PREDICTING THE EFFECT OF TRASS ON THE COMPRESSIVE STRENGTH OF PORTLAND CEMENT WITH FUZZY LOGIC

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Abstract

In this study, Portland cement replaced with trass as a ratio of its weight of 0, 10, 15, 20, 25 and 30. By this procedure, six different cements were prepared and effect of trass was investigated on the compressive strengths of the cement mortars at 2, 7 and 28 days. Also, by using Fuzzy Logic method, a prediction model was formed based on the quantity of trass to predict the compressive strengths of cement mortars which could not be determined with experimental approaches. The experimental results are compared with the fuzzy logic results. As a result, the correlation coefficient for the compressive strength of the cement mortars at 2, 7 and 28 days is found 0.97. This result shows that the developed model can be successfully applied in the cement sector.

Key words: *fuzzy logic, cement, trass, compressive strength*

1. INTRODUCTION

Nowadays various types of mineral additives due to the advantages such as improving the physical and mechanical properties, ecological balance, financial reasons of cement or concrete are widely used (Aruntas & Tokyay 1996; Worrell et al. 2000; Yildiz et al. 2010; Kocak et al. 2013). One of the mineral additives is tuffs.

Tuffs which are known as a trass are used as the additive material in the manufacture of the Portland composed cement. Trass, which is an important pozzolanic material, is used in cement industry, such as various silica minerals together clay, different silica minerals and glassy matix. Added trass provides mechanical, physical and chemical improvement in concrete. Therefore, trass is used as an additive for cement and concrete technology (Sogut et al. 2009; Emir et al. 2011).

Recent experimental works in many areas of civil engineering applications have been modeled with fuzzy logic and the obtained results reached satisfactory levels. Fuzzy logic is one of the methods which give the computers the ability to make a decision. In fuzzy logic crisp input values are fuzzified between 0 and 1. Decision-making criteria of the computer are defined by forming rule table. At the output unit fuzzy output values are defuzzified (Guler 2008). Fuzzy logic is now used in various fields of construction. Gulbandilar and Kocak investigated the effects of the cements formed by substituting Portland cement with different ratios of fly ash and silica fume on initial and final setting times, and they found that all substitution rate delayed the initial and final setting time. Moreover, they tried to estimate these values by using fuzzy logic and as a result, they proposed that fuzzy logic can be used in estimating cement's initial and finish setting time in relation with the fly ash and silica fume (Gulbandilar & Kocak 2013). Topcu et al. investigated the strength development of different mineral admixtures which were prepared from trasses, zeolite (clinoptilolite), fly ash and ground granulated blast furnace slag. Furthermore, ANN and FL system models to predict the strength development of different blended cement mortars with the experimental results were constructed. As a result, they found that both the models are close to the experimental results (Topcu et al. 2008). Nazari investigated water absorption of lightweight geopolymers produced by fine fly ash and rice husk bark ash together with palm oil clinker aggregates with experimentally and modeled by fuzzy logic. As a result, he found that the training, validating and testing results in the fuzzy model shown a strong potential for predicting the water absorption of the geopolymer specimens (Nazari 2012). Akkurt et al. investigated a fuzzy logic prediction model for the 28-day compressive strength of cement mortar under standard curing conditions. The model was compared with the ANN model for its error levels and ease of application. The results indicated that through the application of fuzzy logic algorithm, a

more user friendly and more explicit model than the ANNs could be produced within successfully low error margins (Akkurt et al. 2004). In addition to these, modeling studies of pressure resistance estimation of cement with various pozzolanic material substitutions were made with artificial neural networks and fuzzy logic and the obtained values were very close to experimental results (Topcu & Saridemir 2008; Saridemir 2009; Ozcan et al. 2009; Subasi 2009).

In this study the effects of the cements formed by substituting Portland cement with different ratios of trass on the compressive strengths of the cement mortars at 2, 7 and 28 days are studied. The obtained results are compared with reference values and it is aimed to estimate the compressive strengths of the cement mortars with fuzzy logic method.

2. MATERIALS AND METHODS

In this study, CEM I 42.5 R Portland cement, trass, standard aggregate and water were used as materials. CEM I 42.5 R Portland cement (PC) produced Bolu Cement Factory was used as reference cement. The trass was excavated in Tekke region of Bolu province which was obtained from the Bolu Cement Factory. For the preparation of mortar specimens, CEN standard aggregate, conforming to TS EN 196–1 (TS EN 196-1 2009), and city water of the Mengen region of Bolu province were used. Chemical compositions of the PC and trass are given in Table 1.

Table 1. Chemical compositions of PC and trass

Materials	PC, %	Trass, %
Chemical composition, %		
SiO_2 (S)	19.59	62.44
Al_2O_3 (A)	5.57	16.53
Fe_2O_3 (F)	3.53	4.89
CaO	63.71	4.22
MgO	1.75	1.85
SO_3	2.95	-
Na_2O	0.23	1.99
K_2O	0.53	1.79
Cl^-	0.012	0.0002
Loss on ignition	2.78	2.66

In this study, six different cements are done where PC is reference cement. The produced reference and substituted cement codes are given in Table 2.

Table 2. Codes of PC and trass substituted cements

Number of samples	Cement type	Cement code
1	Portland cement (CEM I 42.5 R)	S1
2	Trass substituted cement, 10 %	S2
3	Trass substituted cement, 15 %	S3
4	Trass substituted cement, 20 %	S4
5	Trass substituted cement, 25 %	S5
6	Trass substituted cement, 30 %	S6

Chemical analyses of PC and trass were performed on ARL 8680 S X-ray diffraction. Cement mortar mixtures were prepared in accordance with TS EN 196-1 (TS EN 196–1 2009). In the preparation of mortar mixtures for compressive strength experiments, 450 g of Portland cement, 1350 g of standard sand and 225 ml of water were used in each mortar mixture according to TS EN 196-1 (TS EN 196-1 2009) and mixed in a mortar–mixing machine. The prepared mortars were poured into three-segmented rectangular prism moulds of size 40x40x160 mm. These mortar specimens were shaken for one minute on a shaking table then settled into the formworks. These specimens were kept in a laboratory environment for 24 hours. At the end of this duration, the specimens were taken out of the formworks and kept in a curing pool. The specimens were taken from the pool after 2, 7, and 28 days and were tested for compressive strengths in accordance with TS EN 196–1 (TS EN 196-1 2009).

3. PREDICTION OF THE COMPRESSIVE STRENGTHS WITH FUZZY LOGIC

The design of the fuzzy system that is used for the estimation operations is done with MatLab Toolbox. The percentage ratios of weights of trass are used as first input for fuzzy logic system. Other input variable is time (days) of compressive strength. In fuzzification of these input values fuzzy sets given in Figure 1 are used.

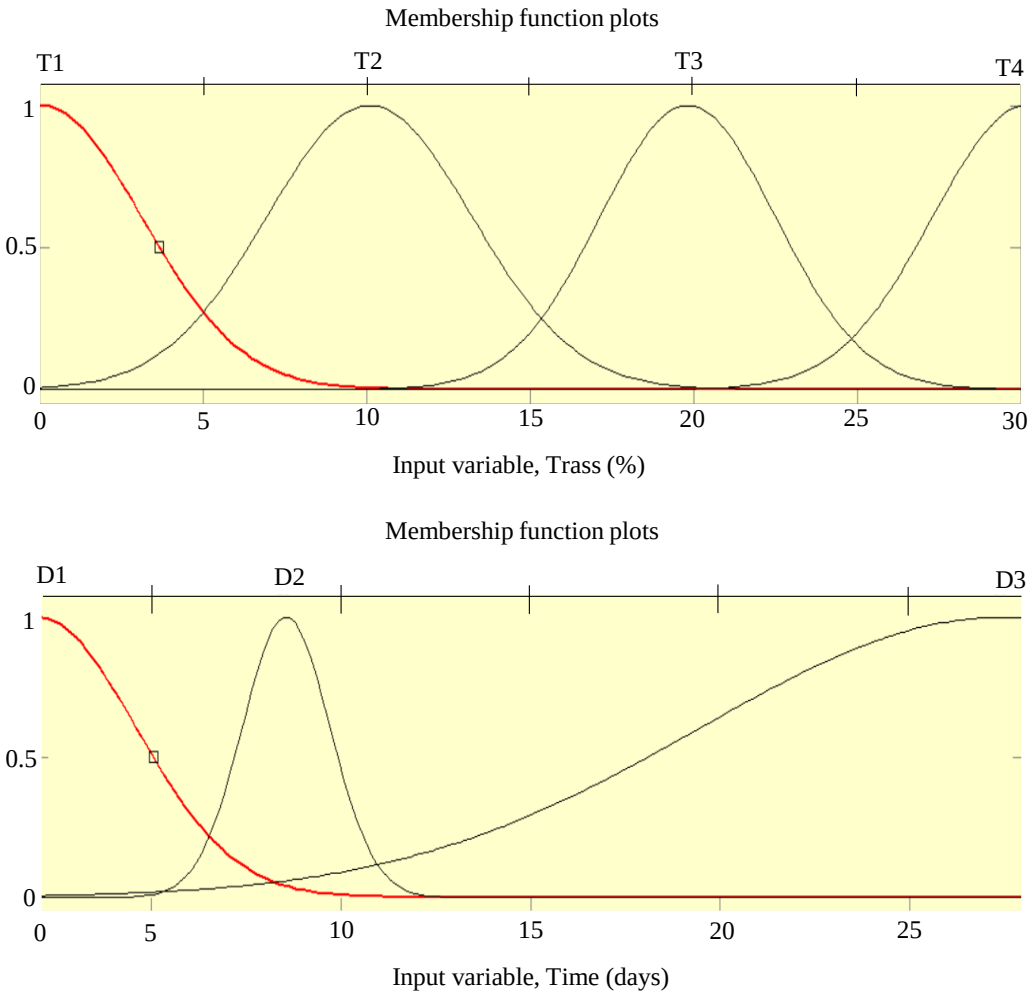


Figure 1. Membership functions of input variables.

For fuzzification process, crisp input variables split into four and tree Gauss membership function for trass percentage ratios and days compressive strength, respectively. While specifying the shape and values of fuzzy sets the experimentally obtained results are taken into account. In relation with these crisp input data are fuzzified. Since Gauss membership functions are used in calculation of membership degrees the following relation is used:

$$\mu(x) = \exp\left(-\left(\frac{x-b}{\sigma}\right)^2\right) \tag{1}$$

where: b is a model value (center), σ is a range factor (width for $\mu(x) = 0.5$). For example, when trass ratio is 15 % and membership degrees of T1 and T4 sets are 0, membership degrees of sets T2 and T3 can be calculated as 0.29 and 0.21, respectively. If the trass ratio is 30 % or above, the membership degree of set T4 is 1 the membership degrees of other sets will be 0.

Days of compressive strength is 5 % and membership degrees of D2 and D3 sets are 0, membership degrees of sets D3 can be calculated as 0.5, respectively. If the days of compressive strength is 10 % or above, the membership degree of D1, D2 and D3 sets will be 0.00, 0.41 and 0.01, respectively. Equation 1 is also used in calculation and fuzzification of membership degrees of days of compressive strength.

The membership functions of the output variable (compressive strength)) are preferred triangle shapes as seen in Figure 2. In determining the shape of output membership functions, again, experimental results are taken into account.

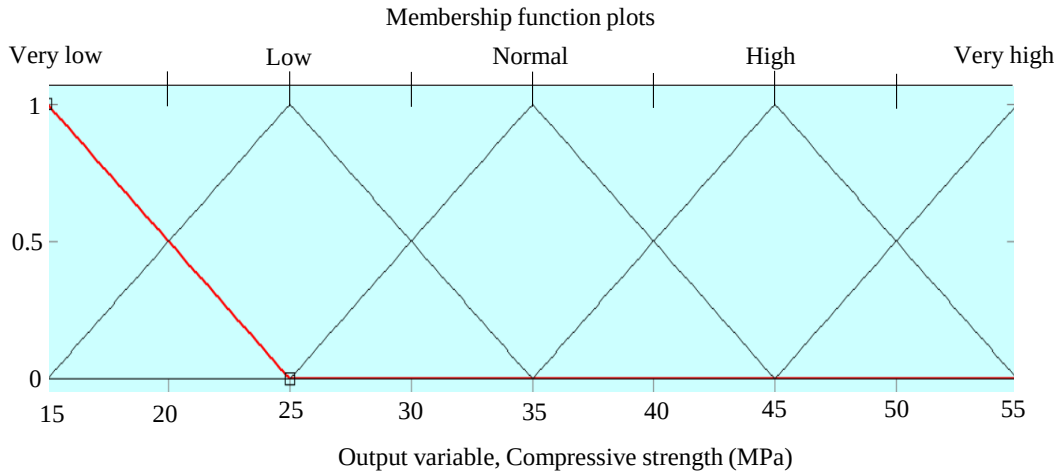


Figure 2. Membership functions of output variables.

The main structure of fuzzy decision-making systems is the rule bases. The computer takes these rules bases into account in order to make a decision. Experts are consulted while forming these matrices. By taking previous professional experiences and experimental results into account rule matrices in Table 3 are formed for the compressive strengths of the cement mortars (Hsu et al. 2010).

Table 3. Rule base of compressive strengths (MPa)

	T1	T2	T3	T4
D1	Low	Low	Very Low	Very Low
D2	High	High	Normal	Low
D3	Very High	High	High	Normal

Since input variables are identical for both the compressive strengths of the cement mortars the rule bases are merged and a total of 12 "If-then" relations are obtained as sampled below.

If input1=T1 and input2=D1 then output=Low

If input1=T4 and input2=D3 then output=Normal

If input1=T2 and input2=D3 then output=High

When the inputs of "If-then" relations are taken into consideration, it can be observed that they are linked with the conjunction "*and"*. In appointing membership degrees to output sets in a logical relation the conjunction "*and"* appoints the minimum of input membership degrees. As a result of this logical relation *max-min* inference method is used in fuzzy inference. For defuzzification which is the last phase of fuzzification operation *weighted average* method is selected. This method is given by the equation below;

$$x^* = \frac{\sum_{i=1}^{n} \mu_i(x).x_i}{\sum_{i=1}^{n} \mu_i(x)} \quad (2)$$

where x* defuzzification output value, μ_i the membership degree of each rule's output and x_i weighted average of each rule (Hsu et al. 2010; Ajayi et al. 2010).

4. RESULTS AND DISCUSSION

Table 4, 5 and 6 show the compressive strengths of the cement mortars at 2, 7 and 28 days, respectively, according to the results obtained from the experiments performed in compliance with TS EN 196-1 (TS EN 196-1 2009) on cement mortars used in this study and the results obtained from fuzzy logic model.

Table 4. Compressive strengths of the cement mortars at 2 days (MPa)

Number of samples	Cements					
	S1	S2	S3	S4	S5	S6
1	24.4	21.9	21.1	19.0	17.9	15.7
2	23.9	22.2	20.2	18.9	16.4	15.3
3	24.0	22.4	20.9	19.2	17.6	15.4
4	24.1	22.1	20.5	19.0	16.9	15.2
5	24.7	22.0	20.7	19.1	16.9	15.8
6	23.8	21.7	20.9	18.7	17.2	15.4
Average	24.2	22.1	20.7	19.0	17.2	15.5
Index,%	100	91	86	79	71	64
Estimates with fuzzy logic	25.2	25.2	25	18.9	21.2	18.6

Table 5. Compressive strengths of the cement mortars at 7 days (MPa)

Number of samples	Cements					
	S1	S2	S3	S4	S5	S6
1	38.7	35.3	33.4	32.2	28.6	25.8
2	39.6	37.0	35.3	32.9	27.4	26.0
3	39.0	36.7	34.8	33.1	28.2	26.1
4	39.6	35.9	33.9	32.6	28.1	25.9
5	39.4	35.8	34.1	32.1	27.6	25.7
6	39.1	36.4	34.8	32.7	28.2	25.8
Average	39.2	36.2	34.4	32.6	28.0	25.9
Index,%	100	92	88	83	71	66
Estimates with fuzzy logic	38.9	38.9	37	32.9	30.3	25.6

Table 6. Compressive strengths of the cement mortars at 28 days (MPa)

Number of samples	Cements					
	S1	S2	S3	S4	S5	S6
1	53.3	46.0	45.8	41.6	38.1	36.5
2	53.1	47.4	47.1	41.8	39.8	35.4
3	52.9	46.8	46.1	40.9	38.8	36.2
4	53.6	46.9	46.9	41.4	39.4	35.7
5	53.4	46.1	46.4	40.2	38.7	35.9
6	52.6	47.0	46.6	40.9	38.5	36.2
Average	53.2	46.7	46.5	41.1	38.9	36.0
Index,%	100	88	87	77	73	68
Estimates with fuzzy logic	51.7	45	45	45	39.3	35

According to the obtained results, with trass addition to PC the compressive strengths of the cement mortars at 2, 7 and 28 days, when compared to reference value, are decreased for all mixture ratios. According to Table 4, 5 and 6, with S2 grade cement used, the compressive strength of the mortar specimens produced decreased by 9% after 2 days, 8% after 7 days and 12% after 28 days compared to that with pure cement used. With S3 grade cement used, the strength of the mortar specimens produced decreased by 14% after 2 days, 12% after 7 days and 13% after 28 days compared to that with pure cement used. With S4 grade cement used, the strength of the mortar specimens produced decreased by 21% after 2 days, 17% after 7 days and 23% after 28 days compared to that with pure cement used. With S5 grade cement used, the strength of the mortar specimens produced decreased by 29% after 2 days, 29% after 7 days and 27% after 28 days compared to that with pure cement used. Finally, with S6 grade cement used, the strength of the mortar specimens produced decreased by 36% after 2 days, 34% after 7 days and 32% after 28 days compared to that with pure cement used.

Based on the data obtained at the end of the tests, the compressive strength obtained for all trass substitution rates were lower than the value obtained for pure cement. However, it was shown that the strength rates increased as the hydration duration progressed. According to the findings obtained in the study, compressive strengths at the end of 28 days of all cement mortar samples are above the minimum compressive strength of 42.5 N/mm^2. Furthermore, at 7 and 28 days compared to 2 days the relative strength shows a clear increase, due mainly to the pozzolanic reaction of the trass. As a result, this fact confirms that even long–term cement strength is affected by the trass in a positive way.

The compressive strengths of the cement mortars at 2, 7 and 28 days which are experimentally obtained and estimated with fuzzy logic are given in Figure 3.

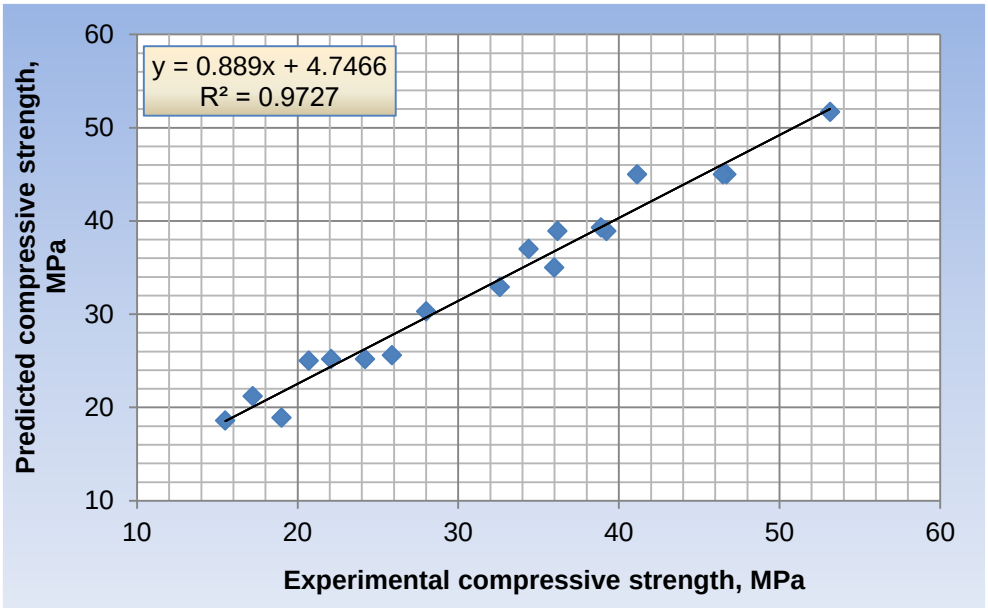


Figure 3. Relationship between experimental and predicted values for compressive strengths of the cement mortars at 2, 7 and 28 days.

When the results obtained from performed experiments and the estimations made by the fuzzy logic and correlation coefficient is taken into account it is observed that very close results are obtained for compressive strengths of the cement mortars at 2, 7 and 28 days (R^2= 0.97) (Figure 3).

5. CONCLUSIONS

In this study, the effects of trass addition to PC on the compressive strengths are studied, estimation models are formed with fuzzy logic method for estimating compressive strengths in accordance with trass amount and experimental results and estimated values are compared and evaluated.

Accordingly:

- As a result of experiments, the compressive strengths of the pure cement mortars (S2) are defined 24.2 MPa after 2 days, 39.2 MPa after 7 days and 53.2 MPa after 28 days.
- When trass is substituted into PC in 10 % ratio (S2), the strength of the mortar specimens are defined 22.1 MPa after 2 days, 36.2 MPa after 7 days and 46.7 MPa after 28 days.
- When trass is substituted into PC in 15 % ratio (S3), the strength of the mortar specimens are defined 20.7 MPa after 2 days, 34.4 MPa after 7 days and 46.5 MPa after 28 days.
- When trass is substituted into PC in 20 % ratio (S4), the strength of the mortar specimens are defined 19.0 MPa after 2 days, 32.6 MPa after 7 days and 41.1 MPa after 28 days.
- When trass is substituted into PC in 25 % ratio (S5), the strength of the mortar specimens are defined 17.2 MPa after 2 days, 28.0 MPa after 7 days and 39.3 MPa after 28 days.
- When trass is substituted into PC in 30 % ratio (S6), the strength of the mortar specimens are defined 15.5 MPa after 2 days, 25.9 MPa after 7 days and 36.0 MPa after 28 days.
- The model formed with fuzzy logic yielded compressive strengths values similar to the ones obtained from experiments. The correlation coefficient between the estimated and experimental values is found as 0.97. When the results are examined it is understood that fuzzy logic method can be used in estimating the compressive strengths of the cement mortars at 2, 7 and 28 days depending on trass amounts.

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