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Comparison of Fuzzy Logic and ANFIS for Prediction of Compressive Strength of RMC

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ABSTRACT : : *In this research work, comparative study for prediction for 28-days compressive strength of Ready Mix Concrete(RMC) have been carried out by using Fuzzy logic and Adaptive Neuro Fuzzy Inference System (ANFIS) modeling. These data are analysed by using three different membership functions viz. Triangular, Trapezoidal and Gaussian. Further these membership functions are fuzzified with fuzzy rule inference with min, max rule principles; these are defuzzified with centroid method. Various models have been developed for different input scenarios, non-dimensional ratios were used for modelling and the ratios such that their changes resulted in corresponding changes in the output. The compressive strength was modeled as a function of various variables viz: w/c ratio, FA/CA ratio, weight of cement, weight of FA & CA, weight of water etc..,. The effects of each parameter on networks were studied for Fuzzy Logic (FL) and ANFIS models. ANFIS and FL are comparable and ANFIS is better than FL, as proved in this work considering the performance index such as Coefficient of Correlation.*

Keywords - *Adaptive Neuro Fuzzy Inference System (ANFIS), Compressive Strength, Fuzzy Logic (FL), Membership Function (MF), Ready Mix Concrete*

1. INTRODUCTION

Recently Ready Mixed Concrete (RMC) is one of the most popular building material developed in construction industry. RMC is prepared generally in a concrete batch plant and ingredient materials for concrete production are weighed and mixed by automated devices consistent with the request of the construction sites. Accordingly, RMC is convenient for all types and all sizes of construction. RMC has several benefits compared to concrete prepared by conventional methods [1].Compressive strength of Ready Mix Concrete is a major and perhaps the most important mechanical property, which is usually measured after a standard curing of 28 days. Concrete strength is influenced by lots of factors like concrete ingredients, age, ratio of water to cementitious materials, etc. Conventional methods of predicting the strength of concrete are usually based on the linear and nonlinear regression methods [2,3]. Nowadays, the artificial intelligence based techniques like the artificial neural networks [4–6] have been successfully applied in this area. In the recent years the prediction of the mechanical properties of construction materials, in particular the 28-days compressive strength of concrete (28-CSC), has been gained a great attention between the researchers of material science [6–10]. This problem is usually used as a key example for verification of the novel soft computing systems [11].

The traditional approach used in modeling the effects of these parameters on the compressive strength of concrete starts with an assumed form of analytical equation and is followed by a regression analysis using experimental data to determine unknown coefficients in the equation, Dias [12].Many researcher works can be found in the literature that focused on prediction of the various properties of concrete. Ramezanianpour et al. practiced ANFIS to predict 28-CSC. They examined 56 ANFIS structure with various membership functions to predict the 28-CSC of high strength concrete [13]. So we compare Fuzzy Logic and ANFIS for prediction of compressive strength of RMC.

So far very few literatures are available in application of soft computing technique RMC modelling and comparison of Fuzzy Logic and ANFIS. Hence an attempt has been made to carry comparative study and to develop predicting model for compression strength of RMC by soft computing technique and evaluate the performance of each network for selection of best network.

2. OBJECTIVE

The main objective was to compare and to explore the feasibility of Fuzzy Logic and ANFIS models for predicting the strength and recommend the most suitable model for RMC batch plant.

3. METHODOLOGY

3.1 ANFIS

The architecture of an ANFIS model with two input variables is shown in Fig.1 Suppose that the rule base of ANFIS contains two fuzzy IF–THEN rules of Takagi and Sugeno's type as follows:
Rule 1: IF x is A1 and y is B1,

THEN f1 = p1x + q1y + r1.
Rule 2: IF x is A2 and y is B2,
THEN f2 = p2x + q2y + r2.

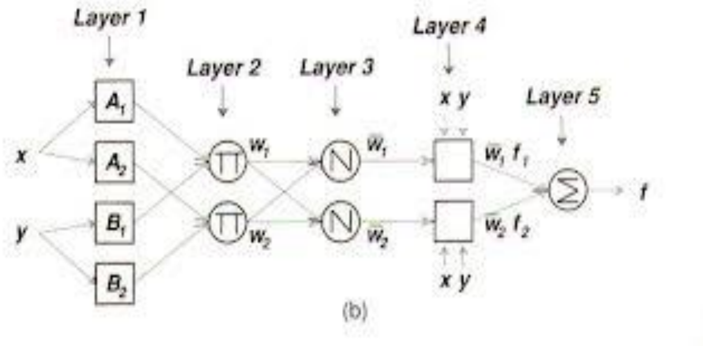

Fig.1- Structure of ANFIS

3.2 Fuzzy Logic

The fuzzy methodology is shown in Fig.2. A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. In a crisp set, membership or nonmembership of element *x* in set *A* is described by a characteristic function $\mu_A(x)$, where $\mu_A(x) = 1$ if $x \in A$ and $\mu_A(x) = 0$ if $x \notin A$. Fuzzy set theory extends this concept by defining partial membership. A fuzzy set *A* on a universe of discourse *U* is characterized by a membership function $\mu_A(x)$ that takes values in the interval [0 1]. Fuzzy sets represent commonsense linguistic labels like low, medium, high. Fuzzy models are developed for different membership function like triangular, trapezoidal, Gaussian by creating rules in fuzzy model.

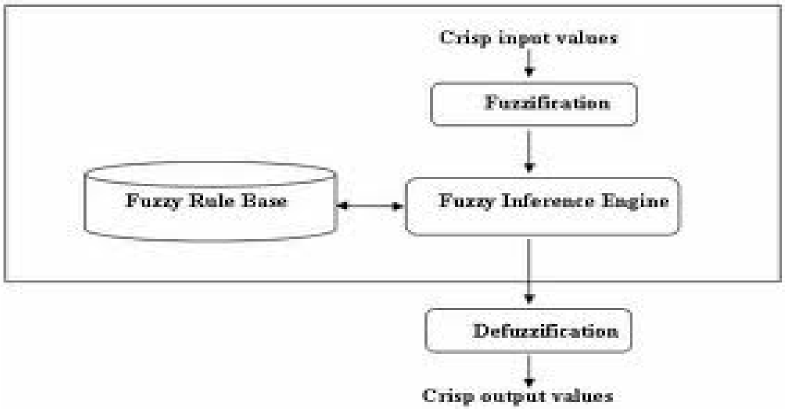

Fig.2- Fuzzy Logic

The fuzzy rules are created for mamdani architecture and mentioned in Table 1.

Table 1-Fuzzy Rules

Sr. No	if	if	if	if	if	then
1	High	Low	High	Low	Medium	Low
2	High	Low	High	Low	Low	Low
3	High	Medium	High	Low	Medium	Low
4	High	High	Medium	Low	Medium	Low
5	Medium	Medium	Medium	Low	Low	Low
6	Medium	Medium	Medium	Low	Medium	Low
7	Medium	High	Medium	High	Medium	Low
8	High	Medium	Medium	Low	High	Low

9	Medium	Medium	Low	Low	High	Medium
10	Medium	Medium	Medium	Medium	Medium	Medium
11	Medium	High	Low	Low	High	Medium
12	Medium	High	Medium	Medium	High	Medium
13	Medium	Medium	Medium	Medium	Low	Medium
14	Medium	Medium	Low	Low	High	Medium
15	Medium	High	Low	Medium	High	Medium
16	Low	Medium	Medium	High	Low	High
17	Low	Medium	Medium	High	Medium	High
18	Low	Medium	Low	High	High	High
19	Low	Medium	Low	High	Low	High
20	Low	Medium	Medium	High	High	High
21	Low	Low	Low	High	Medium	High
22	Low	High	Low	Medium	High	High
23	Low	High	Low	High	Medium	High
24	Low	High	Medium	High	Medium	High

3.3 Data Collection and Pre-processing

The data for the ready mixed concretes (RMC) were collected from RMC batching plant. Of these records were used for training and for testing. The input variables for the prediction of 28 days compressive strength were, w/c ratio, FA/CA ratio, weight of cement, weight of FA & CA, weight of water etc.., and the output variable is 28-day concrete strength. Three different models are created by considering different parameters each time one parameter replaced to study the effect of parameters on model. The models are as below:

Model 1:- Considering all five parameters w/c , fa/ca, cement, fa, water.
Model 2:- Considering parameters w/c, fa/ca, ca,fa, water.
Model 3:- Considering parameters w/c, fa/ca, cement, ca, water.

The training data set collected from batching plant is given in Table 2, whereas testing data set given in Table 3.

Table 2-Training Data Set

W/C	FA/CA	CEMENT	CA	WATER	OBSERVED STRENGTH (N/mm^2)
0.38	0.52	440	1241	167.2	54.7
0.46	0.52	375	1260	172.5	44.5
0.38	0.67	475	1089	180.5	58.94
0.45	0.54	320	1339	144	32.5
0.46	0.52	375	1260	172.5	45.4
0.38	0.48	450	1260	171	55
0.38	0.5	435	1260	165.3	55
0.38	0.48	435	1279	165.3	55.8
0.46	0.52	385	1246	177.1	44.9

Table 3-Testing Data Set

W/C	FA/CA	CEMENT	CA	WATER	OBSERVED STRENGTH (N/mm^2)
0.38	0.5	435	1260	165.3	55.8
0.45	0.54	345	1304	155.2	37.3
0.38	0.48	435	1269	165.3	54.6

3.4 Modelling Performance Criterions

In order to evaluate the prediction accuracy of Fuzzy Logic and ANFIS models norms were used for comparative evaluation of the performance of each model. These norms are Mean Absolute Error (MAE), Mean Square Error (MSE), Mean Relative Error (MRE) and Coefficient of Correlation (Cc) was employed.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\text{observed} - \text{predicted})^2 \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|\text{observed} - \text{predicted}| \quad (2)$$

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{(\text{observed} - \text{predicted})}{(\text{observed})} \quad (3)$$

$$CC = \frac{\sum(x-x')(y-y')}{\sqrt{\sum(x-x')^2(y-y')^2}} \quad (4)$$

Where n is the number of data patterns in the independent data set. Where x and y are the sample means AVERAGE (observed) and AVERAGE (predicted), X' and y' are average of observed and predicted values.

4. RESULT AND DISCUSSION

In order to predict the 28-day compressive strength of Ready Mix Concrete, FUZZY LOGIC, ANFIS models having five inputs and one output was applied successfully, and ANFIS model exhibited the more reliable predictions than the fuzzy models. Fuzzy model with five inputs and 24 rules with inputs as w/c, ca, cement, fa, water, using Gaussian membership function and ANFIS model having 243 rules and Gaussian membership function could predict the 28-day compression strength in a best manner and the minimum required error in comparison. In fact, the coefficient of correlation, MAE, MSE and MRE between the measured and predicted values are good indicator to check the prediction performance of the model. ANFIS model shows the excellent performance where the Coefficient of correlation shows the very good nearly 1.while FUZZY shows less performance than ANFIS.

In the current study, three models were developed using five input variables. The fuzzy logic has been used in the Matlab for present analysis. Correlation coefficient has been taken as the reference to compare and select the best model. Here Different Fuzzy variable combinations are used. Fuzzy Inference System was used in the Fuzzy logic toolbox in Matlab for analysis. These different fuzzy variable combinations are been tested and analysed using three membership functions viz. Triangular, Trapezoidal, and Gaussian Membership functions.

ANFIS models are created by using different membership function like triangular, trapezoidal, and Gaussian Membership functions. All three models while training showing the error nearly equal to zero but while testing the error changes, Gaussian MF ANFIS model shows very less error and high degree of correlation between observed and predicted values. ANFIS model having Gaussian membership function shows the excellent performance. ANFIS model having Gaussian membership function is suitable for all criterion of data set the performance is very excellent for prediction of ready mix concrete.

The different analysis results and graphs are shown.

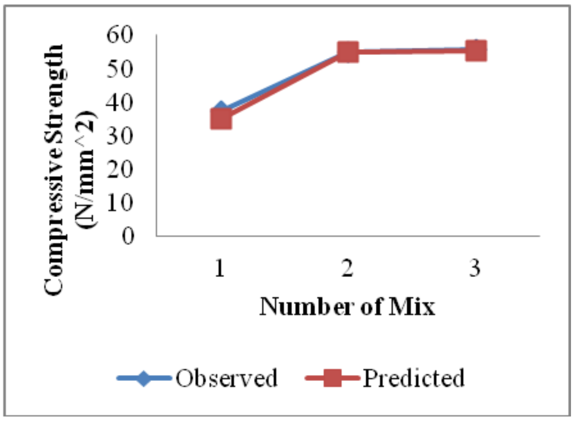

Fig.3-Triangular MF for Model 1 Using FL

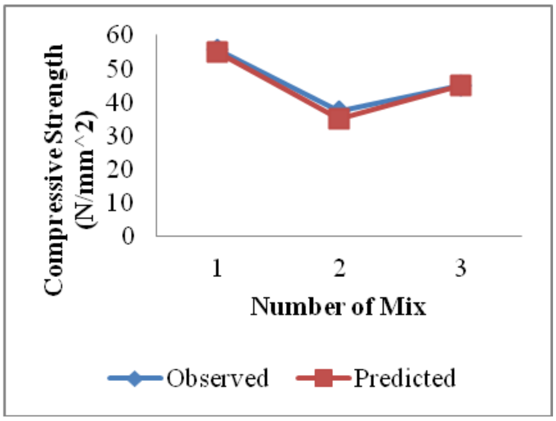

Fig.4- Triangular MF for Model 2 Using FL

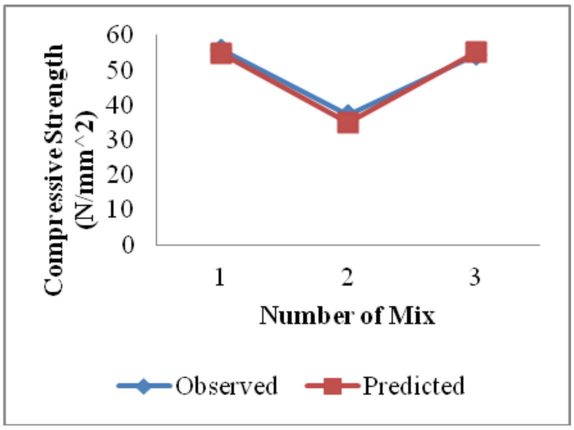

Fig.5- Triangular MF for Model 3 Using FL

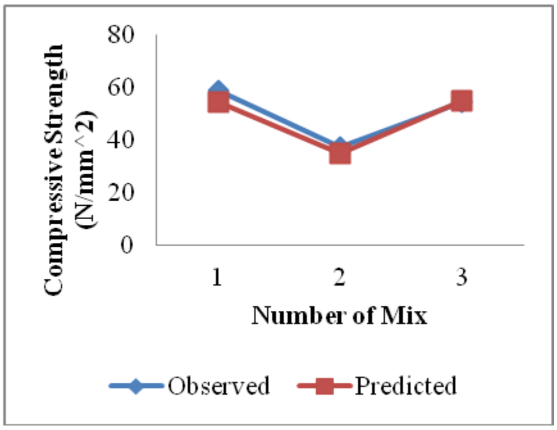

Fig.6- Trapezoidal MF for Model 1 Using FL

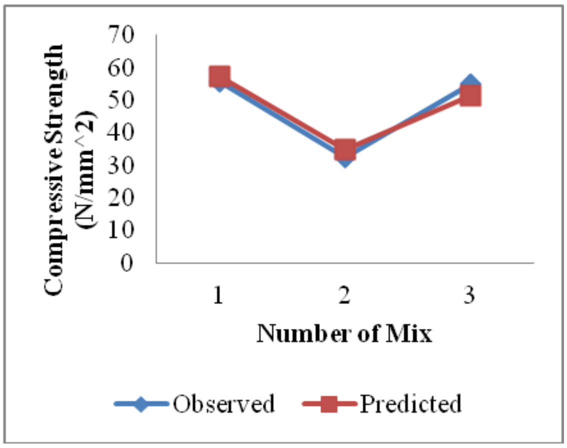

Fig.7- Trapezoidal MF for Model 2 Using FL

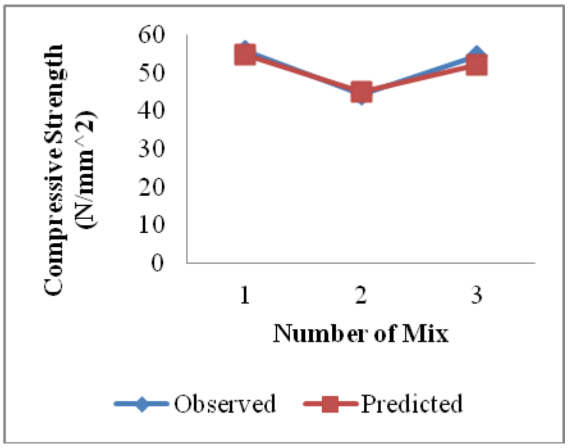

Fig.8- Trapezoidal MF for Model 3 Using FL

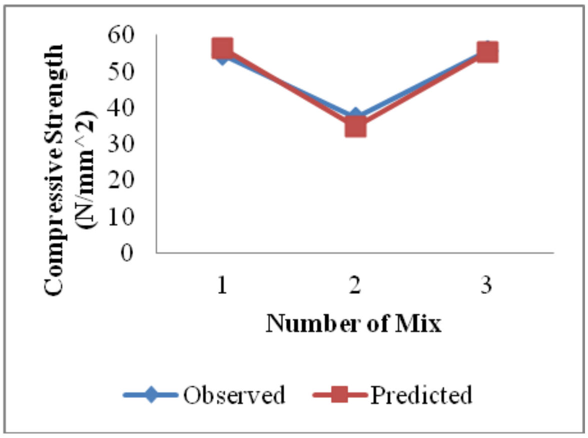

Fig.9- Gaussian MF for Model 1 Using FL

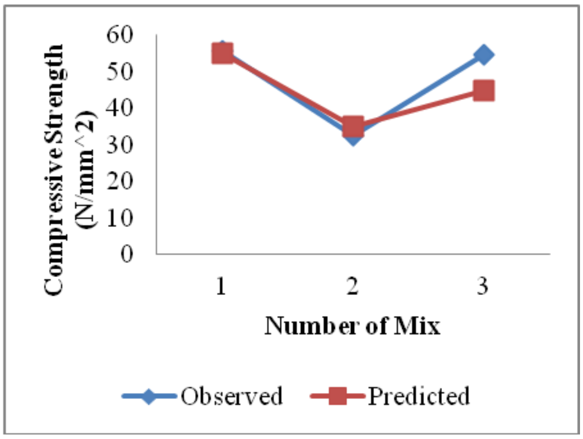

Fig.10- Gaussian MF for Model 2 Using FL

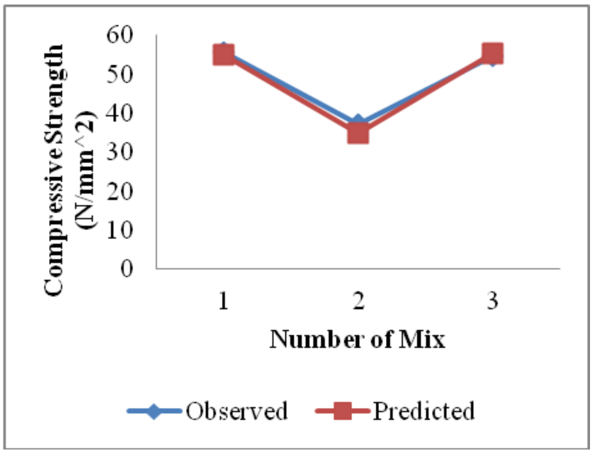

Fig.11- Gaussian MF for Model 3 Using FL

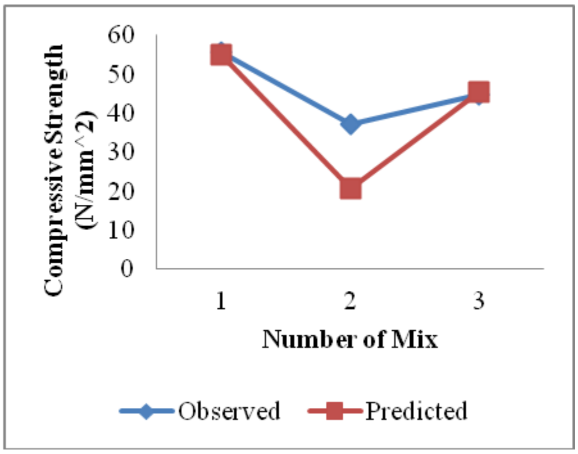

Fig.12- Triangular MF for Model 1 Using ANFIS

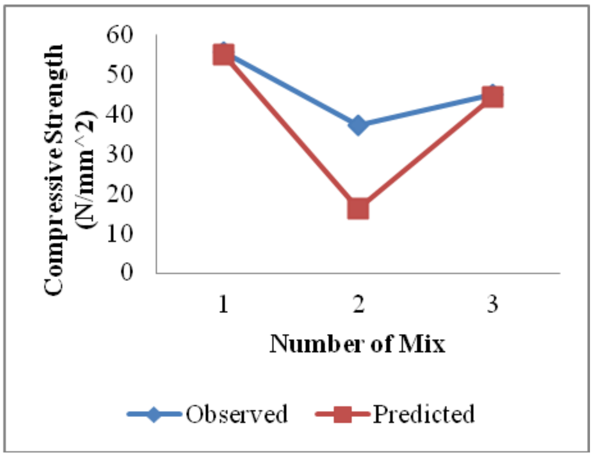

Fig.13-Triangular MF for Model 2 Using ANFIS

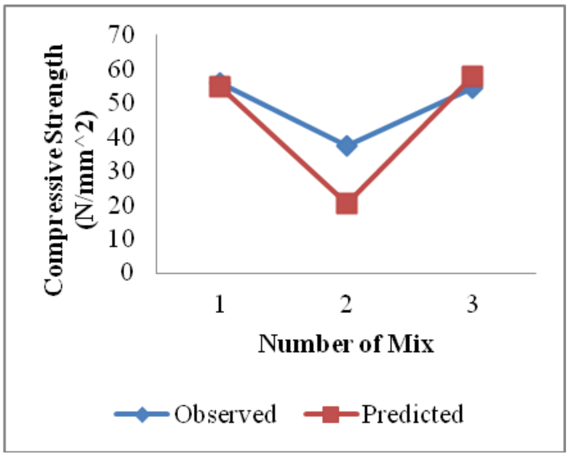

Fig.14-Triangular MF for Model 3 Using ANFIS

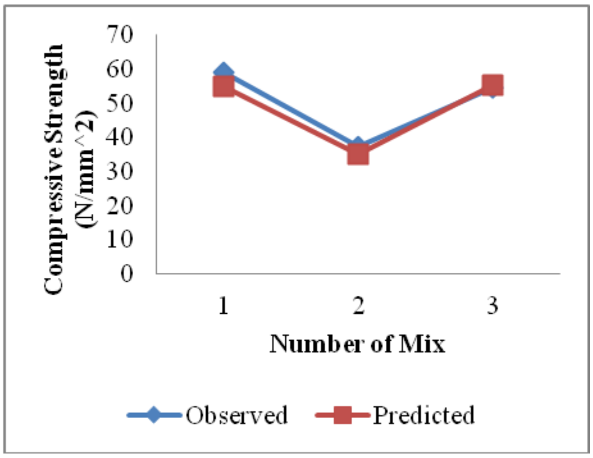

Fig.15-Trapezoidal MF for Model 1 Using ANFIS

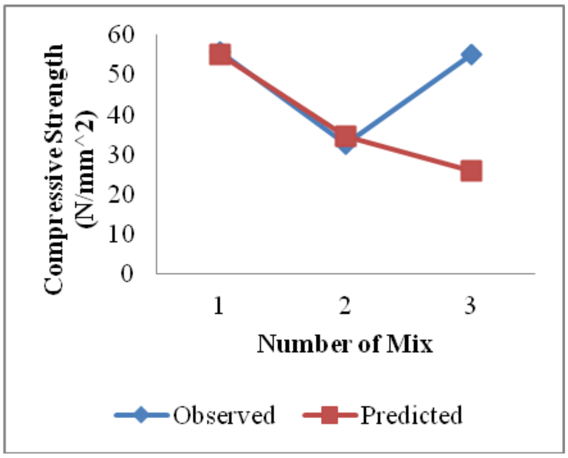

Fig.16-Trapezoidal MF for Model 2 Using ANFIS

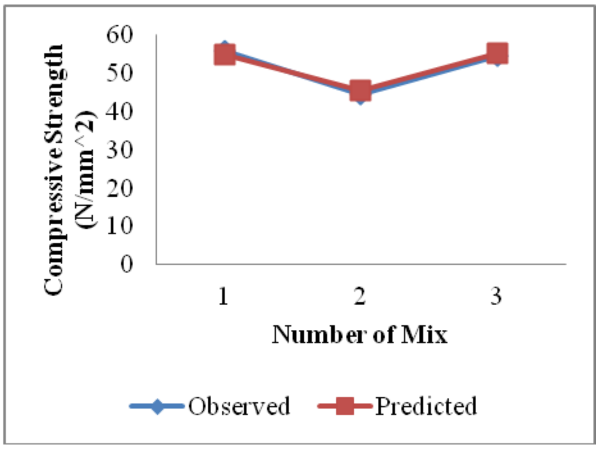

Fig.17-Trapezoidal MF for Model 3 Using ANFIS

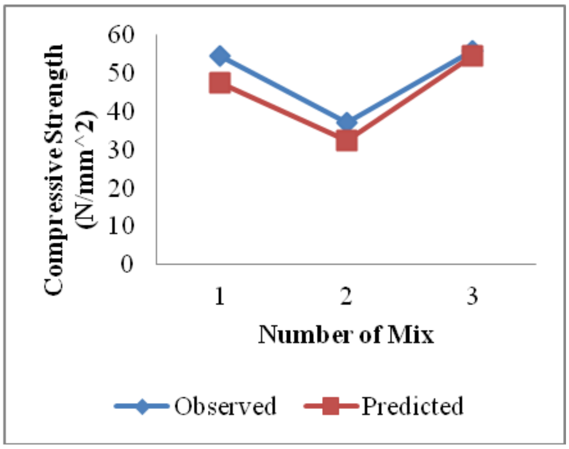

Fig.18-Gaussian MF for Model 1 Using ANFIS

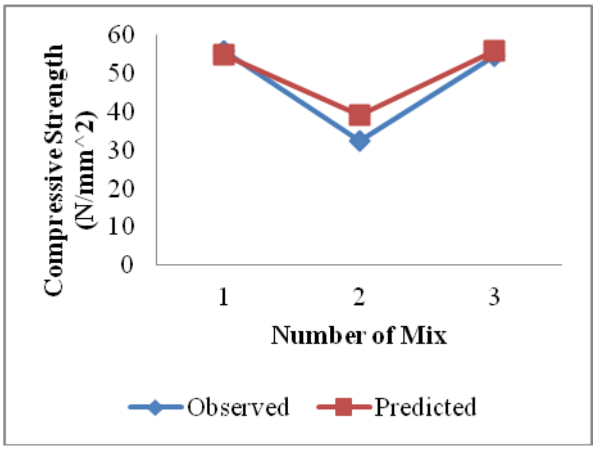

Fig.19- Gaussian MF for Model 2 Using ANFIS

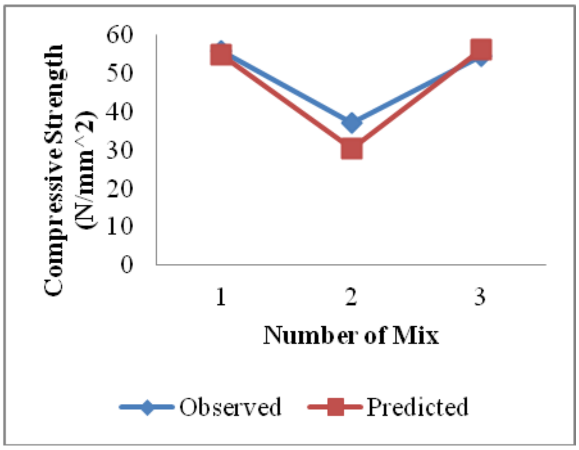

Fig.20- Gaussian MF for Model 3 Using ANFIS

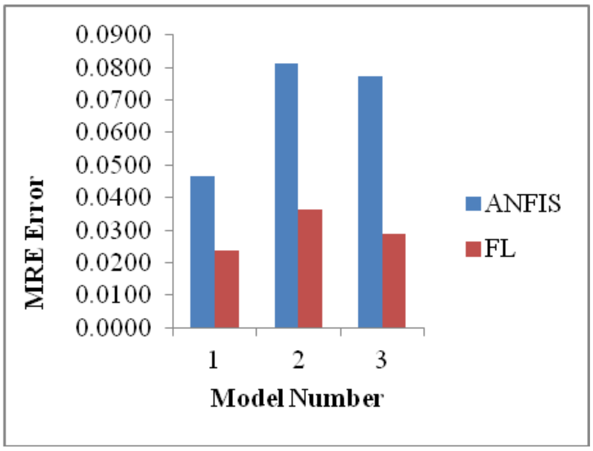

Fig.21- Comparison w.e.f. MRE Error

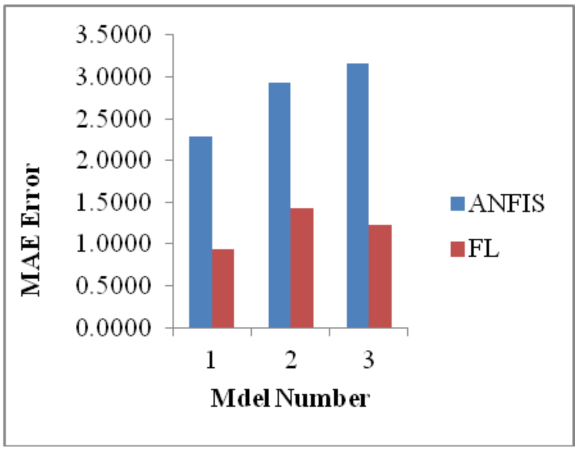

Fig.22- Comparison w.e.f. MAE Error

Model	Training	Testing
	Cc	Cc
FL	0.969	0.997
ANFIS	1	0.944

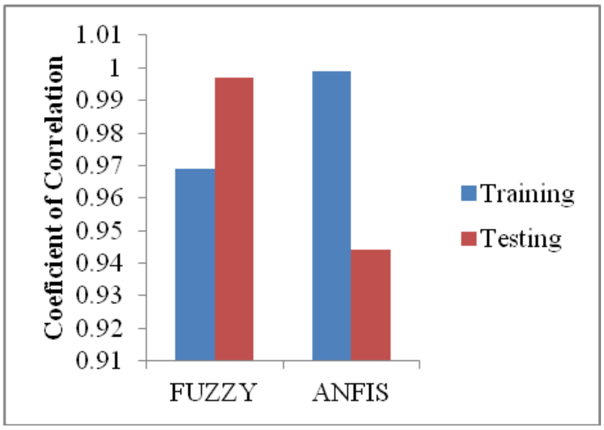

Fig.23- Comparison of CC with Training and Testing data of Fuzzy and ANFIS models.

5. CONCLUSION

The following conclusions can be drawn from this study

- The ANFIS having the Gaussian membership function could predict the 28-day compression strength of ready mix concrete with satisfactory performance.
- The fuzzy model with five inputs as W/C, CA, CEMENT, FA, WATER and by using Gaussian membership function along with24 fuzzy rules and centroid defuzzification method could predict the 28-day compression strength of ready mix concrete in a best manner and the minimum required error in comparison with the other fuzzy models.
- Fuzzy logic approach presents a more understandable and objective way of RMC classification and these approaches can be used as a practical tool to access the RMC related problems.
- From the results obtained it can be concluded that the Fuzzy models are more suitable in modeling of complex problems and save a lot of computational effort compared to conventional methods significantly. The use of these networks will help in solving more complex problems.

  The study can be carried out for more number of parameters and properties of different materials used for Ready Mix Concrete. It can be extended to different site conditions, different grade of the concrete with different inputs.

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