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Modeling of mechanical properties of roller compacted concrete containing RHA using ANFIS

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Abstract. In recent years, the use of supplementary cementing materials, especially in addition to concrete, has been the subject of many researches. Rice husk ash (RHA) is one of these materials that in this research, is added to the roller compacted concrete as one of the pozzolanic materials. This paper evaluates how different contents of RHA added to the roller compacted concrete pavement specimens, can influence on the strength and permeability. The results are compared to the control samples and determined optimal level of RHA replacement. As it was expected, RHA as supplementary cementitious materials, improved mechanical properties of roller compacted concrete pavement (RCCP). Also, the application of adaptive neuro-fuzzy inference system (ANFIS) in predicting the permeability and compressive strength is investigated. The obtained results shows that the predicted value by this model is in good agreement with the experimental, which shows the proposed ANFIS model is a useful, reliable, fast and cheap tool to predict the permeability and compressive strength. A mean relative error percentage (MRE %) less than 1.1% is obtained for the proposed ANFIS model. Also, the test results and performed modeling show that the optimal value for obtaining the maximum compressive strength and minimum permeability is offered by substituting 9% and 18% of the cement by RHA, respectively.

Keywords: rice husk ash; roller compacted concrete pavement; servopac gyratory compactor; mechanical properties; adaptive neuro-fuzzy inference system; modeling

1. Introduction

Roller-compacted concrete (RCC) is being used in many parts of the world for the construction of dams. Use of RCC for pavements is relatively new and growing interest. RCC for pavement is a relatively stiff mixture of aggregates, cementitious materials, and water, which is generally placed by asphalt paving equipment and compacted by vibratory rollers (Palmer 1987, Marchand *et al.* 1997). Roller compacted concrete pavement (RCCP) is placed without forms, finishing and surface texturing. RCCP does not require joints, dowels, reinforcing steel, or formwork. Therefore, relatively large quantities of RCCP can be placed rapidly with minimal labor and equipment, resulting in speedy completion of tightly scheduled pavements (ACI 325.10R-95 2001). Because of the low water to cementitious materials ratio in a RCCP mixture, it typically exhibits strengths equivalent to, or greater than, the conventional concrete pavements (ACI 325.10R-95 2001, PCA 1987, Brendel and Kelly 1991). The RCC main benefit is the cost savings, resulting from its method of production, construction and the speed of paving operations (Canadian Portland Cement Association 2010).

In the last decade, the use of supplementary cementing materials has become an integral part of high strength and high performance concrete mix design. These can be natural materials, by-products or industrial wastes, or the ones requiring less energy and time to produce. Some of the commonly used supplementary cementing materials are the fly ash, Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBFS) and Rice Husk Ash (RHA) etc. (Givi *et al.* 2010). One of the most promising materials is RHA (Habeeb and Mahmud 2009). Globally, approximately 600 million tons of the rice paddies are produced each year. On average 20% of the rice paddy is husk, giving an annual total production of 120 million tones (Bronzeoak Ltd 2003). Rice husk is the outer covering of the grain of rice plant with a high concentration of silica, generally more than 80-85% (Siddique 2008), highly porous and lightweight, with a very high external surface area. The non-crystalline silica and high specific surface area of the RHA are responsible for its high pozzolanic reactivity (Smith and Kamwanja 1986, Zhang *et al.* 1996, Nicole *et al.* 2000, Sakr 2006, Sata *et al.* 2007). The RHA absorbent and insulating properties are useful to many industrial applications. RHA is a general term describing all types of ash produced from burning rice husks. In practice, the type of ash varies considerably according to the burning technique.

The silica in the ash undergoes structural transformations depending on the conditions (time, temperature etc.) of combustion. At 550°C-800°C,

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Table 1 Chemical compositions of the studied type I cement (Esfahan Cement Factory 1993)

Component %	Type I cement	RHA
SiO_2	21.68	85.02
Al_2O_3	5.72	0.393
Fe_2O_3	3.28	0.393
CaO	63.53	0.45
MgO	1.75	2.39
SO_3	1.62	0.785
K_2O	0.52	0.557
Na_2O	0.20	5.98
LOI	1.24	2.46
Total	100	100

Table 2 ASTM C-618 specifications

ASTM C-618 min	SiO2+Al2O3+Fe2O3 (%)=70	Max SO_3 (%)=4	Max LOI (%)=6
Current RHA	85.86%	0.557%	2.46%

Table 3 Grading of combined aggregates with ACI standard limit (% passed)

Sieve Size (mm)	Lower limit of ACI 325.10R	Middle limit of ACI 325.10R	Aggregate grading	Upper limit of ACI 325.10R
25.4	100	100	100	100
19	83	91.5	97	100
12.4	72	82.5	83.9	93
9.5	66	75.5	75.89	85
4.75	51	60	62.03	69
2.38	38	47	44.52	56
1.2	28	37	32	46
0.6	18	27	22.25	36
0.3	11	19	14.32	27
0.15	6	12	9.35	18
0.075	2	5	5.62	8

amorphous ash is formed and at the temperatures greater than this, the crystalline ash is formed. These types of silica have different properties and it is important to produce the ash with the correct specification for the particular end use (Bronzeoak Ltd 2003). RCC is a friendly pavement material in which to incorporate by-products from industries. The use of by-product materials in RCC can be achieved by directly adding these materials to the mixture proportions or by replacing the fine mineral aggregate content (Modarres and Hosseini 2014). There are several reports that have addressed the effects of RHA as a substitute material on RCCP mixtures.

During a laboratory study, natural RHA has been utilized in order to the partially substitute the mineral aggregate in diverse proportions within the RCC dosage. The evaluated properties were the compressive strength, flexural strength, and modulus of elasticity. It was found that the addition of 5% RHA to the RCC produces increases the compressive strength, flexural strength, and modulus of elasticity values. These increments were independent of the curing age of the mixtures or the cement consumption utilized. The addition of 5% RHA in the RCC also diminishes the cement consumption necessary to reach the desired flexural strength and produces a reduction in the quantity of necessary mineral aggregates in RCC dosage (Villena *et al.* 2011).

In a similar study, the effects of RHA on the mechanical properties of RCC designed with original and reclaimed asphalt pavement (RAP) materials have been investigated. In this research, the RCC mixes were produced by partial substitution of cement with RHA at varying amounts of 3% and 5%. The main experimental design consisted of the compressive strength and three points bending tests. It was concluded that the Addition of 3% RHA reduces the porosity especially after 120 days curing and improves the fatigue resistance. However, the addition of RHA to 5% resulted in higher porosities and lower fatigue lives (Modarres and Hosseini 2014).

During an another laboratory research, the effects of addition of 5% of RHA in partial substitution of the mineral aggregate and its influence on the compressive strength, flexural strength and modulus of elasticity in 3, 7, 14, 28 and 90 days after moulding has been analyzed. The results revealed that the optimal value for these properties was obtained by substituting 5% of the aggregate by RHA. Regarding the compressive strength, the achieved increase exceeded 135% in comparison to the mixture without RHA. For the flexural strength this increase exceeded 60% and for the modulus of elasticity, 70% (ArnaldoVillena Del Carpio 2009).

In this study, the impact of adding RHA to RCC in substitution of the cement on mechanical properties of the mixture is investigated. The results are compared to those obtained for the mixtures without RHA. For this purpose, mixtures of RCC are dosed, containing 0, 5%, 15%, 30%, 45% and 50% RHA, replacing the cement. In the testing process, the following properties are observed: compressive strength and permeability.

2. Experimental design

2.1 Materials

2.1.1 Cement

The used cement is type I Portland cement of Esfahan cement factory. The specific gravity of the used cement is 3.15. The initial and final setting times of the cement are 110 and 210 min, respectively. Its Blaine specific surface area is 310 m^2/kg.

2.1.2 Rice husk ash

Rice husks were burnt approximately 4 hours under the controlled combustion process in two stages: the carbonation and decarbonation in two furnaces. First the rice husks were burnt in free air condition in a special furnace for about 2 h. Then, the resulting black powder was transferred to an electric arc furnace with the capability of discharging the CO_2 content of RHA. The burning temperature was within the range of 530 to 650°C. The ash

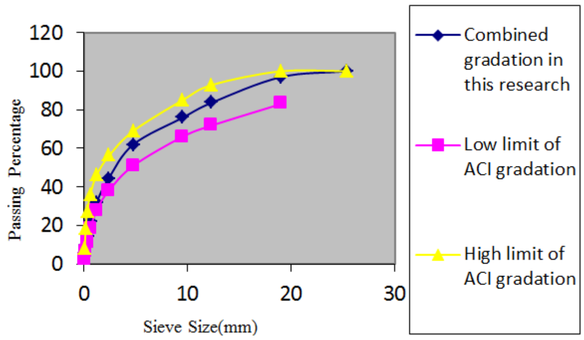

Fig. 1 Comparison of the research combined gradation with ACI gradation specifications

Table 4 Test results on the coarse aggregates

Description of test	Value	Standard
maximum nominal size	19 mm	ASTM C136
Density	2673 kg/m^3	ASTM C127
Natural moisture percent	0.17%	ASTM C566
Water absorption value(SSD)	0.35%	ASTM C127
Los Angeles	23%	ASTM C131

Table 5 Test results on the fine aggregates

Description of test	Value	Standard
Density	2620 kg/m^3	ASTM C128
Natural moisture percent	2.33%	ASTM C566
Water absorption value(SSD)	1.37%	ASTM C128
Fineness coefficient	2.81%	ASTM C136
Sand Equivalent Value	81.3%	ASTM D2419
Plastic Index	No plastic	ASTM D4318

obtained was ground in a ball mill for 30 minutes and in a disk mill for 15 minutes. Grounded ash was passed from 300 μm sieve. Thus, the grounded ash with the disk mill was used. The ash appearance color was grey.

The cement and RHA chemical compositions and the specifications of ASTM C-618 are given in Table 1 and Table 2, respectively. Table 2 shows that current RHA fully meets these specifications.

According to the chemical characteristics by XRF analysis, the RHA has a high level of silicon dioxide, approximately 86%. Also, XRD analysis results showed that the silica is in the amorphous phase. This silica is suitable for the pozzolanic reaction with cement.

2.1.3 Aggregate

In this research, the coarse and fine aggregates were provided from Naien road way project (Sejzi industrial town) in Esfahan. The fine aggregates were containing of combination of the natural and crushed sand and the coarse aggregates were crushed stones with the maximum nominal size of ¾ in (19 mm). In order to provide finer aggregates less than 0.075 mm, filler was used, too. The fine aggregates was included of 13% lime filler, 78% crushed sand and 9% natural sand. Combined gradation of aggregates are shown in Table 3 and its comparison with

Table 6 Concrete mixture proportions in this research

Mix number	Optimal W/(C+RHA) ratio	Water Lit/m^3	Cementitious materials			Total of cementitious material (kg/m^3)	Cement weight by the total dry materials (%)	Aggregates		(Gravel/Sand) ratio
			RHA kg/m^3	Cement kg/m^3	RHA /Cement (%)			Sand kg/m^3	Gravel kg/m^3	
Rcc-P0	0.48	131.52	0	274	0					
Rcc-P5	0.5	137	13.7	260	5					
Rcc-P15	0.53	145.22	41.1	233	15	274	13	1155.42	935.55	45.55
Rcc-P30	0.6	164.4	82.2	192	30					
Rcc-P45	0.646	177	123.3	151	45					
Rcc-P50	0.648	177.55	137	137	50					

Table 7 Results of compressive strength

Mix No.	Gyration No.	Density (kg/m^3)	Compressive strength (7days, MPa)	Compressive strength (28days, MPa)
Rcc-P0	50	2464.2	24	32.04
Rcc-P0	60	2478.3	27.67	35.42
Rcc-P0	70	2494.8	28.5	37.82
Rcc-P5	50	2440.0	25.31	33.25
Rcc-P5	60	2459.3	28.2	36.49
Rcc-P5	70	2473.2	29.45	39.42
Rcc-P15	50	2395.1	23.06	33.52
Rcc-P15	60	2412.3	25.12	35.63
Rcc-P15	70	2424.6	27.06	38.13
Rcc-P30	50	2363.9	20.4	30.33
Rcc-P30	60	2376.0	25.56	33
Rcc-P30	70	2402.1	26.07	33.42
Rcc-P45	50	2343.1	16.41	25.45
Rcc-P45	60	2356.2	17.04	26.93
Rcc-P45	70	2378.8	17.54	27.02
Rcc-P50	50	2324.0	13.84	22
Rcc-P50	60	2333.5	14	22.32
Rcc-P50	70	2336.2	15.3	22.7

ACI 325.10R gradation specifications are given in Fig. 1. This comparison shows that the research gradation is adopted with ACI gradation specifications.

The results of the fine and coarse aggregates are shown in Tables 4 and 5.

2.1.4 Water

The used water for the making concrete and curing of samples was the drinkable water of Esfahan city.

3. Composition of concrete mixtures

In this research, five different concrete mixture proportions were prepared. The mix proportion of materials was done based on the soil compaction procedure (Standard ASTM D1557). In this study, the concrete mixtures were prepared with cement 11%, 13% and 15% of the total mass of the dry materials. For the mixtures with mentioned binder contents, water was used at the levels of 4%, 5%, 6%, 7% and 8% by the mass (aggregates and cement) and

Table 8 Results of permeability (cm/sec)

Mix No.	Gyration No.	28 days
Rcc-P0	50	1.71E-11
Rcc-P0	60	1.58E-11
Rcc-P0	70	1.44E-11
Rcc- P5	50	1.44E-11
Rcc- P5	60	1.37E-11
Rcc- P5	70	1.16E-11
Rcc-P15	50	8.90E-12
Rcc-P15	60	7.00E-12
Rcc-P15	70	6.30E-12
Rcc-P30	50	1.22E-11
Rcc-P30	60	9.70E-12
Rcc-P30	70	8.90E-12
Rcc-P45	50	1.76E-11
Rcc-P45	60	1.73E-11
Rcc-P45	70	1.69E-11
Rcc-P50	50	2.31E-11
Rcc-P50	60	2.28E-11
Rcc-P50	70	2.21E-11

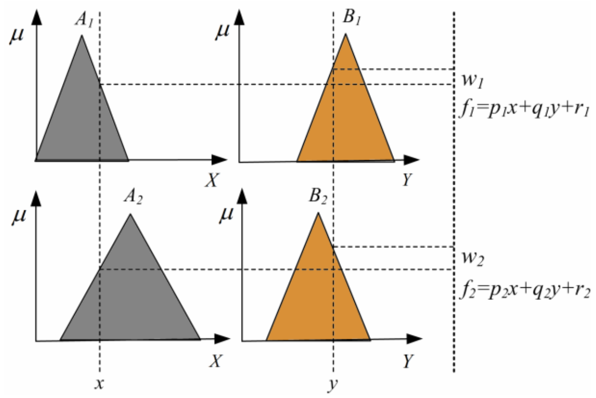

Fig. 2 The inference method of Sugeno model

by use of the standard ASTM D1557, the optimum moisture was obtained. Finally, level of cement (13%) that its mixtures compressive strength was 34 MPa, was selected. For the purpose of investigating the influence of the RHA on the mechanical properties of RCC specimens, some of the samples were produced using RHA as the cement replacement at the levels of 5%, 15%, 30%, 45% and 50% by the mass. Table 6 presents the composition of the concretes produced and tested.

4. Samples preparation

The samples compaction and their preparation were done with Gyratory compactor machine in the cylinder moulds with 150 mm diameter and 200 mm height. After producing, the samples were maintained for 24 hours in the air and then cured under water with 23℃ temperature. They were kept in curing chamber until they were tested.

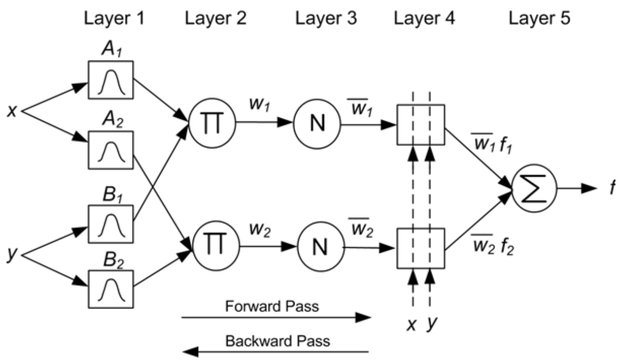

Fig. 3 ANFIS architecture based on Takagi-Sugeno

5. Results and discussion

5.1 Determination of optimum number gyration

The gyration number that can be applied with gyratory compactor machine is ranged from 0 to 999. In this research, the Gyration number was determined so that the samples exert intact. Thus, the samples were prepared with 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 gyrations. Finally, the produced samples with 50-70 gyration were exerted quite intact from the mould. The main samples were prepared with these gyration numbers.

5.2 Compressive strength

The compressive strength of the produced concrete is shown in Table 7. Each of the strengths is the average of three samples strength. This table shows that the compressive strength and the density of total mixtures increase as the gyration number increases. Because with increasing of the gyration number, the compaction effort increases and the voids percentage decreases.

It is obvious that the samples contained RHA have lower density compared with the control samples due to the lower density of RHA in comparison with the density of cement. Table 6 shows that the optimal w/c ratio increases as the replacement ratio of RHA increases due to more fineness and higher specific surface area of RHA particles in comparison with cement. It is concluded that by replacing cement with RHA in the range of 5 to 15%, compressive strength is increased rather than the control samples. It is due to presence of amorphous silica in RHA that reacts with cement and results in producing C-H-S. C-H-S is the main responsible for the strength in pozzolanic samples. By adding the RHA out of the mentioned range, the compressive strength decreases that may be caused by the increase in the optimal w/c ratio for a constant cementations material content that decreases the compaction effort.

5.3 Permeability

The results of the samples permeability are given in Table 8. As shown in this table, in constant RHA, with increasing gyration number (increasing compaction effort), the samples permeability decreases. This matter is due to reducing voids and filling them with the fine particles (filler, RHA) and formation the good grading skeleton. In constant gyration number, with increasing RHA content, the permeability increases that may be caused of increasing w/c ratio that increases the capillary property and following permeability. The highest reducing in permeability rather than the control samples is occurred by replacing cement with RHA in the range of 15 to 30%. In addition, in all mix designs, with increasing the density, permeability decreased. It is concluded that in the denser mixture, many of voids are filled with the fine particles and there is a lower space for filling with water.

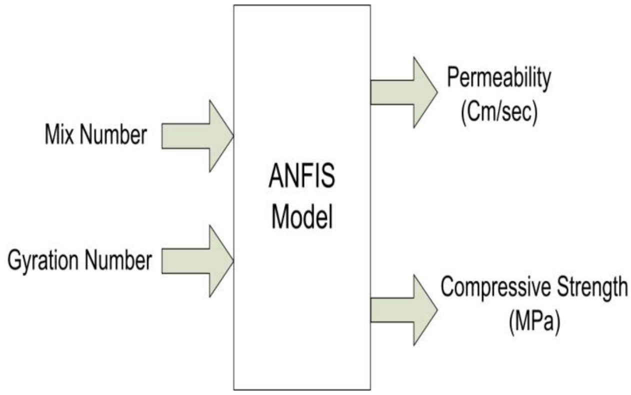

Fig. 4 The proposed ANFIS model

6. Modeling approach

6.1 Adaptive Neuro-Fuzzy Inference System (ANFIS)

In recent years, the application of Artificial Neural Network in civil engineering research including research related to concrete has been grown (Demir 2015, Beycioğlu 2015, Tabatabaei 2014, Duan and Poon 2014, Erdem *et al.* 2013, Mazloom and Yoosefi 2013). ANFIS (Takagi and Sugeno 1985, Jang and Sun 1995, Jang *et al.* 1997) is a fuzzy inference system implemented in the framework of neural networks. This combination merges the advantages of fuzzy systems and neural networks. The main target of ANFIS is to find a model which can model the inputs with the outputs accurately. An ANFIS is used to map out input characteristics to input membership functions, input membership function to a set of fuzzy *if-then* rules, rules to a set of output characteristics, output characteristics to output membership functions, and the output membership function to a single-valued output or a decision associated with the output (Fuzzy Logic Toolbox User's Guide 2015). For simplicity, assume that the fuzzy inference system has two inputs (x, y) and one output (f). For the first order Sugeno fuzzy model, a single fuzzy *if-then* rule assumes the form

Rule 1: if x is A_1 and y is B_1, then $f1=p_1x+q_1y+r_1$

Rule 2: if x is A_2 and y is B_2, then $f2=p_2x+q_2y+r_2$

Where p_i, q_i and r_i are linear output parameters (consequent parameters or linear parameters) and i=1, 2. The reasoning mechanism for this Sugeno model is illustrated in Fig. 2. Also, the corresponding equivalent ANFIS architecture is shown in Fig. 3.

The layers shown in Fig. 3 are defined as follow:

Layer 1: Every node in this layer is an adaptive node with a node function

$$O_{1,i} = \mu_{A_i}(x)\ , \qquad i=1,2, \tag{1}$$

$$O_{1,i} = \mu_{B_{i-2}}(y)\ , \qquad i=3,4 \tag{2}$$

Where i is the membership grade of a fuzzy set (A_1, A_2, B_1, B_2) and $O_{1,i}$ is the output of the node i in the layer 1. A typical membership function is Gaussian function with

$$\mu_A(x) = \exp\left(-\frac{(x-c)^2}{2\sigma^2}\right) \tag{3}$$

Where c, σ are referred to premise parameters (nonlinear parameters).

Layer 2: Every node in this layer is a fixed node labeled $\prod$, the nodes multiply all incoming signals and the outputs are given by

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y)\ , \qquad i=1,2 \tag{4}$$

Each node in this layer represents the firing strength of a rule.

Layer 3: Every node in this layer is a fixed node labeled N which calculates the ratio of the *ith* rule's firing strength to the sum of all rule's firing strengths. The output of each node in this layer is called normalized firing strength and is given by

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1+w_2}\ , \qquad i=1,2 \tag{5}$$

Layer 4: In this layer, all nodes are adaptive nodes with a node function

$$O_{4,i} = \overline{w_i} f_i = \overline{w_i}\ (p_i x + q_i y + r_i)\ , \qquad i=1,2 \tag{6}$$

Where w_i is a normalized firing strength from layer 3 and (p_i, q_i, r_i) is the modifiable parameter set, referred to as consequent parameters.

Layer 5: This layer is a fixed node labeled $\sum$, computing the overall output as the summation of all incoming signals

$$O_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}\ , \qquad i=1,2 \tag{7}$$

In ANFIS structure, the parameters sets are divided into two categories, one called adaptive parameters and the other called consequent parameters. If the modeling is carried out properly, using both sets of parameters then the difference between the predicted outputs and observed ones, should give us the lowest possible level of error. In this regard, ANFIS uses a hybrid algorithm to identify the parameters being a two-step process. In the first process, the adaptive

Table 9 Optimal architecture and specification of the proposed ANFIS model

Specification	ANFIS Model for Permeability	ANFIS Model for Compressive strength
Type	Sugeno	Sugeno
Inputs/outputs	2/1	2/1
No. of input membership functions	11 for each input	4 for each input
No. of output membership functions	11	4
Input membership function type	Gaussian	Gaussian
Output membership function type	linear	linear
No. of fuzzy rules	11	4
No. of nonlinear parameters	88	48
No. of linear parameters	44	32
No. of epochs	200	100

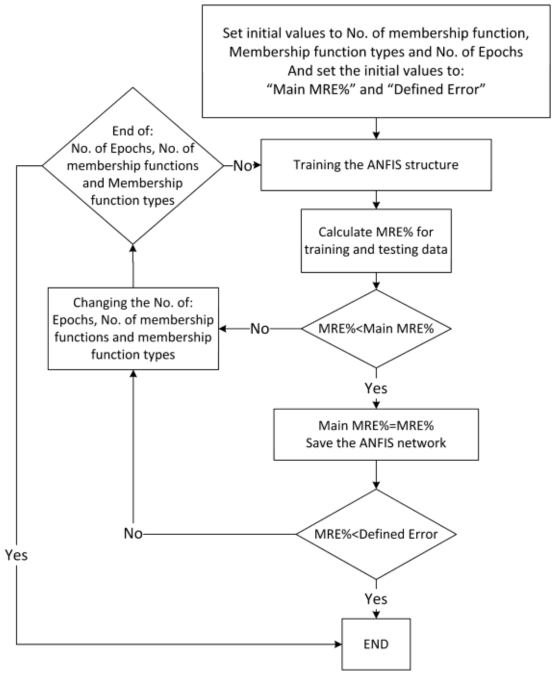

Fig. 5 The ANFIS training process algorithm

parameter sets are assumed to be constant and the consequent parameter sets are calculated by least-squares method; this process is called forward pass. In the second process which is called backward pass, the consequent parameters are assumed to be constant and the adaptive parameters set is obtained by gradient descends method. When the parameters sets of the model are obtained, the values of the model output can be calculated for each orderly pair of training data and compared with values that have been anticipated by the model.

6.2 The proposed ANFIS model

In this paper, an accurate model based on ANFIS in order to predict the permeability and compressive strength is presented. The proposed model is shown in Fig. 4, where the inputs are mix Number and gyration Number and the outputs are permeability and compressive strength. The data set required for training the ANFIS model is obtained using

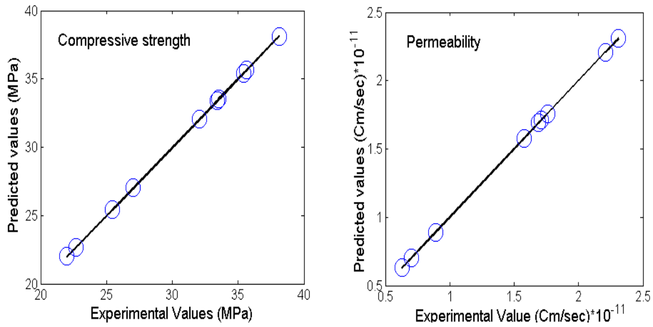

Fig. 6 Comparison of the experimental and predicted results for training data using the proposed ANFIS model

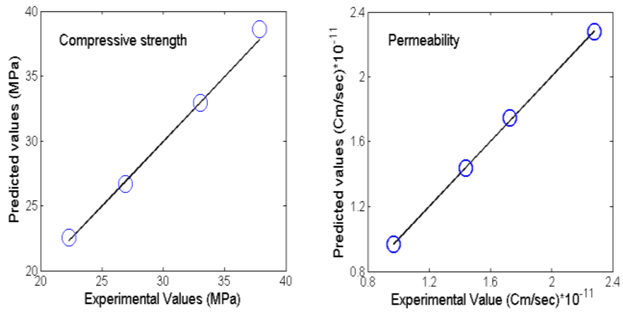

Fig. 7 Comparison of the experimental and predicted results for testing data using the proposed ANFIS model

the experimental data. The experimental data were divided into two sets: training (about 70%) and testing (about 30%). MATLAB 7.0.4 software was used for training the proposed model. To obtain the best ANFIS model, various configurations have been constructed and tested. We have several parameters i.e., number of membership functions, membership function type and the number of epoch. We changed the parameter "number of epoch" from 50 to 500 and also the type of membership function for each input is changed. Table 9 shows the specification of the best obtained ANFIS models being used in this study.

To choose the optimum model for ANFIS, MRE% is used. The process algorithm for the ANFIS networks is shown in Fig. 5. At first, the initial values for the minimum and maximum number of Membership functions and Epochs are set. Also, we are defined "Main MRE%" for the MRE% obtained by the best ANFIS structure and "Defined Error" to end the process. By changing the number of Membership functions and Epochs and also membership function types, different ANFIS structures will be obtained. If the MRE% of this new structure is less than "Main MRE%", the best ANFIS structure will be replaced by it. If The MRE% of this new structure is less than "Defined Error", the goal error is obtained and the process will be ended.

6.3 Modeling results

In order to examine the performance of the proposed ANFIS model, the obtained results are compared with the known results. Figs. 6 and 7 and Table 10 show the

Table 10 The obtained errors for the proposed ANFIS model

Data	ANFIS Model for Permeability				ANFIS Model for Compressive strength			
	MAE	RMSE	CF	MRE%	MAE	RMSE	CF	MRE%
Train	0.00023	0.00024	0.9999998	0.0074	0.3264	0.4228	0.9985770	1.026
Test	0.00009	0.00009	0.9999999	0.0062	0.0048	0.0086	0.9998660	0.270

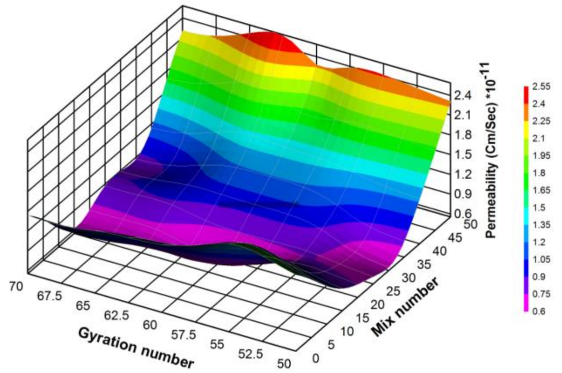

Fig. 8 The obtained permeability using the proposed ANFIS model

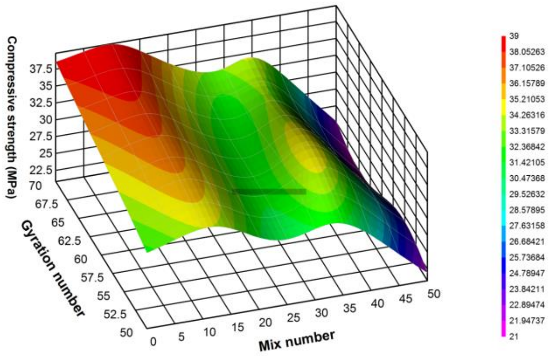

Fig. 9 The obtained compressive strength using the proposed ANFIS model

obtained results for the proposed ANFIS model, where the mean absolute error (MAE), the root mean square error (RMSE), the correlation factor (CF) and the mean relative error percentage (MRE %) of the proposed ANFIS model are calculated by

$$MAE = \frac{1}{N}\sum_{i=1}^{z}\left|X_i(Exp) - X_i(Pred)\right| \quad (8)$$

$$RMSE = \left[\frac{\sum_{i=1}^{N}(X_i(Exp) - X_i(Pred))^2}{N}\right]^{0.5} \quad (9)$$

$$CF = 1 - \left[\frac{\sum_{i=1}^{N}(X_i(Exp) - X_i(Pred))^2}{\sum_{i=1}^{N}(X_i(Exp))^2}\right] \quad (10)$$

$$MRE\% = 100 \times \frac{1}{N}\sum_{i=1}^{N}\left|\frac{X_i(Exp) - X_i(Pred)}{X_i(Exp)}\right| \quad (11)$$

Where N is the number of data and '$X(Exp)$' and '$X(Pred)$' stand for experimental and predicted (ANFIS) values, respectively.

From Table 10 and Figs. 6 and 7, it is clear that the predicted permeability and compressive strength by the proposed ANFIS model is close to the experimental results, which shows the applicability of ANFIS as accurate and reliable models for the prediction of permeability and compressive strength. Figs. 8 and 9 show the obtained permeability and compressive strength using the proposed ANFIS model, respectively. From these figures the maximum compressive strength is 39.86 MPa, in (Mix number, Gyration number)=(9, 70). Also, the minimum permeability is 0.55×10^{-11} Cm/Sec, in (Mix number, Gyration number)=(18, 61). From these results, it is clear that the ANFIS model can be used as an accurate model to prediction of the permeability and compressive strength.

As illustrated in Fig. 8, the permeability sensitivity for mix number is higher than gyration number. When the gyration number is fixed and the mix number is changed, the permeability changes will be significant but when the mix number is fixed and the gyration number is changed, the permeability changes will not be significant.

As illustrated in Fig. 9, the compressive strength sensitivity for mix number is higher than gyration number. When the gyration number is fixed and the mix number is changed, the compressive strength changes will be significant but when the mix number is fixed and the gyration number is changed, the compressive strength changes will not be significant.

7. Conclusions

In this laboratory work, the compressive strength and permeability of RCCP mixes containing RHA as cement replacement were investigated. Also, two structures based on adaptive neuro-fuzzy inference system (ANFIS) were employed in order to model and predict the compressive strength and permeability of RCCP samples. Based on the test results and performed Modeling, the following conclusions can be drawn:

• Samples contained RHA, had lower density compared with control samples. It was because of lower density of RHA than cement;

•As the replacement ratio of rice husk ash increased, w/c ratio increased. It was due to more fineness and higher specific surface area of RHA particles than cement;

•According to the results of laboratory tests and performed modeling, optimal content for the increasing of the compressive strength, was obtained by substituting 9% of the cement by RHA in gyration number 70 (maximum compressive strength was 39.86 MPa). However, adding a little more than 15% RHA reduced the compressive strength;

•Also, based on the test results and modeling, the optimal value for reducing of the permeability, was obtained by substituting 18% of the cement by RHA in gyration number 61 (Minimum permeability was 0.55E-11 cm/sec);

•The comparison between the experimental and predicted values of the proposed models showed that there is an excellent consistency between the predicted and experimental results with the least error. This means that the proposed models are reliable and flexible mathematical structures due to their high accuracy and therefore, they can be used to simulate the experiments precisely.

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