

PREDICTION THE EFFECTS OF BLAST FURNACE SLAG AND WASTE TIRE RUBBER POWDER ON THE SETTING TIME OF PORTLAND CEMENT WITH FUZZY LOGIC

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Abstract

In the present study, the effects of the cements formed by substituting Portland Cement (PC) with different ratios of blast furnace slag and waste tire rubber powder on initial and final setting times are investigated. To this purpose, Portland cement replaced with blast furnace slag as a ratio of its weight of 0, 5, 10, 15 and 20%, waste tire rubber powder as a ratio of its weight of 0, 2.5, 5%, both blast furnace slag and waste tire rubber powder as a ratio of its weight of 2.5+2.5%, 7.5+2.5%, 5+5%, 10+5% and 15+5%. By this procedure, twelve different mixtures were prepared and effect of cement was investigated on the initial and final setting time. According to the results obtained in the initial and final setting times all the mixing ratio of the prolonged period of time was determined. Also, by using Fuzzy Logic method, prediction model was formed based on the quantity of blast furnace slag and waste tire rubber powder to predict the initial and final setting times of cement. The experimental results are compared with the fuzzy logic results and the correlation coefficients for the initial and final setting time are found 0.93 and 0.95, respectively. These results show that the developed model can be successfully applied in the cement and concrete industry.

Keywords: Fuzzy logic, Portland cement, blast furnace slag, waste tire rubber powder, setting time

1. INTRODUCTION

Various types of additive materials that improve cement and concrete properties have been used in the cement and concrete industry for a long time. These materials are trass, zeolite, diatomite, metakaolin, silica fume, fly ash, blast furnace slag, waste tire rubber powder and so on. The use of additive materials due to economic reasons, facilitate waste recycle for ecological balance, advantages such as resistance and endurance, permeability reduction, control of alkaline aggregate development, providing chemical resistance has become very common in modern cement and concrete technology (Kocak & Nas 2014; Worrell, Martin & Price 2000; Yung, Yung and 2012).

In addition to these advantages additive materials are also effective on setting time. Setting of the cement can be defined as the hardening of the cement upon its reaction with water. When this process occurs rapidly some problems may arise during the transportation and placement of the fresh concrete. On the other hand, when hardening takes longer then concrete may not acquire the resistance in desired time and molding time may be delayed. For this reason standards specify the initial setting time as at least 60 min. and final setting time as 600 min. (TS EN 197-1, 2002). For this purpose chemical or mineral materials having different characteristics are added to cement in different amounts in order to increase or decrease setting time according to desired properties. The setting time of cement mortar with blast furnace slag is generally greater than that of similar cement mortar with Portland cement only. Miyazawa S. et al. (1995) investigated the effect of blast furnace slag additions on the setting times. Cements were partially replaced with 12, 20 and 25% of blast furnace slag. According to the obtained results it is found setting time of cements was increased with the increase in blast furnace slag content. Wainwright and Ait-Aider (1995) found that blast furnace slag substituted cements with 40 and 70 % substitution ratio delay initial setting times 56 minutes and 133 minutes, final setting times 42 minutes and 136 minutes, respectively. Al-Akhras and Smadi (2004) studied the properties of

tire-rubber ash mortar. Tire-rubber ash was utilized as partial replacement of sand in five percentages ranging from 0 to 10% with an increment of 2.5% by weight of sand. According to the obtained results, both initial and final setting time increased with the increase in tire-rubber ash content.

Expert systems in the recent studies have been generally used for prediction, classification and clustering. 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 and it makes inferences. At the output unit, fuzzy output values are defuzzified (Guler, Tunca & Gulbandilar, 2008). Fuzzy logic and artificial neural networks are now used in various fields of construction. The modeling studies of setting time and 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 (Gulbandilar & Kocak, 2013; Ozgan & Yildiz; 2009; Saridemir, 2009).

In this work the effects of the cements formed by substituting Portland cement with different ratios of blast furnace slag and waste tire rubber powder on initial and final setting times are studied. The obtained results are compared with reference values and it is aimed to estimate initial and final setting times of cements with fuzzy logic method.

2. MATERIAL AND METHOD

The materials used in this study are Portland cement (PC), blast furnace slag (BFS) and waste tire rubber powder (WTRP). The PC was CEM I 42.5 R in accordance with TS EN 197-1, which was provided from SET Istanbul Ambarli Cement Plant which is used as reference. BFS was obtained from the Eregli Iron and Steel Plant in Zonguldak (Turkey). WTRP was obtained from the A Commercial Business in Ankara (Turkey). WTRP, in the bottom during the making various grades and sizes of granules obtained from waste tires in very fine powder, and was obtained by sieving 125 µm sieve. In preparation of cement paste city water supply of Istanbul Province Buyukcekmece District is used.

In this study twelve different mixtures are done where PC is reference. The produced reference and blended cement codes are given in Table 1. Analysis results depicting the chemical compositions of the blended cements are given in Table 2.

Table 1. Codes of reference and blended cements.

Number of samples	Cement type	Cement code
1	Portland cement (PC 42.5 R)	S1
2	BFS substituted cement, 5 %	S2
3	BFS substituted cement, 10 %	S3
4	BFS substituted cement, 15 %	S4
5	BFS substituted cement, 20 %	S5
6	WTRP substituted cement, 2.5 %	S6
7	WTRP substituted cement, 5 %	S7
8	BFS and WTRP substituted cement, 2.5+2.5 %	S8
9	BFS and WTRP substituted cement, 7.5+2.5 %	S9
10	BFS and WTRP substituted cement, 5+5 %	S10
11	BFS and WTRP substituted cement, 10+5 %	S11
12	BFS and WTRP substituted cement, 15+5 %	S12

Table 2. Chemical compositions of used materials.

Materials	S1, %	S2, %	S3, %	S4, %	S5, %	S6, %	S7, %	S8, %	S9, %	S10, %	S11, %	S12, %
Chemical composition, %												
SiO ₂	19,84	20,20	20,89	22,00	23,43	19,67	19,66	19,85	21,36	20,72	21,37	22,18
Al ₂ O ₃	5,16	5,47	5,85	6,45	7,24	5,16	5,17	5,30	6,03	5,70	6,09	6,52
Fe ₂ O ₃	2,62	2,57	2,53	2,44	2,30	2,66	2,70	2,63	2,55	2,63	2,55	2,51
CaO	63,48	62,35	61,32	59,53	57,33	62,44	61,25	61,71	59,93	59,95	58,93	57,37
MgO	1,11	1,33	1,60	2,04	2,61	1,14	1,16	1,25	1,74	1,54	1,81	2,13
SO ₃	2,81	2,81	2,64	2,56	1,98	1,79	0,82	1,95	1,20	0,33	0,90	0,22
K ₂ O	0,78	0,81	0,79	0,80	0,82	0,79	0,80	0,79	0,81	0,81	0,82	0,83
Na ₂ O	0,41	0,43	0,44	0,46	0,47	0,43	0,46	0,44	0,54	0,54	0,54	0,56

Initial and final setting times of each cement are determined with 3 experiments in accordance with (TS EN 196-3, 2002). Initial and final setting times are performed in SET Istanbul Cement Factory. This process is undertaken in a laboratory environment where ambient temperature is 20 °C and relative humidity is 65 %. With the help of Vicat apparatus initial and final setting times are determined as follows; the time needed for the Vicat needle to sink into cement paste until there is 4±1 mm distance between the needle and the glass board is said to be initial setting time whereas the time needed for the needle to sink into cement paste until there is 0.05 mm distance between the needle and the top of cement paste is taken as final setting time.

3. PREDICTION OF THE SETTING TIME WITH FUZZY LOGIC

The design of the fuzzy system that is used for the estimation operations is done with C# programming language. The percentage ratios of BFS and WTRP's weights are used as inputs for fuzzy logic system. In fuzzification of these input values fuzzy sets given in Figure 1 are used.

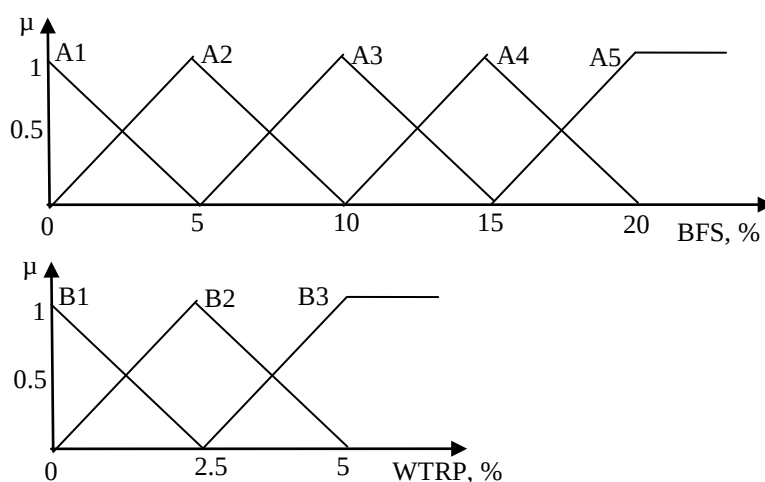


Figure 1. Membership functions of input variables.

For fuzzification, BFS and WTRP percentage ratios are split into five input sets and tree input sets, 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 triangular membership functions are used in calculation of membership degrees the following relation is used (Guler, Tunca & Gulbandilar. 2008).

$$\mu(x) = \begin{cases} 0 & \text{for } x < a \\ \frac{x-a}{b-a} & \text{for } a < x < b \\ \frac{c-x}{c-b} & \text{for } b < x < c \\ 0 & \text{for } c > 0 \end{cases} \quad (1)$$

Here a, b and c indexes show the crisp values of triangular membership functions. For example when BFS ratio is 14 % and membership degrees of A1, A2 and A5 sets are 0, membership degrees of sets A3 and A4 can be calculated as 0.2 and 0.8, respectively. If the BFS ratio is 35 % or above, when the membership degree of set A5 is 1 the membership degrees of other sets will be 0. Equation 1 is also used in calculation and fuzzification of membership degrees of WTRP. For example when WTRP ratio is 1 % and membership degrees of sets B1 and B2 are 0.6 and 0.4 respectively then membership degrees of other sets will be 0.

For membership functions of the output variables, i.e. initial and final setting times, triangle and trapezoid shapes are preferred as seen in Figure 2. In determining the shape of output membership functions, again, experimental results are taken into account.

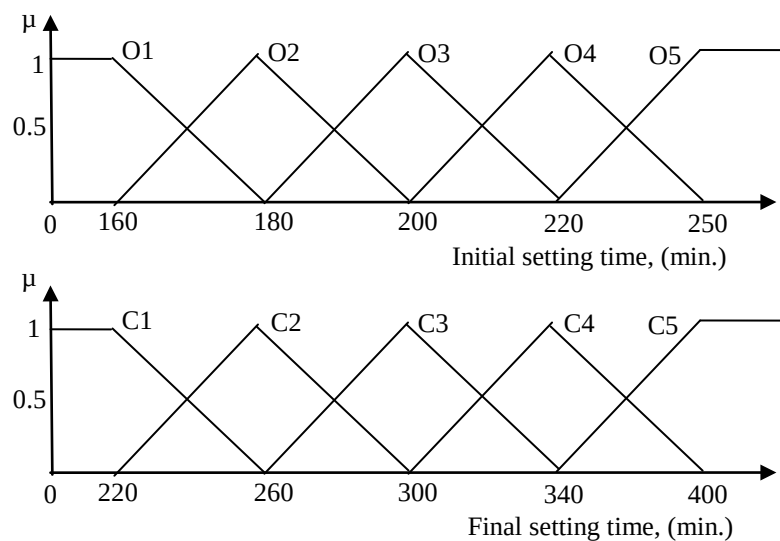


Figure 2. Membership functions of output variables.

The main structure of fuzzy decision making systems is the rule bases. 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 and Table 4 are formed for initial and final setting times, respectively (Hsu, Lee, Kreng, 2010).

Table 3. Rule base of initial setting time.

	A1	A2	A3	A4	A5
B1	O1	O2	O3	O3	O3
B2	O3	O4	O5	O5	O5
B3	O5	O4	O5	O5	O5

Table 4. Rule base of final setting time.

	A1	A2	A3	A4	A5
B1	C1	C2	C2	C3	C3
B2	C4	C4	C4	C4	C4
B3	C5	C5	C5	C5	C5

Since input variables are identical for both initial and final setting times the rule bases are merged and a total of 15 “If-then” relations are obtained as sampled below.

If input1=A1 and input2=B1 then output1=O1 and output2=C1

If input1=A4 and input2=B3 then output1=O5 and output2=C5

If input1=A5 and input2=B2 then output1=O5 and output2=C4

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;

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

where x^* defuzzification output value, μ_i the membership degree of each rule’s output and x_i weighted average of each rule (Hsu, Lee & Kreng, 2010; Ajayi, Aderounmu, Soriyan & David, 2010).

4. FINDINGS

Table 5 and Table 6 show the Initial and final setting times, respectively, according to the results obtained from the experiments performed in compliance with TS EN 196-3 on cement pastes used in this study and the results obtained from fuzzy logic model.

Table 5. Initial setting times of the blended cements (minute)

Number of samples	Cements											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	160	190	190	190	210	210	250	220	240	220	250	240
2	160	185	190	195	205	210	250	225	240	225	245	245
3	165	195	195	190	215	215	245	215	235	215	250	240
Average	162	190	192	192	210	212	248	220	238	220	248	242
Index, %	100	118	119	119	130	131	154	136	147	136	154	149
Estimates with fuzzy logic, $R^2 = 0.93$	166	180	200	200	200	200	240	214	228	223	240	240

Table 6. Final setting times of the blended cements (minute)

Number of samples	Cements											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	230	240	260	280	310	320	360	330	350	370	370	400
2	230	245	265	280	305	320	365	335	350	365	375	395
3	235	240	255	285	310	325	360	325	345	375	370	400
Average	232	242	260	282	308	322	362	330	348	370	372	398
Index, %	100	104	112	122	133	139	156	142	150	160	160	172
Estimates with fuzzy logic, $R^2 = 0.95$	233	260	260	300	300	347	381	348	348	381	381	381

According to Table 5 with BFS and WTRP addition to PC the initial setting time of the cement paste, when compared to reference value, is extended for all mixture ratios. In BFS substituted cement initial setting time is extended, in direct proportion with admixture ratio, by 18 % in S2 coded cement paste specimen, by 19 % in S3 coded cement paste specimen, by 19 % in S4 coded cement paste specimen and 30 % in S5 coded cement paste specimen. In WTRP substituted cement initial setting time is extended by 31 % in S6 coded cement paste specimen whereas S7 coded cement paste specimen has a significant effect which extends the initial setting time by 54 %. In cements with both BFS and WTRP substitution initial setting time is extended by 36 % in S8 coded cement paste specimen, by 47 % in S9 coded cement paste specimen, by 36 % in S10 coded cement paste specimen, by 54 % in S11 coded cement paste specimen and 49 % in S12 coded cement paste specimen due to the fact that both of the additives extend the setting time. When a general assessment is made the minimum extension with respect to reference cement (S1) is found to be 26 % in S2 coded cement paste specimen while the maximum extension is found as 54 % in S8 and S11 coded cement paste specimen and a linear increase for all mixture ratios is observed. When these times are examined it can be observed that minimum setting time is provided to be more than 60 minutes.

According to Table 6 with BFS and WTRP addition to PC the final setting time of the cement paste, when compared to reference value, is extended for all mixture ratios. In BFS substituted cement final setting time is extended, in direct proportion with admixture ratio, by 4 % in S2 coded cement paste specimen, by 12 % in S3 coded cement paste specimen, by 22 % in S4 coded cement paste specimen and 33 % in S5 coded cement paste specimen. In WTRP substituted cement initial setting time is extended by 39 % in S6 coded cement paste specimen and 56 % in S7 coded cement paste specimen.

In cements with both BFS and WTRP substitution initial setting time is extended by 42 % in S8 coded cement paste specimen, by 50 % in S9 coded cement paste specimen, by 60 % in S10 coded cement paste specimen, by 60 % in S11 coded cement paste specimen and 72 % in S12 coded cement paste specimen due to the fact that both of the additives extend the setting time. S12 coded cement paste specimen has a significant effect which extends the final setting time by 54 %. When a general assessment is made the minimum extension with respect to reference cement (S1) is found to be 12 % in S2 coded cement paste specimen while the maximum extension is found as 72 % in S12 coded cement paste specimen and a linear increase for all mixture ratios is observed. When these times are examined it can be observed that maximum setting time is provided to be less than 600 minutes.

In general, when average initial setting times are compared the reference (S1) cement has the minimum time which is 162 minutes and S7 and S11 coded cement paste specimen has the maximum time which is 248 minutes (Table 5). Average final setting times are compared the reference (S1) cement has the minimum time which is 232 minutes and S12 coded cement paste specimen has the maximum time which is 398 minutes (Table 6).

Initial setting times which are experimentally obtained and estimated with fuzzy logic are given in Figure 3 whereas final setting times are given in Figure 4.

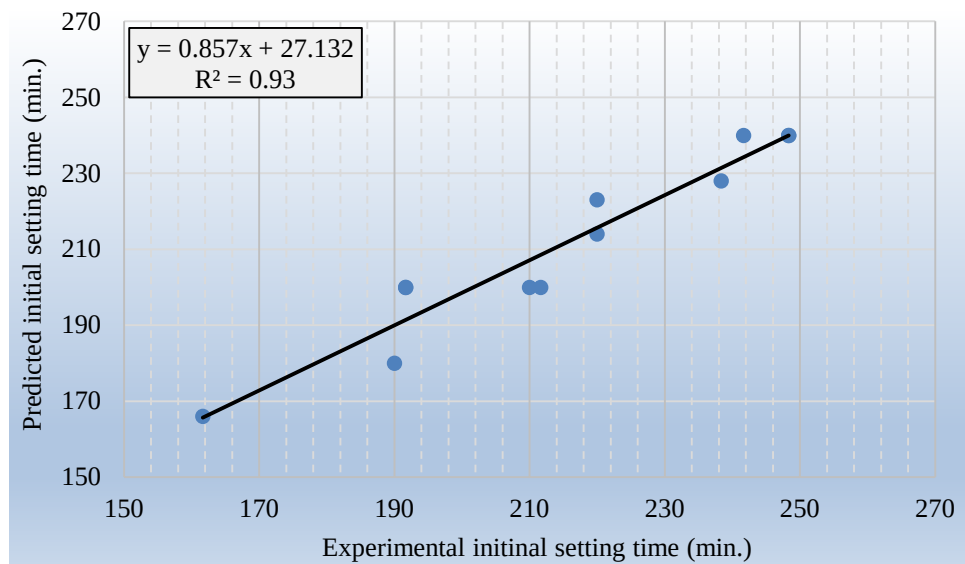


Figure 3. Relationship between experimental and predicted values for initial setting times.

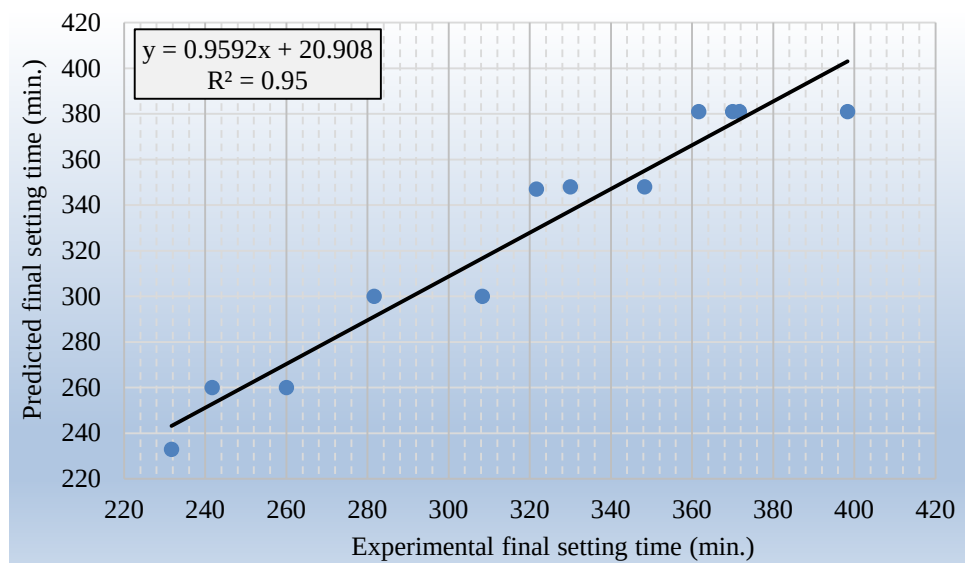


Figure 4. Relationship between experimental and predicted values for final setting times.

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 initial setting time ($R^2 = 0.93$) and final setting time ($R^2 = 0.95$) (Figure 3 and Figure 4).

5. RESULTS AND RECOMMENDATIONS

5.1. Results

In this study the effects of reference BFS and WTRP substituted cements on the initial and final setting times are studied, estimation models are formed with fuzzy logic method for estimating initial and final setting times in accordance with BFS and WTRP amount and experimental results and estimated values are compared and evaluated. Accordingly;

- As a result of experiments minimum initial setting time is found to be 230 minutes for reference samples (S1) while average initial setting time is 232 minutes. On the other hand average final setting time is determined as 242 minutes.
- When BFS is substituted into PC in 5 % ratio (S2) initial and final setting times are measured on average as 190 minutes and 242 minutes, respectively. On the other hand it is determined that average initial setting time is 18 % more than the reference value while final setting time is 4 % longer.
- When BFS is substituted into PC in 10 % ratio (S3) initial and final setting times are measured on average as 192 minutes and 260 minutes, respectively. On the other hand it is determined that average initial setting time is 19 % more than the reference value while final setting time is 12 % longer.
- When BFS is substituted into PC in 15 % ratio (S4) initial and final setting times are measured on average as 192 minutes and 282 minutes, respectively. On the other hand it is determined that average initial setting time is 19 % more than the reference value while final setting time is 22 % longer.
- When BFS is substituted into PC in 20 % ratio (S5) initial and final setting times are measured on average as 210 minutes and 308 minutes, respectively. On the other hand it is determined that average initial setting time is 30 % more than the reference value while final setting time is 33 % longer.
- When WTRP is substituted into PC in 2.5 % ratio (S6) Initial and final setting times are measured on average as 212 minutes and 322 minutes, respectively. On the other hand it is determined that average initial setting time is 31 % more than the reference value while final setting time is 39 % longer.
- When WTRP is substituted into PC in 5 % ratio (S7) Initial and final setting times are measured on average as 248 minutes and 362 minutes, respectively. On the other hand it is determined that average initial setting time is 54 % more than the reference value while final setting time is 56 % longer.
- When BFS (2.5%) and WTRP (2.5%) are substituted into PC (S8) Initial and final setting times are measured on average as 220 minutes and 330 minutes, respectively. On the other hand it is determined that average initial setting time is 36 % more than the reference value while final setting time is 42 % longer.
- When BFS (7.5%) and WTRP (2.5%) are substituted into PC (S9) Initial and final setting times are measured on average as 238 minutes and 348 minutes, respectively. On the other hand it is determined that average initial setting time is 47 % more than the reference value while final setting time is 50 % longer.
- When BFS (5%) and WTRP (5%) are substituted into PC (S10) Initial and final setting times are measured on average as 220 minutes and 370 minutes, respectively. On the other hand it is

determined that average initial setting time is 36 % more than the reference value while final setting time is 60 % longer.

- When BFS (10%) and WTRP (5%) are substituted into PC (S11) Initial and final setting times are measured on average as 248 minutes and 372 minutes, respectively. On the other hand it is determined that average initial setting time is 54 % more than the reference value while final setting time is 60 % longer.
- When BFS (15%) and WTRP (5%) are substituted into PC (S12) Initial and final setting times are measured on average as 242 minutes and 398 minutes, respectively. On the other hand it is determined that average initial setting time is 49 % more than the reference value while final setting time is 72 % longer.
- The model formed with fuzzy logic yielded initial setting time values similar to the ones obtained from experiments. The correlation coefficient between the estimated and experimental values is found as 0.93. Likewise it is determined that the estimated and experimental values for final setting time are very similar and the correlation coefficient between them is 0.95. When the results are examined it is understood that fuzzy logic method can be used in estimating initial and final setting times of cement depending on BFS and WTRP amounts.

5.2. Recommendations

In today's world set delaying or accelerating admixtures are widely used with cement. However in this study the feasibility of using BFS and WTRP, which have an important place among materials for environment pollution and ecological balance protection, as set delaying or accelerating agents in cement is studied. Using the obtained experimental results estimation models are formed with fuzzy logic for setting times and it is observed that these models can be used for estimating setting times of BFS and WTRP. For this reason it is thought that these materials can be used with chemical additives in cement as set delaying or accelerating agents. However, it will be beneficial to conduct experiments on cements obtained with the substitution of these materials in order to assess physical characteristics such as pressure resistance, expansion values, void ratio, unit volume weights and water absorption ratios. Furthermore it is anticipated that some of these experiments, pressure resistance being the first, can be modeled with fuzzy logic.

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