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A Computational Model for Estimating the Compressive Strength of Mortars Admixed with Mineral Materials

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ABSTRACT

In this paper, a new computational model is presented to estimate the compressive strength of mortars admixed with Microsilica and a mineral material namely Wollastonite. For this purpose, an equation with fourteen unknown parameters was considered based on a large experimental data, which were published in the literature. The model used five independent parameters including the amounts of the Microsilica, cement, Wollastonite, water and also the age of the specimens (day). For calculating the unknown parameters, the author used artificial neural network method and divided the experimental database into three parts for three phases of the train, validate and test to tune the coefficients of the considered equation. After determining the coefficients, the final equation was validated and tested to estimate the compressive strength of the considered mortars. The results indicated that the proposed equation of this research could be able to determine the compressive strength of mortars admixed with Wollastonite.

1. Introduction

Soft computing methods can consider as flexible and powerful computational methods. They can use to estimate relationships between inputs and outputs better and easier than conventional

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methods like regression. One of the soft computing approaches is artificial neural network (ANN). This type of models can use as an estimator in such a way that in civil engineering they are considered for capacity prediction or other similar goals. There are models for predicting the compressive strength of mortars. Some researchers used several methods such as analysis of surface waves for in place cement mortars [1], ultrasonic wave reflection method [2], electromagnetic characterization [3] and optimized support vector machine [4] to estimate the compressive strength of mortar. In some cases, soft computing approaches were considered to create the compressive strength models for mortars [5]. Naderpour and Mirrashid [6] investigated the effective parameters on compressive strength of mortars and proposed a neural network to predict it. They also presented an equation based neural network, which can be able to determine the compressive strength with suitable accuracy [6]. A comparison between the results of the above references showed that the new models base soft computing have more accuracy than the traditional methods.

This research presents an equation to determine the compressive strength of mortars admixed with a mineral material namely Wollastonite. The authors created a computational model for estimating the considered target by several effective parameters and tuned all unknown coefficients of the proposed equation based experimental results and the ability of artificial neural networks. The obtained equation was validated and finally tested to specify the accuracy of the presented equation.

2. Base equations

There are several methods to determine a relationship between independent and dependent parameters. In some methods, researchers select an initial format and try to specify unknown coefficients of the considered equation. For this purpose, researchers can use the available acknowledge about the problem, details of the parameters, the effect of each considered parameters on target and also environmental conditions of the mortar. Therefore, the application and the ability of any relationship depends on the initial definitions. To solve this issue, flexible equation with some biases can be used and in this research, the authors consider Eq.1 to estimate the compressive strength of mortars:

$$f_c' = \begin{bmatrix} f_1 & f_2 \end{bmatrix} \begin{bmatrix} c_{13} \\ c_{14} \end{bmatrix} + c_{15} \tag{1}$$

There are three unknown coefficients in this equation including c_{13}, c_{14} and c_{15}. Other two parameters f_1 and f_2 ,which are related to activation functions of the neural network, can determine by Eq.2 and Eq.3.

$$f_1 = \frac{2}{1+e^{-2Z_1}} - 1 \tag{2}$$

$$f_2 = \frac{2}{1+e^{-2Z_2}} - 1 \tag{3}$$

There are two unknown parameters Z_1 and Z_2, which are calculated by Eq. 4. These two parameters are related to the amount of each neuron with considering its weight and bias. In this equation, $x_1, \ldots, x_5$ are the normal values of the inputs 1 to 5 respectively. There are also twelve unknown coefficients in Eq.4. The aim of this study is determination of these fifteen coefficients to estimate the compressive strength of mortars admixed with Wollastonite.

$$\begin{bmatrix} Z_1 & Z_2 \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix}^T \begin{bmatrix} C_1 & C_6 \\ C_2 & C_7 \\ C_3 & C_8 \\ C_4 & C_9 \\ C_5 & C_{10} \end{bmatrix} + \begin{bmatrix} C_{11} & C_{12} \end{bmatrix} \tag{4}$$

3. Database

In civil engineering, soft computing methods are widely used in many fields [7, 8]. Against analytical approaches such as finite element methods, which needs some influence parameters about the analysis, the use of a trained soft computing model is simple. Therefore, the authors considered neural network methods to determine the unknown coefficients of this research. Each neural network needs a database for training. In this paper, a collection of 126 experimental data, which were published in the previous studies [9], was used to tune the coefficients of Eq.1. Fig. 1 shows the details of the considered database and the considered parameters. This database is divided into three parts including 76, 25, 25 for the train, validate and test, respectively. Also, to decrease the dimension of intervals, all amounts of each parameter was limited to -1 to +1 (See Table 1) as normal values.

Table 1
Details of the parameters.

Definition	Notation	Minimum	Maximum	Range	Normal value
Microsilica (Mix proportion by weight)	x_1	0.0	12.5	12.5	$x_{1,n} = \frac{2x_1}{12.5} - 1$
High range water reducer (Mix proportion by weight)	x_2	0.32	2.0	1.68	$x_{2,n} = \frac{2(x_2 - 0.32)}{1.68} - 1$
Cement (Mix proportion by weight)	x_3	70.0	97.5	27.5	$x_{3,n} = \frac{2(x_3 - 70)}{27.5} - 1$
Wollastonite (Mix proportion by weight)	x_4	0.0	30.0	30	$x_{4,n} = \frac{2x_4}{30} - 1$
Age (day)	x_5	3.0	365.0	362	$x_{5,n} = \frac{2(x_5 - 3)}{362} - 1$
Compressive strength (MPa)	f_c'	13.2	66.2	53	$f_{c,n}' = \frac{2(f_c' - 13.2)}{53} - 1$

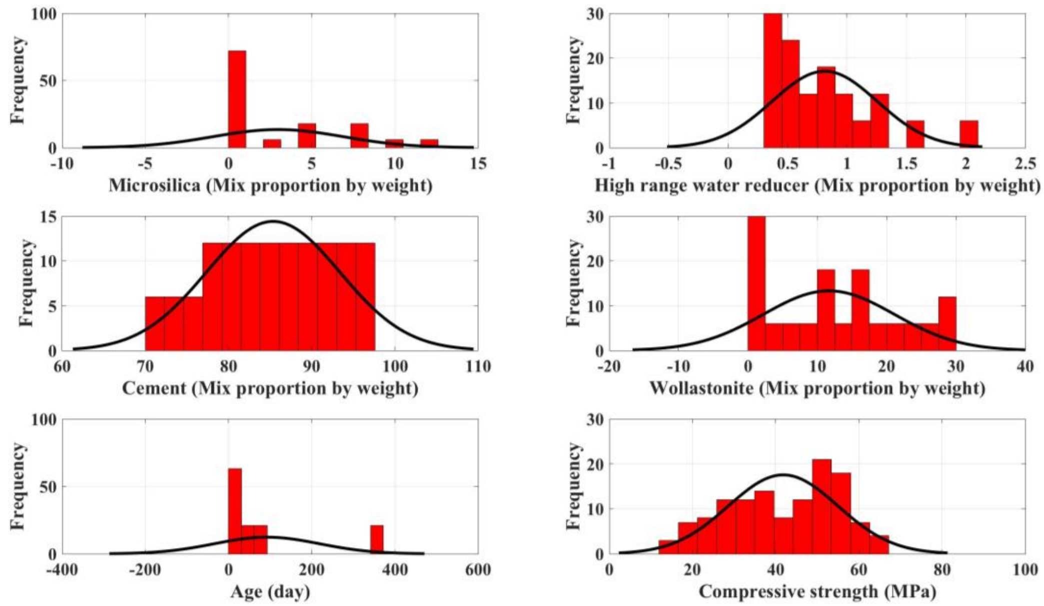

Fig 1. histograms of the considered variables.

4. Proposed equation

There are fifteen unknown coefficients that need to calculate. As mentioned in the previous section, the authors selected neural networks to estimate these unknown coefficients. The obtained coefficients from the trained networks are presented in Eq.5 to Eq.7. Also, based on the selected neural network model, c_{15} is determined equal to -4.985.

$$\begin{bmatrix} C_1 & C_6 \\ C_2 & C_7 \\ C_3 & C_8 \\ C_4 & C_9 \\ C_5 & C_{10} \end{bmatrix} = \begin{bmatrix} 2.7385 & -0.1757 \\ -1.5169 & -0.1084 \\ 0.1874 & -0.4330 \\ 0.0857 & -0.2449 \\ 0.1040 & 7.2680 \end{bmatrix} \quad \textit{for normal values of the inputs} \tag{5}$$

$$\begin{bmatrix} C_{11} & C_{12} \end{bmatrix} = \begin{bmatrix} 2.1314 & 8.3768 \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} C_{13} \\ C_{14} \end{bmatrix} = \begin{bmatrix} 0.7131 \\ 4.9665 \end{bmatrix} \tag{7}$$

Since the coefficients of Eq.5 are derived from the normal values of inputs (taken from Table 1), the authors used Eq.8 to Eq.12 to convert the normal values into real values. After that, the final form of $[Z_1 \quad Z_2]$ can specify by Eq.13:

$$x_1 = 12.5\left(\frac{x_{1,n}+1}{2}\right) \tag{8}$$

$$x_2 = 1.68\left(\frac{x_{2,n}+1}{2}\right)+0.32 \tag{9}$$

$$x_3 = 27.5\left(\frac{x_{3,n}+1}{2}\right)+70 \tag{10}$$

$$x_4 = 30\left(\frac{x_{4,n}+1}{2}\right) \tag{11}$$

$$x_5 = 362\left(\frac{x_{5,n}+1}{2}\right)+3 \tag{12}$$

$$\begin{bmatrix} Z_1 & Z_2 \end{bmatrix} = \begin{bmatrix} 0.4381x_1 - 1.806x_2 + 0.01363x_3 + 0.0057x_4 + 0.0006x_5 + 0.1551 \\ -0.0281x_1 - 0.1291x_2 - 0.0315x_3 - 0.0163x_4 + 0.0402x_5 + 4.196 \end{bmatrix}^T \tag{13}$$

According to the obtained coefficients, the final relationship to determine the compressive strength of the mortars is Eq.14:

$$f_c^{'}(MPa) = \begin{bmatrix} f_1 & f_2 \end{bmatrix} \begin{bmatrix} 0.7131 \\ 4.9665 \end{bmatrix} - 4.985 \tag{14}$$

The parameters f_1 and f_2 in the Eq.14 are determined from equations 2 and 3. Also, the parameters Z_1 and Z_2 in these equations are obtained from Eq.13.

5. Discussion

In the previous section, a relationship was proposed that was able to determine the compressive strength of mortars based on expethe rimental database and the ability of neural networks. In this section, details of the results and performance obtained from the proposed equation are evaluated. Fig.1 shows the results of the training database (including 76 data). It can be seen from this figure that RMSE and Error mean for all 76 datasets were 2.0077 and 0.14392, which is indicated that the proposed relationship (Eq.14) with a suitable accuracy was worked well on the training data. The results of the evaluation phase of the proposed equation are shown in Fig. 3. It is clear from the figure that the equation has a low RMSE equal to 3.2016 on all 25 evaluation datasets. Also, in the test phase, the results with RMSE equal to 2.6647 indicated the accuracy of the system and its efficiency (Fig.4).

Comparison of the results for the whole 126 laboratory data is shown in Fig. 5. Correlation coefficient values for training, evaluation, testing as well as whole data, which were 0.98, 0.97, 0.98 and 0.98, are illustrated in Fig.6. It is clear the figures, and the obtained correlation coefficient that the equation proposed in this paper (Eq.14) can estimate the compressive strength of mortars with high accuracy. A summary of the results is also presented in Table 2.

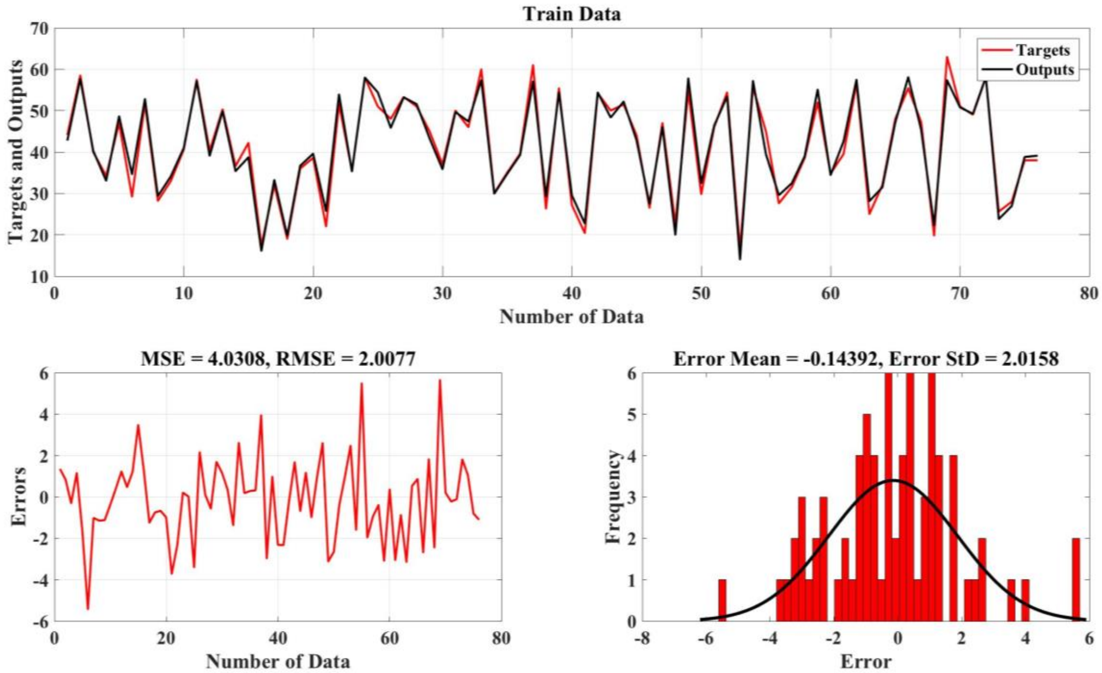

Fig.2. Results of the train data.

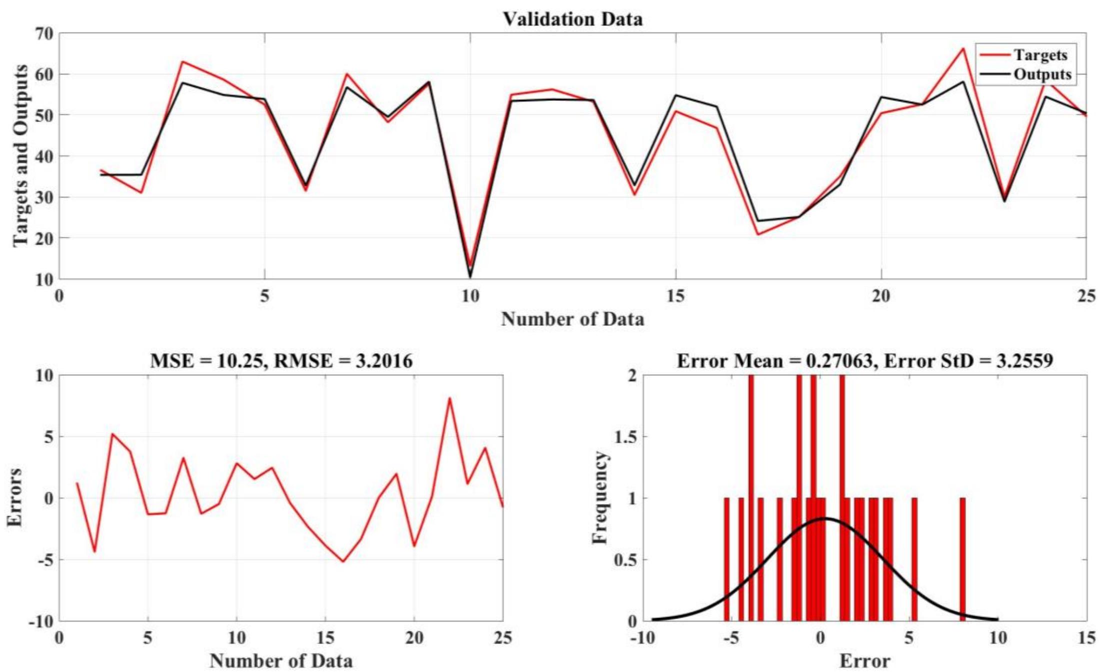

Fig.3. Results of the validation data.

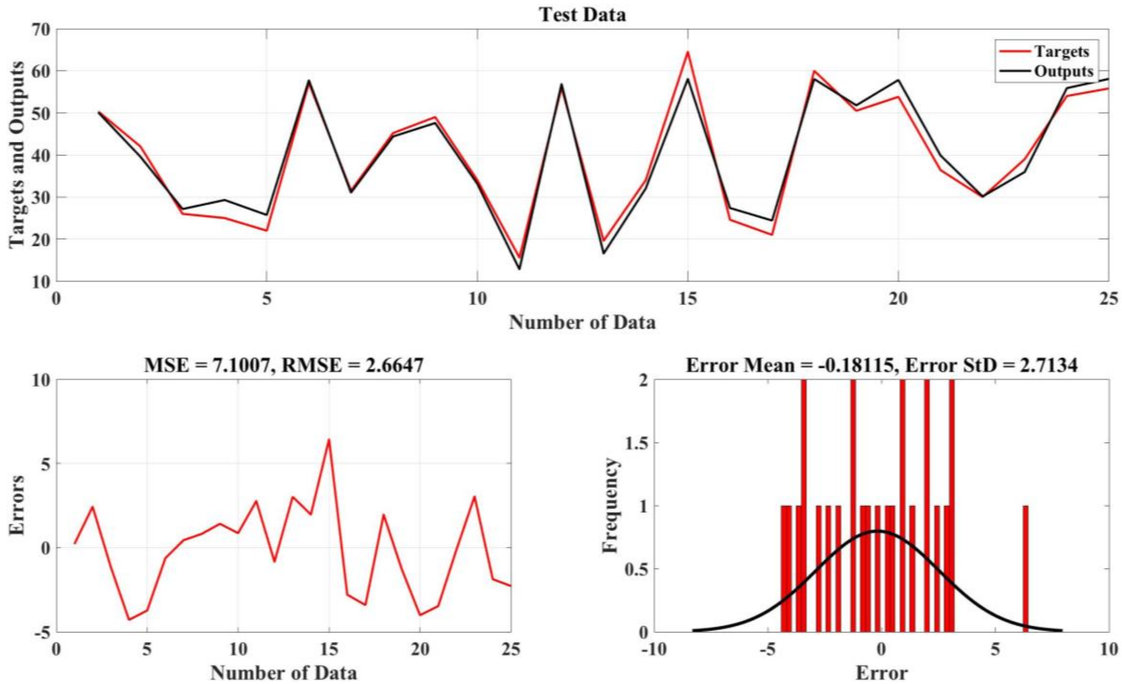

Fig.4. Results of the test data.

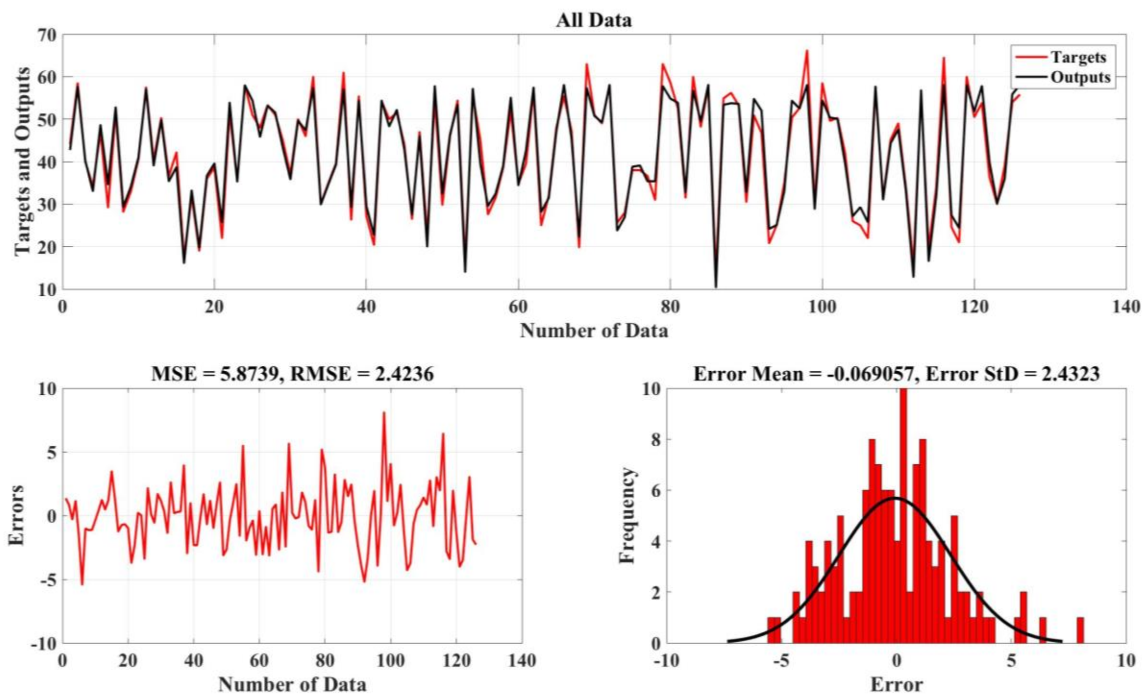

Fig.5. Results of all data.

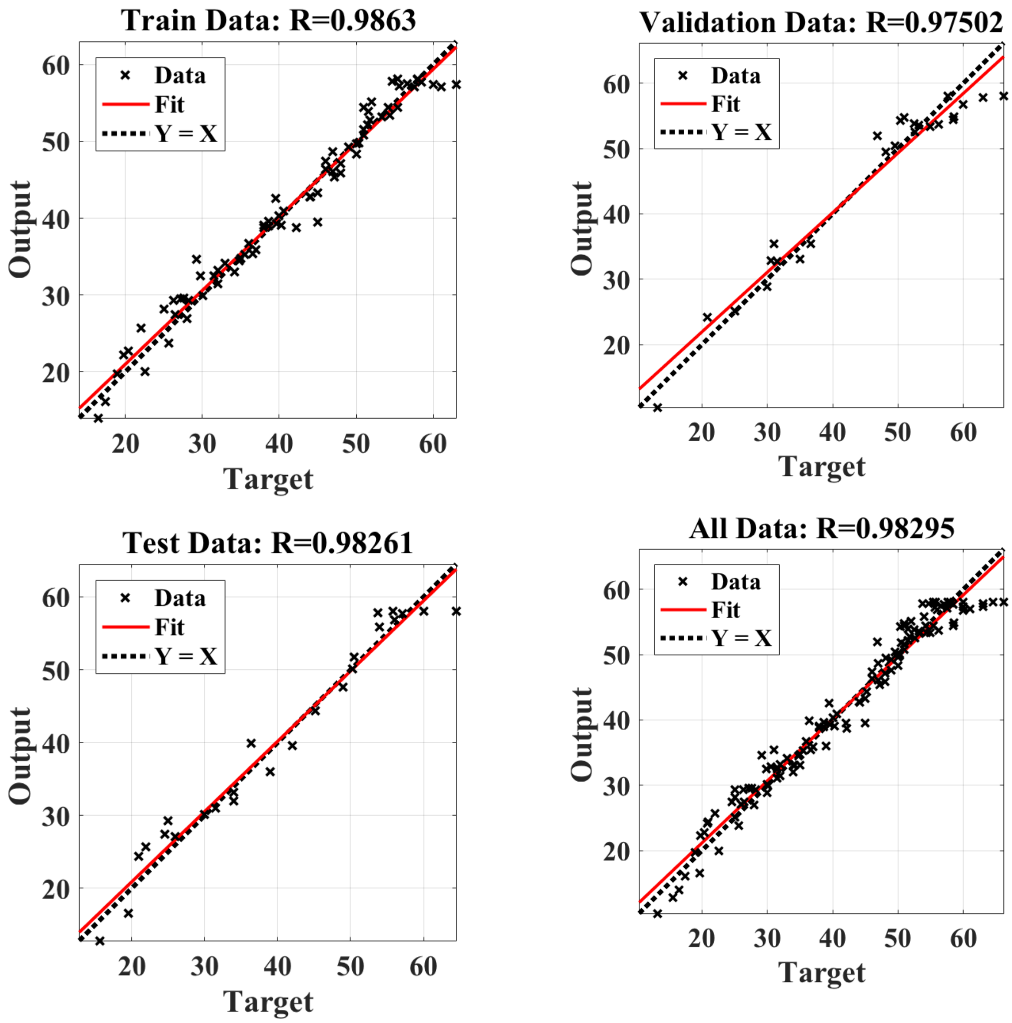

Fig.6. Results of Eq.14 for the considered database.

Table 2
Summary results of the proposed equation.

Definition	Train	Validation	Test	All
R2	0.98	0.97	0.98	0.98
RMSE	2.008	3.202	2.665	2.42
Error Mean	0.144	0.271	0.181	0.069
Error Standard deviation	2.02	3.26	2.71	2.43

6. Conclusion

Although mortars are considered as one of the non-structural elements,, their capacity in the bearing is very important of constructions. In civil engineering, the compressive strength of this type of elements is considerable due to their effect on the quality of the building. In this paper, a simple matrix equation is proposed to determine the compressive strength of mortars admixed with Microsilica and Wollastonite. For this purpose, an initial form for the proposed equation was selected, and then, the unknown coefficients were obtained using artificial neural networks. To calculate the unknown coefficients, a laboratory dataset was used to train the selected neural network and finally to tune the final equation. Also, the proposed equation was evaluated and tested by several experimental datasets. In the form of the proposed equation in this paper, five independent parameters have been used to estimate the target, which was the compressive strength of the mortar in this research. The results of the evaluation and test of the proposed equation showed a has high accuracy, and therefore, it can be used as a suitable tool for predicting the compressive strength of mortars.

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