Received: 5 December 2022 | Revised: 16 January 2023 | Accepted: 31 January 2023 | Published online: 3 February 2023

RESEARCH ARTICLE

Journal of Computational and Cognitive Engineering
2023, Vol. 00(00) 1–11
DOI: 10.47852/bonviewJCCE3202558

BON VIEW PUBLISHING

Investigating the Effect of Curing Type on Compressive Strength of Normal Concrete Containing Zeolite Using Experimental Analysis and Fuzzy Logic

Nima Navidi Aghdam[1], Payam Rajabzadeh Kanafi[2,*] and Keivan Sohrabpour[3]

[1]*Department of Civil Engineering, Ayandegan Institution of Higher Education, Iran*

[2]*Department of Civil Engineering, Islamic Azad University, Iran*

[3]*Department of Environmental Engineering, University of Calabria, Italy*

Abstract: Nowadays, concrete is one of the most widely used building materials around the world. The requirement and wide application of concrete have made it necessary to investigate its behavior and the factors affecting its behavior. In the process of concrete production, more precision is necessary to fulfill the requirements of efficiency and strength. In estimating the behavior of concrete, various mathematical techniques have been presented by researchers, and as a result, the theory of fuzzy sets provides a very effective tool for modeling and analyzing vague and imprecise concepts. The present research aims to predict the 28-day strength of concrete based on the 7-day strength in the presence and absence of zeolite pozzolan models with different curing methods in water, sack, and plastic using fuzzy logic. One of the novel aspects of this study is that it uses fuzzy logic to analyze lab data. This is because fuzzy logic can be used to analyze data even when there is uncertainty. Thus, 12 mixing designs have been prepared to check the grade of cement on the researched parameters based on the values of 300, 400, and 500 kg/m^3 containing zeolite in the amounts of 0, 5, 10, and 15 weight percent of cement. All samples have been subjected to tests of concrete performance (slump test) and hardened concrete (compressive strength) at the age of 28 days. After completing the tests, the 28-day compressive strength of concretes has been predicted using fuzzy logic. This study shows that fuzzy logic can be applied as a powerful tool for modeling the compressive strength of concrete.

Keywords: concrete, fuzzy logic, compressive strength, zeolite, curing, cement grade

1. Introduction

Due to the extensive use of concrete in the construction of various structures and hazards such as earthquakes, wind, mankind has always tried to produce concrete with better properties since the beginning of cement and concrete production. Ordinary Portland cement (OPC) is used as the main binding material in construction industries, and it is an energy-intensive material and is also responsible for the carbon dioxide (CO2) gas emission across the globe. Thus, to reduce consumption and dependency on cement, efforts have been made in various fields, such as replacing other materials with part of cement (pozzolanic concrete) as supplementary cementing materials has become the leading research interest in the area of cement and materials research in recent decades [1]. However, the general focus of these experiments was in the field of concrete production with greater density and cohesion and of course economic efficiency. In concrete, as a construction material, several properties are desired. These properties include compressive, tensile, and abrasion strengths, some of which are interrelated. Portland pozzolanic cement refers to the mixtures of Portland cement and pozzolanic materials. Pozzolanic materials can be natural or artificial. These materials often do not possess cementitious properties, but when they are mixed with water, moisture, or lime to undergo reaction with calcium hydroxide, they form compounds possessing cement properties. Some of artificial pozzolana are fly ash, silica fume, rice husk, and blast furnace slag, and natural pozzolana such as burnt clay, pumicite, diatomaceous Earth [2]. Pozzolanic materials are often cheaper than Portland cement that replaces it, while their main advantage lies in slow hydration and, in turn, low heat development process. It is very important in massive concrete structures, and it is better to replace natural pozzolan with part of cement. In Kriptavičius' work, Natural zeolite and soda lime glass were used as partial replacement of OPC, and the effect of these additives on hydration, mechanical properties, and porosities of OPC was studied [3]. Lo et al. investigated using rice husk ash (RHA), coal fly ash (CFA), and coal bottom ash (CBA), and after analyzing the carbon footprint, they showed that the replacement of ash

*Corresponding author: Payam Rajabzadeh Kanafi, Department of Civil Engineering, Islamic Azad University, Iran. Email: payamrajabzadehkanafi@gmail.com

materials reduced the total carbon footprint by 9.9%–20.6% per m^3, and the general result indicated that CFA, CBA, and RHA replacement in cement materials yielded an acceptable compressive strength and water permeability [4]. In another research, Raju et al. replaced part of OPC with LCD glass powder obtained from electronic glass scrap in concrete. In this experiment, it was found that the workability of concrete mixtures increased marginally with an increasing percentage of LCD glass powder. Also, after 7 days, 28 days, and 56 days, the compressive strength of sample with 5% partial replacement of cement (LC5) was 20%, 28%, and 36% higher than control specimen (LC0), respectively. The mix LC5 showed lesser value for sorptivity and rapid chloride permeability test (RCPT) of all the mixes containing LCD glass powder. The mix LC20 (sample with 20% partial replacement of cement) has shown better resistance toward sulfate, acid, and alkali-silica reaction test. Scanning electron microscopy micrograph of LC5 shows a dense and mature gel confirming the improved strength and durability performance as compared to LC0. They concluded that using waste LCD glass powder minimizes the impact of solid waste disposal on the environment and could save the cost of cement in cementitious mixtures [5].

Also, pozzolanic Portland cements show good resistance against the attack of sulfates and some other destructive factors. As one of these pozzolans, zeolites are clay minerals that are composed of aluminum hydrosilicates along with some cations and oxides of alkaline and alkaline earth metals [6]. The main physical and chemical properties of zeolites are related to their chemical composition and crystal structure; in other words, their properties depend on the chemical and physical nature of water in the structure of zeolites, as well as how water is placed in molecular networks [7]. The bonding of water molecules in the network of these minerals is weak, and due to the temperature, they lose their water without collapsing the structure of the network, and this process is done in a reversible way [6]. Zheng et al. [8] experimentally investigated the effect of pozzolanic reaction of zeolite on its internal curing performance in cement-based materials by testing the pozzolanic activity of zeolite particles, then studying the influences of zeolite pozzolanic reaction on the pore structure, morphology, water absorption, and water release performance of zeolite particles, and finally testing the hydration degree of cement, pozzolanic reaction degree of zeolite, and internal relative humidity of a prepared cement paste specimens with zeolite internal curing and showed promising improvements of cement paste.

The presence of alkaline and alkaline earth metals and the existence of void spaces and numerous interrelated mineral substances in them are other reasons for the variety of zeolite properties [7]. We also know that curing concrete has a great impact on the characteristics of hardened concrete, such as permeability and resistance to freezing and thawing. Curing should be started immediately after the concrete is compacted to protect concrete from harmful factors. Concrete curing consists of care and protection or cultivation based on Iran Aba Concrete Regulation [9, 10]. Today, modeling using fuzzy logic has found a special place in technical and engineering sciences. Fuzzy sets are derived from the generalization of classical set theory, which is used in fuzzy logic. The theory of fuzzy sets was first established in 1965 by Professor Lotfi Askarzadeh. After several years and in the early seventies, with the introduction of fuzzy logic, the first applications of this theory were presented in engineering sciences. Fuzzy logic, which was proposed against classical logic, is considered a powerful tool for solving problems related to complex systems that are difficult to understand or problems that depend on human reasoning, decision-making, and inference. Choosing an appropriate method and approach for modeling, a system depends entirely on the complexity of that system, and complexity has an inverse relationship with our knowledge and understanding of that system. It is clear that man tends to model a system with the highest possible accuracy, but if he does not have sufficient knowledge about it, he is forced to match the accuracy expected from the model with his knowledge of the system [11].

Many studies have been conducted on the use of zeolite pozzolan and the type of processing and Fuzzy analysis. Sabet et al. [12] investigated the effect of replacing cement with percentages of zeolite, fly ash, and microsilica on the durability of concrete. When performing the slump test, they concluded that zeolite reduced the fluidity of concrete more than microsilica and fly ash, so when using zeolite, more superplasticizer should be used. They came to the conclusion that when using these pozzolans, the compressive strength as well as the electrical strength of the samples increases significantly. Furthermore, with the application of these pozzolans, the amount of water absorption of the samples can be reduced [12]. Razavi Toosi et al. [13] investigated the effect of different curing methods on the strength of concrete and came to the conclusion that curing in a water basin with the sack covering method had similar results, and the time intervals of watering were effective on the results of all types of processing [13]. Madandoust et al. [14] evaluated the compressive strength of concrete using fuzzy logic system and ultrasonic waves [14]. Najimi et al. [15] predicted the compressive strength of concrete and its properties without slump using an adaptive neuro-fuzzy inference system [15]. Heydari & Heydari [16] found the compressive strength of polymer concrete by applying fuzzy logic [16]. Khademi et al. [17] predicted the 28 days of compressive strength of concrete with 173 different mix designs using three different methods of multiple linear regression model, artificial neural network (ANN), and adaptive neuro-fuzzy inference system (ANFIS) and showed that the ANN and ANFIS models enable us to reliably evaluate the compressive strength of concrete with different mix designs. Also, Zarandi et al. [18] developed an effective model for the compressive strength of concrete with six inputs and one output using the combination of Group method of data handling (GMDH) neural networks and fuzzy logic. Topcu and Sarıdemir [19] predicted the compressive strength of concrete containing fly ash using the neural network and fuzzy logic.

By studying the past literature, the importance of the subject is clearly defined, and the need for more studies is also felt. Therefore, the purpose of this study is to investigate the effect of curing type on the compressive strength of normal concrete containing zeolite, and for the innovation of this study, fuzzy logic has been used to model and predict the results.

Here is how the rest of the paper is structured: A basic summary of fuzzy set theory is given in Section 2. Materials and laboratory setup are discussed in Section 3. The outcomes of the examination are discussed in Section 4. The case study's features and their interrelationship are discussed in Section 5. In

Section 6, the statistical modeling that is presented. Fuzzy logic modeling is presented in Section 7. In the last section, conclusion, and suggestions for further research are made.

2. Fuzzy Logic

When it came to dealing with the imprecision and fuzziness of human mind, Zadeh was the first to establish the fuzzy set theory, which is focused toward the rationality of uncertainty owing to imprecision or fuzziness [20]. The capacity to accurately describe imprecise information is a significant step forward thanks to fuzzy set theory. The theory also makes it possible to apply mathematical operations and computer programming to the fuzzy area [21, 22]. The membership criteria for a fuzzy set are qualitative rather than quantitative. In the absence of full and accurate knowledge, common sense thinking may be facilitated by the use of fuzzy sets and fuzzy logic, two strong mathematical techniques used for modeling uncertain systems in business, the natural world, and the human experience [23–25]. When trying to develop a decent approximation solution, they play a crucial role, particularly when applied to complicated phenomena that are difficult to explain using standard mathematical approaches.

Some variables cause unpredictability and uncertainty in laboratory tests, which can lead to errors in results. So, fuzzy logic is used in this study to predict the lab results, which will be explained in more detail in the next sections.

3. Laboratory Design

3.1. Materials

3.1.1. Sand

River sand was used in this research. The sand used in this study was not within the allowed range according to the granulation. In this way, all the used sand was passed through sieve No. 4 and the granulation test was performed again. The sand diameter is 0.75–4 mm, its apparent density in saturated state with dry surface is equal to 2700 Kg/m^3, and its water absorption in 24 h is 1.5%. Granulation of both types of sand is according to ASTM C33 standard [26–28].

3.1.2. Gravel

In this research, the gravel passed through the sieve is and the residue on the sieve No. 4 is 4.75 mm. It is worth noting that the granulation of the consumed gravel is within the standard range of ASTM C33 [26, 29, 30].

3.1.3. Cement

In this research, Khazar Portland cement type 1–425 was used.

3.1.4. Water

Water is used in concrete in three ways: water used for washing aggregates, water as one of the components of concrete that is used during its construction, and water used for curing concrete [31, 32]. The quality of water is important because the impurities in it may affect the setting of cement and cause disturbances. In most standards, water suitable for mortar and concrete is the same water suitable for drinking.

3.1.5. Superplasticizers

Nowadays, superplasticizers are widely used as additives in concrete to achieve high fluidity. In the present research, superplasticizer FARCO PLAST P10-3R was used, produced by Shimisakhteman Company. This type is the third-generation superplasticizer used in concrete and is based on modified polycarboxylates. This product can maintain the optimal efficiency of concrete for about 1 to 2 h at 20°C (concrete internal temperature). The consumption amount of the superplasticizer varies between 0.2% and 1.6% of the weight of the cement compounds used in the concrete mixture depending on the amount of cement used, fineness of cement grains, and some other parameters. The optimal amount of the superplasticizer for each mixture should be obtained by making test samples.

3.2. Sample mixing and processing design

To obtain concrete with the desired properties and performance, the first step is to select the material components. The next step is the process known as mixing, in which the correct combination of concrete components is obtained. Determining concrete mixing ratios is a step that can be used to achieve the appropriate combination of cement, aggregates, water, and additives for making concrete according to the relevant specifications. This process is considered an art instead of being a science. The purpose of determining the mixing ratios is to obtain a concrete mixture that meets the performance requirements at the lowest cost. In the present study, zeolite pozzolan was used in amounts of 0, 5, 10, and 15 weight percent of cement. Furthermore, 12 mixing designs have been prepared to check the grade of cement on the researched parameters based on the values of 300, 400, and 500 kg/m^3 containing zeolite in the amounts of 0, 5, 10, and 15 weight percent of cement. For this, the required materials were first weighed and, then, entered the construction step. To make the samples, first the aggregates were entered into the mixer, and after mixing, half of the mixing water was added to the mixture, and after a few minutes, cement was added to the mixture, and, then, the superplasticizer, which was mixed with the rest of the mixing water, was added to the concrete mixer. After the concrete reached a suitable fresh state, the mixture was poured into the molds that were prepared and lubricated in advance. Then, the samples were placed in the laboratory environment for 24 h to harden, and after 24 h, they were taken out of the mold and kept in a water tank for 28 days. In total, to achieve the goals of this research, 12 mixing designs were prepared, which can be seen in Table 1.

After making concrete, it was poured into 15 cm-cube molds and kept at a constant temperature and humidity for 24 h to harden. After 24 h, the samples were removed from the molds and placed in a water basin. Then, they were placed in the air and in a saturated plastic bag with a temperature of 20 ± 2°C for curing. To determine the compressive strength after 28 days of curing, concrete samples were removed and a compressive strength test was performed on them. In Figures 1 and 2, the curing of the samples can be seen.

Table 1
Designs prepared in this study

No.	Name of design	Cement (Kg/m^3)	Type of Pozzolan	Pozzolan (Kg/m^3)	Gravel (Kg/m^3)	Sand (Kg/m^3)	Water (Kg/m^3)	SP	w/c	s/c
1	C300	300	—	0	1225	849	120	0.3	0.4	0
2	C400	400	—	0	1130	780	160	0.3	0.4	0
3	C500	500	—	0	1040	675	200	0.3	0.4	0
4	C300Z5	285	Zeolite	15	1225	849	120	0.3	0.4	0.05
5	C400Z5	380	Zeolite	20	1130	780	160	0.3	0.4	0.05
6	C500Z5	475	Zeolite	25	1040	675	200	0.3	0.4	0.05
7	C300Z10	270	Zeolite	30	1225	849	120	0.3	0.4	0.1
8	C400Z10	360	Zeolite	40	1130	780	160	0.3	0.4	0.1
9	C500Z10	450	Zeolite	50	1040	675	200	0.3	0.4	0.10
10	C300Z15	255	Zeolite	45	1225	849	120	0.3	0.4	0.15
11	C400Z15	340	Zeolite	60	1130	780	160	0.3	0.4	0.15
12	C500Z15	425	Zeolite	75	1040	675	200	0.3	0.4	0.15

Figure 1
Curing of the samples in sacks and plastics

Figure 2
Curing of the samples in air

4. Test Results

4.1. Slump results of manufactured concretes

After making the 12 designs mentioned above, each slump test was conducted. In Figure 3, the values obtained from the slump test are drawn as a bar graph.

The reason for this increase in slump is the increase of paste in concrete with more powder materials. As the paste in the concrete increases, the fluidity of the concrete also increases, and this will cause the slump to increase.

It is also observed that concrete containing more zeolite has a lower slump since zeolite is finer-grained than cement. Thus, zeolite grains have a higher specific surface area than cement grains, and as a result, more water will be used for hydration, which in turn reduces the free water available for the concrete to flow, and therefore, the mixture becomes rougher and fluidity decreases.

4.2. The results of the compressive strength test

After conducting the concrete slump test, 15-cm cubic samples were taken from all the designs and cured in water, air, sack, and plastic for 28 days. After 28 days, the samples were tested in terms of their compressive strength. The results are shown in Figure 4.

Figure 3
Slump test results for all designs

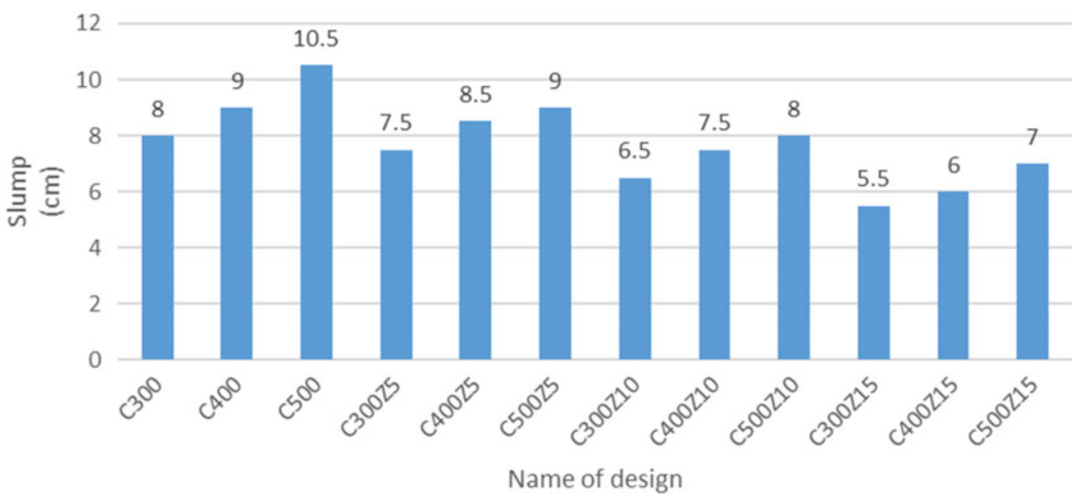
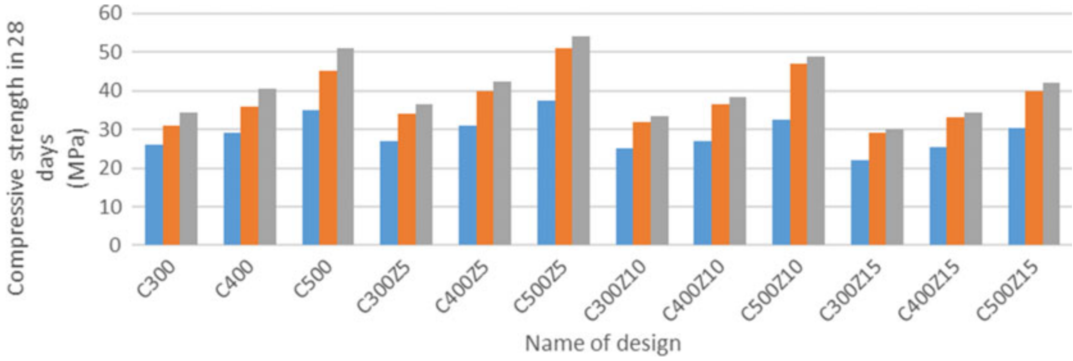


Figure 4
Compressive strength (28-day) for all designs



The reason for the increase in the 28-day compressive strength of the samples can be attributed to the increase in the amount of cement. Also, with the addition of 5% zeolite, it is seen that the compressive strength has increased. 10% zeolite as a substitute for cement has led to an increase in strength compared to the concrete without zeolite, but this increase in strength is less than the case of 5% zeolite. However, the addition of 15% zeolite has led to a decrease in strength even compared to concrete without zeolite. Thus, the optimal amount of zeolite can be considered as a 5% substitute for cement. The addition of zeolite as a partial substitute for cement leads to a decrease in the compressive strength of concrete at very early ages (1–3 days), which is due to the reduction of the heat produced due to the slowing down of the heat of hydration. But, after that we will see an increase in compressive strength. Since zeolite is smaller than cement, it fills smaller pores and creates a denser mixture.

5. The Relationship between the Compressive Strength of the Samples under Different Curing Conditions

Figures 5, 6, 7 and 8 show the effect of different curing conditions on the 28-day compressive strength of the concrete samples. As it is known, the best result is obtained in the case of curing in a saturated sack wrapped with plastic so that there are no holes. The reason is that when the water in the concrete evaporates, the plastic does not allow the steam to escape. Therefore, this steam puts pressure on the concrete, and since the concrete is under the

Figure 5
Effect of curing condition on concrete without zeolite

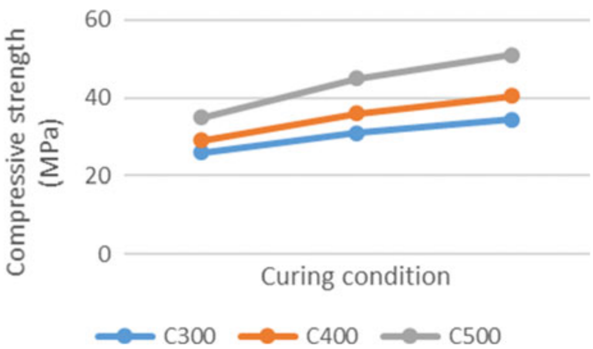


Figure 6
Effect of curing condition on concrete with 5% zeolite

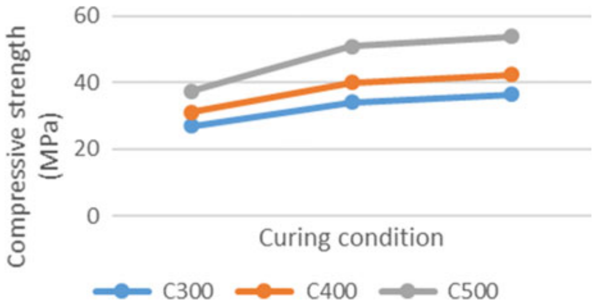


Figure 7
Effect of curing condition on concrete with 10% zeolite

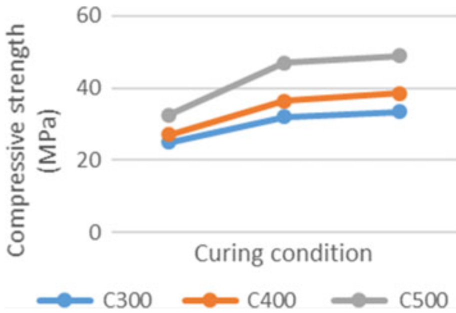


Figure 8
Effect of curing condition on concrete with 15% zeolite

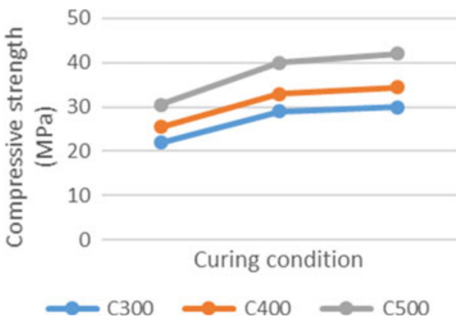


Table 2
Percentage of increase in 28-day compressive strength of concretes cured in water, sack, and plastic compared to the condition without curing

Name of design	Curing in water (%)	Curing in sack and plastic (%)
C300	19.23	32.69
C400	24.14	39.66
C500	28.57	45.71
C300Z5	25.93	35.19
C400Z5	29.03	37.10
C500Z5	36	44
C300Z10	28	34
C400Z10	35.19	42.59
C500Z10	44.62	50.77
C300Z15	31.82	36.36
C400Z15	29.41	35.29
C500Z15	31.15	37.7
Σ	30.26	39.26

pressure of water vapor – however low – it gives better results than curing in water. It is worth noting that every few days, the plastic around the screw was opened and the sack was saturated again because there are holes for the exit of water vapor that cannot be blocked in the laboratory. Table 2 shows the increase in the 28-day compressive strength of concrete under the conditions of curing in water, sacks, and plastic compared to the condition without curing.

As can be seen from the table, processing in water increases the compressive strength of concrete by 26.30% and processing in sack and plastic by 26.39%.

6. Prediction of 28-Day Strength Using SPSS Statistical Software

Also, by using statistical analysis with the help of SPSS 22 software, a relationship is obtained to predict the 28-day compressive strength of concrete based on the method of curing, the grade of cement, and the amount of zeolite replacement. Using linear regression analysis, the following relationship is suggested with very appropriate accuracy ($R^2 = 0.850$) to determine the 28-day compressive strength of normal concrete with and without zeolite:

$$CS28 = -1.403 + 0.071\,CE + 5.771\,CU - 0.017\,ZE$$

where

CS28: The 28-day compressive strength of concrete in megapascals,
CE: Cement grade in Kg/m^3,
ZE: Amount of zeolite in Kg/m^3, and
CU (curing condition): Number 1 for curing in air, Number 2 for curing in water, and Number 3 for curing in sacks and plastic.

7. Prediction of 28-Day Strength Using Fuzzy Logic

Using MATLAB 2015 software and fuzzy logic toolbox in this software, the 28-day compressive strength of concretes was predicted by taking into account the effective parameters, that is, the method of curing, the grade of cement, and the amount of zeolite replacement.

Fuzzy inference system with minimum-maximum fuzzy relation is used in this research. The surface center method has also been used to defuzzify the results. Mamdani fuzzy inference system is also used. Figures 9, 10, 11, 12 and 13 show membership functions of inputs,

Figure 9
Built fuzzy model

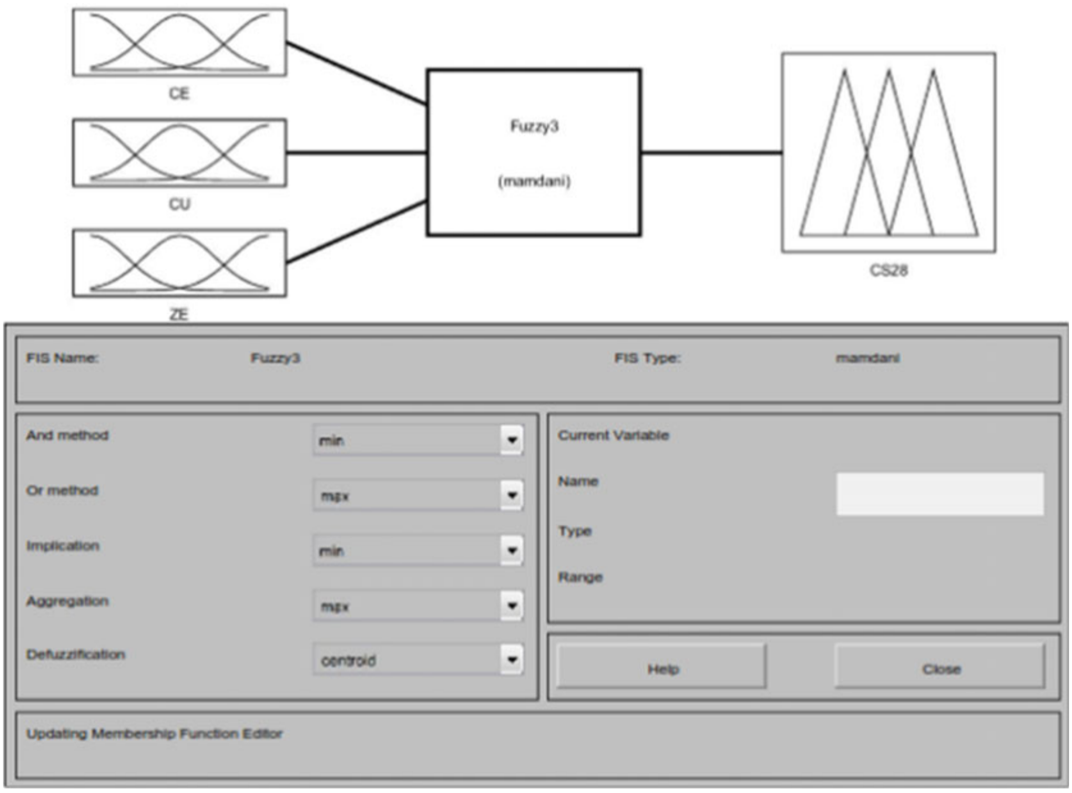


Figure 10
Membership function of the curing method (CU)

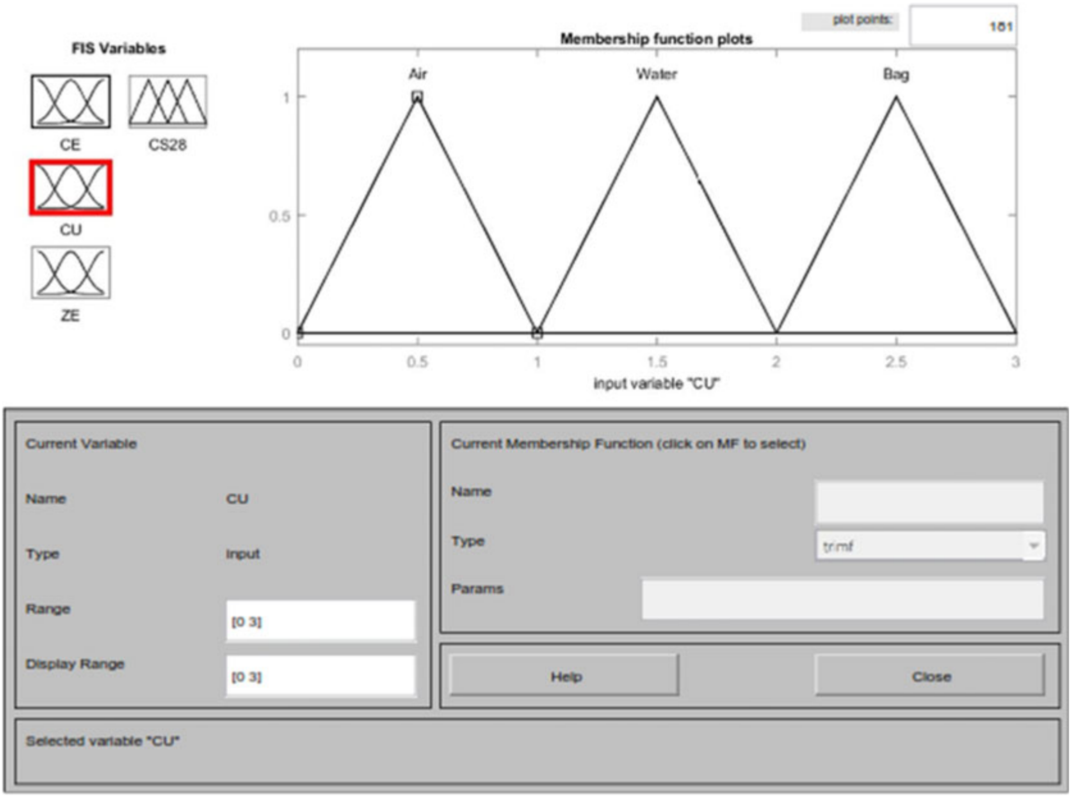


Figure 11
Membership function of cement amount (CE)

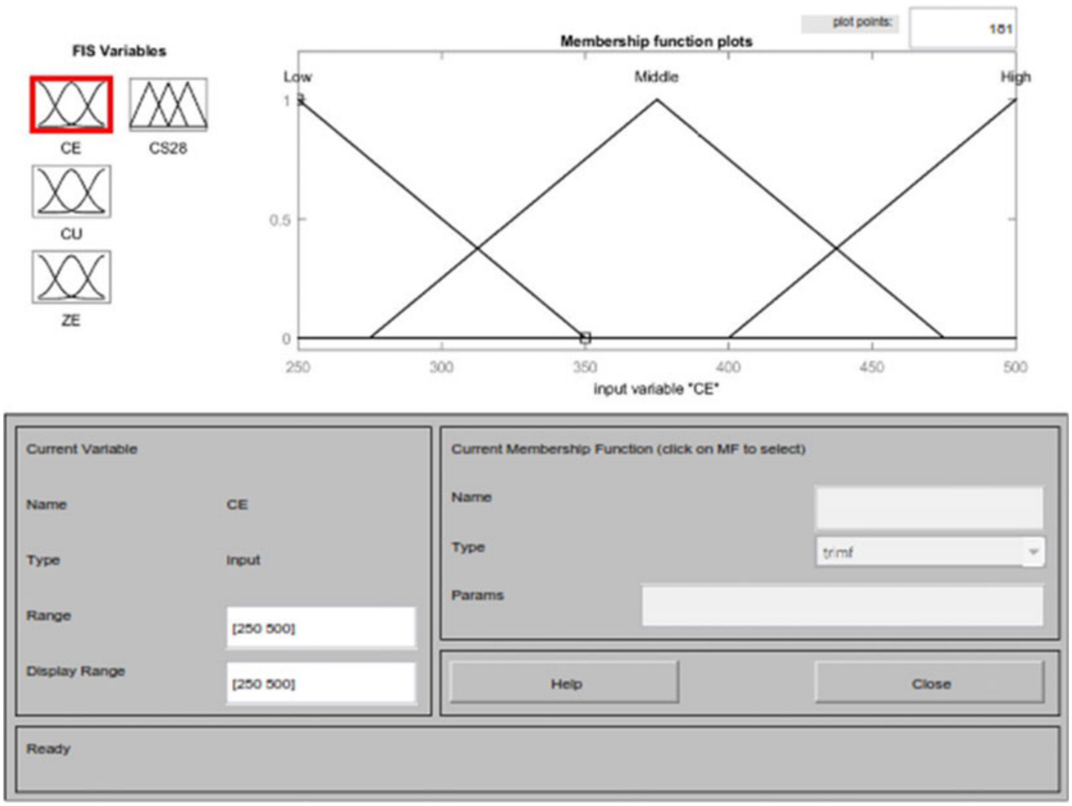


Figure 12
Membership function of zeolite replacement (ZE)

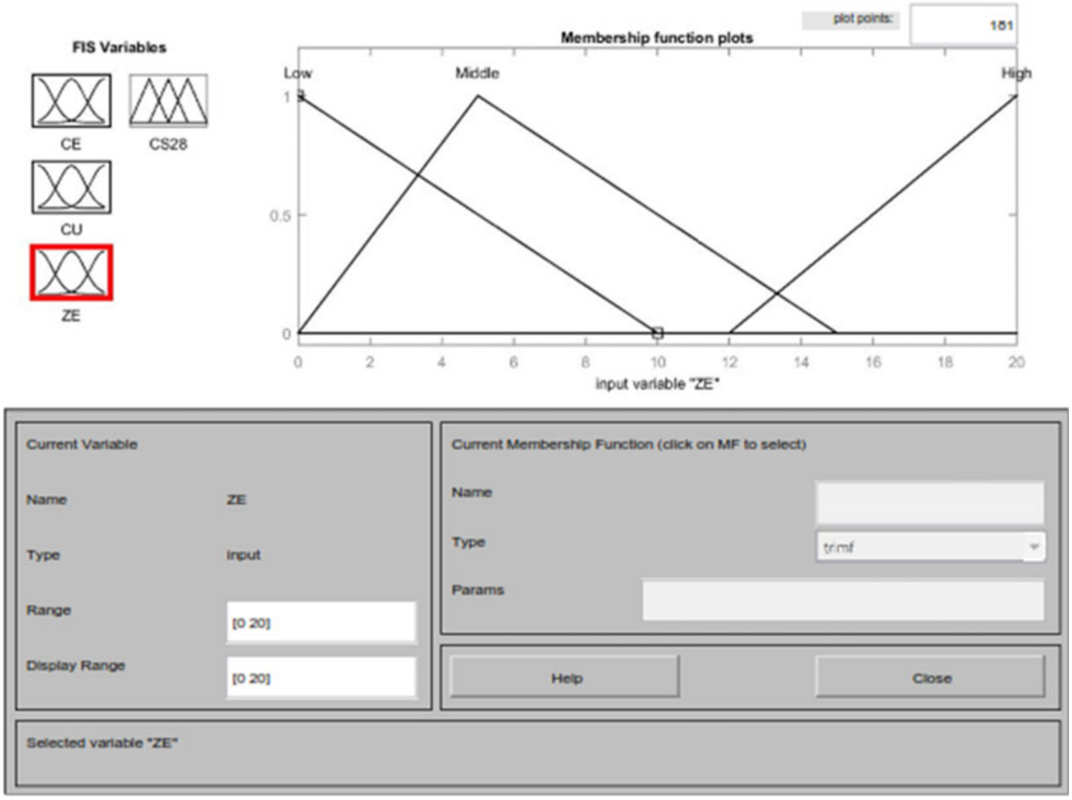


Figure 13
Membership function of 28-day compressive strength (CS28)

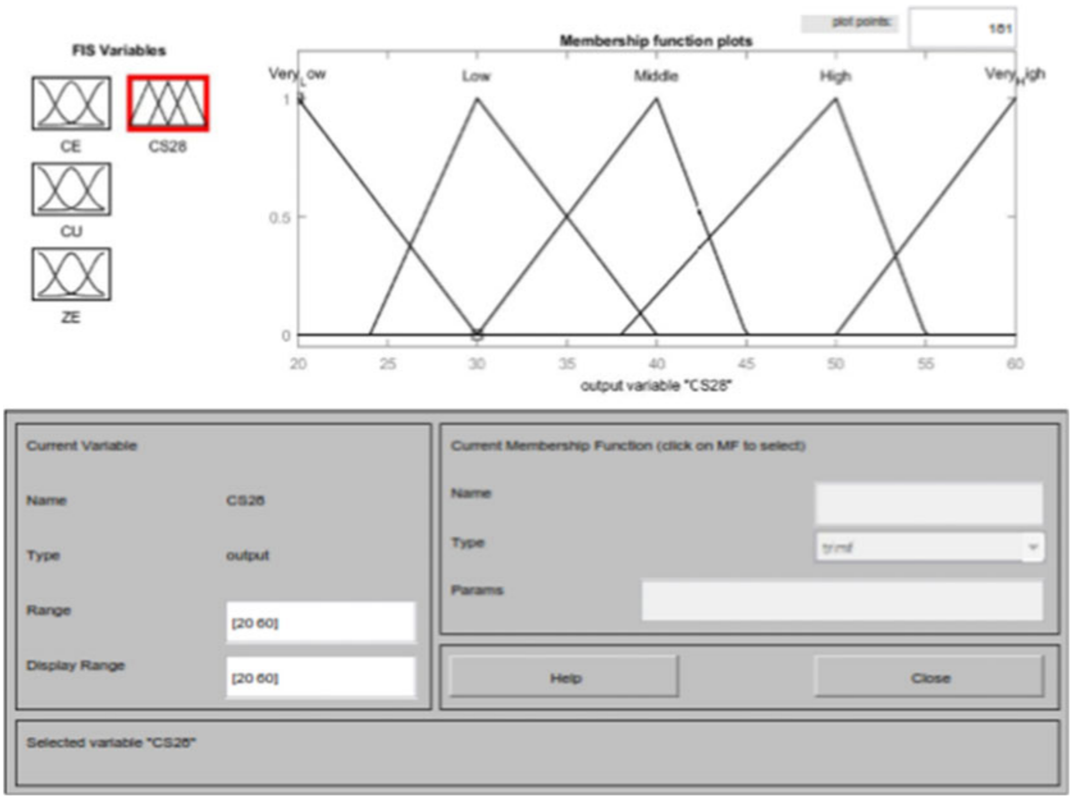
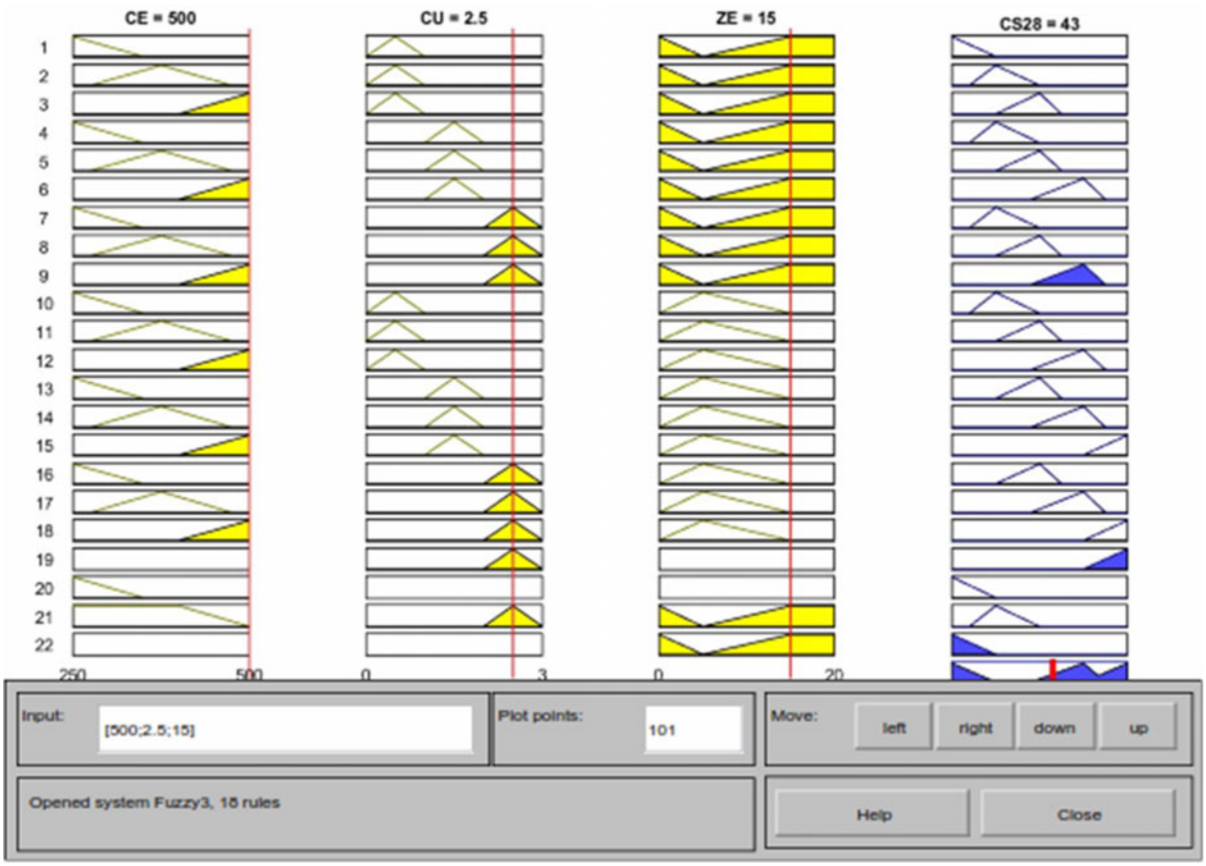


Figure 14
If-then rules and result



including curing method (CU), amount of cement (CE), amount of zeolite replacement (ZE) and the output of the fuzzy system, that is, 28-day compressive strength (CS28). Figure 14 also shows the if-then rules made in the model to connect the inputs with the output of the model and determine the results. Although the obtained results have shown sufficient accuracy and the ability of fuzzy logic to predict the results, there were also limitations in this study. Among the most important limitations that can be mentioned was the number of samples in the laboratory, which was limited due to the high cost of the tests. Although the number of samples was acceptable, more samples could provide a more complete data set.

As can be seen, both fuzzy analysis and linear regression have predicted the results with appropriate accuracy (the error in both cases is less than 10%).

8. Conclusion

The goal of the current study is to use fuzzy logic to estimate the concrete's 28-day strength based on its 7-day strength in the presence and absence of zeolite pozzolan models with various curing techniques in water, sacks, and plastic. All samples were put through tests to determine how concrete performs (the slump test) and how well-hardened concrete performs (compressive strength) after 28 days. Following the testing, fuzzy logic was used to provide a prediction about the concretes' 28-day compressive strength. Furthermore, the following remarks can be concluded:

- With the increase in cement grade and powdered materials (cement + zeolite), the amount of slump has also increased.
- With the increase in cement grade and powdered materials (cement + zeolite), the 28-day compressive strength has also increased.
- The best result is obtained when cured in a saturated sack wrapped with plastic so that there are no holes. The reason is that when the concrete water evaporates, the plastic does not allow the steam to escape. Thus, this steam puts pressure on the concrete, and since the concrete is under the pressure of water vapor – however low – it gives better results than curing in water.
- Curing in water and curing in sack and plastic increase the compressive strength of concretes by 30.26% and 39.26%, respectively, compared to the case without curing.
- Both fuzzy analysis and linear regression have predicted the results with appropriate accuracy (the error in both cases is less than 10%).
- With the addition of 5% zeolite, it is observed that the compressive strength has increased. 10% zeolite as a substitute for cement has led to an increase in strength compared to concrete without zeolite, but this increase in strength is less than the case of 5% zeolite. However, the addition of 15% zeolite has led to a decrease in strength even compared to concrete without zeolite. Therefore, the optimal amount of zeolite can be considered as 5% replacement of cement.
- For future studies, it is also suggested to use other artificial intelligence methods, such as the support vector machine algorithm for predicting the compressive strength of concrete.

Conflicts of Interest

The authors declare that they have no conflicts of interest in this work.

References

[1] Karim, M. R., Hossain, M. M., Khan, M. N. N., Zain, M. F. M., Jamil, M., & Lai, F. C. (2014). On the utilization of pozzolanic wastes as an alternative resource of cement. *Materials*, *7*, 7809–7827.
[2] Waghmare, J. D., Patil, S. S., Patil, S. M., & Maske, M. (2021). Study and review of properties and applications of Portland Pozzolana cement. *ASEAN Journal of Science and Engineering*, *1*, 13–18.
[3] Kriptavičius, D., Girskas, G., & Skripkiūnas, G. (2022). Use of Natural Zeolite and Glass Powder Mixture as Partial Replacement of Portland Cement: The Effect on Hydration, Properties and Porosity. *Materials*, *15*(12), 4219.
[4] Lo, F. C., Lee, M. G., & Lo, S. L. (2021). Effect of coal ash and rice husk ash partial replacement in ordinary Portland cement on pervious concrete. *Construction and Building Materials*, *286*, 122947.
[5] Raju, A. S., Anand, K. B., & Rakesh, P. (2021). Partial replacement of Ordinary Portland cement by LCD glass powder in concrete. *Materials Today: Proceedings*, *46*, 5131–5137.
[6] Fouladi Mahani, A. (2012). *Investigation of engineering properties and durability of ordinary concrete containing zeolite and nanosilica*. Civil Engineering Master's Thesis. *Faculty of Engineering. University of Sistan and Baluchistan.*
[7] Razi Kargar, M., & Habibi, S. (2013). Familiarity with zeolite and its applications. Specialized processing monthly, North Tehran Azad University, Faculty of Chemistry.
[8] Zheng, X., Liu, K., Gao, S., Wang, F., & Wu, Z. (2023). Effect of pozzolanic reaction of zeolite on its internal curing performance in cement-based materials. *Journal of Building Engineering*, *63*, 105503.
[9] Alizadeh, A., Chini, M., Ghods, P., & Alizadeh, R. (2005). Assimilation of Iranian concrete code (ABA) compared to ACI code about the mechanical properties of HSC beams subjected to pure bending moment. *Innovations and Structural Implications*.
[10] Bidsardareh, I. M., & Mohammadi, M. (2018). Redefining existing concrete compressive strength Acceptance Standard in Iran Concrete Code (ABA), by experimental data. *Civil Engineering Journal*, *4*, 1127–1134.
[11] Kourepezan Dezfuli, A. (2005). Principles of Fuzzy Set Theory and its Applications in Modeling Water Engineering Problems. Academic Center for Education, Culture, and Research (ACECR), Amirkabir Industrial Unit.
[12] Sabet, F. A., Libre, N. A., & Shekarchi, M. (2013). Mechanical and durability properties of self consolidating high performance concrete incorporating natural zeolite, silica fume and fly ash. *Construction and Building Materials*, *44*, 175–184.
[13] Razavi Toosi, V., Shakuri Mahmoudabadi, A., & Farhadi, M. (2007). Effect of different processing methods on the mechanical strength of concrete. In *3rd National Congress of Civil Engineering*, Tabriz, Tabriz University, Faculty of Civil Engineering.
[14] Madandoust, R., Ghorbani Vaghei, Z., & Ghorbani Vaghei, B. (2007). Evaluation of compressive strength of concrete by ultrasonic wave method and using fuzzy logic system, 3rd National Congress of Civil Engineering, Tabriz, Tabriz University, Faculty of Civil Engineering.
[15] Najimi, M., Sobhani, J., & Pourkhorshidi, A. (2010). Designing and modifying the properties of concrete without slump and predicting its compressive strength using the adaptive neuro-fuzzy inference system. *Concrete Research*, Guilan.
[16] Heydari, A., & Heydari, N. (2015). The application of fuzzy logic in predicting the compressive strength of polymer concrete. In *10th Science and Technology Advances Symposium*, Khavaran Institute of Higher Education, Mashhad.
[17] Khademi, F., Akbari, M., Jamal, S. M., & Nikoo, M. (2017). Multiple linear regression, artificial neural network, and fuzzy logic prediction of 28 days compressive strength of concrete. *Frontiers of Structural and Civil Engineering*, *11*, 90–99.
[18] Zarandi, M. F., Türksen, I. B., Sobhani, J., & Ramezanianpour, A. A. (2008). Fuzzy polynomial neural networks for approximation of the compressive strength of concrete. *Applied Soft Computing*, *8*, 488–498.
[19] Topcu, I. B., & Sarıdemir, M. (2008). Prediction of compressive strength of concrete containing fly ash using artificial neural networks and fuzzy logic. *Computational Materials Science*, *41*, 305–311.
[20] Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338–353.
[21] Daftaribesheli, A., Ataei, M., & Sereshki, F. (2011). Assessment of rock slope stability using the Fuzzy Slope Mass Rating (FSMR) system. *Applied Soft Computing*, *11*, 4465–4473.
[22] Nezarat, H., Sereshki, F., & Ataei, M. (2015). Ranking of geological risks in mechanized tunneling by using Fuzzy Analytical Hierarchy Process (FAHP). *Tunnelling and Underground Space Technology*, *50*, 358–364.
[23] Guido, G., Haghshenas, S. S., Haghshenas, S. S., Vitale, A., Gallelli, V., & Astarita, V. (2022). Prioritizing the potential smartification measures by using an integrated decision support system with sustainable development goals (a case study in southern Italy). *Safety*, *8*, 35.
[24] Jafarzadeh Ghoushchi, S., Shaffiee Haghshenas, S., Memarpour Ghiaci, A., Guido, G., & Vitale, A. (2022). Road safety assessment and risks prioritization using an integrated SWARA and MARCOS approach under spherical fuzzy environment. *Neural Computing and Applications*, 1–19.
[25] Zinno, R., Haghshenas, S. S., Guido, G., Rashvand, K., Vitale, A., & Sarhadi, A. (2022). The State of the Art of Artificial Intelligence Approaches and New Technologies in Structural Health Monitoring of Bridges. *Applied Sciences*, *13*, 97.
[26] ASTM C33 (2008). Standard specification for concrete aggregates. Annual Book of ASTM Standards.
[27] Arulmoly, B., Konthesingha, C., & Nanayakkara, A. (2021). Performance evaluation of cement mortar produced with manufactured sand and offshore sand as alternatives for river sand. *Construction and Building Materials*, *297*, 123784.
[28] Lu, D., Shi, X., Wong, H. S., Jiang, Z., & Zhong, J. (2022). Graphene coated sand for smart cement composites. *Construction and Building Materials*, *346*, 128313.

[29] Naidu, P. G., Satyanarayana, P. V. V., Ganja, C. S., & Rani, K. D. (2021). Effect of cement on cement stabilized low plastic graded gravel soils. *Materials Today: Proceedings*.

[30] Wang, N., Ma, T., Chen, F., & Ma, Y. (2022). Compaction quality assessment of cement stabilized gravel using intelligent compaction technology—A case study. *Construction and Building Materials*, *345*, 128100.

[31] Babaei, A., Ghazavi, M., & Ganjian, N. (2022a). Experimental investigation of nano-ZnO effect on mechanical properties of cemented clayey sand. *Bulletin of Engineering Geology and the Environment*, *81*, 73.

[32] Babaei, A., Ghazavi, M., & Ganjian, N. (2022b). Shear strength parameters of clayey sand treated with cement and nano titanium dioxide. *Geotechnical and Geological Engineering*, *40*, 133–151.

How to Cite: Aghdam, N. N., Kanafi, P. R., & Sohrabpour, K. (2023). Investigating the Effect of Curing Type on Compressive Strength of Normal Concrete Containing Zeolite Using Experimental Analysis and Fuzzy Logic. *Journal of Computational and Cognitive Engineering* https://doi.org/10.47852/bonviewJCCE3202558