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Using of Backpropagation Neural Network in Estimation of Compressive Strength of Waste Concrete

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ABSTRACT

Waste concrete is one of the most usable and economic kind of concrete which is used in many civil projects all around the world, and its importance is undeniable. Also, the explanation of constructional process and destruction of them cause the extensive growth of irreversible waste to the industry cycle, which can be as one of the main damaging factors to the economy. In this investigation, with using of constructional waste included concrete waste, brick, ceramic and tile and stone new aggregate was made. Also it was used with different weight ratios of cement in the mix design. The results of laboratory studies showed that the using of the ratio of sand to cement 1 and waste aggregate with 20% weight ratio (W20), replacing of normal aggregate, increased the 28 days compressive strength to the maximum stage 45.23 MPa. In the next stage, in order to develop the experimental results backpropagation neural network was used. This network with about 91% regression, 0.24 error, and 1.41 seconds, is a proper method for estimating results.

1. Introduction

Concrete is one of the most used building materials; its world consumption is more than one tone for one person, which makes it is one of the most usable materials on the earth after water. Also,

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more than million tons of waste is produced in the world every year. Many of these waste is non-recyclable and accumulate in a variety of tools. Therefore, it is very important to restore this waste to the industry cycle. One of the main parts of this waste is due to tiles and ceramics. Waste of tiles and ceramics are created in transition, during or after burning due to human mistakes or error of construction and even inferior raw materials. Most of this waste is because of demolishing of buildings [1]. The waste increases due to the extensive growth of production and consumption of these valuable materials. Various studies have been undertaken to recycle the waste in concrete in 2000. The investigation of chemical properties of waste tiles based on standards and then making samples with pozzolan and tests of compressive and bending strength were done. The results showed that it is possible to use waste tiles in concrete. Also, they have pozzolanic properties [2]. In 2013, Heidari et al. studied the effects of ceramic aggregates in concrete. For this purpose, the ceramic was replaced as coarse-grained of 0 to 40% as well as sand as 0 to 100%. The results showed that the use of ceramic has no significant negative effect on concrete properties. The optimum sample in the case of ceramic replacement with sand was about 25 to 50 Percent. The best sample, using ceramic as coarse-grained, was between 10 to 20%. In this case, not only the increase in compressive strength is observed, but also the specific weight is reduced without any significant negative effect on water absorption [1]. In order to improve the mechanical properties and reduce the water absorption, Nanoparticles of silica were used. Final results showed that using Nano particles can highly improve the concrete waste parameters because of filling of capillary voids in cement past [3]. In the bricks industry, due to the high quantity of bricks in the building industry, researchers have proposed different combinations for the manufacture of concrete containing this type of waste with various tests and studies. In 1983, one of the first experimental studies in this field was carried out, and finally it showed a compressive strength of a downward trend and a reduction of 10-35% for coarse-grained of replacing brick with natural aggregate. However, compared to conventional concrete with this reduced compressive strength, the tensile strength increases by 11% [4]. In another study in 2014, in the first phase, Tavakoli and Heidari investigated the effect of replacing sand with clay brick in different proportions and observed that there is not a big problem in using of brick as sand in optimum percent and mechanical properties like compressive strength. However, due to the high water absorption, a longer examination is required [5]. In 1993, Merlet and Pimienta investigated the use of waste concrete in the reproduction of constructional concrete. They used the waste concrete in different ratios as fine grained in new concrete for the first time [6]. Later, shrinkage of drying of this concrete was evaluated. The results showed that there is a high shrinkage in comparison with conventional concrete [7], which can be controlled by adding fly ash [8]. Several studies have also been carried out on the use of different neural networks in estimating laboratory values. In 2017, Kalman et al. used a neural network to estimate the properties of concrete with waste brick aggregate. The results showed that the neural network can estimate these properties and show very close results to experimental ones [9]. In another study, neural network, ANFIS, and multi-layer regression (MLR) were used to estimate 28 days compressive strength of concrete with waste aggregate. Finally, due to input data to the network, although all of the modeling ways acted well, but MLR network showed the most exact answers for estimating the values [10]. In the same field, the neural network and ANFIS were used simultaneously to study the compressive strength of concrete blocks. 102 samples were used to construct the network and parameters such as the ratio of height to the thickness of the concrete charter and compressive strength as the input of the model were used. Finally, it was determined that these models can estimate the required values with high precision [11]. Using of neural networks with a mixture of optimization algorithms such as genetic, PSO and etc. which is used to improve the workability, not only exist in all of the fields, but also has a wide usage in concrete production. In a study, in order to the simulation of a concrete slump, a genetic algorithm was used to optimize the bias and weights. In this study, backpropagation neural network was processed and developed [12].

In this investigation, two phases were considered. In the first phase, experimental studies about using waste materials such as brick, ceramic tile, and concrete as fine aggregate. The results showed that this method is not only practical but also economical. In this method, in order to have the best answer for mix design, the ratio of sand to cement should be 1. Also a design with 20% of waste had the best results. In the second phases, numerical methods such as the practice of data in Excel and backpropagation neural network were used to develop the prediction of values. The results of this phase showed that neural network with a high accuracy of measurement could be used to predict the values.

2. Materials

2.1. Aggregate preparation

In this study, in order to use the constructional waste as aggregate in concrete, it should be crushed enough. Also, its condition in concrete should be examined. In this kind of concrete, gravel was not used, and the used aggregate is in size of sand. At first, constructional waste like concrete, brick, stone also tile and ceramic waste should be crushed completely with the help of impact crusher, and then particles of gravel are separated from sand by the sieve 4. Ordinary sand and waste sand are shown in figure1.

Fig. 1. A: waste of sand. B: ordinary sand.

Before doing the experiments, it is essential to make sure about the pozzolanic property or lack of it in the waste sand, because this property can influence the whole aspects of experimental results. So, the experiment of XRF was done on the samples of this two kind of sand.

Table 1
XRF analysis of sands.

Element	Sand constituents in percent	
	Ordinary sand	Waste sand
Al_2O_3	0.59	1.45
SiO_2	0.32	0.56
CaO	54.21	53.76
Fe_2O_3	0.06	0.96
K_2O	0.26	0.43
MgO	1.04	2.27
MnO	0.01	0.03
Na_2O	2.15	1.74
P_2O_5	0.08	0.08
S_2O_3	0.57	3.78
TiO	0.01	0.15
LOI	40.58	33.40

Investigating these results showed that there is no pozzolanic property in the waste sand and it is similar to stone. Also, grading of these two kinds of sand was done based on figure3. The results of the study of these two graphs based on the Iran standard of grading showed that both of these two kinds of sand are in the standard area and they can be used in concrete.

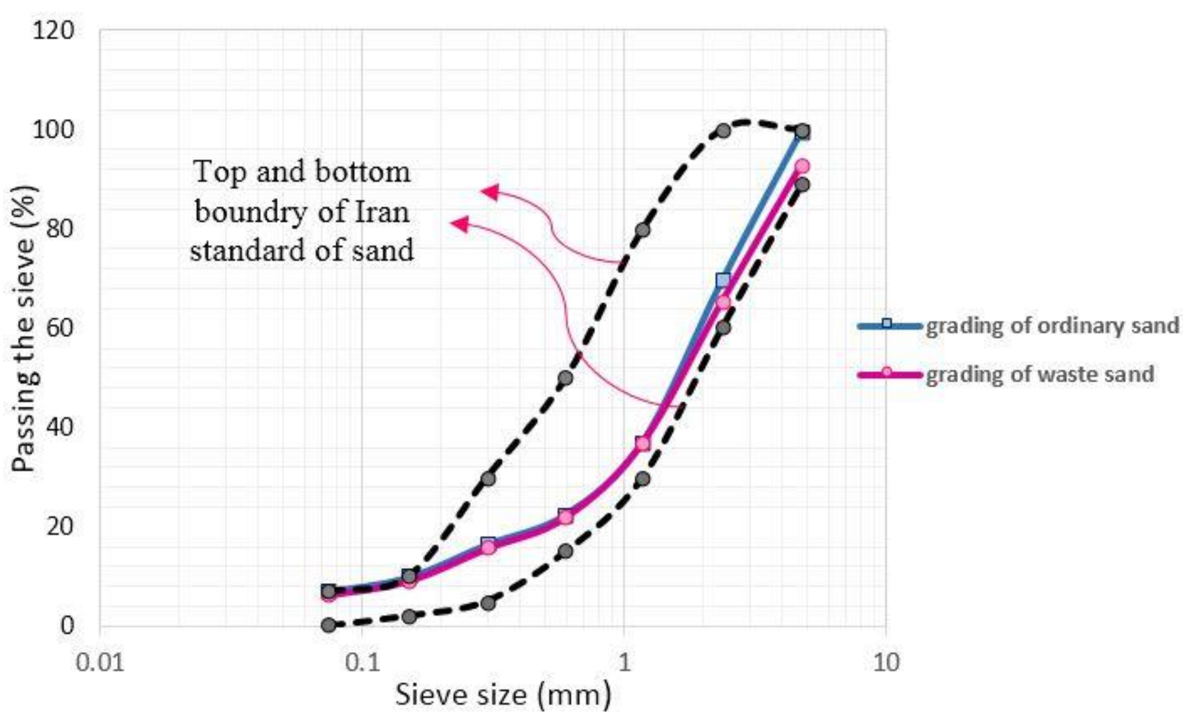

Fig. 2. Grading of sands.

2.2. Cement

The cement which was used is the 1-525 type of Shahrekord cement factory. Analysis of this material is shown in table 2.

Table 2
Properties of cement.

Chemical properties	%	Physical properties	Value
SiO_2	20.30	Blain(cm^2/gr)	≥3200
Al_2O_3	5.65	Setting initial time (minute)	90
Fe_2O_3	3.30	Setting final time(minute)	170
CaO	65.70	Autoclave expansion	≤3.0
MgO	≤1.60	2 days compressive strength	≥24.0
SO_3	≤2.80	3 days compressive strength	≥35.0
CL	≤0.03	7 days compressive strength	≥47.0
F.CaO	≤1.80	28 days compressive strength	≥61.0
I.R	≤0.65		
L.O.I	≤1.30		
Total Alkali	≤0.70		

2.3. Water

Potable water was used in this study. In this water, PH is 7.8, Chloride 40 $^{mg}/_{l}$ and Sulphate 29$^{mg}/_{l}$. So potable water has standard parameters, and it is proper for mix design.

2.4. Superplasticizer

The superplasticizer which was used in this study is high water reducer based on polycarboxylate copolymer that has a wide range in ultra-high performance concrete. This brown superplasticizer with 1.08 density, less 0.01 CL ion, and 6 to 8 PH is manufactured to be used in UHPC, SCC, impermeable, and concrete with high workability. This superplasticizer with high distribution property of cement particles is an admixture to produce UHPC concrete with a minor ratio of water to cement. Moreover, it does not have any CL ion, so it is usable in producing the reinforced concrete. Also, with less using of this material, a homogenous mixture can be made.

3. Mix design

In this investigation, two phases with ratios of sand to cement, 1 and 1.5 are considered and each phase has 11 mix designs, which ordinary and waste sand were used as a percent of total aggregate from 0 to 100 percent in each design. Also, in both phases, the ratio of water to cement was 0.5. Table of mix design for this concrete is shown as follows. Meanwhile, W is used in order to name each design and the number of after it shows the percent of waste sand.

Table 3
Mix design.

Sample	Type of sand		Superplasticizer (weight ratio of cement)	
	Waste sand (%)	Ordinary sand (%)	Phase 2	Phase 1
W100	100	0	0.4	0.3
W90	90	10	0.3	0
W80	80	20	0.2	0
W70	70	30	0.1	0
W60	60	40	0.1	0
W50	50	50	0	0
W40	40	60	0	0
W30	30	70	0	0
W20	20	80	0	0
W10	10	90	0	0
W0	0	100	0	0

After preparing the aggregate, the total weight of 5 Kgs of cement and aggregate based on the mix design, was poured into the mixer, then the water contained superplasticizer was added. This concrete was mixed for 3 minutes which was adjusted based on the ACI304-37 standard. Finally, this made concrete was poured into the 5 centimeters cube molds.

4. Experimental results

After curing the concrete samples in water, compressive strength tests were done, and the results were analyzed. Figure 3 shows concrete samples with the different percent of waste.

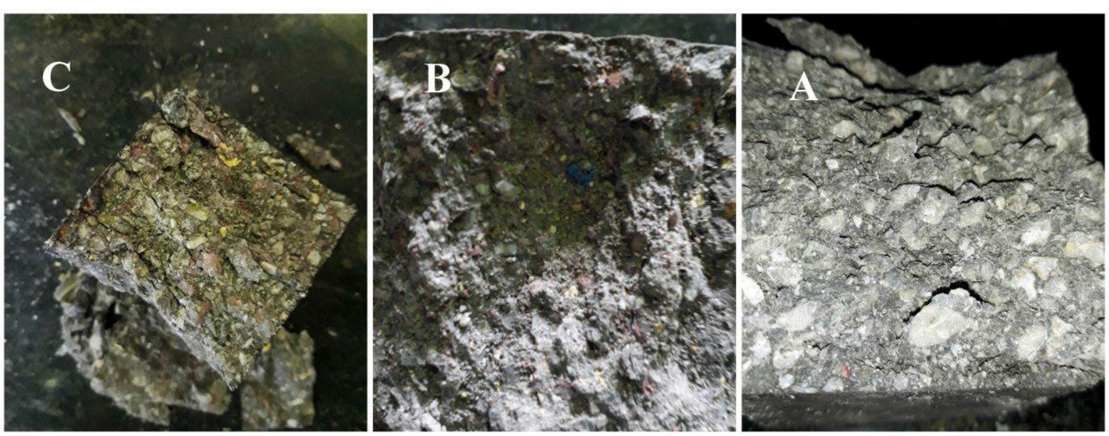

Fig. 3. A: Reference sample. B: W50 sample. C: W100 sample.

4.1. Compressive strength

The most important experimental test is compressive strength test. This test is based on ASTM C-109 standard. In this investigation, 1, 7 and 28 days samples were broken by 2000KN under hydraulic load jack and then the results were determined. Figure 4 shows the results of phase 1 and 2.

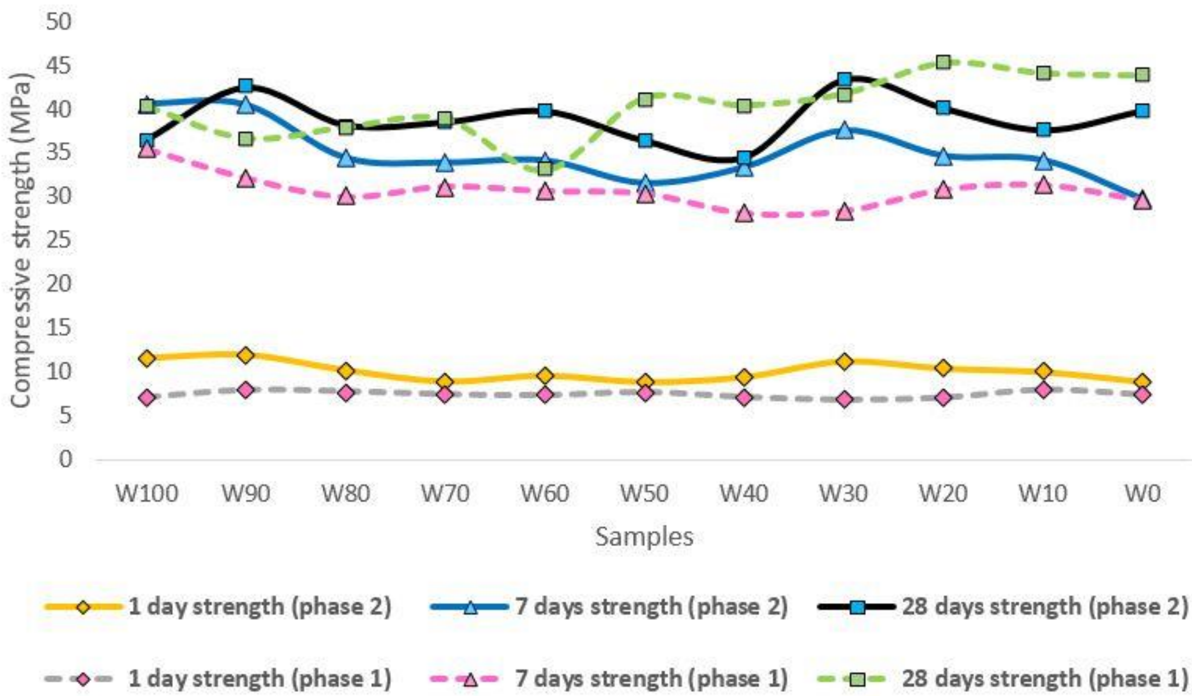

Fig. 4. Results of compressive strength in phase 1 and 2.

As it was shown, samples which were cured for 28 days had higher compressive strength in comparison with other samples. Also, 28 compressive strength and 7 days compressive strength were close because of using the cement type 1-525 which can cause strength in the short term. Moreover, with increasing the ordinary sand, strength will increase, too. This fact is because of replacing high strength ordinary sand with low strength waste sand. So, mechanical properties of the microstructure of concrete will improve. Nevertheless, in the first phase, the sample with 20% waste sand had the highest strength. Also, in the second phase, the sample with 30% of waste had the highest strength.

5. Neural network

Neural networks are derived from human biological intelligence. Each human neuron's cell consists of three main parts called axon, dendrite and soma, which dendrites are the agent of receiving information from other cells and axons are the agents of information transmission from other cells. The soma or cell body is also the place where the data is entered into the cell. The neural network also has the same mechanism by which the neuron receives signals that are affected by the weights and biases, as well as the neuron cell as the processor and the information get processed. The processed information is transferred to the neuronal cell again, and this cycle is repeating. On the other hand, the neural network can be similar to the model multivariate linear regression is also known. Input neurons similar to independent variables and output neurons like the dependent variable acts and the weights have the same function width of the source or constant sentence in the regression. In general, the role of neurons in the neural network is information processing. This is the case in artificial networks that is the same as the activation function [13].

Since the estimation and prediction of values using neural networks are fast and relatively new, it is, therefore, necessary to avoid conclusive results from other values that were not possible due to the limitation of laboratory conditions. Assured. First, we estimate the values for fitting the results using Excel software. It is shown in linear fitting data of figure 5.

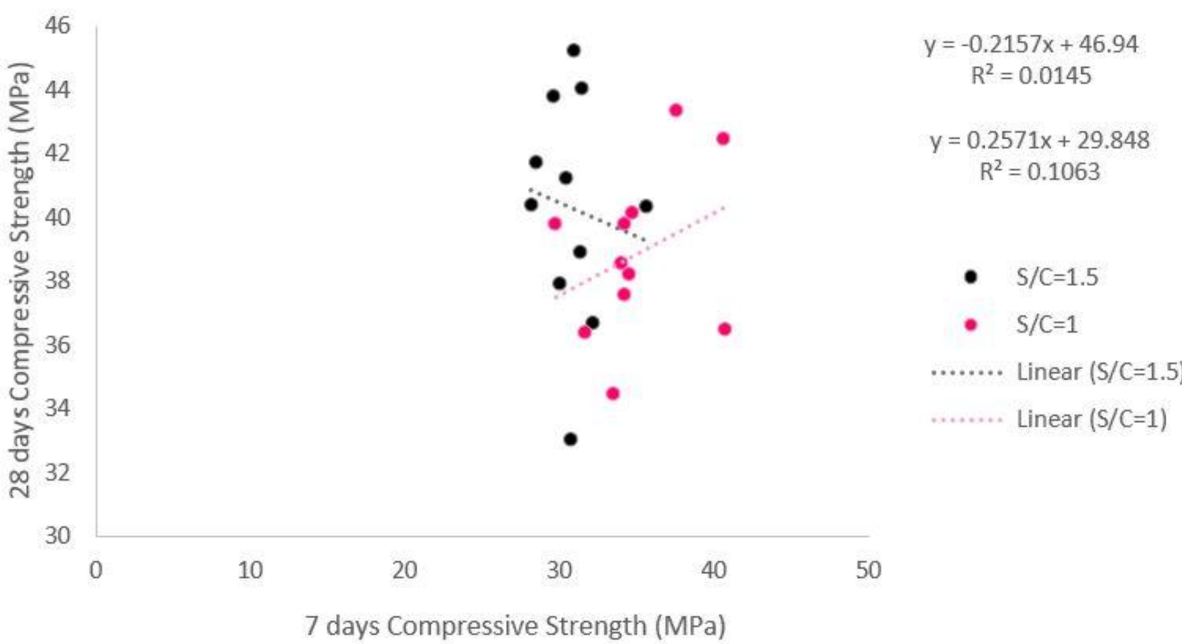

Fig. 5. Fitting data in Excel.

Excel fittings with low regression cannot estimate the values, and they are unreliable. So, in this stage, backpropagation neural network with artificial intelligence basic and optimization algorithms was used. In order to prepare the network, at first layered status and input and output data, were determined. For a basic network, five kinds of input, two hidden layers, and three kinds of output based on compressive strength were used. Figure 6 shows this graph.

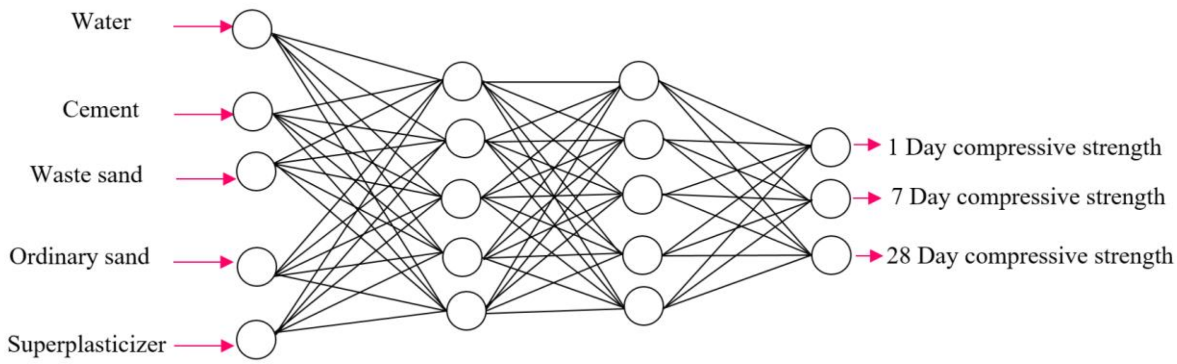

Fig. 6. Layered status for the neural network.

Before importing the data and training the network, in order to decrease the errors, Eq. (1) was used to normalize the data [14].

$$X_i = 0 \cdot 8\left(\frac{X - X_{min}}{X_{max} - X_{min}}\right) + 0 \cdot 1 \tag{1}$$

Where X_i is normalized data, X input or output parameter, X_{min} minimum input or output parameter, X_{max} is the maximum input or output parameter. In order to, create the network, 70% of data for training, 15% for evaluating and 15% for testing were used. The final answer is in figure 7.

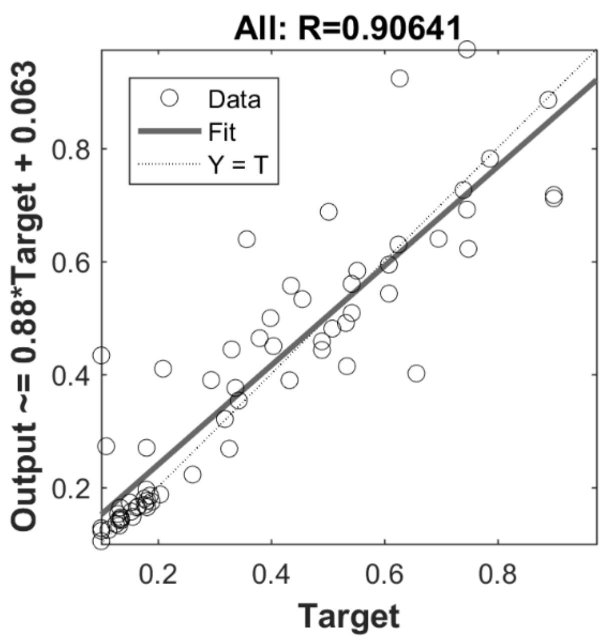

Fig. 7. Regression of neural network.

As it is shown, network regression is higher and more acceptable than excel. Network errors are shown in figure 8. In this figure, a neural network with high regression and fewer errors could create the best answer for estimating the values.

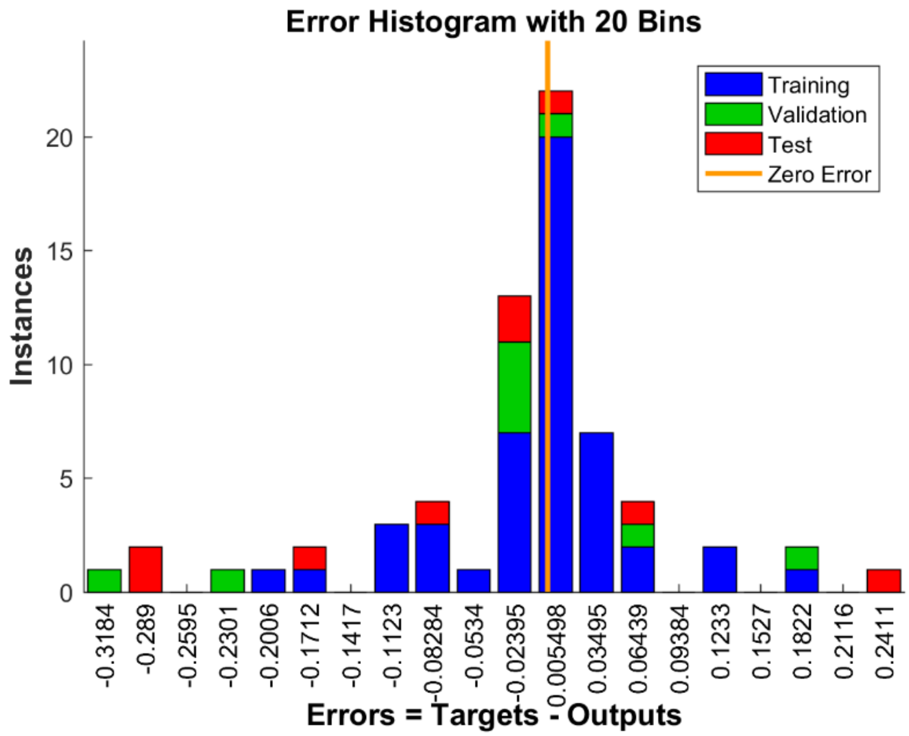

Fig. 8. The error of neural network.

Maximum time consumption in this study was 1.46 seconds, which was recorded for core i7 CPU and 16-gigabyte ram. This value is different for other systems. This item is proper because of selecting two hidden layers and considering Levenberg Marquardt training function which is one of the fastest functions of the toolbox of MATLAB.

6. Conclusion

This study has two experimental and numerical parts which the results are as follows:

1. Adding construction waste as aggregate in concrete is an acceptable and not only compressive strength has not diminished, but has also been remarkable for some designs. For example, the maximum compressive strength for phase 1 is sand-to-cement ratio 1, and the waste is 20% up to 45.23 MPa.
2. The results of compressive strength in 7 and 28 days samples, were so close, which was because of using of cement type 1-525 and its short-term strength.
3. In order to develop and estimate the experimental data, two layers of back propagation neural network was used.
4. The results of fitting data of neural network were more accurate and closer to real values in comparison with fitting data of Excel.
5. Finally, it was concluded that back propagation neural network is accurate and accelerator in estimating and fitting processing the experimental data.

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