possible to better understand the fact that they interact only when all of them have been built. The basis of bagging incorporated in decision tree forest are bootstrap resampling method and aggregating. Different training sub-sets are drawn randomly with replacement from the training data set. From these sub-sets separate models can be produced and applied to predict the entire data. Next, by applying majority voting for classification problems or the mean for regression problems the estimated models can be aggregated.

$$D_i^* = (Y_i^*, X_i^*) \tag{2}$$

where D_i^* represents a bootstrapped sample according to the empirical distribution of the pairs Di = (Xi, Yi), and (i=1, 2, . . . ; n).

In the second step, by applying plug-in principle the bootstrapped predictor is estimated using the following Equation [32]:

$$C_n^*(x) = h_n(D_i^*, \ldots, D_i^*)(x) \tag{3}$$

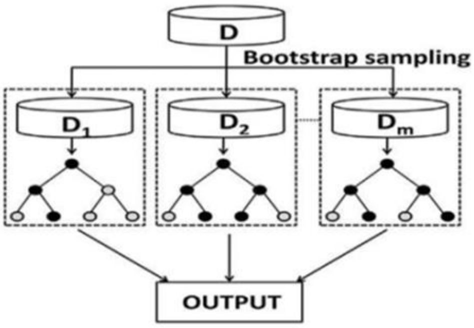


Figure 6. Conceptual diagram of decision tree forest

where Cn(x)=hn(Di, ...,Dn)(x) represents the n-th hypothesis. In the final step, the bagged predictor is determined using the following equation [32]:

$$C^*_{nB}(x) = E^*[D^*_n(x)] \tag{4}$$

Bagging reduces the variance with a good performance when combined with the base learner generation. The out of bag data rows for model validation is applied for the decision tree forest gaining strength from bagging technique. By this way the independent test set is provided, which does not require a separate data set or holding back rows from the tree construction. The decision tree forest algorithm is highly resistant to over-fitting due to the stochastic element in it.

In the present research, the random forest method was applied in order to predict the compression strength in terms of aggregate size, drying temperature, and aggregate geometry.

6. RESULTS AND DISCUSSION

The experimental results of the concrete strength under axial compression loading for different types of concrete samples are reported in Table 4. In addition, the diagram of concrete strength in terms of aggregate size (the drying process performed at room temperature) is depicted in Figure 7. According to the experimental result, the compressive strength of the concrete increases as the aggregate size for both sharp and round corners increases which is completely consistent with the results achieved by the authors published paper in literatures [34-35]. It is stated that the compressive strength of concrete of the same mix is directly proportional with increase in coarse aggregate size. However, an inverse relationship has been observed between the size of the aggregate and concrete flexural strength. Moreover, it was revealed that the concrete compressive strength of round corner aggregates is much greater than that of sharp corner. It is worth to mention that some researchers have stated it and is reported in literatures [36-37]. However, they only studied the effects of different types of aggregate shapes with a specific aggregate size on the concrete compressive strength. In addition, they conclude that the application of rounded corner aggregates increases the concrete compressive strength. However, in this study, the author considered three different aggregate sizes in order to investigate the effect of aggregate geometry. Additionally, as it is shown in Figure 7, the trend of increasing concrete compressive strength with aggregate size does not depend on the type of aggregate geometry.

Next, the designed decision tree using the random forest method is demonstrated in Figure 8. This is presented to easily identify the path for achieving the desired target (maximum compressive strength of concrete).

TABLE 4. Experimental results for compressive strength of different types of concrete samples

Experiment No.	Specimen No.	Strength (N)
1	S1010	56391.1
2	S1020	63010.9
3	S1030	96700.9
4	S2010	60510.3
5	S2020	91000.5
6	S2030	101249.1
7	S3010	40844.7
8	S3020	45949
9	S3030	70529.1
10	R1010	43761
11	R1020	66372
12	R1030	73665.8
13	R2010	63308.4
14	R2020	71245.5
15	R2030	107317.5
16	R3010	68967.4
17	R3020	98894.7
18	R3030	115963.1

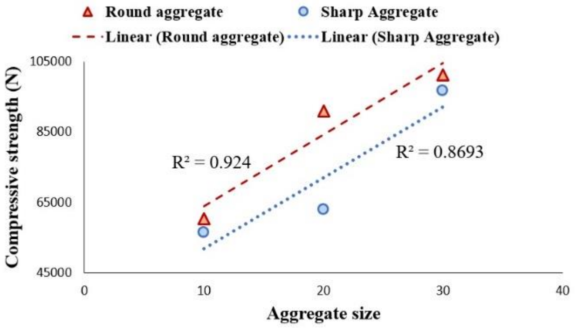


Figure 7. Concrete compressive strength graph in terms of aggregate size (drying temperature = room temperature)

Based on the results obtained by both TA and DTA the compressive strength of ordinary concrete is mainly affected by aggregate size following by drying temperature (Figure 9). Moreover, the results showed that the aggregate geometry has the least impact, which is about 1/4 of the effective weight in comparison with the aggregate size parameter.

In TA, the main effect plot is used to compare the relative strength of the effects against other factors [38] as shown in Figure 10.

From the highest S/N ratio given in the Figure 10, it is conducted that the highest compressive strength of concrete is obtained with the round aggregate, largest

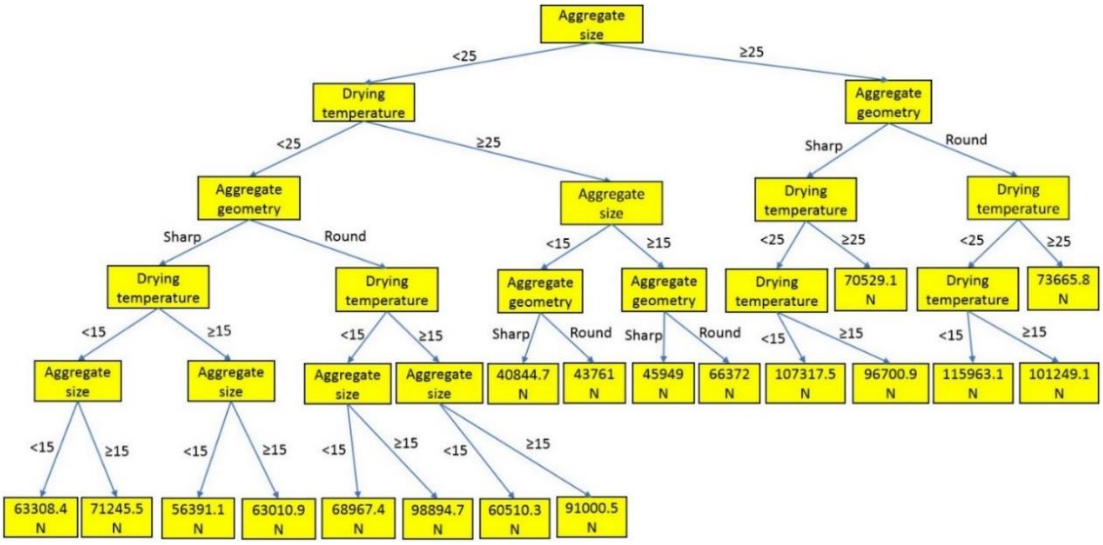


Figure 8. Decision tree graph based on the random forest method

aggregate size, and the lowest drying temperature. Figure 11 shows the relationship between the response and variables. This contour graph is useful to find the optimal output value via area range for each variable [38].

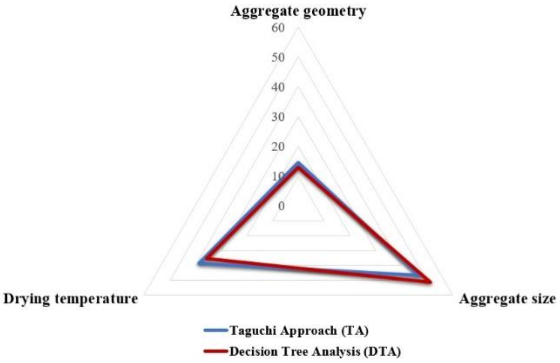


Figure 9. Most effective parameter on the concrete compressive strength using DTA and TA

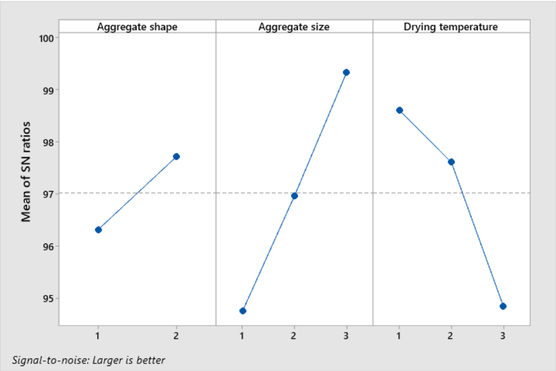


Figure 10. The Main effects plot S/N ratios compressive strength

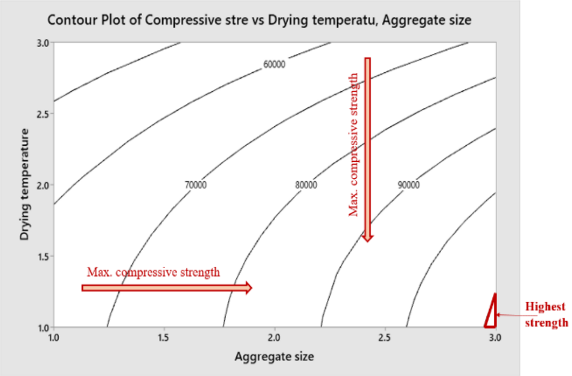


Figure 11. Contour plot of concrete compressive strength via both parameters of aggregate size and drying temperature

Next, the concrete compressive strength under different conditions was predicted using TA and MLR, and compared with laboratory data. In the following, the Taguchi sensitivity analysis and Taguchi prediction algorithm were performed in Minitab software. Nevertheless, in MLR method, since the aggregate geometry is a qualitative quantity and cannot be directly incorporated into the mathematical model, the mathematical model for each of the aggregate forms including sharp and round corners was obtained separately.

The first-order and the second-order equations obtained by MLR for different geometrical shapes of the aggregates are as follows:

For sharp aggregate

First-order

$$R = 58548 + 1900 \times A - 1409 \times C \qquad (5)$$

Second-order

$$R = 81698 - 3079 \times A + 792 \times C + 124.5 \times A^2 - 55 \times C^2 \quad (6)$$

For round aggregate

First-order

$$R = 74172 + 1961 \times A - 1667 \times C \quad (7)$$

Second-order

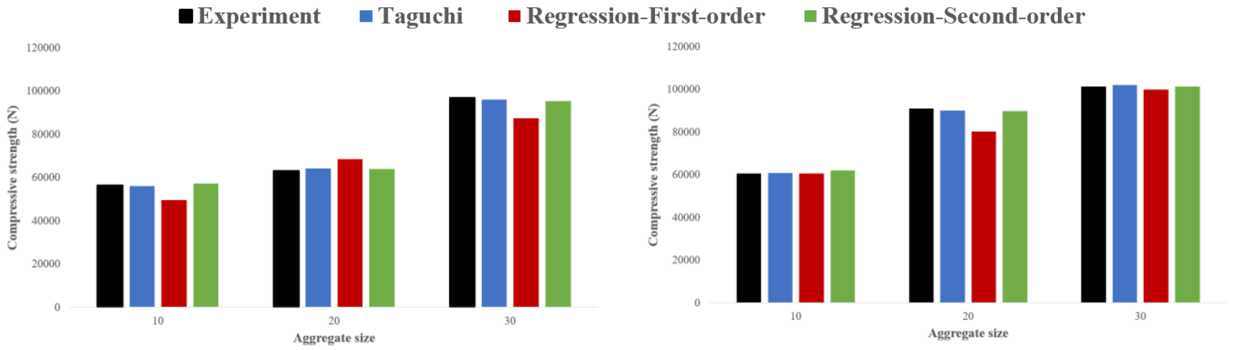
$$R = 26220 + 5189 \times A + 859 \times C - 80.7 \times A^2 - 63.2 \times C^2 \quad (8)$$

where R represent concrete compressive strength and parameters of A and C are aggregate size (mm) and drying temperature (℃), respectively.

Concrete strength prediction via aggregate size and drying temperature are illustrated in Figure 12 and Figure 13, respectively.

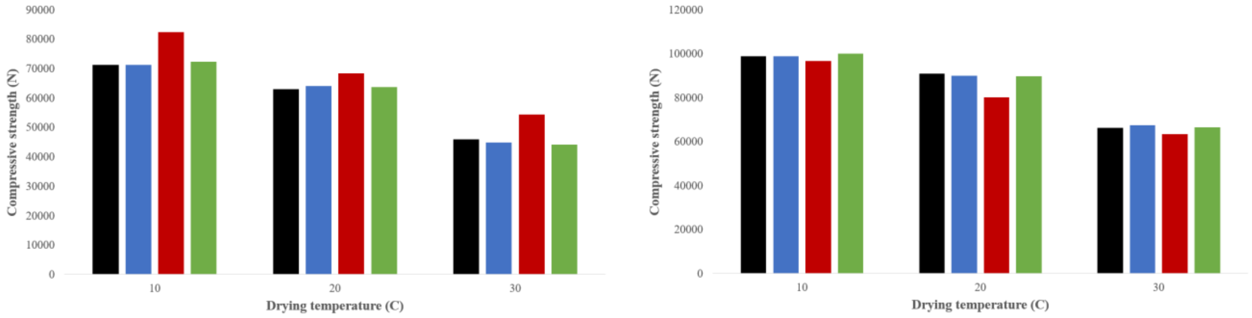
The results showed that as the aggregate size increases, generally, the concrete compressive strength increases. However, the increasing trend varies with aggregate geometry. Figure 12 depicts that there is a little impact on the concrete compressive for aggregate sizes 10 and 20 in sharp corner geometry, but as soon as aggregate size 30 is used, this increase is significant. On the other hand, while using round corner geometry for aggregates, increase in concrete strength by changing the size of the aggregate from 10 to 20 is evident. Furthermore, this trend has been proven in laboratory results. In addition, it should be mentioned that all the methods applied in this study for prediction of the compressive strength of ordinary concrete are in full agreement.

As it can be seen from Figure 13 as the drying temperature reduces the compressive strength of the concrete increases. Therefore, the compressive strength of concrete dried by a cold wind (10 °C) is much more than that of dried at room temperature. Moreover, the concrete which is dried by a hot wind (30 °C) has a water content lower than usual concrete and it becomes absurd from within because of the water evaporation. It is often found in experiments that it is powdered from the inside and concrete fails even under static load below half of its strength. In other words, the cement in the sample does not have the required strength and it results in fracture of the concrete.



(A) (B)

Figure 12. Comparison of estimation of concrete compressive strength in terms of aggregate size with laboratory data for the constant drying temperature of 20 and different aggregate geometries including (A) sharp corners and (B) round corners



(A) (B)

Figure 13. Comparison of estimation of concrete compressive strength in terms of drying temperature with laboratory data for the constant aggregate size of 20 and different aggregate geometries including (A) sharp corners and (B) round corners

Further, the comparison of predicted error percentage using different methods with the experimental data for considering variable aggregate size and drying temperature are reported in Tables 5 and 6, respectively.

The results indicated that the Taguchi method and its prediction algorithm is the best method based on the error level of concrete strength prediction compared to laboratory data. Moreover, it is achieved that when using the first-order equation of MLR, it is not possible to predict the concrete compressive strength with acceptable accuracy. But the results indicated that concrete strength with higher accuracy can be predicted by using the second-order equation of MLR in comparison with the first-order and it is even acceptable compared to the results obtained by Taguchi method.

TABLE 5. Comparison between the predicted error percentage of concrete compressive strength using different methods with laboratory data for drying at room temperature

Aggregate geometry	Aggregate size	Error in comparison with experiment data (%)		
		Taguchi approach	**Regression (First-order)**	**Regression (Second-order)**
Sharp	10	0.71003	1.56752	0.088001
	20	1.14999	12.03125	1.517025
	30	0.54123	0.112873	2.362738
Round	10	0.74353	9.651306	1.533491
	20	1.66082	8.501862	1.185668
	30	0.58076	12.45427	1.4309

TABLE 6. Comparison between the predicted error percentage of concrete compressive strength using different methods with laboratory data for the aggregate size of 20

Aggregate geometry	Aggregate size	Error in comparison with experiment data (%)		
		Taguchi approach	**Regression (First-order)**	**Regression (Second-order)**
Sharp	10	1.566926	4.504912	0.35858
	20	1.149994	12.03125	1.51702
	30	0.006573	2.196983	1.10754
Round	10	2.263379	18.12662	3.85427
	20	1.660824	8.501862	1.18566
	30	0.009123	15.73784	1.53343

7. CONCLUSION

In this study three different data mining methods including MLR, TA, and DTA were applied to predict the compressive strength of the concrete in terms of different parameters of aggregate geometry, aggregate size, and drying temperature. It is concluded that the most reliable technique is TA model (approximately 1% error compared to experiment results). Moreover, the first-order and the second-order equations were presented based on the MLR that can estimate the ordinary concrete strength by 9 % and 1.5 % error compared to reality. In addition, according to the results achieved by TA and DTA, the most important factor affecting the concrete compressive strength is the aggregate size with impact weight of 47.02 % and 51.38 %, respectively. Among all parameters studied in this research, the aggregate geometry had the least effect on the concrete compressive strength. The results of the analysis indicated that the effect of drying temperature on the concrete strength is several times greater than the effect of the aggregate geometry. The efficiency ratio of drying temperature to aggregate geometry based on the TA and DTA is 2.69 and 2.8, respectively. However, the trend of increasing concrete compressive strength with aggregate size (increasing aggregate size leads to increase strength) is independent of aggregate geometry. Finally, the most important finding of this study is that application of cold wind for drying operation increases the compressive strength by 8.67% and 11.55% for ordinary concrete containing a constant aggregate size of 20 and aggregate geometries of round and sharp corners, respectively.

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Persian Abstract

چکیده

هدف اصلی این مقاله ارزیابی تأثیر هندسه و اندازه‌ی سنگ‌دانه و همچنین فرایند خشک کردن (دمای خشک کردن) بر مقاومت فشاری بتن معمولی است. برای این منظور، دو هندسه‌ی متفاوت سنگ‌دانه شامل تیزگوشه و گردگوشه در سه اندازه‌ی مختلف سنگ‌دانه تهیه شده است. پس از آماده سازی آزمونه‌های بتنی، عملیات خشک کردن در مجاورت دمای اتاق، باد سرد و باد گرم انجام شد. سپس، به منظور دست‌یابی به رابطه‌ای خطی بین استحکام بتن و پارامترهای مطالعاتی از روش رگرسیون خطی چندگانه استفاده شد. در نهایت، میزان اهمیت پارامترها بر استحکام فشاری بتن با تحلیل حساسیت تاگوچی و تحلیل درخت تصمیم‌گیری انجام شد. هر دو تحلیل حساسیت تاگوچی و درخت تصمیم گیری نشان دادند که اندازه ی سنگ دانه و به دنبال آن دمای خشک کردن بیشترین اثر را بر مقاومت فشاری بتن معمولی دارند. همچنین، درصد تاثیر گزارش شده برای هر پارامتر با روش تقریب تاگوچی و روش درخت تصمیم‌گیری مطابقت دارد. نتایج نشان داد که پیش‌بینی استحکام توسط الگوریتم تاگوچی و رگرسیون مرتبه‌ی دوم در مقایسه با داده‌های تجربی تطابق بسیار خوبی دارند. چنین نتیجه می‌شود که تأثیر دمای خشک کردن بر مقاومت بتن چندین برابر بیشتر از اثر هندسه‌ی سنگ‌دانه است. در نهایت، دستاورد اصلی این مقاله پژوهشی مربوط به کاربرد جریان باد سرد در عملیات خشک کردن است که منجر به افزایش مقاومت فشاری به اندازه‌ی ۸.۶۷ ٪ و ۱۱.۵۵ ٪ به ترتیب برای بتن‌های معمولی حاوی اندازه سنگ‌دانه‌ی ۲۰ و هندسه‌های سنگ‌دانه‌ی گردگوشه و تیزگوشه می‌شود.