ANFIS BASED MODELING FOR PERFORMANCE EVALUATION OF RUBBERIZED CONCRETE BEAMS

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ABSTRACT

The main objective of this study is to evaluate the performance of rubberized concrete beams with micro-reinforcement using ANFIS software. The input parameters considered were rubber volume fraction, steel fibre volume fraction, concrete compressive strength, yield strength of steel and area of steel. The output parameters considered were first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load and ductility. The test data required for ANFIS modeling were collected from relevant literature. The ANFIS modeling has been conducted and the performance parameters were predicted using eight membership functions. The results predicted through ANFIS modeling show good convergence with the experimental results.

KEY WORDS: ANFIS, Chipped rubber, Fibre reinforced concrete, Rubberized concrete beams, Steel fibre. .

1. Introduction

Due to the immense amount of waste tyre rubber, there is an enormous potential for reclamation and reuse of waste rubber in developing countries. Whether rubber tyres are reused, reprocessed or hand crafted into new products, the end result is that there is less waste and less environmental degradation [1]. From the waste tyre, two different technologies were obtained for rubber aggregate (mechanical grinding and cryogenic grinding) [2]. The crack resistance, high ductility and strong energy dissipation capacity have been achieved by introducing certain amount of crumb rubber in normal concrete and it is known as crumb rubber concrete [3]. Depending on the rubber content and w/c ratio, the compressive strength and density of rubberized concrete get affected [4]. The bonding strength of rubber aggregates can be increased by treating it with carboxylic acids and styrene butadiene copolymer latex admixtures [5].

The ductility, energy dissipation, damping ratio, impact resistance and toughness of concrete can be enhanced by substituting fine or coarse aggregates with crumb or shredded rubber particles. Utilizing upto 10% CR can enhance the beams deformation capacity, ductility and toughness without affecting the ultimate flexural load. However, 10 to 20% CR repalcement may keep on improving the beams deformation capacity, ductility and toughness yet with a slight decrease in the ultimate flexural load [6].

Sadrmomtazi and others [7] proposed ANN, ANFIS and Regression models for predicting the compressive strength of EPS concrete beams. The outcome demonstrate that ANN and ANFIS models give desirable predication of compressive strength over regression model. Rahmat Madandoust and others [8] predicted the concrete compressive strength by means of core testing using ANFIS models and GMDH-type neural network. Singular value decomposition (SVD) and Genetic algorithm (GA) methods was sent for ideal plan of GMDH-type neural systems. The results showed that a generalized ANFIS and GMDH-type neural network remain a reliable tool for predicting the compressive strength on the basis of core testing.

1.1 Adaptive Neuro Fuzzy Inference System (ANFIS)

Adaptive Neuro - Fuzzy Inference System (ANFIS) is a famous hybrid neuro-fuzzy network for modeling complex systems. ANFIS incorporates human-like reasoning style of fuzzy systems through the use of fuzzy sets. Fuzzy inference system collects and models input/output data of the system. The parameters could be chosen to adjust the membership functions for the input/output data. This adaptation can be achieved by ANFIS with neural learning techniques.

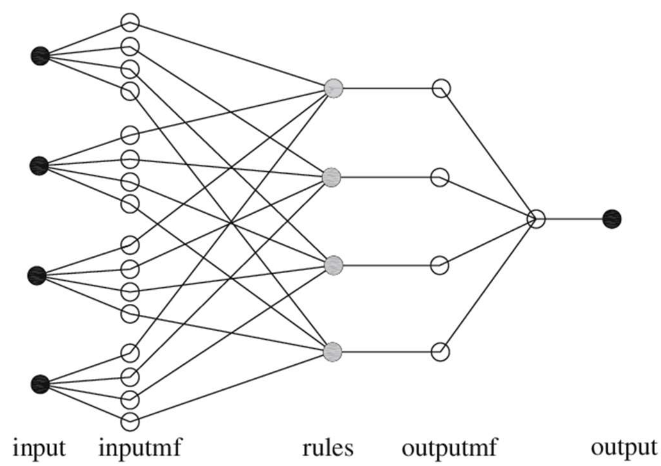
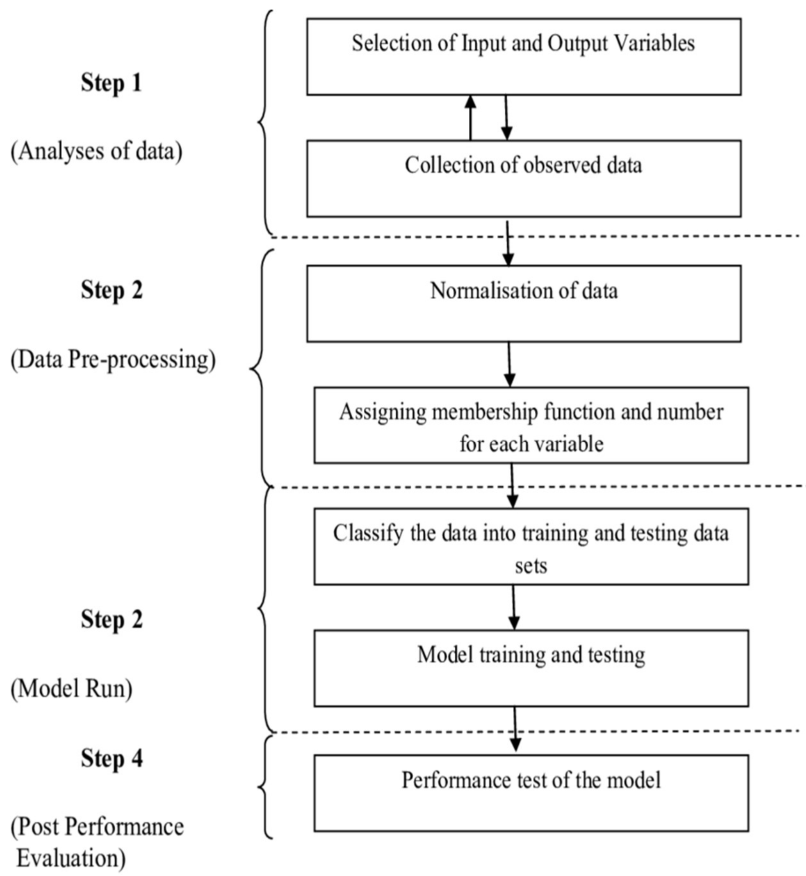


Fig. 1. Architecture of ANFIS

Adaptive Neuro - Fuzzy Inference System (ANFIS) are a class of adaptive neural networks that are functionally equivalent to fuzzy inference systems and offer the combination of learning, adaptability and nonlinear, time-variant problem solving characteristics of Artificial Neural Networks plus the important concepts of approximate reasoning and treatment information provided by the fuzzy set theory.

1.2 Development of ANFIS Model

ANFIS network control systems represent a hybrid platform for solving actual complex problems that require the use of intelligent systems and are a viable alternative to the conventional model-based control schemes. They allow dealing effectively with the common issues of uncertainty and unknown variations in plant parameters and structures, hence improving robustness of the control system. MATLAB Fuzzy Logic Toolbox (FLT) from math works was selected as the development tool. ANFIS consists of a FIS editor, the rule editor, the surface editor.



2. Method

The performance parameteres were evaluated for trimf, trapmf, gaussmf, gauss2mf, gbellmf, dsigmf, psigmf and pimf membership functions.

2.1 Data used in ANFIS modeling

The inputs of the adaptive neuro fuzzy inference system consists of four elements: rubber volume fraction, steel fibre volume fraction, concrete compressive strength, yield strength of steel and area of steel. The targets are: first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load and ductility. Only one output is allowed and therefore ANFIS must be executed for each target individually. The membership function of each input was tuned up to 50 epochs. Several different models were constructed to achieve satisfying results with various training options such as the type of member functions. The Input and Output parameters for rubberized concrete beams with micro-reinforcement are shown in Tables 1 - 2.

Table 1
Input Parameters for ANFIS Modeling.

Beam Designation	% of Rubber Volume Fraction	% of Fibre Volume Fraction	Compressive Strength (MPa)	Tensile Strength (MPa)	Area of Steel (mm^2)
500C-0CR	0.0	0.00	50.20	400	1138.82
500C-5CR	5.0	0.00	43.00	400	1138.82
500C-10CR	10.0	0.00	41.80	400	1138.82
500C-15CR	15.0	0.00	35.30	400	1138.82
550C-15CR	15.0	0.00	37.60	400	1138.82
550C-20CR	20.0	0.00	32.80	400	1138.82
550C-20CR-MK	20.0	0.00	40.80	400	1138.82
550C-30CR-MK	30.0	0.00	34.80	400	1138.82
550C-30CR-MK-MA	30.0	0.00	30.20	400	1138.82
550C-40CR-MK-MA	40.0	0.00	26.40	400	1138.82
550C-40CR-MK-VRC	40.0	0.00	28.90	400	1138.82
550C-50CR-MK-VRC	50.0	0.00	22.40	400	1138.82
B1-0CR	0.0	0.00	65.61	400	1138.82
B2-5CR	5.0	0.00	58.44	400	1138.82
B3-15CR	15.0	0.00	48.35	400	1138.82
B4-25CR	25.0	0.00	38.35	400	1138.82
B5-5CR-0.35SF	5.0	0.35	59.15	400	1138.82
B6-15CR-0.35SF	15.0	0.35	49.45	400	1138.82
B7-25CR-VRC	25.0	0.00	40.26	400	1138.82
B8-35CR-VRC	35.0	0.00	29.73	400	1138.82
B9-35CR-0.35SF-VRC	35.0	0.35	31.10	400	1138.82
B10-35CR-1SF-VRC	35.0	1.00	32.38	400	1138.82
B11-35CR-0.35LSF-VRC	35.0	0.35	30.71	400	1138.82
B12-35CR-1LSF-VRC	35.0	1.00	31.51	400	1138.82
SC	0.0	0.00	26.60	415	383.27
S11	2.5	0.50	30.22	415	383.27
S12	2.5	1.00	40.35	415	383.27
S21	5.0	0.50	41.71	415	383.27
S22	5.0	1.00	50.60	415	383.27
S31	7.5	0.50	29.54	415	383.27
S32	7.5	1.00	31.60	415	383.27

Table 2
Output Parameters for ANFIS Modeling

Beam Designation	First Crack Load	Deflection at First Crack Load	Yield Load	Deflection at Yield Load	Ultimate Load	Deflection at Ultimate Load	Ductility Ratio
500C-0CR	32.80	1.50	200.00	10.30	250.00	27.00	2.62
500C-5CR	25.30	1.10	170.00	9.30	251.10	28.50	3.06
500C-10CR	22.80	1.00	150.00	8.80	249.20	28.20	3.20
500C-15CR	21.40	0.90	160.00	9.10	243.30	30.80	3.38

550C-15CR	22.00	2.00	140.00	8.80	246.60	25.90	2.94
550C-20CR	18.20	1.00	130.00	8.90	243.20	26.80	3.01
550C-20CR-MK	20.80	0.80	125.00	9.00	245.00	21.90	2.43
550C-30CR-MK	17.20	0.90	150.00	9.20	228.00	21.30	2.32
550C-30CR-MK-MA	16.50	0.70	120.00	8.10	219.00	17.90	2.21
550C-40CR-MK-MA	13.90	0.60	145.00	9.20	203.60	15.70	1.71
550C-40CR-MK-VRC	14.80	0.50	130.00	9.00	205.70	16.20	1.80
550C-50CR-MK-VRC	14.00	0.50	155.00	9.30	197.50	15.90	1.71
B1-0CR	132.55	0.50	180.00	0.80	250.70	1.92	2.40
B2-5CR	123.87	0.75	170.00	0.80	230.13	2.13	2.66
B3-15CR	111.21	0.80	140.00	0.80	195.97	1.95	2.44
B4-25CR	102.31	0.90	120.00	0.80	174.24	2.11	2.64
B5-5CR-0.35SF	136.12	1.20	280.00	2.20	283.59	2.47	1.12
B6-15CR-0.35SF	126.77	0.80	200.00	1.20	244.74	2.31	1.93
B7-25CR-VRC	105.87	1.00	142.00	1.00	181.25	1.81	1.81
B8-35CR-VRC	91.19	1.30	119.00	1.00	145.10	1.84	1.84
B9-35CR-0.35SF-VRC	117.88	1.80	225.00	2.00	233.76	1.50	0.75
B10-35CR-1SF-VRC	149.02	1.50	350.00	11.00	366.57	1.80	0.16
B11-35CR-0.35LSF-VRC	111.21	1.70	210.00	2.50	209.32	1.40	0.56
B12-35CR-1LSF-VRC	142.34	1.60	325.00	4.00	343.65	1.20	0.30
SC	18.50	1.95	32.00	5.50	60.00	12.00	2.18
S11	20.00	2.75	34.50	6.00	62.50	14.40	2.40
S12	22.50	3.10	37.50	6.50	65.00	15.60	2.40
S21	23.00	3.20	38.25	6.90	66.50	16.80	2.43
S22	25.00	3.26	41.00	7.45	68.50	18.60	2.50
S31	25.75	3.28	42.50	7.95	69.75	20.80	2.62
S32	27.50	3.35	45.00	8.10	72.50	24.90	3.07

2.2 Steps involved in ANFIS modeling

The step-wise procedure for ANFIS modeling is presented through Figs. 2 to 8.

2.2.1 Building ANFIS model

MATLAB Fuzzy Logic Toolbox (FLT) from math works was selected as the development tool. ANFIS consists of a FIS editor, the rule editor, the surface editor.

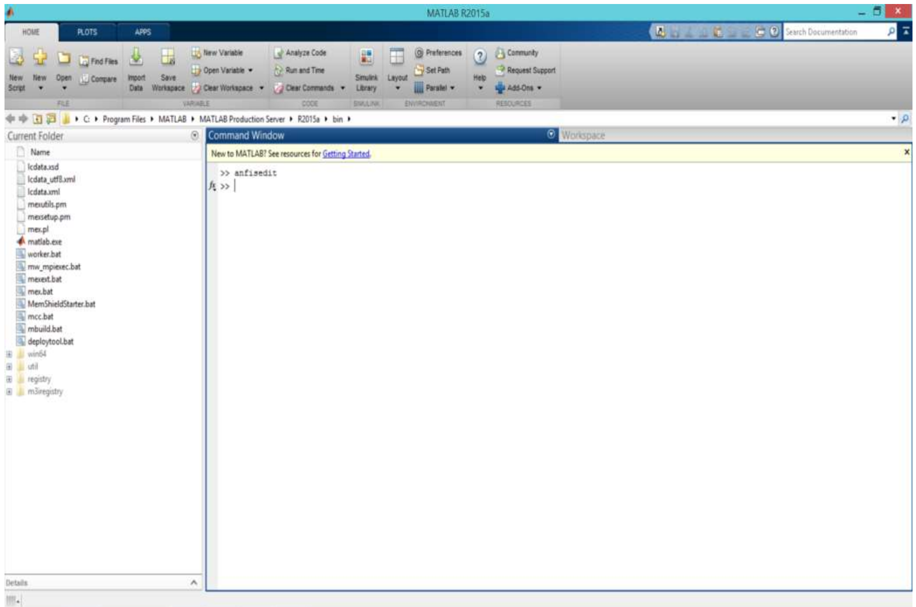


Fig. 2. Command window

2.2.2 Training ANFIS model

To develop ANFIS model, the data's has been trained from workspace and to generate Fuzzy inference system the membership function type has been chosen. The training processes are shown through Figs. 3 to 5.

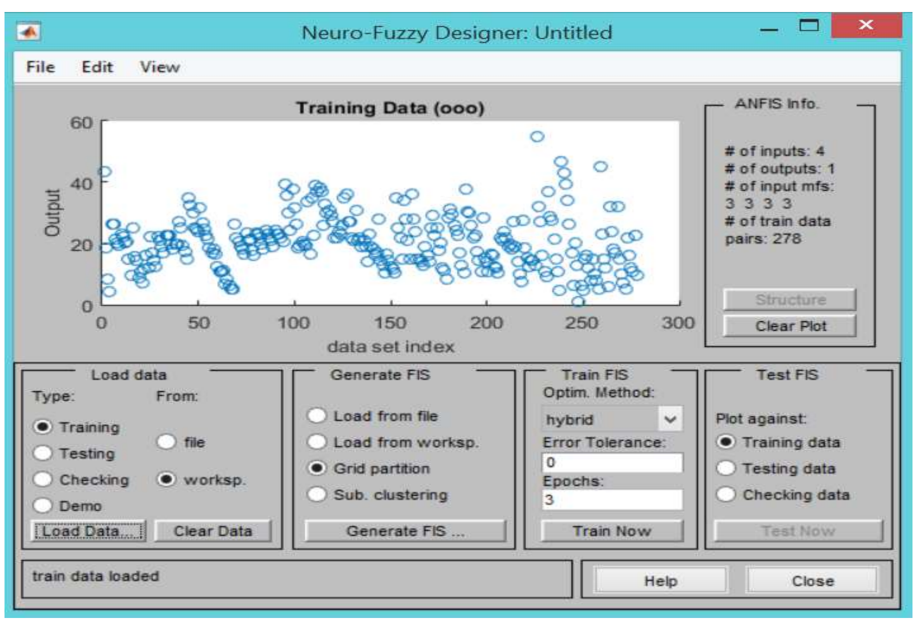


Fig. 3. Training the Data

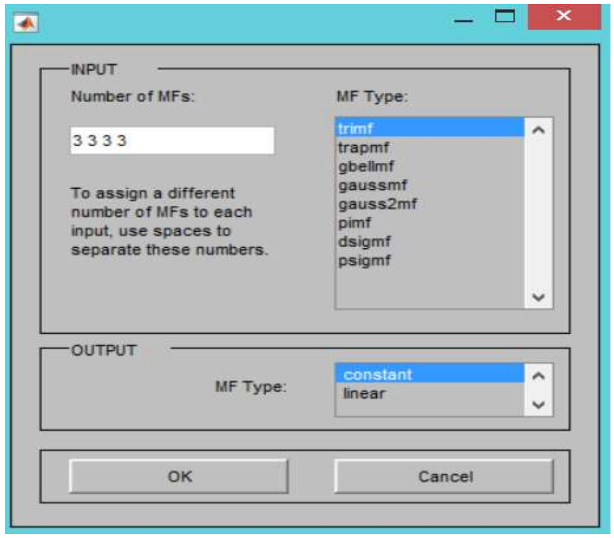


Fig. 4. Generate FIS

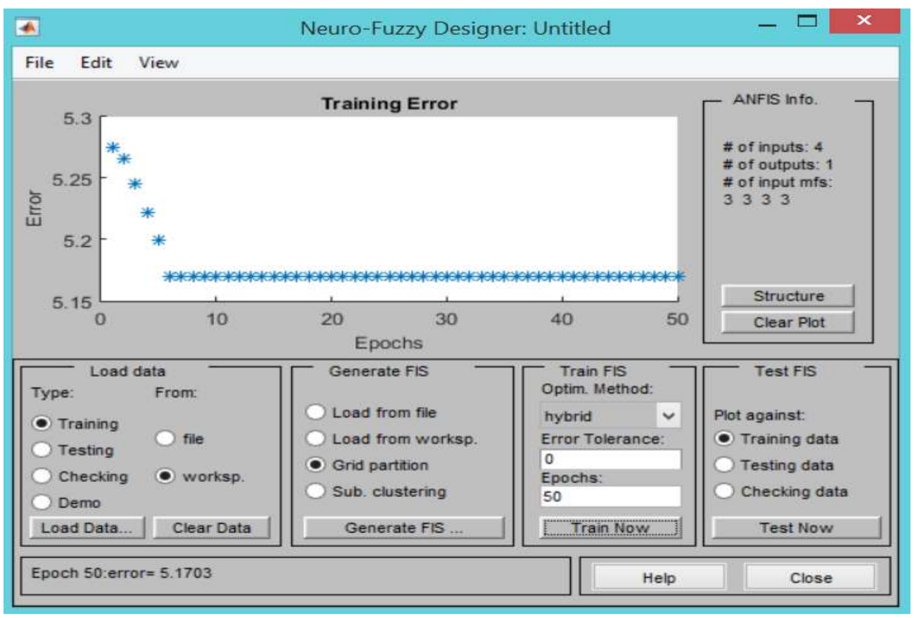


Fig. 5. Training the Error

2.2.3 Testing ANFIS model

The trained data's has been tested and the FIS output is shown through Figs. 6 to 8.

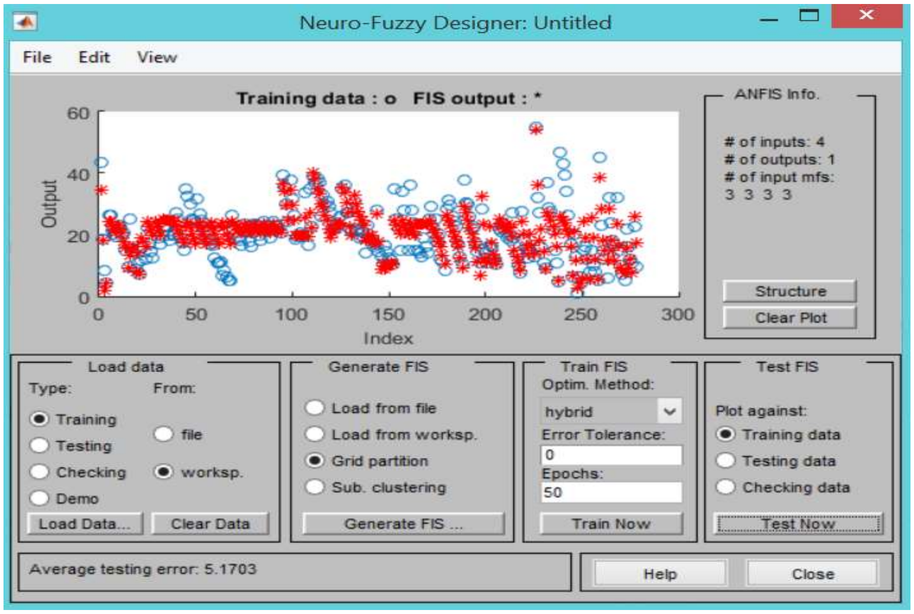


Fig. 6. Tested Training Data

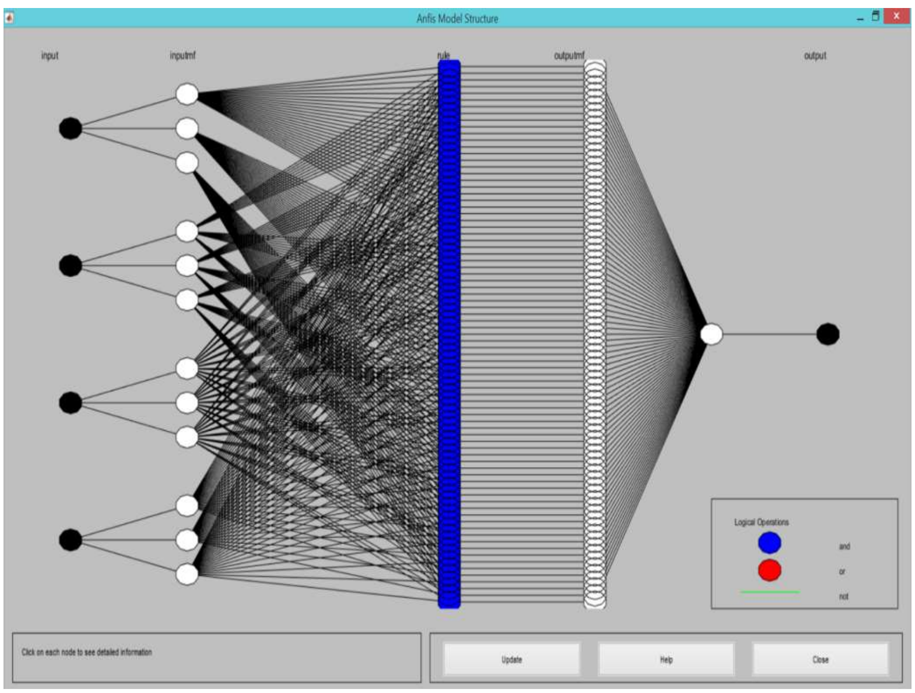


Fig. 7. ANFIS Architecture

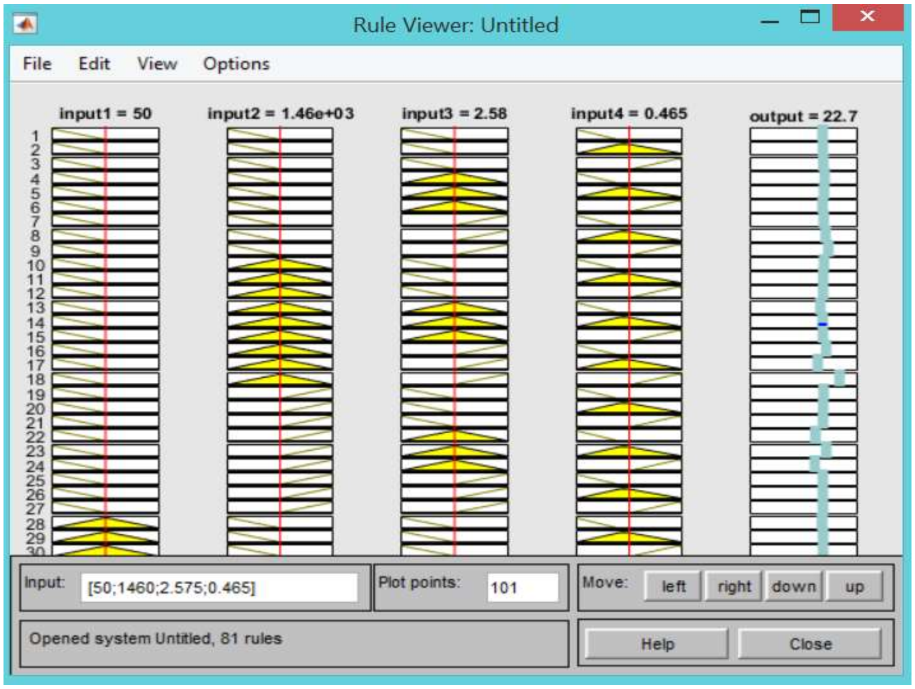


Fig. 8. Rule Viewer

2.3 Comparison of results

The performance parameters were predicted for eight membership functions . The results predicted through ANFIS modeling using Gaussian Membership Function are presented in Table 3.

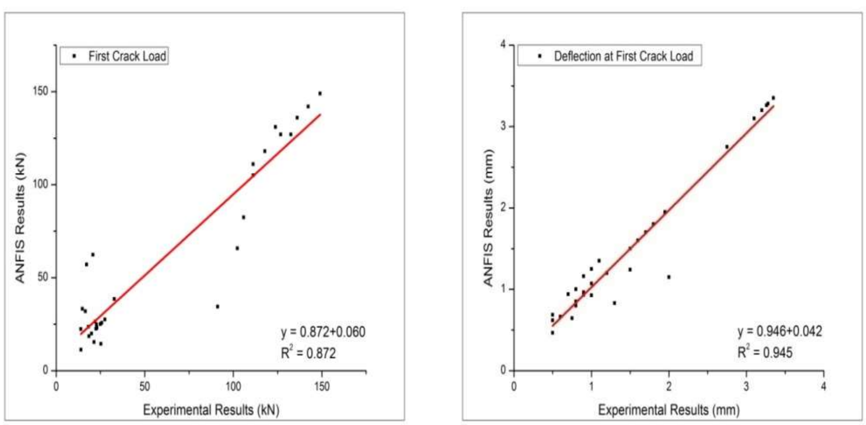
Table 3
Comparison of Experimental and ANFIS results

Author	Test Specimen	First Crack Load (kN)	Deflection at First Crack Load (mm)	Yield Load (kN)	Deflection at Yield Load (mm)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)	Ductility
	500C-0CR	38.5	1.24	184.0	8.94	250.0	24.40	2.69
	500C-5CR	14.4	1.35	177.0	10.70	255.0	31.90	3.08
	500C-10CR	24.8	1.25	163.0	9.32	247.0	27.80	3.01
	500C-15CR	15.4	1.16	147.0	9.36	253.0	31.50	3.41
	550C-15CR	26.4	1.15	146.0	8.53	244.0	26.50	3.09
Ismail et al (2016)	550C-20CR	23.6	1.07	131.0	8.03	233.0	24.30	2.93
	550C-20CR-MK	62.3	1.00	133.0	5.05	215.0	12.80	2.45
	550C-30CR-MK	57.1	0.93	128.0	5.03	197.0	11.00	2.12
	550C-30CR-MK-MA	31.9	0.94	123.0	6.91	206.0	15.80	2.23
	550C-40CR-MK-MA	22.4	0.67	139.0	8.15	196.0	14.70	1.81
	550C-40CR-MK-VRC	33.3	0.69	139.0	7.10	188.0	12.70	1.77
	550C-50CR-MK-VRC	11.3	0.46	152.0	9.59	200.0	15.80	1.64
	B1-0CR	127.0	0.62	185.0	1.45	252.0	3.45	2.45
	B2-5CR	131.0	0.65	168.0	0.21	228.0	0.55	2.57
	B3-15CR	105.0	0.85	137.0	1.27	199.0	3.27	2.50
	B4-25CR	65.8	0.96	130.0	4.51	205.0	10.60	2.27
Ismail et al	B5-5CR-0.35SF	136.0	1.20	280.0	2.20	284.0	2.47	1.12
	B6-15CR-0.35SF	127.0	0.80	200.0	1.20	245.0	2.31	1.93

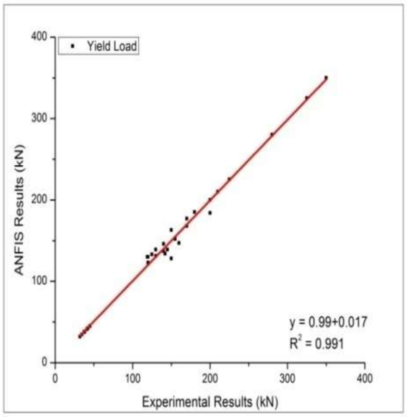
(2017)	B7-25CR-VRC	82.4	0.93	134.0	3.12	197.0	7.02	2.19
	B8-35CR-VRC	34.4	0.83	130.0	6.84	196.0	13.70	1.99
	B9-35CR-0.35SF-VRC	118.0	1.80	225.0	2.01	234.0	1.50	0.74
	B10-35CR-1SF-VRC	149.0	1.50	350.0	10.20	367.0	1.80	0.16
	B11-35CR-0.35LSF-VRC	111.0	1.70	210.0	2.49	210.0	1.40	0.56
	B12-35CR-1LSF-VRC	142.0	1.60	325.0	4.00	344.0	1.20	0.30
Mr. Karthikeyan	SC	18.5	1.95	32.0	5.50	60.0	12.00	2.18
	S11	20.0	2.75	34.5	6.00	62.5	14.40	2.40
	S12	22.5	3.10	37.5	6.50	65.0	15.60	2.40
	S21	23.0	3.20	38.3	6.90	66.5	16.80	2.43
	S22	25.0	3.26	41.0	7.45	68.5	18.60	2.50
	S31	25.7	3.28	42.5	7.95	69.7	20.80	2.62
	S32	27.5	3.35	45.0	8.10	72.5	24.90	3.07

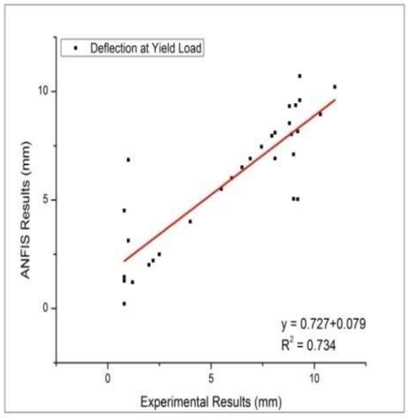
3. Results and discussions

The potential of ANFIS model for predicting the performance parameters of rubberized concrete beams has been explored in this study. 31 experimental data values were used for training and testing models with micro-reinforcement. ANFIS model has been performed with different membership functions such as trimf, trapmf, gaussmf, gauss2mf, pimf, desigmf and psigmf, to identify the membership function which will provide better convergence. Adaptive Neuro-Fuzzy Inference System (ANFIS) performed well for predicting the first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load, ductility for rubberized concrete with micro-reinforcement. To evaluate the accuracy of the models, scatter plots were drawn between the experimental and predicted results as shown in Fig. 9.

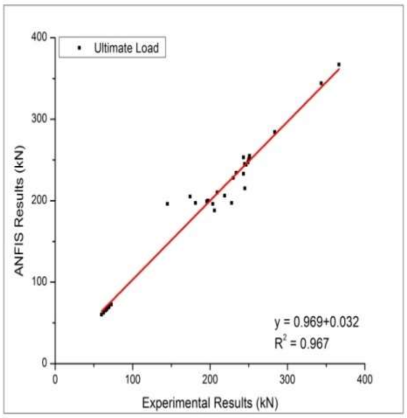


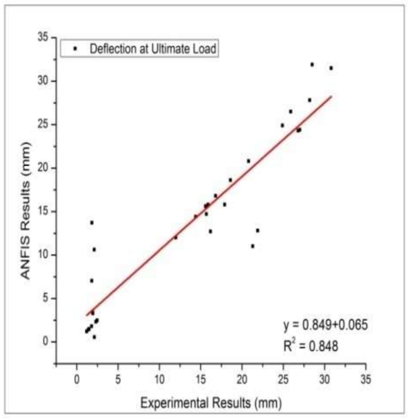
(a) (b)


Yield Load
ANFIS Results (kN)
Experimental Results (kN)
y = 0.99+0.017
R^2 = 0.991

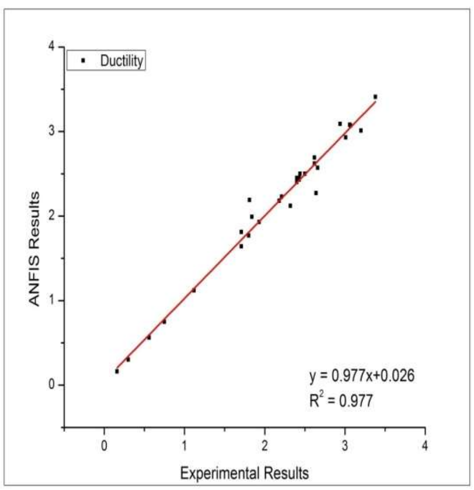

Deflection at Yield Load
ANFIS Results (mm)
Experimental Results (mm)
y = 0.727+0.079
R^2 = 0.734

(c) (d)


Ultimate Load
ANFIS Results (kN)
Experimental Results (kN)
y = 0.969+0.032
R^2 = 0.967


Deflection at Ultimate Load
ANFIS Results (mm)
Experimental Results (mm)
y = 0.849+0.065
R^2 = 0.848

(e) (f)


Ductility
ANFIS Results
Experimental Results
y = 0.977x+0.026
R^2 = 0.977

(g)

Fig. 9. Comparison of Experimental and ANFIS results

A RMSE error, Co-efficient of determination and MAPE errors of 1.73, 0.995 & 2.37, 0.09, 0.996 & 5.02, 7.35, 0.998 & 2.52, 0.52, 0.990 & 4.31, 10.82, 0.997 & 0.04, 1.34, 0.994 & 3.36, 0.03, 0.997 & 2.83 were observed while predicting the first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load and ductility of rubberized concrete beams. Table 4 provide the statistical indicators such as the coefficient of determination (R^2), RMSE and MAPE for estimating the accuracy of predicted results.

Table 4
Statistical Indicators (rubberized concrete beams)

Parameters	trimf	trapmf	gbellmf	gaussmf	gauss2mf	pimf	dsigmf	psigmf
Root Mean Square Error (RMSE)								
FCL	7.46	5.91	4.46	1.73	4.99	2.99	2.40	2.37
Defl at FCL	0.11	0.11	0.10	0.09	0.09	0.12	0.10	0.10
YL	7.81	7.37	7.80	7.35	7.44	8.12	7.41	7.41
Defl at YL	0.67	1.15	0.75	0.52	0.70	0.72	0.68	0.68
UL	11.32	14.02	12.19	10.82	13.69	13.73	13.35	13.32
Defl at UL	1.37	1.45	2.29	1.34	1.62	1.19	2.08	2.08
Ductility	0.14	0.18	0.12	0.03	0.12	0.18	0.13	0.13
Coefficient of determination (R^2)								
FCL	0.993	1.000	0.998	0.995	0.997	0.999	0.999	0.999
Defl at FCL	0.996	0.997	0.997	0.996	0.998	0.996	0.997	0.997
YL	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998
Defl at YL	0.992	0.975	0.990	0.990	0.990	0.995	0.991	0.991
UL	0.997	0.996	0.997	0.997	0.996	0.996	0.996	0.996
Defl at UL	0.995	0.993	0.993	0.994	0.992	0.995	0.987	0.987
Ductility	0.996	0.994	0.997	0.997	0.994	0.993	0.997	0.997
Mean Absolute Percentage Error (MAPE)								
FCL	4.83	4.96	4.64	2.37	6.09	5.39	3.60	3.54
Defl at FCL	7.02	6.30	6.79	5.02	7.92	7.20	6.26	6.26
YL	3.55	2.87	3.30	2.52	2.69	4.03	3.22	2.52
Defl at YL	4.71	5.97	5.05	4.31	4.48	4.41	4.92	4.92
UL	2.85	4.10	3.31	0.04	3.64	2.91	3.60	3.54
Defl at UL	3.43	4.09	3.90	3.36	3.53	3.89	4.60	4.60
Ductility	3.43	4.07	2.95	2.83	4.42	4.11	3.05	3.05

It can be seen from the results that the ANFIS model constituted with gauss membership function gives the reliable results. This is evident from a lower value of RMSE and MAPE errors and higher value of co-efficient of determination.

4. Conclusions

Rubberized concrete beams incorporating pre-treated rubber aggregates exhibit improved performance in terms of load carrying capacity, deformation capacity and ductility. ANFIS modeling has been proposed for rubberized concrete beams using different membership functions in MATLAB. The results predicted through ANFIS modeling exhibited better convergence with experimental results. This is ascertained through the statistical indicators. A correlation co-efficient of 0.734 to 0.997 for rubberized concrete beams were observed. ANFIS model constituted with Gaussian membership function gives the most reliable and accurate results than the other membership functions.

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