INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
ISSN: 2180-3242 e-ISSN: 2600-7959

IJSCET

Vol. 15 No. 4 (2024) 64-80
https://publisher.uthm.edu.my/ojs/index.php/ijscet

Effectiveness of Rubberized Concrete by Using Adaptive Network-Based Fuzzy Inference System

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DOI: https://doi.org/10.30880/ijscet.2024.15.04.006

Article Info

Received: 3 June 2024
Accepted: 24 December 2024
Available online: 28 December 2024

Keywords

Rubbershreds, RMSE, ANFIS, compressive strength, water cement ratio

Abstract

Rubberized concrete, a mixture prepared with different ratio of waste rubber shreds as a partial substitute of coarse aggregates, was found in this research by experiments and modeling. For this purpose, cubes, prisms and cylinders were cast by replacing 2.5%,5% and 7.5% of coarse aggregates. Compressive strength, flexural strength and Young's modulus tests were carried out on cubes,prisms and cylinders respectively. ANFIS models were created in order to stimulate and forecast the mechanical properties of rubberized concrete specimens. The input parameters of this modelswere percentage of rubber volume fraction, coarseaggregate, binder/sandratioconcrete .The output parameters of this models were compressive strength, Flexural strength and modulus of elasticity .The test data required for ANFIS modeling were obtained from relevant literature.The ANFIS modeling has been conducted and the mechanical properties of rubberized concrete were predicted using four membership functions. The results predicted through ANFIS modeling show good convergence with the experimental results.

1. Introduction

There is an enormous potential for waste rubber reuse and reclamation in emerging nations because of the immense amount of dump tyre rubber. The ultimate result is less waste and less environmental harm, regardless of whether rubber tires are recycled, reprocessed, or made into new items [1]. Two distinct rubber aggregate technologies—mechanical grinding and a cold grinding—were extracted from the scrap tire [2]. A particular proportion of crumb rubber has been added to regular concrete to provide crack resistance, high ductility, and high energy dissipation capability; this type of concrete is called crumb rubber concrete [3]. The density and compressive strength of rubberised concrete are impacted by the w/c ratio and rubber content [4]. The rubber aggregates' strength of bonding [5].By replacing fine or coarse aggregates with crumb or shredded rubber particles, concrete's ductility, energy dissipation, damping ratio, impact resistance, and toughness can all be developed. The deformation capacity, ductility, and toughness of the beams can be upgraded by using up to 10% CR without affecting the ultimate flexural load. However, with a modest reduction in the final flexural stress, 10 to 20% CR replacement might continue to boost the beams' toughness, ductility, and deformation capacity [6]. ANN, ANFIS, and regression models were proposed through Sadrmomtazi and colleagues [7] to forecast the compressive strength of EPS concrete beams. The results show that ANN and ANFIS models predict compressive strength more accurately than regression models. Rahmat Madandoust and colleagues [8] used GMDH-type neural networks and ANFIS models to estimate the concrete's compressive strength through core testing. For the optimal design of GMDH-type neural systems, the singular value decomposition (SVD) and genetic algorithm (GA) techniques were used. The findings demonstrated that, based on core testing, a generalised ANFIS and GMDH-type neural network is still a valid method for predicting compressive strength.

The objective of study is to expand on the earlier analysis conducted by the researchers employing different ratio of rubber shreds (2.5%,5% and 7.5%) in order to get insight into the performance of rubberised concrete using ANFIS. Flow chart of proposed work is shown in Figure 1. In this case, the study sought to close the gap created by earlier research by creating rubberised concrete that is both cost-effective and efficient. By using a neural approach, our work seeks to address specific research concerns by determining the effect of the pre-treatment rubber shreds content on the mechanical properties of rubberised concrete.

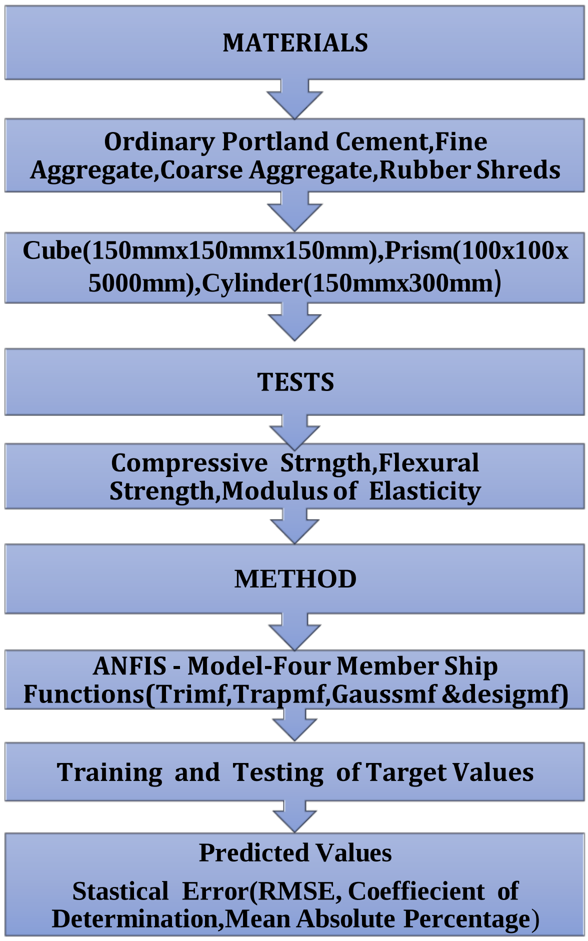

Fig. 1 *Flowchart of the proposed work*

2. Materials and Methods

2.1 Materials Used

Concrete had a compressive strength of 26 MPa. The concrete's composition was fine aggregate (715 kg/m3), coarse aggregate (20 mm) (702 kg/m3) &12.5 (468kg/m3), and Portland cement (380 kg/m3) with a w/c of 0.45. Rubber -cut pieces with a size of 20 mm and a specific gravity of 1.24 that were prepared from conveyer belts. Sand coated rubber shreds as shown in Fig.2. Different proportions of rubber shreds (2.5%, 5.0%, 7.5%) were used to prepare the concrete specimens. Process of sandcoated rubber shreds are shown in Fig 3.

Fig. 2 *Sand coated rubber shreds*

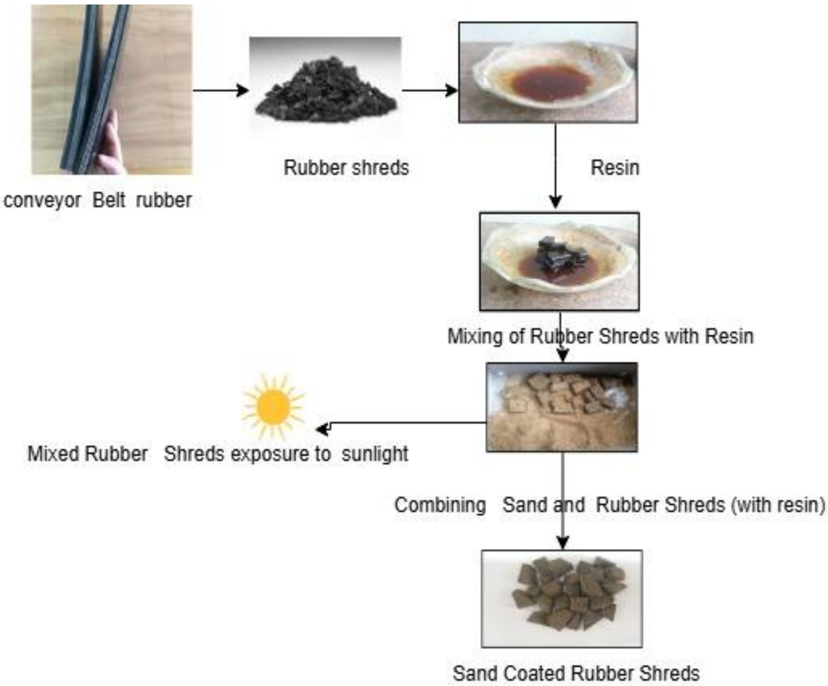

Fig. 3 *Process of sand coated rubber shreds*

2.2 Test Methods

a) Compressive Strength

The compressive strength test was conducted following 28 days of curing. 150 x 150 x 150 mm cubes were constructed for each of the three mixtures. The test protocol was based on the IS516: 2004 standard code. Compressive strength of Rubberized concrete is presented in Table1.

Table 1 *Compressive strength of rubberized concrete specimens*

S. No.	Specimen Designation	Rubber Content (%)	Average Compressive Strength (MPa) at 28 days
1	CC	0	26.20
2	RC1	2.5	28.53
3	RC2	5	29.50
4	RC3	7.5	29.20

b) Modulus of Elasticity Test on Cylinders

The typical cylinder specimens in a 1000kN capacity was used for each specimen. Each specimen type's results were determined by averaging the values of three specimens from the same group. Each specimen's upper and lower surfaces were levelled prior to testing in order to remove any loading eccentricity. Modulus of Elasticity of Rubberized Concrete Specimens are presented in Table 2.

Table 2 *Modulus of elasticity of rubberized concrete specimens*

S. No.	Specimen Designation	Rubber Content (%)	Modulus of elasticity (GPa) at 28 days
1	CC	0	23
2	RC1	2.5	26
3	RC2	5	27
4	RC3	7.5	28

c) Flexural Strength

Tests were conducted in accordance with IS516: 2004 standard 16 prisms, each measuring 100 x 100 x 500mm were tested. Table 3 is shown as flexural strength of flexural strength of concrete.

Table 3 *Modulus of rupture of rubberized concrete specimens*

S. No.	Specimen Designation	Rubber Content (%)	Fibre Content (%)	Average Flexural strength (MPa) at 28 days
1	CC	0	0	4.64
2	RC1	2.5	0	6.52
3	RC2	5	0	7.92
4	RC3	7.5	0	8.54

2.3 Adaptive Network-Based 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. 4 is shown as architecture of ANFIS.

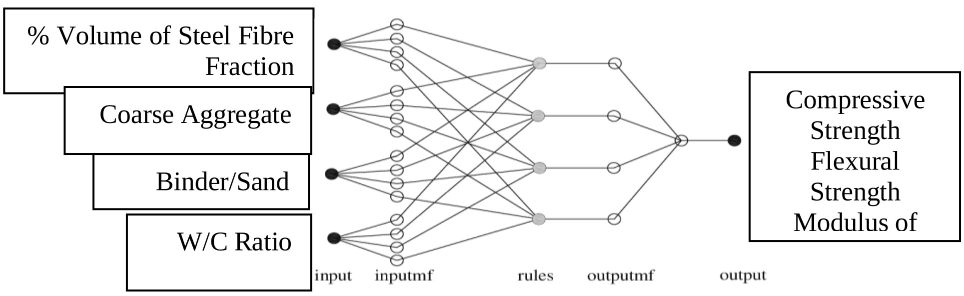

Fig. 4 *Architecture of ANFIS*

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.

2.3.1 Construction of the ANFIS Model

ANFIS network control systems are an ideal replacement for typical model-based control schemes and provide a hybrid platform for solving real-world complicated issues that call for the use of intelligent systems. They promote the control system's resilience by permitting effective resolution of the everyday challenges of uncertainty and unknown variations in plant parameters and structures. Math Works' MATLAB Fuzzy Logic Toolbox (FLT) was used as the development tool. Eight member ship function such as trimf, trapmf, gaussmf, gauss2mf, gbellmf, dsigmf, psigmf, and pimf is shown in Fig. 5. Above eight membership function, where four member ship function (trimf, trapmf, gaussmf, gauss2mf) was used for predicting the performance of rubberized concrete.

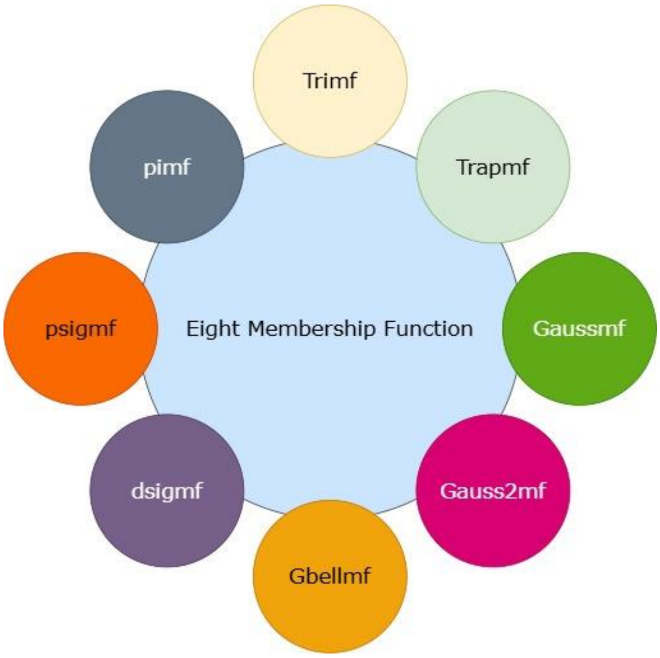

Fig. 5 *Eight membership functions*

2.3.2 Variables Utilized in ANFIS Modelling

The inputs of the adaptive neuro fuzzy inference system consist of five elements Rubber Volume Fraction, fibre volume fraction, Coarse Aggregate, Binder Sand Ratio and W/C Ratio. The targets are compressive strength, flexural strength and modulus of elasticity. 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 membership functions. The Input and Output parameters for rubberized concrete are shown in Tables 4-5

Table 4 *Input values for ANFIS modelling*

References	Test specimen	% of Rubber Volume Fraction	Coarse Aggregate	Binder/Sand Ratio	W/C Ratio
[1]	RA20	20	1001.00	0.52	0.350
	RA40	40	1001.00	0.52	0.350
	RA60	60	1001.00	0.52	0.350

[2]	NC	0	907.00	0.53	0.460
	SFC	0	907.00	0.53	0.460
	CRC5	5	907.00	0.53	0.460
	CRC10	10	907.00	0.58	0.460
	CRC15	15	907.00	0.62	0.460
	SFCRC5	5	907.00	0.55	0.460
	SFCRC10	10	907.00	0.58	0.460
	SFCRC15	15	907.00	0.62	0.460
	60FR	60	1001.00	1.29	0.423
	80FR	80	1001.00	2.59	0.423
[3]	100FR	100	1001.00	2.59	0.423
	40CR	40	600.60	0.52	0.423
	60CR	60	400.40	0.52	0.423
	80CR	80	200.20	0.52	0.423
	100CR	100	0.00	0.52	0.423
	40CR40FR	40	600.60	0.86	0.423
	60CR60FR	60	400.40	1.29	0.423
[4]	R15	15	1151.81	0.67	0.500
	R20	20	1151.81	0.67	0.500
	R25	25	1151.81	0.67	0.500
[5]	CR0	0	1122.00	0.58	0.450
	CR5	5	1122.00	0.58	0.450
	CR10	10	1122.00	0.58	0.450
	CR15	15	1122.00	0.58	0.45
	PF0	0	1122.00	0.58	0.45
	PF5	5	1122.00	0.58	0.45
	PF10	10	1122.00	0.58	0.45
	PF15	15	1122.00	0.58	0.45
	NC0	0	1067.27	0.52	0.50
	RC1	0.5	1067.27	0.52	0.50
[6]	RC2	1	1067.27	0.52	0.50
	RC3	1.5	1067.27	0.52	0.50
	RC4	2	1067.27	0.53	0.50
	RC5	1.5	1067.27	0.52	0.50
	RC6	2	1067.27	0.53	0.50
[7]	NC0	0	1202.55	0.74	0.45
	RC5	5	1202.55	0.74	0.45
	RC10	10	1202.55	0.74	0.45
	RC15	15	1202.55	0.74	0.45
	RC20	20	1202.55	0.74	0.45
	NCO	0	1052.00	0.75	0.35
	RC0	0	954.00	0.75	0.35
	RC4	4	954.00	0.75	0.35
	RC8	8	954.00	0.75	0.35
[8]	RC12	12	954.00	0.75	0.35
	RC16	16	954.00	0.75	0.35
	NC0	0	1052.00	0.75	0.35
	RC0200	0	954.00	0.75	0.35
	RC4200	4	954.00	0.75	0.35
	RC8200	8	954.00	0.75	0.35
	RC12200	12	954.00	0.75	0.35
	RC16200	16	954.00	0.75	0.35
	NC0400	0	1052.00	0.75	0.35
	RCO400	0	954.00	0.75	0.35
	RC4400	4	954.00	0.75	0.35
	RC8400	8	954.00	0.75	0.35

	RC12400	12	954.00	0.75	0.35
	RC16400	16	954.00	0.75	0.35
	NC0600	0	1052.00	0.75	0.35
	RC0600	0	954.00	0.75	0.35
	RC4600	4	954.00	0.75	0.35
	RC8600	8	954.00	0.75	0.35
	RC12600	12	954.00	0.75	0.35
	RC16600	16	954.00	0.75	0.35
	NC0	0	1105.00	0.64	0.49
	RC1	2	1105.00	0.66	0.49
[9]	RC2	4	1105.00	0.68	0.49
	RC3	6	1105.00	0.70	0.49
	RC4	8	1105.00	0.73	0.49
	RC5	10	1105.00	0.76	0.49
	RC6	2	1105.00	0.66	0.49
	RC7	4	1105.00	0.68	0.49
	RC8	6	1105.00	0.70	0.49
	RC9	8	1105.00	0.73	0.49
	RC10	10	1105.00	0.76	0.49
	RC11	2	1105.00	0.66	0.49
	RC12	4	1105.00	0.68	0.49
	RC13	6	1105.00	0.70	0.49
	RC14	8	1105.00	0.73	0.49
	RC15	10	1105.00	0.76	0.49
	RC16	2	1105.00	0.66	0.49
	RC17	4	1105.00	0.68	0.49
	RC18	6	1105.00	0.70	0.49
	RC19	8	1105.00	0.73	0.49
	RC20	10	1105.00	0.76	0.49
	RC21	2	1105.00	0.66	0.49
	RC22	4	1105.00	0.68	0.49
	RC23	6	1105.00	0.70	0.49
	RC24	8	1105.00	0.73	0.49
	RC25	10	1105.00	0.76	0.49
[10]	M1	0	620.30	1.66	0.40
	M2	5	620.30	1.66	0.40
	M3	15	620.30	1.66	0.40
	M4	25	620.30	1.66	0.40
	M5	5	616.50	1.66	0.40
	M6	15	616.50	1.66	0.40
	M7	25	620.30	1.66	0.40
	M8	35	620.30	1.66	0.40
	M9	35	616.50	1.66	0.40
	M10	35	609.60	1.66	0.40
	M11	35	616.50	1.66	0.40
	M12	35	609.60	1.66	0.40
[11]	PC	0	1092.00	0.54	0.54
	PRC	18	994.00	0.59	0.54
	SCC	0	881.00	0.41	0.54
	SCRC	14	819.00	0.44	0.54
[12]	T1	0	2920.00	0.24	0.35
	T2	5	2920.00	0.25	0.35
	T3	10	2920.00	0.27	0.35
	T4	15	2920.00	0.28	0.35
	T5	20	2920.00	0.30	0.35
	T6	0	2920.00	0.18	0.45
	T7	5	2920.00	0.19	0.45
	T8	10	2920.00	0.21	0.45
	T9	15	2920.00	0.22	0.45
	T10	20	2920.00	0.23	0.45

	T11	0	2920.00	0.15	0.55
	T12	5	2920.00	0.16	0.55
	T13	10	2920.00	0.17	0.55
	T14	15	2920.00	0.18	0.55
	T15	20	2920.00	0.19	0.55
	S1	0	2920.00	0.27	0.35
	S2	5	2920.00	0.28	0.35
	S3	10	2920.00	0.30	0.35
	S4	15	2920.00	0.32	0.35
	S5	20	2920.00	0.35	0.35
	S6	25	2920.00	0.37	0.35
	S7	0	2920.00	0.21	0.45
	S8	5	2920.00	0.22	0.45
	S9	10	2920.00	0.23	0.45
	S10	15	2920.00	0.25	0.45
	S11	20	2920.00	0.27	0.45
	S12	25	2920.00	0.29	0.45
	S13	0	2920.00	0.17	0.55
	S14	5	2920.00	0.18	0.55
	S15	10	2920.00	0.19	0.55
	S16	15	2920.00	0.20	0.55
	S17	20	2920.00	0.22	0.55
	S18	25	2920.00	0.23	0.55
[13]	C1	0	780.00	2.28	0.52
	RC1	25	780.00	2.28	0.52
	RC2	50	780.00	2.28	0.52
	RC3	75	780.00	2.28	0.52
	B1	0	780.00	1.97	0.60
	RB1	15	780.00	1.97	0.60
	RB2	30	780.00	1.97	0.60
	RB3	50	780.00	1.97	0.60
	RB4	75	780.00	1.97	0.60
	C1	0	1092.00	0.54	0.48
[14]	RC1	5	1092.00	0.54	0.48
	RC2	10	1092.00	0.54	0.48
	RC3	15	1092.00	0.54	0.48
	A1	0	1092.00	0.54	0.48
	RA1	5	1092.00	0.54	0.48
	RA2	10	1092.00	0.54	0.48
	RA3	15	1092.00	0.54	0.48
	B1	0	881.00	0.41	0.48
	RB1	5	881.00	0.41	0.48
	RB2	10	881.00	0.41	0.48
	RB3	15	881.00	0.41	0.48
[15]	C1	0	936.00	0.35	0.45
	RC1	0.5	936.00	0.35	0.45
	RC2	1	936.00	0.35	0.45
	B1	0	936.00	0.35	0.45
	RB1	0.5	936.00	0.35	0.45
	RB2	1	936.00	0.35	0.45
[16]	C1	0	1025.00	0.21	0.45
	RC1	5	1025.00	0.21	0.45
	RC2	10	1025.00	0.21	0.45
	RC3	15	1025.00	0.21	0.45
	RC4	20	1025.00	0.21	0.45
	RC5	25	1025.00	0.21	0.45
	RC6	30	1025.00	0.21	0.45
	RC7	40	1025.00	0.21	0.45
	RC8	50	1025.00	0.21	0.45
	B1	0	1025.00	0.19	0.50

	RB1	5	1025.00	0.19	0.50
	RB2	10	1025.00	0.19	0.50
	RB3	15	1025.00	0.19	0.50
	RB4	20	1025.00	0.19	0.50
	RB5	25	1025.00	0.19	0.50
	RB6	30	1025.00	0.19	0.50
	RB7	40	1025.00	0.19	0.50
	RB8	50	1025.00	0.19	0.50
	A1	0	1025.00	0.17	0.55
	RA1	5	1025.00	0.17	0.55
	RA2	10	1025.00	0.17	0.55
	RA3	15	1025.00	0.17	0.55
	RA4	20	1025.00	0.17	0.55
	RA5	25	1025.00	0.17	0.55
	RA6	30	1025.00	0.17	0.55
	RA7	40	1025.00	0.17	0.55
	RA8	50	1025.00	0.17	0.55
[17]	C1	0	465.00	1.20	0.52
	RC1	25	350.00	1.20	0.52
	RC2	50	233.00	1.20	0.52
	RC3	75	115.00	1.20	0.52
	A1	0	465.00	1.20	0.59
	RA1	15	465.00	1.41	0.59
	RA2	30	465.00	1.71	0.59
	RA3	50	465.00	2.39	0.59
	RA4	75	465.00	4.78	0.59
[18]	C1	0	927.00	0.44	0.50
	RC1	5	884.00	0.44	0.50
	RC2	7.5	861.00	0.44	0.50
	RC3	10	839.00	0.44	0.50
	RB1	5	927.00	0.42	0.50
	RB2	7.5	927.00	0.41	0.50
	RB3	10	927.00	0.39	0.50
	C1	0	355.80	0.42	0.40
	RC1	10	355.80	0.42	0.40
	RC2	15	355.80	0.42	0.40
	RC3	20	355.80	0.42	0.40
	RC4	25	355.80	0.42	0.40
[20]	C1	0	1180.00	0.60	0.45
	RC1	15	1003.00	0.60	0.45
	RC2	30	826.00	0.60	0.45
	RC3	45	649.00	0.60	0.45
	RA1	15	1003.00	0.60	0.45
	RA2	30	826.00	0.60	0.45
	RA3	45	649.00	0.60	0.45
The Proposed work	CC	0	1170	0.53	0.45
	RC1	2.5	1170	0.53	0.45
	RC2	5	1170	0.53	0.45
	RC3	7.5	1170	0.53	0.45

Table 5 *Output parameters for ANFIS modelling*

Reference	Test specimen	Compressive strength (MPa)	Flexural strength (MPa)	Modulus of esasticity (GPa)
[1]	RA20	29.70	3.81	19.60
	RA40	13.30	2.55	14.12
	RA60	7.06	1.85	9.02
	NC	41.20	4.49	33.00
[2]	SFC	43.10	4.59	35.00
	CRC5	34.90	4.13	29.90
	CRC10	33.10	4.02	28.40
	CRC15	29.90	3.80	26.90
	SFCRC5	37.50	4.28	32.10
	SFCRC10	35.00	4.14	30.20
	SFCRC15	32.50	3.99	28.90
[3]	60FR	27.80	3.69	26.36
	80FR	19.50	3.10	22.07
	100FR	13.00	2.50	18.02
	40CR	34.00	4.08	29.15
	60CR	21.80	3.26	23.30
	80CR	19.40	3.00	22.00
	100CR	11.90	2.41	17.20
	40CR40FR	14.30	2.60	18.90
	60CR60FR	9.80	2.20	15.60
[4]	R15	20.59	6.26	22.68
	R20	21.51	6.33	23.18
	R25	21.03	6.25	22.92
[5]	CR0	33.32	5.50	28.86
	CR5	31.55	6.16	28.08
	CR10	28.73	5.42	26.80
	CR15	26.07	5.25	25.52
	PF0	33.32	5.50	28.86
	PF5	24.84	5.66	24.91
	PF10	20.59	5.25	22.68
	PF15	18.36	4.58	21.42
	NC0	32.00	3.60	28.28
[6]	RC1	32.00	3.60	28.28
	RC2	32.00	3.60	28.28
	RC3	27.50	3.10	26.22
	RC4	24.00	2.80	24.49
	RC5	32.00	3.70	28.28
	RC6	32.00	3.60	28.28
[7]	NC0	36.20	4.60	30.08
	RC5	32.20	4.10	28.37
	RC10	27.70	3.30	26.31
	RC15	24.80	2.80	24.89
	RC20	22.70	1.40	23.82
[8]	NCO	56.52	5.26	37.58
	RC0	51.41	3.98	35.85
	RC4	49.06	3.82	35.02
	RC8	39.41	4.39	31.38
	RC12	37.61	4.29	30.66
	RC16	35.88	4.19	29.94
	NC0	45.66	4.73	33.78
	RC0200	43.55	4.61	32.99
	RC4200	40.44	4.45	31.79
	RC8200	34.54	4.11	29.38
	RC12200	32.15	3.96	28.35

	RC16200	31.18	3.90	27.91
	NC0400	24.71	3.47	24.85
	RCO400	28.64	3.74	26.75
	RC4400	26.21	3.58	25.59
	RC8400	19.71	3.10	22.19
	RC12400	17.61	2.93	20.98
	RC16400	17.17	2.90	20.71
	NC0600	16.28	2.82	20.17
	RC0600	10.98	2.31	16.56
	RC4600	12.79	2.50	17.88
	RC8600	10.21	2.23	15.97
	RC12600	8.31	2.01	14.41
	RC16600	8.28	2.01	14.38
[9]	NC0	43.66	4.62	40.80
	RC1	35.97	4.19	29.70
	RC2	32.81	4.00	28.60
	RC3	30.34	3.85	25.90
	RC4	28.66	3.74	24.20
	RC5	25.42	3.52	23.70
	RC6	37.16	4.26	29.90
	RC7	34.34	4.10	29.50
	RC8	31.29	3.91	27.70
	RC9	26.98	3.63	25.60
	RC10	25.86	3.55	25.10
	RC11	38.17	4.32	30.90
	RC12	36.08	4.20	30.60
	RC13	34.97	4.13	28.70
	RC14	32.27	3.97	27.90
	RC15	29.57	3.80	27.00
	RC16	39.09	4.37	32.50
	RC17	35.31	4.15	31.50
	RC18	34.03	4.08	31.00
	RC19	33.55	4.05	31.10
	RC20	30.70	3.87	27.80
	RC21	39.88	4.42	33.50
	RC22	36.35	4.22	31.90
	RC23	35.80	4.18	31.30
	RC24	34.12	4.08	31.00
	RC25	32.68	4.00	29.20
[10]	M1	65.61	5.67	39.36
	M2	58.44	5.35	35.64
	M3	48.35	4.86	29.97
	M4	38.35	4.33	24.16
	M5	59.15	5.38	37.85
	M6	49.45	4.92	31.60
	M7	40.26	4.41	26.16
	M8	29.73	3.81	18.43
	M9	31.10	3.90	19.59
	M10	32.38	3.98	20.70
	M11	30.71	3.87	19.96
	M12	31.51	3.92	19.53
[12]	PC	54.00	5.14	33.48
	PRC	26.00	3.56	16.38
	SCC	56.00	5.23	34.72
	SCRC	36.00	4.20	22.68
[13]	T1	59.00	4.50	39.00
	T2	59.00	4.40	37.00
	T3	58.00	4.00	38.00
	T4	58.00	3.90	37.00
	T5	42.00	3.20	26.00

	T6	50.00	3.20	33.00
	T7	49.00	3.10	30.00
	T8	48.00	3.00	31.00
	T9	45.00	2.90	29.00
	T10	45.00	2.80	27.00
	T11	33.00	2.50	22.00
	T12	35.00	2.10	22.00
	T13	35.00	2.00	24.00
	T14	36.00	2.10	23.00
	T15	38.00	1.50	26.00
	S1	58.00	4.00	35.00
	S2	55.00	4.10	36.00
	S3	45.00	4.20	27.00
	S4	43.00	4.30	27.00
	S5	35.00	4.40	22.00
	S6	32.00	4.40	21.00
	S7	49.00	3.00	31.00
	S8	35.00	3.20	21.00
	S9	33.00	3.20	22.00
	S10	32.00	3.20	19.00
	S11	31.00	3.20	21.00
	S12	30.00	3.20	19.00
	S13	22.00	2.80	14.00
	S14	35.00	3.00	23.00
	S15	30.00	3.00	19.00
	S16	29.00	3.00	18.00
	S17	25.00	3.10	16.00
	S18	25.00	3.10	17.00
[14]	C1	45.80	4.70	33.80
	RC1	23.90	3.40	24.40
	RC2	20.90	3.20	22.80
	RC3	17.40	2.90	20.80
	B1	27.10	3.60	26.00
	RB1	24.00	3.40	24.50
	RB2	20.40	3.20	22.50
	RB3	19.50	3.00	22.00
	RB4	780.00	0.60	10.40
[15]	C1	55.00	8.30	37.00
	RC1	38.00	7.40	30.00
	RC2	32.00	7.10	28.00
	RC3	23.00	5.50	24.00
	A1	55.00	8.30	37.00
	RA1	42.00	8.00	32.00
	RA2	31.00	6.00	27.00
	RA3	22.00	5.30	23.00
	B1	55.00	8.30	37.00
	RB1	42.00	7.50	32.00
	RB2	38.00	6.10	31.00
	RB3	25.00	5.90	25.00
[16]	C1	24.00	3.40	21.50
	RC1	21.00	3.20	19.50
	RC2	19.00	3.00	18.50
	B1	28.00	3.70	24.00
	RB1	25.00	3.50	22.00
	RB2	23.00	3.40	20.50
[17]	C1	30.80	3.80	27.70
	RC1	30.10	3.80	27.40
	RC2	25.00	3.50	25.00
	RC3	25.30	3.50	25.10
	RC4	20.40	3.20	22.50

	RC5	19.90	3.10	22.30
	RC6	15.80	2.70	19.80
	RC7	10.50	2.30	16.20
	RC8	9.50	2.10	15.40
	B1	32.40	3.90	28.50
	RB1	35.40	4.10	29.70
	RB2	32.70	4.00	28.50
	RB3	28.20	3.70	26.50
	RB4	26.40	3.60	25.60
	RB5	24.80	3.50	24.80
	RB6	20.20	3.10	22.50
	RB7	15.40	2.70	19.60
	RB8	12.50	2.50	17.60
	A1	42.50	4.50	32.50
	RA1	35.00	4.10	29.50
	RA2	31.90	3.90	28.20
	RA3	29.50	3.80	27.10
	RA4	26.30	3.60	25.60
	RA5	22.80	3.30	23.80
	RA6	20.10	3.10	22.40
	RA7	16.30	2.80	20.10
	RA8	12.40	2.50	17.60
[18]	C1	45.80	3.51S	33.80
	RC1	23.90	2.93	24.40
	RC2	20.87	2.52	22.80
	RC3	17.42	2.52	20.80
	A1	27.11	5.34	26.00
	RA1	23.97	5.10	24.50
	RA2	20.41	5.03	22.60
	RA3	19.45	4.95	22.00
[19]				
	RA4	17.06	4.95	20.60
	C1	33.00	5.40	28.00
	RC1	34.00	5.40	24.00
	RC2	30.00	3.80	22.00
	RC3	25.00	3.30	20.00
	RB1	30.00	4.90	24.00
	RB2	27.00	4.80	22.10
	RB3	20.00	3.90	18.00
	C1	43.00	4.50	32.00
	RC1	30.00	3.80	27.00
	RC2	20.00	3.10	22.00
	RC3	15.00	2.70	19.00
	RC4	11.00	2.30	16.00
[20]	C1	40.40	4.45	31.80
	RC1	29.40	3.79	27.10
	RC2	23.20	3.37	24.10
	RC3	19.80	3.11	22.30
	RA1	21.34	3.23	23.10
	RA2	23.61	3.40	24.30
	RA3	19.50	3.09	22.10
The Proposed work	CC	26.20	4.64	23
	RC1	28.53	6.52	26
	RC2	29.50	7.92	27
	RC3	29.20	8.54	28

2.3.3 Comparison of Results

The performance parameters were predicted for eight membership functions. The results predicted through ANFIS modeling using four membership function are presented in Fig 6-8.

The graph drawn between the experimental results and those predicted through ANFIS modeling for compressive strength is shown through Fig. 6 . This graph consists of four different membership functions and experimental values such as Exp, trimf, trapmf, Gbell mf, and gaussmf. Experimental and predicted data represented through graph in different colour such as Exp (in blue), trimf (in red), trapmf (in green), Gbell mf (in purple), and gaussmf (in light blue)—each representing different approaches to predicting compressive strength. Gaussian membership function provides higher accuracy when compared to other membership function.

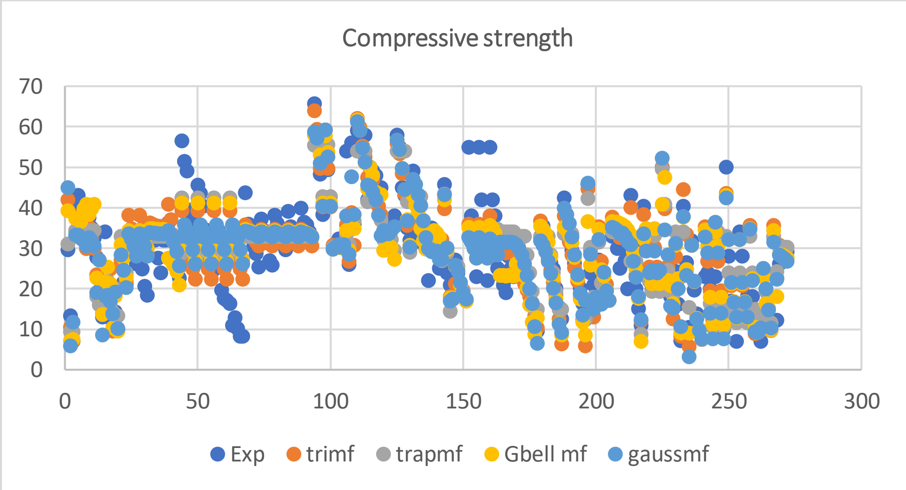

Fig. 6 *Comparison of experimental and ANFIS results*

The graph drawn between the experimental results and those predicted through ANFIS modeling for flexural strength are shown through Fig. 7. This graph consists of experimental values and four different membership functions. Experimental and predicted data represented through graph in different colours such as Exp (in blue), trimf (in red), trapmf (in green), Gbell mf (in purple), and gaussmf (in light blue)—each representing different approaches to predicting flexural strength. Gaussian membership function provides higher accuracy compared to other membership function.

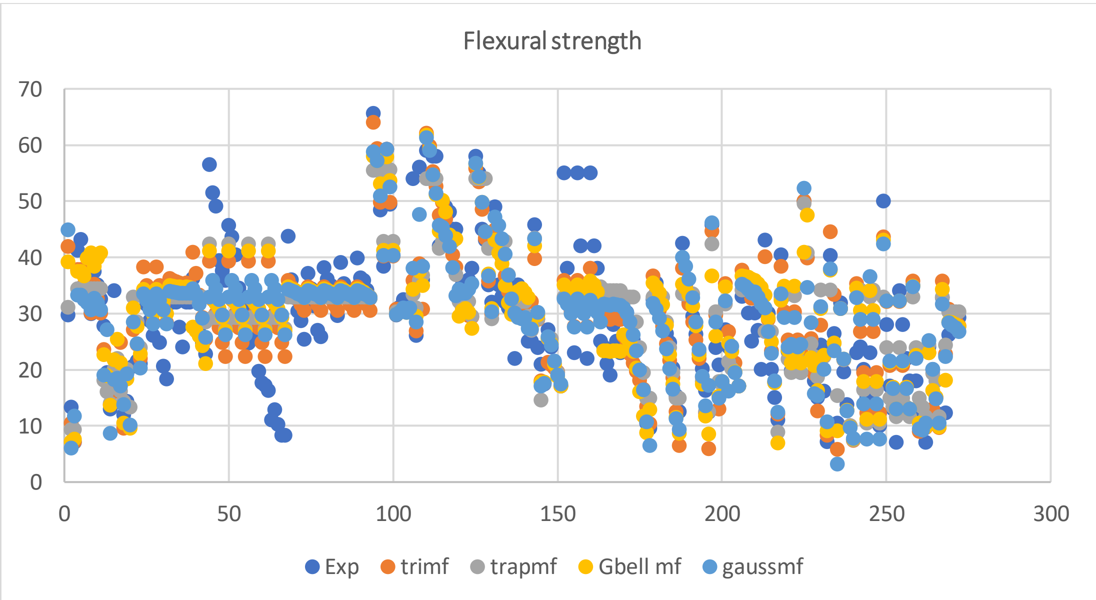

Fig. 7 *Comparison of experimental and ANFIS results*

The graph drawn between the experimental results and those predicted through ANFIS modeling for modulus of elasticity are shown through Fig. 8. This graph consists of experimental values and four different membership functions. Experimental and predicted data represented through graph in different colours such as Exp (in blue), trimf (in red), trapmf (in green), Gbell mf (in purple), and gaussmf (in light blue)—each representing different approaches to predicting modulus of elasticity. Gaussian membership function provides higher accuracy compared to other membership function

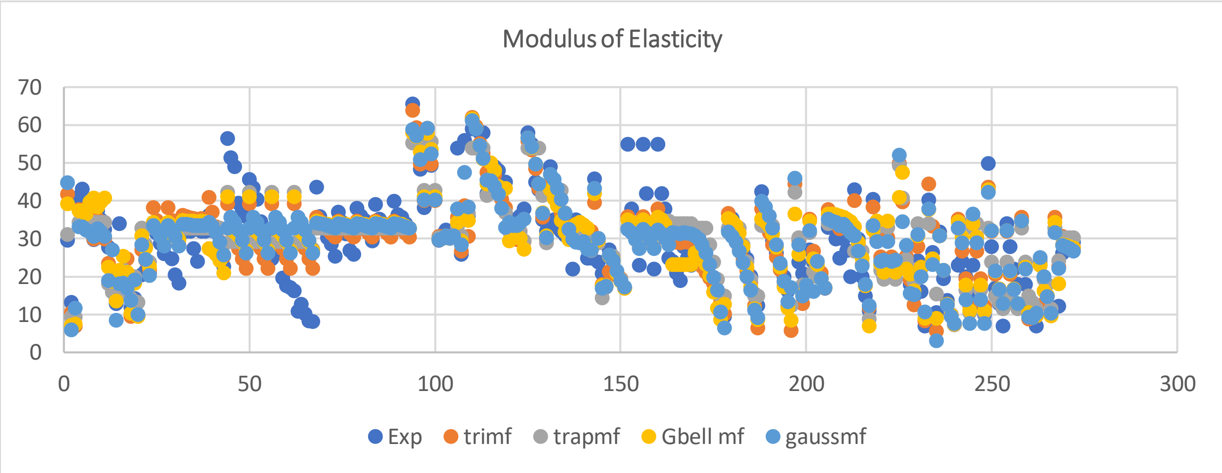

Fig. 8 *Comparison of experimental and ANFIS results*

3. Results and Discussion

The potential of ANFIS model for predicting the performance parameters of rubberized concrete has been exposed in this study. 270 experimental data values were used for training and testing models of rubberized concrete and experimental data values 37 for models of rubberized concrete. ANFIS model performed under different membership functions such as trimf, trapmf, gaussmf, to define the model which has the best ability to predict experimental results. Adaptive Neuro - Fuzzy Inference System (ANFIS) performed well for predicting the Compressive strength, Flexural strength and Modulus of elasticity for rubberized concrete. To evaluate the accuracy of the models, graphs were drawn between the experimental and predicted results as shown in Figs. 6 to 8. Tables 6 provide the statistical indicators such as the coefficient of determination (R^2), RMSE and MAPE for estimating the accuracy of predicted results. Figs. 6 to 8 show that the experimental and predicted values of performance parameters of rubberized concrete correlate well and the representative points in the graph correlate to the line of equality.

Table 6 *Statistical error*

Parameters	Root Mean Square Error (RMSE)			
	trimf	trapmf	gbellmf	gaussmf
CST	3.791	4.112	3.883	3.548
FST	0.445	0.497	0.444	0.433
E	2.719	3.040	2.971	2.752
Coefficient of determination (R^2)				
CST	0.987	0.984	0.986	0.988
FST	0.986	0.983	0.986	0.987
E	0.988	0.986	0.986	0.988
Mean Absolute Percentage Error (MAPE)				
CST	9.682	9.629	8.884	8.157
FST	8.869	9.854	8.965	8.462
E	7.978	8.706	8.566	7.704

Firstly, the performance of all the proposed ANFIS models (using various membership function) for the prediction of performance parameters of rubberized concrete has been evaluated through standard errors, (RMSE, R^2,MAPE) and statistical indicators (coefficient of determination and Karl Pearson's coefficient).Also, the effects of various membership functions on the performance of proposed ANFIS model have been examined.

RMSE error, coefficient of determination and MAPE errors of 3.548, 0.988 & 8.157, 0.433, 0.987 & 8.462, 2.752, 0.988 & 7.704 were observed while predicting the compressive strength and flexural strength and elasticity modulus of rubberized respectively.

It can be seen from the results that the ANFIS model constituted with gauss membership function gives reliable results. This was evident from a lower value of RMSE and MAPE errors and higher value of coefficient of determination. Thus, the high prediction ability of the ANFIS model can be realized in a short period of time.

4. Conclusions

Rubberized concrete specimens incorporating pre-treated rubber aggregates exhibit improved performance in terms of compressive strength, flexural strength and modulus of elasticity. ANFIS modeling has been proposed for rubberized concrete 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 coefficient of 0.88 to 0.998 for rubberized concrete were observed. ANFIS model constituted with Gaussian membership function gives the most reliable and accurate results than the other membership functions.

Acknowledgement

The authors acknowledged to the Institutions for the support on publication.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Assisted by experiments work and testing:*** *Rajendran karthikeyan:* ***Assisted in the manuscript preparation:*** *Kannan Suguna:* ***Helped in Development of ANFIS modeling:*** *Pachavannan partheeban and Shanmugam Karthikeyan. All authors reviewed the results and approved the final version of the manuscript.*

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