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DOI: https://doi.org/10.15332/iteckne.v20i1.2917

Predicting the strength of seashell concrete using Adaptive Neuro-Fuzzy Inference System: An experimental study

Predicción de la resistencia del concreto de conchas marinas usando Sistema de Inferencia Adaptativo Neuro-Fuzzy: Un estudio experimental

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Article DOI: https://doi.org/10.15332/iteckne.v20i1.2917

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Received Date: 6 June 2022 **Accepted Date:** 10 September 2022

Abstract

Seashell is a hard, protective outer layer created by an animal that lives in the sea. Empty seashells are often found washed up on beaches by beachcombers. This marine by-product can be used to partial replacement of coarse aggregate or cement in concrete. This paper describes the use of seashell powder and aggregate in the concrete for the replacement of cement and coarse aggregate. The effect of seashell waste in the concrete was studied in terms of its compressive strength, tensile strength and flexural strength after 28, 56 and 90 days of curing. The replacement of cement by seashell powder were 10%, 20% and 30% and replacement of coarse aggregate by seashell aggregate are 5%, 10% and 15%. The properties of seashell concrete were compared with control mix specimen of M25 grade of concrete. Also, it has been tried to predict the strength of the seashell concrete utilizing adaptive neuro-fuzzy inference system (ANFIS). The prediction of strength with the tool was agreeable with the experimental strength with the minimal error of less than 5%. This study concludes, that partial replacement of cement and coarse aggregate by seashell waste enhances the mechanical properties of the concrete significantly and enable proper utilization of these seashell waste as sustainable material for the concrete.

Keywords: *Seashell concrete, seashell powder, seashell aggregate, curing time, ANFIS, sustainable concrete*

Resumen: La concha marina es una capa exterior dura y protectora creada por un animal que vive en el mar. A menudo se encuentran conchas marinas vacías y lavadas por las olas sobre las playas. Este producto marino puede ser utilizado como reemplazo parcial del agregado grueso en el concreto o del cemento en el concreto. Este artículo describe el uso de polvo de conchas marinas y agregados en el concreto para reemplazar el cemento y los agregados gruesos. El efecto de los residuos de conchas marinas en el concreto fue estudiado en términos de su resistencia a la compresión, resistencia a la tracción y resistencia a la flexión después de 28. 56 y 90 días de curado. El reemplazo de cemento por polvo de conchas marinas fue de 10%, 20% y 30% y el reemplazo de agregado grueso por agregado de concha marina fue 5%, 10% y 15%. Las propiedades del concreto de concha marina fueron comparadas con una muestra de mezcla control de grado M25 de concreto. También se ha intentado predecir la resistencia del concreto de concha marina utilizando un Sistema de Inferencia Adaptativo *Neuro-Fuzzy* (*ANFIS*). La predicción de la fuerza con este sistema estuvo de acuerdo con la fuerza experimental con un error mínimo de menos del 5%.

Este estudio concluye que el reemplazo parcial de cemento y de agregado grueso por residuos de concha marina aumenta significativamente las propiedades mecánicas del concreto y permite la utilización adecuada de estos desechos de conchas marinas como material sostenible para el concreto.

Palabras clave: concreto de concha marina, polvo de concha marina, agregado de concha marina, tiempo de curado, ANFIS, concreto sostenible

1. INTRODUCTION

The way to protect the environment is to reduce, reuse and recycling of waste from various industries such as ceramic scraps, slag, steel scraps, shell [1-4]. etc. More the production for growing population, more waste is generated and dumped into the landfill. Most of these wastes are non-biodegradable and biodegradable in nature. Improper and haphazard disposal of these wastes will create a lot of environmental issues and hence recycling is must. The shell, a part of sea animal found to deposited along the seashore. The shells of the animals become empty after it dies.

This marine by-product can be utilized as aggregate or cement in concrete. The specimens made with crushed refractory brick as fine aggregate along with sand for four different percentage variation (25, 50, 75, and 100%) along with or without cement (0 and 100%) for elevated temperatures [5]. Unlike the other recycled aggregates, non-conventional organic seashell and calcareous aggregates are used in concrete which enhances the properties and reduces the waste to provide sustainable environment [6,7]. In past studies, ceramic wastes were used as coarse [8,9], fine [10,11] aggregates and cement [12,13] across countries. There are reports on the usage of waste from mining and metallurgical industry in the preparation of building bricks and blocks [14]. However, sawing waste from silicon carbide industry (SCI), was deposited to the landfill without recycling, as recycling process was complicate and it's not economical [15–18].

Researches have used the concepts of data-driven methods such as artificial intelligence technique broadly in the various field of civil engineering. Torkian et al. [19] have successfully used the ANFIS model for estimating the drift in a reinforced concrete building. Khademi et al [20] have successfully performed three different data-driven models such as ANN, ANFIS, and MLR to estimate of 28 days' compressive strength of recycled aggregate concrete. They have reported the both ANN and ANFIS is more capable of predicting the compressive strength of the recycled aggregate concrete comparison to MLR. Madani et al. [21] examined the performances of ANFIS, ANN models and linear and nonlinear regression analyses in predicting the strength of cementitious mixes and also showed the capability of the models of ANFIS and ANN compared with the traditional regression methods.

In this work seashell waste has been utilized for the manufacturing of concrete as replacement of cement up to 15% and coarse aggregate up to 30 %. The composition of seashell powder was analyzed using X-ray Diffraction (XRD) analysis was made to know the physical properties of powder of the waste. The utilization of seashell waste as the partial replacement of cement and coarse aggregate reduces the problem of producing the concrete at low rate.

2. EXPERIMENTAL STUDIES

2.1 Materials and methods

2.1.1 Seashell powder

The seashell waste collected from the seashore was used to produce concrete. Fig. 1(a) shows the seashell aggregate and Fig. 1(b) shows grained powder from the shell.

Fig. 1 (a) Seashell & (b) Grained form of seashell.

(a) Source: Source: The Author's (b)

XRD analysis was carried out to know the chemical composition of the seashell powder. Fig. 2 presents the XRD report of the seashell grained powder. The plots represent that major elements present in the seashell waste are O (47.96%), Ca (40.04%) and C (12%). The major composition C CaO_3 is 100%.

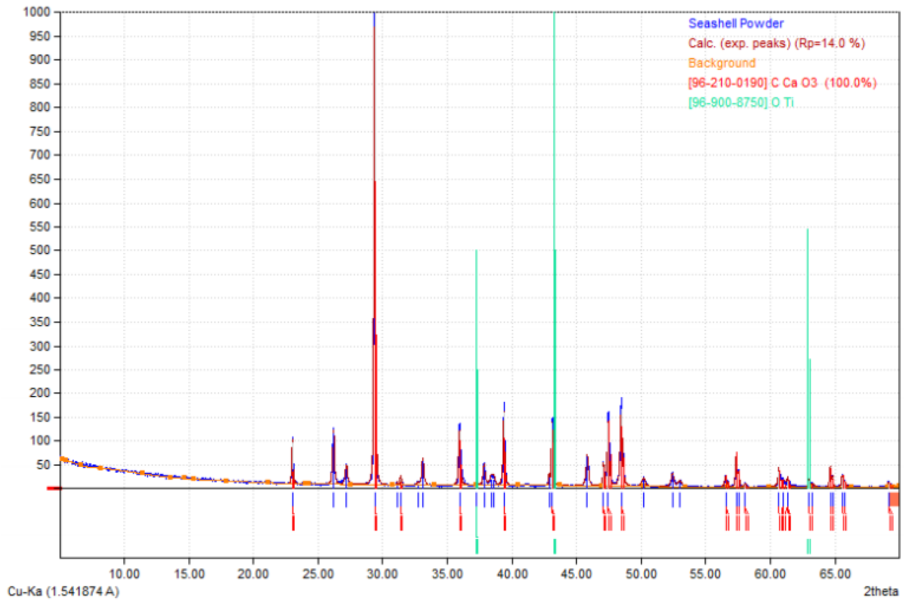


Fig. 2 XRD analysis of seashell powder

Source: The Author's

2.1.2 Mix proportion

The ingredients of concrete were studied to know its properties in accordance with IS codes [31]. Table I, shows the mix design of seashell concrete was performed as per IS 10260 [31].

TABLE I.
MIX PROPORTION OF SEASHELL CONCRETE

Specimen Details	Seashell Powder(SP) (%)	Cement (kg/m³)	Sand (kg/m³)	Seashell Aggregate(SA) (%)	Gravel (kg/m³)	Seashell waste (kg/m³)	w/c
SP0SA0	0	360	584	0	1223.8	0	0.5
SP5SA10	5	342	584	10	1101.42	140.38	0.5
SP10SA20	10	324	584	20	979.04	280.76	0.5
SP15SA30	15	306	584	30	856.66	421.14	0.5

Source: The Author's

2.1.3 Experimental study

All the specimens were cast under control environment and were cured in water for 7days, 28 days, 56 days and 90 days. Fig. 3 shows all the specimens under curing in water. After curing all the specimens were wiped with cloth and dried under room temperature and were subjected to loading. Seashell concrete specimens were tested under compression testing machine and universal testing machine. Fig. 4 shows the concrete specimens under various loading.

Fig. 3. SPECIMENS UNDER CURING FOR ALL CONCRETE MIX DESIGN

Source: The Author's

Fig. 4. CONCRETE SPECIMENS UNDER VARIOUS LOADING

Source: The Author's

3. Estimation techniques

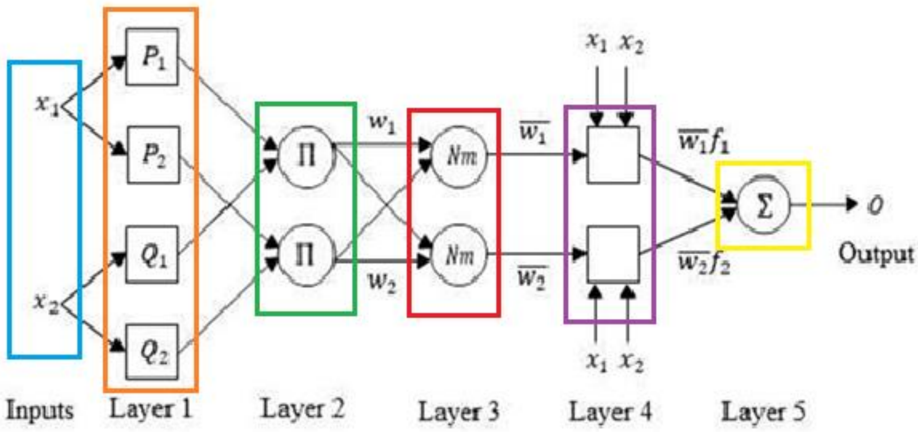
In recent years, the new kind of soft computing techniques such as Artificial Neural Networks (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and their hybrid technique ANN-ANFIS etc. have been used to estimate the necessary parameters for developing predictive models. This is an alternate statistical tool to estimate the strength and ductility of FRP Wrapped Concrete Columns, Behaviour of Cold-Formed Steel Box Struts, mechanical and durability properties of concrete, fatigue life, polypropylene fibre reinforced concrete, etc. [22-26]. In the current study the Adaptive Neuro-Fuzzy Inference System (ANFIS) are used to the strength of the seashell concrete and explained briefly in the following.

3.1 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro Fuzzy Inference System (ANFIS) is identified as a universal approximation estimator for responding to complex problems, which is to make a powerful mixture of an artificial neural network and fuzzy logic [27]. ANFIS is a class of adaptive, multi-layer and feed-forward networks which is comprised with two inputs x_1 and x_2, and one output, O of input–and a fuzzy rule base of the Takagi–Sugeno type [28]. The two fuzzy if-then rules based on the first-order Sugeno fuzzy model is expressed as follows:

Rule1: IF x_1 is P_1 and x_2 is Q_1, THEN $f_1 = a_1x_1 + b_1x_2 + c_1$
Rule2: IF x_1 is P_2 and x_2 is Q_2, THEN $f_2 = a_2x_1 + b_2x_2 + c_2$

Fig. 5. THE ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM ARCHITECTURE



Source: The Author's

Fig. 5 demonstrates the structure of adaptive neuro-fuzzy inference system which comprised of five different layers such as the fuzzy layer**,** product layer**,** normalized layer**,** de-fuzzy layer, and total output layer, and their nodes' functions are explained briefly below [29]:

Layer1: This layer contains adaptive nodes, and the node function for each node k is given by (1):

$$O_k^1 = \mu_{P_k}(x_1), \quad for \quad k = 1,2 \quad (or)$$

$$O_k^1 = \mu_{Q_{k-2}}(x_2), \quad for \quad k = 3,4 \quad (1)$$

here x_1 and x_2 are the inputs of the k^{th} node, and P_k and Q_{k-2} are the linguistic labels related to the node. The output O_k^1 produces the membership function of the input variable, and the parameters associated with the membership function are the premise parameters.

Layer 2: In this layer, each node k is a fixed node labelled with Π, which multiplies the incoming signals received from the previous layer. Equation 2.

$$O_k^2 = w_k = \mu_{P_k}(x_1)\mu_{Q_k}(x_2), \quad k = 1,2 \quad (2)$$

where w_k denotes the firing strength of the k^{th} rule.

Layer 3: This layer has fixed nodes labelled with Nm. The output of each node k is the ratio of firing strength of the k^{th} rule to the sum of firing strengths of all rules, equation 3.

$$O_k^3 = \overline{w_k} = \frac{w_k}{w_1 + w_2}, \quad k = 1,2 \quad (3)$$

here $\overline{w_k}$ represents the normalized firing strength.

Layer 4: In this layer, each node k is an adaptive node with the node function expressed by (4):

$$= \overline{w_k}f_k = \overline{w_k}(a_k x_1 + b_k x_2 + c_k), \quad k = 1,2 \quad (4)$$

where a_k, b_k, and c_k are the consequent parameters.

Layer 5: This layer has a single fixed node labelled Σ that sums up all the input signals to calculate the overall output of the network, equation (5)

$$O_1^5 = \sum_{k=1}^{2} \overline{w_k} f_k = \frac{\sum_{k=1}^{2} w_k f_k}{\sum_{k=1}^{2} w_k} \qquad (5)$$

3.2 Methodology

ANFIS are investigated for modeling compressive strength, tensile strength and flexural strength of concrete containing seashell waste at different ages. The results obtained from the experimental were used to predict the mechanical strength of the concrete. The dataset was divided into three subsets of training (70% data), validation (15% data), and testing (15% data) for ANFIS model. In this study, a total of 144 input-output data pairs were acquired through experimental result for the input parameters like percentage of cement placement by shell powder, percentage of aggregate placement by shell aggregate, period of curing (days), dimension of cube, dimension of beam and dimension of cylinder of range [0,10] and the output parameters are compressive strength, flexural strength and split tensile strength, respectively.

Three different ANFIS models were constructed for anticipating the compressive, flexural and split tensile strength which contains five and six inputs and an output. Hybrid- learning algorithm, which is a combination of “gradient descent” and “least squares” was applied to update the model parameters of ANFIS [30]. The fulfillment of the suggested ANFIS models were estimated through statistical variability characteristics like Mean Squared Error (MSE), Mean Absolute Error (MAE), Sum of Squared Error (SSE), Root Mean Squared Error ($RMSE$) and Coefficient of Determination (R^2). The least RSME values, and maximum R^2 value were the criteria selected to identify the optimum number and form of fuzzy rules. The definitions of these statistical parameters are defined in (6), (7), (8), (9), (10).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_{tar} - y_{pre}\right)^2 \qquad (6)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\left(y_{tar} - y_{pre}\right)\right| \qquad (7)$$

$$SSE = \sum_{i=1}^{n}\left(y_{tar} - y_{pre}\right)^2 \qquad (8)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_{tar} - y_{pre}\right)^2} \qquad (9)$$

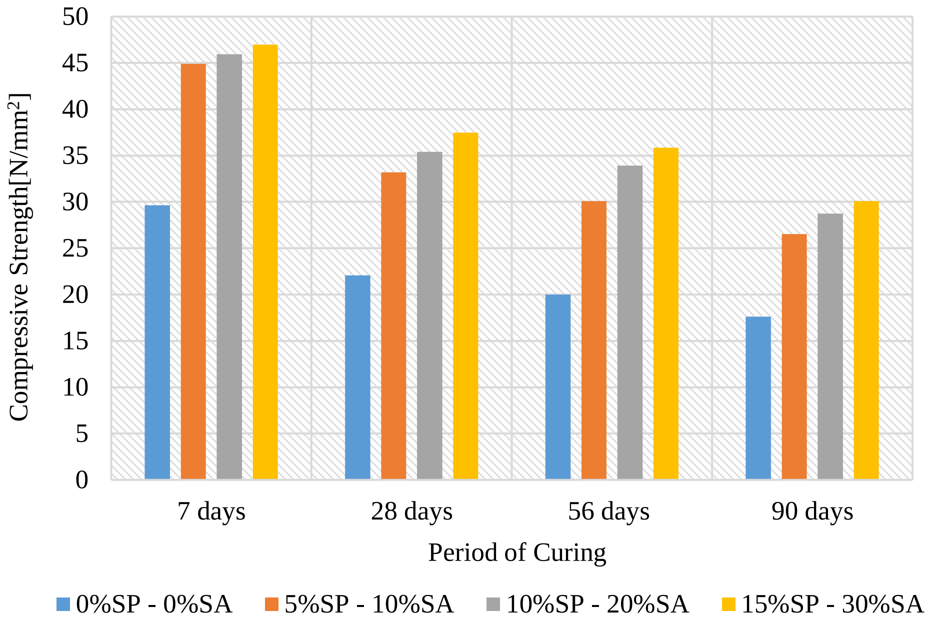
$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_{tar} - y_{pre}\right)^2}{\sum_{i=1}^{n}\left(y_{tar} - \overline{y_{tar}}\right)^2} \qquad (10)$$

4. RESULT AND DISCUSSION

4.1 Effect of seashell powder and aggregate on the compressive strength

The cube specimens of size 150 mm were testing under the hydraulic control CTM (Compression Testing Machine) of capacity 2000 kN according to IS 516: 1959 [32]. The load subjected to the specimen was recorded. The percentage variation of seashell powder from 5%, 10% & 15 % and 10%, 20% & 30% of seashell aggregate in the mix proportion, reduces the compressive strength by 23.6 %, 28.8% and 38.7 % respectively as compared to control specimen. The strength can be enhanced by adding admixtures in the concrete mix. The compressive strength of the concrete also gets improved by increasing curing period from 7 days to 90 days under control environment. Fig.6 shows the chart representing the variation in the compressive strength of the seashell concrete.

Fig.6. COMPRESSIVE STRENGTH VALUES OF ALL THE CONCRETE MIX TESTED



Source: The Author's

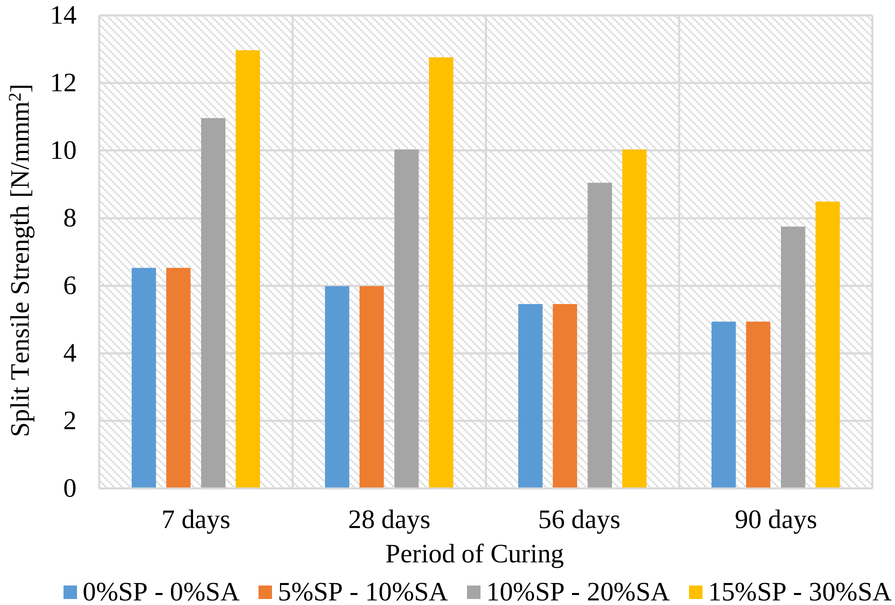
4.2 Effect of seashell powder and aggregate on the tensile strength

The structural elements are more vulnerable to tensile cracking because of very low split tensile strength of concrete. To study the tensile strength of seashell concrete, the standard cylindrical specimen of diameter of 100 mm and length 300 mm was casted for four different mix proportion.

The tensile strength was performed according to IS 516: 1959 [32]. All the specimens were applied load using CTM of capacity 2000kN, which is indirect method of determining the tensile strength of concrete. The increase in the percentage of seashell powder from 5%, 10% & 15 % and 10%, 20% & 30% of seashell aggregate in the mix proportion, reduces the tensile strength by 7.4 %, 18.4% and 27.4 % respectively when compared to control specimen.

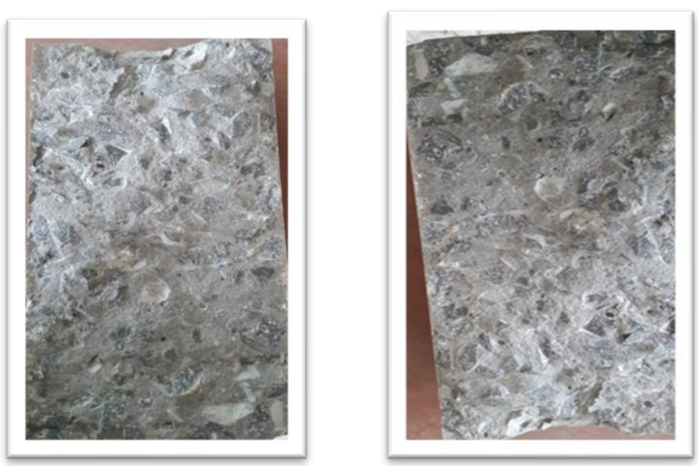
The observed average tensile strength of the specimens was equal to 9.25 % of compressive strength of concrete. The specimen with the mix proportion SP- 5% and SA-10% able to provide the same tensile strength compared to control specimen SP-0% and SA – 0%. Thus, the seashell powder (5%) and seashell aggregate (10%) can be utilized as replacement of cement and coarse aggregate in concrete to achieve tensile strength. Hence, better utilization of waste in concrete can be made to develop the sustainable environment. Fig. 7 shows the tensile strength comparison between the different mix proportion for varying period of curing of the specimen. Fig. 8 shows the seashell concrete cylindrical specimen after test. From the Fig. 8 it is observed that, the seashell aggregates well bonded with other ingredients of concrete and provided uniform homogeneity.

Fig.7. TENSILE STRENGTH VALUES OF ALL THE CONCRETE MIX TESTED



Source: The Author's

Fig. 8 CYLINDER SPECIMEN AFTER FAILURE

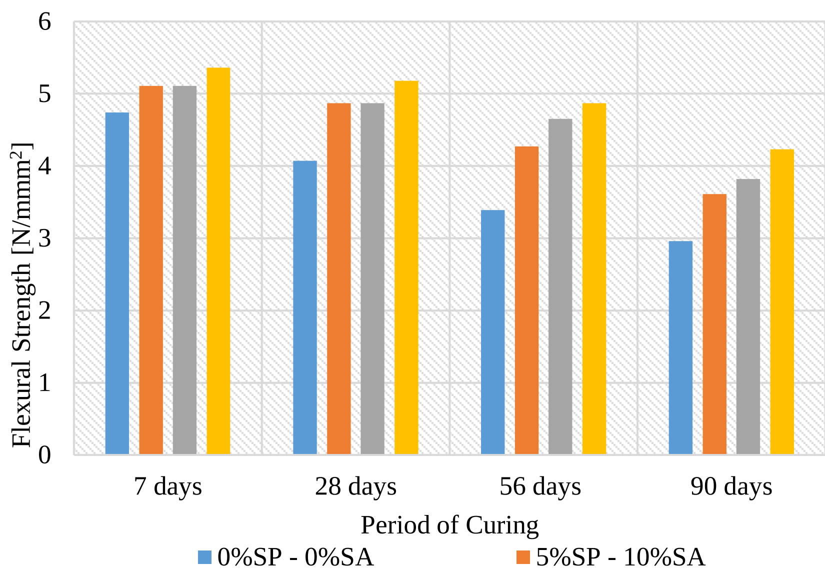


Source: The Author's

4.3 Effect of seashell powder and aggregate on the flexural strength

The flexural strength of seashell concrete was measured by loading 100 mm x 100 mm x700 mm and it expressed as Modulus of Rupture and tested as per IS 516: 1959 [32] for center point loading method. The increase in the percentage of seashell powder from 5%, 10% & 15 % and 10%, 20% & 30% of seashell aggregate in the mix proportion, reduces the flexural strength by 6.7 %, 15.8% and 28.3 % respectively when compared to control specimen. The observed average flexural strength of the specimens was equal to one-fourth of compressive strength irrespective of the different mix proportion. Fig.9 shows the flexural strength comparison of the specimens made by partial replacement of seashell powder and seashell aggregate.

Fig.9. FLEXURAL STRENGTH OF THE SEASHELL CONCRETE

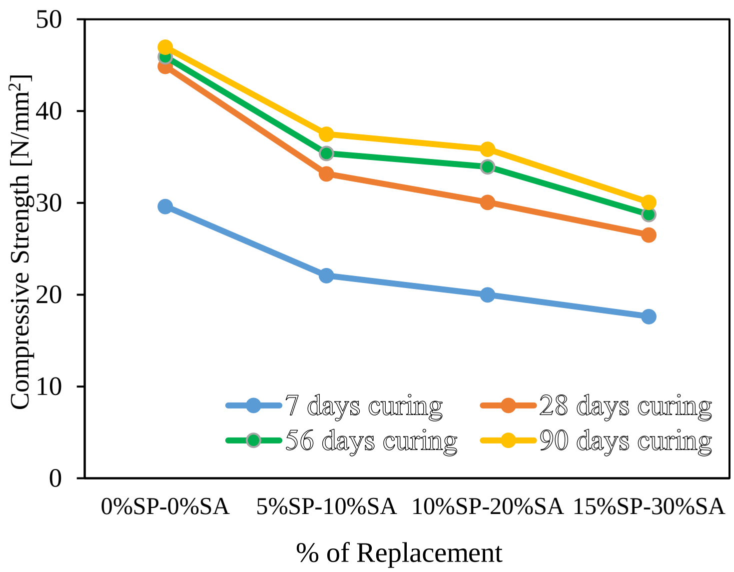


Source: The Author's

4.4 Effect of curing time on the seashell concrete

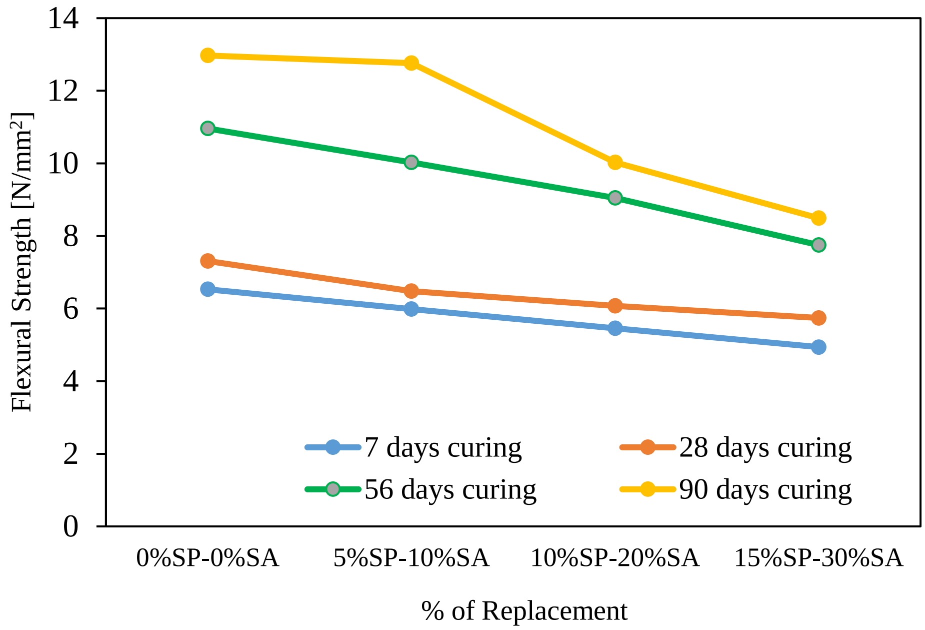
The properties of concrete are influenced by period of curing. Proper curing method and time produces suitable environment for hydration of cement process, reduces the pores in the concrete and increases the density of microstructure of concrete. The gain in the performance of the seashell concrete at later days was observed for all the mix proportion. Fig. 10, Fig. 11 and Fig. 12 shows the correlation between the compressive, flexural and split tensile strength for different curing time (7, 28, 56 & 90 days).

Fig.10 COMPARISON OF COMPRESSIVE STRENGTH OF CONCRETE FOR DIFFERENT CURING TIME



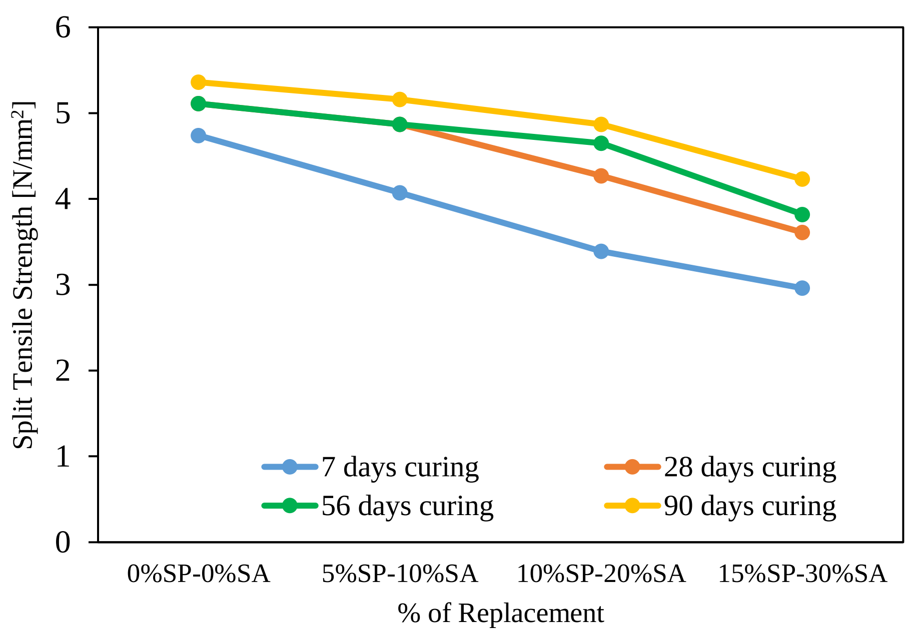
Source: The Author's

Fig.11 COMPARISON OF FLEXURAL STRENGTH OF CONCRETE FOR DIFFERENT CURING TIME



Source: The Author's

Fig.12 COMPARISON OF TENSILE STRENGTH OF CONCRETE FOR DIFFERENT CURING TIME



Source: The Author's

4.5 ANFIS Results

ANFIS modeling, the first stage of FIS structure was generated using training data (70%) with two number of membership function (MF) and various MF type. ANFIS training starts with constructed FIS, training data and checking data and the training process was carried out for sundry number of epochs and errors were measured. The RMSE value and the R^2 coefficient of ANFIS model with different MF types are shown in Table III. Normally, the higher values of R^2 coefficient would indicate the better capability of the model in predicting the exact studied aspect. From this table, the least RMSE and maximum R^2 coefficient are observed for the MF type psigmf in compressive strength, dsigmf in flexural strength, dsigmf in split tensile strength, respectively.

TABLE.III
PERFORMANCE OF ANFIS PREDICTION MODELS FOR VARIOUS MEMBERSHIP FUNCTIONS

MF type	Compressive Strength (N/mm^2)		Flexural Strength (N/mm^2)		Split Tensile Strength (N/mm^2)	
	RMSE	R^2	RMSE	R^2	RMSE	R^2
trimf	2.507756485	0.916315471	0.253611160	0.989659905	0.135441929	0.962092203
trapmf	2.507758620	0.916315471	0.253609345	0.989660053	0.135440579	0.962092958
gbellmf	2.507759775	0.916315252	0.253617167	0.989659415	0.135440579	0.962091446
gaussmf	2.507757327	0.916315415	0.253609568	0.989660035	0.135440579	0.962092331
gauss2mf	2.507752749	0.916315721	0.253619668	0.989659211	0.135443512	0.962091316
pimf	2.507752784	0.916315718	0.253609310	0.989660056	0.135440287	0.962093121
dsigmf	2.507765221	0.916314888	**0.253606523**	**0.989660283**	**0.135439936**	**0.962093318**
psigmf	**2.507752375**	**0.916315746**	0.253607969	0.989660165	0.135445817	0.962090026

Source: The Author's

Using Table III, the new optimum FIS structures of ANFIS models were constructed and the training process was performed for the training and checking data sets. Fig.13 (a) and Fig.13 (b) present the compressive strength, flexural strength and tensile strength between the number of epochs and RMSE for the training and checking error plot of the optimum ANFIS models, respectively. Table IV demonstrate measured MSE, MAE, SSE, RMSE and R^2 values of new optimum FIS structures of ANFIS models. The least error values and highest R^2 values of training and checking data shows that ANFIS model is more capable in estimating the mechanical properties of concrete. The correlation between the experimental and predicted compressive strengths flexural strength and tensile strength and a comparison among the experimental and ANFIS results are illustrated in Fig. 14, Fig. 15, Fig. 16. and Table V. From these figures, we observed that there is a close agreement lies with the predicted and experimental values of the training data set and the checking data points fall adjacent to the diagonal line and lie within the prediction intervals. Also, from Table V shows the predicted ANFIS results are in good agreement with experimental results with less than 5% error. Therefore, the created ANFIS model is more satisfactory in predicting the compressive strength, tensile strength and flexural strength of seashell waste in the concrete after 28, 56 and 90 days of curing.

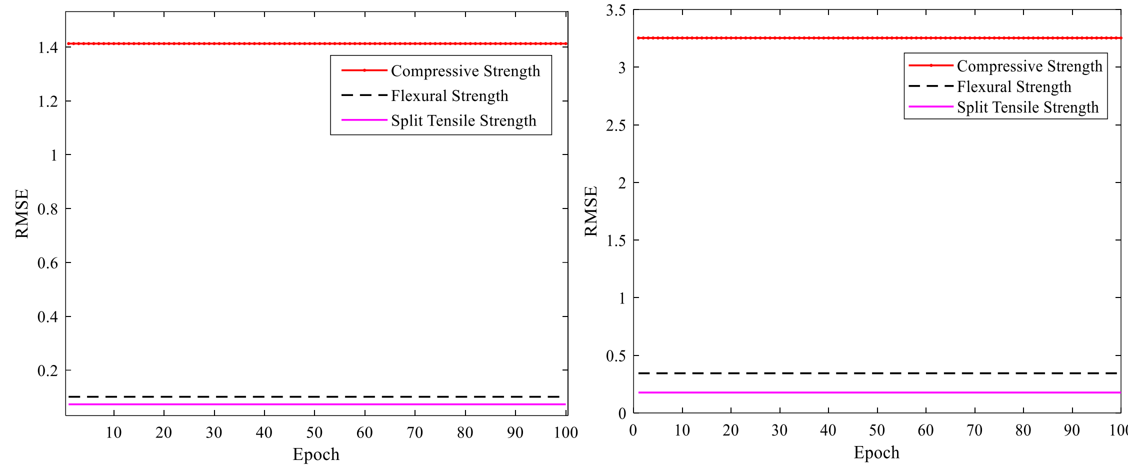
TABLE.IV

PERFORMANCE MEASURES OF NEW OPTIMUM FIS STRUCTURES OF ANFIS MODELS

Mechanical properties	Data set	MSE	MAE	SSE	MAPE	RMSE	R^2	R
Compressive Strength(N/mm^2)	Training	1.99508	0.778765	47.88205	2.516488	1.412474	0.974907	0.987374
	Checking	10.58199	1.943438	253.9677	6.634928	3.252997	0.844434	0.918931
Flexural Strength(N/mm^2)	Training	0.010216	0.074173	0.245200	0.957096	0.101077	0.998378	0.999188
	Checking	0.118376	0.296211	2.841029	3.740877	0.344058	0.980585	0.990245
Split Tensile Strength(N/mm^2)	Training	0.005354	0.055000	0.128500	1.203884	0.073172	0.989562	0.994767
	Checking	0.031320	0.166624	0.751680	3.885247	0.176974	0.92906	0.963877

Source: The Author's

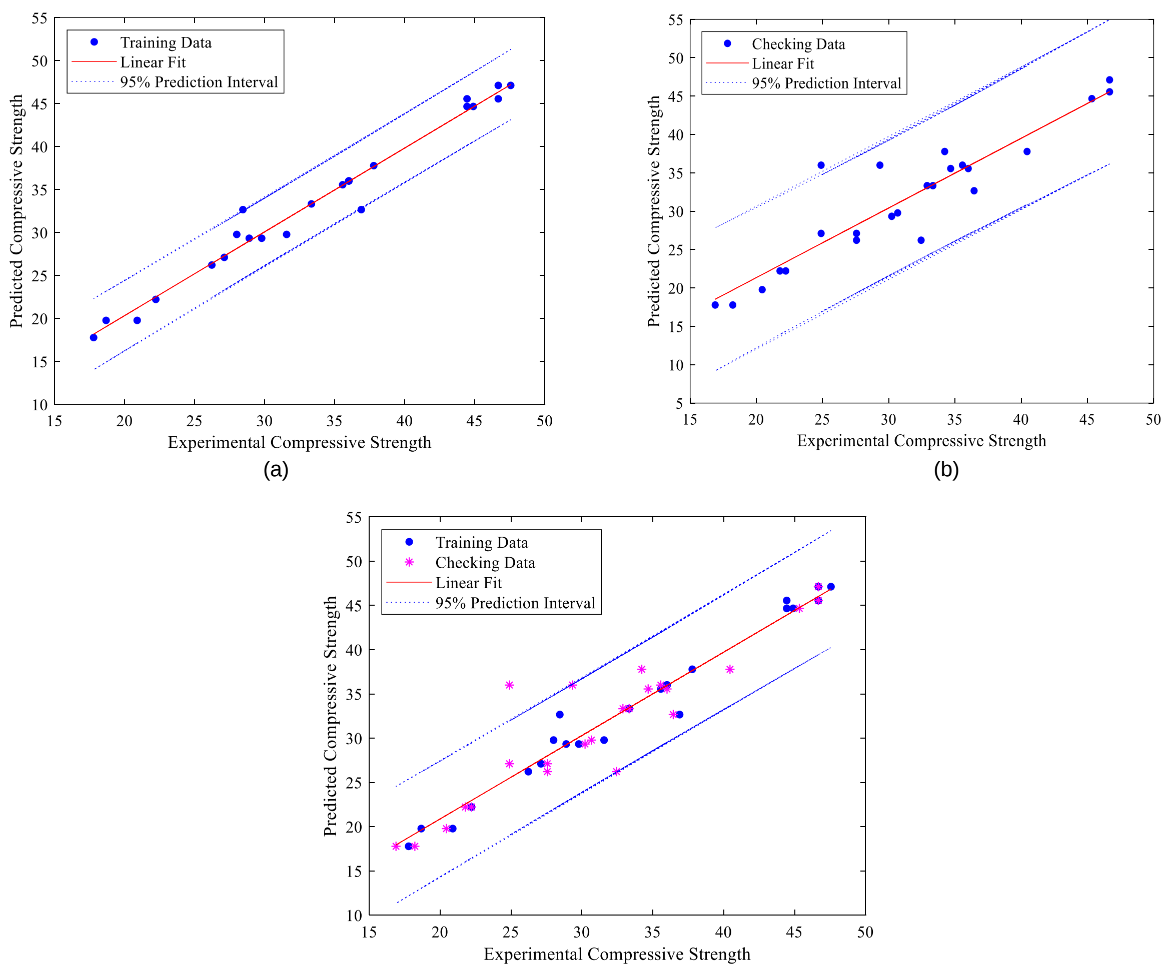
Fig. 13 (a) TRAINING & (b) CHECKING ERROR PLOT OF THE NEW OPTIMUM FIS STRUCTURES OF ANFIS MODELS



(a) (b)

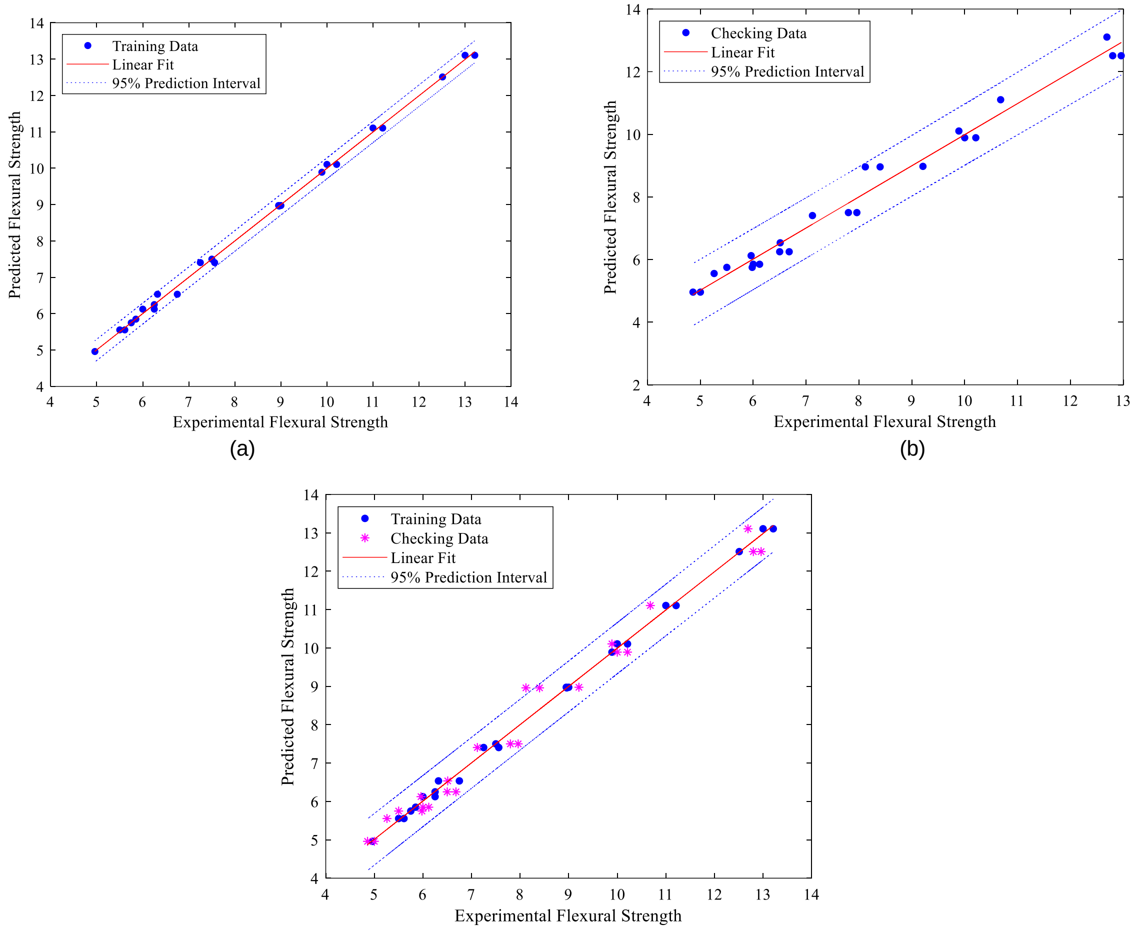
Source: The Author's

Fig. 14 Relationship between the experimental and predicted Compressive Strength: (a) Training (b) Checking & (c) Over all data.



(a) (b) (c)

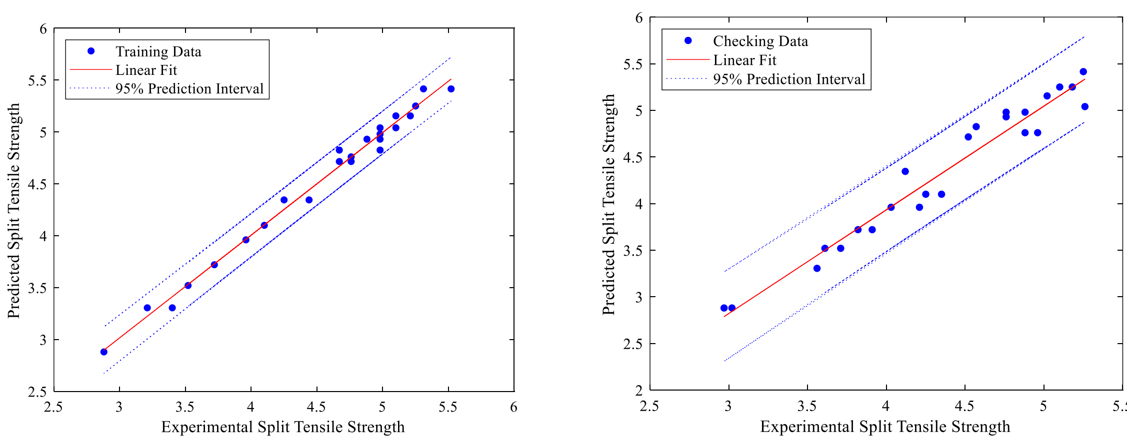
Fig. 15 Relationship between the experimental and predicted Flexural Strength: (a) Training (b) Checking & (c) Over all data



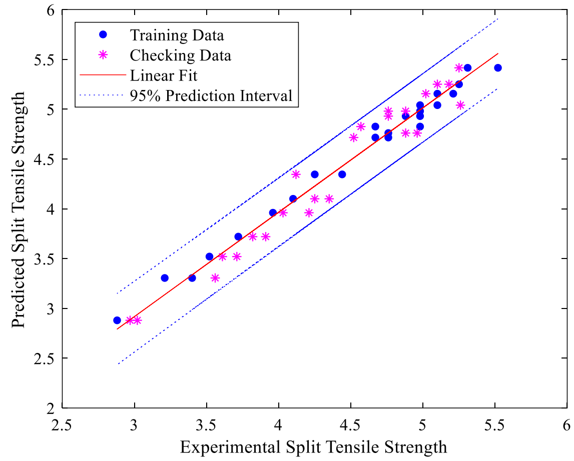
(a) (b) (c)

Source: The Author's

Fig. 16 Relationship between the experimental and predicted Tensile Strength: (a) Training (b) Checking & (c) Over all data



(a) (b)



(c)

Source: The Author's

TABLE.V
EXPERIMENTAL AND PREDICTED ANFIS VALUES OF CHECKING DATA

Period of curing (days)	Experimental Compressive Strength (N/mm²)	ANFIS value	Experimental Flexural Strength (N/mm²)	ANFIS value	Experimental Split Tensile Strength (N/mm²)	ANFIS value
7	29.78	29.33506	11.00	11.10505	4.67	4.824987
7	30.22	29.33506	10.68	11.10505	4.57	4.824987
7	28.89	29.33506	11.21	11.10505	4.98	4.824987
7	21.78	22.22001	10.00	9.890046	4.03	3.960004
7	22.22	22.22001	9.89	9.890046	3.96	3.960004
7	22.22	22.22001	10.21	9.890046	4.21	3.960004
7	18.67	19.77986	9.00	8.974897	3.40	3.305067
7	20.44	19.77986	9.21	8.974897	3.56	3.305067
7	20.89	19.77986	8.95	8.974897	3.21	3.305067
7	18.22	17.7799	7.80	7.500038	2.97	2.880002
7	17.78	17.7799	7.50	7.500038	2.88	2.880002
7	16.89	17.7799	7.96	7.500038	3.02	2.880002
28	44.89	44.665	13.00	13.10502	5.10	5.040002
28	45.33	44.665	12.69	13.10502	5.26	5.040002
28	44.44	44.665	13.21	13.10502	4.98	5.040002
28	32.89	33.33003	12.80	12.50996	4.88	4.979996
28	33.33	33.33003	12.51	12.50996	4.98	4.979996
28	33.33	33.33003	12.96	12.50996	4.76	4.979996
28	28.00	29.77997	10.00	10.10502	4.25	4.345002
28	30.67	29.77997	9.89	10.10502	4.12	4.345002
28	31.56	29.77997	10.21	10.10502	4.44	4.345002
28	27.56	27.11004	8.40	8.959963	3.61	3.519996
28	27.11	27.11004	8.96	8.959963	3.52	3.519996

28	24.89	27.11004	8.12	8.959963	3.71	3.519996
56	46.67	45.55502	6.75	6.535111	5.10	5.154989
56	46.67	45.55502	6.51	6.535111	5.02	5.154989
56	44.44	45.55502	6.32	6.535111	5.21	5.154989
56	34.67	35.55997	6.00	5.850005	4.88	4.759999
56	35.56	35.55997	5.85	5.850005	4.76	4.759999
56	36.00	35.55997	6.12	5.850005	4.96	4.759999
56	28.44	32.66507	5.50	5.554834	4.67	4.715029
56	36.44	32.66507	5.26	5.554834	4.52	4.715029
56	36.89	32.66507	5.61	5.554834	4.76	4.715029
56	32.44	26.21995	5.00	4.959993	3.82	3.720003
56	26.22	26.21995	4.96	4.959993	3.72	3.720003
56	27.56	26.21995	4.86	4.959993	3.91	3.720003
90	47.56	47.11500	7.25	7.405005	5.31	5.414999
90	46.67	47.11500	7.12	7.405005	5.25	5.414999
90	46.67	47.11500	7.56	7.405005	5.52	5.414999
90	34.22	37.77999	6.50	6.250003	5.10	5.249999
90	37.78	37.77999	6.25	6.250003	5.25	5.249999
90	40.44	37.77999	6.68	6.250003	5.18	5.249999
90	36.00	35.99997	6.00	6.125000	4.88	4.930003
90	35.56	35.99997	5.96	6.125000	4.76	4.930003
90	36.00	35.99997	6.25	6.125000	4.98	4.930003
90	29.33	35.99997	5.50	5.750000	4.25	4.100003
90	36.00	35.99997	5.75	5.750000	4.10	4.100003
90	24.89	35.99997	5.98	5.750000	4.35	4.100003

Source: The Author's

5. CONCLUSION

In this paper, Adaptive Neuro-Fuzzy Inference System (ANFIS) were used to predict the compressive strength, tensile strength and flexural strength of seashell waste in the concrete after 28, 56 and 90 days of curing. The following outcomes were drawn from the experimental and artificial intelligent approaches:

1. The correlation between the compressive strength, flexural strength and tensile strength with different curing period and different mix proportion of seashell powder and seashell aggregate were presented.
2. The X-ray Diffraction (XRD) analysis shows the presence of high calcium oxide content in seashell powder, which densifies the microstructure of the concrete mixture.
3. The mechanical properties of seashell concrete at later ages(90 days) increases significantly for all mix proportions. It was observed that split tensile strength of the concrete with seashell powder (5%) and seashell aggregate(10%) gives the strength exactly same as that of control mix(M25 grade of concrete) for all curing periods.
4. Artificial intelligence technique (ANFIS) can be applied to determine the mix of seashell waste in the concrete and predicts the compressive strength, tensile strength and flexural strength with a good correlation, which conclusions in perserving both time and expenditure.
5. ANFIS model with R^2 = 0.974907, $R^2 = 0.99918$ and $R^2 = 0.99476$ was found to be accomplished in approximating the 28, 56 and 90 days compressive strength, tensile strength and flexural strength of seashell waste in the concrete.

6. From both experimental and artificial intelligent approaches, the seashell waste found to have good replacement in the concrete as it contains limestone as major component. Thus it can be used to produce sustainable/green concrete.
7. The significant reduction in mechanical properties of concrete with seashell powder(15%) and seashell aggregate(30%) was observed and the strength in this concrete will get enhanced by adding proper admixtures in it. Hence further extension of work will be carried out in the same mix proportion with admixtures.

DECLARATIONS

Conflict of interest: The authors declare no competing interests.

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