

An Experimental Interpretation of High-Performance Fiber-Reinforced Polymer Concrete with FNN Paradigms



Biju C Thomas, Y. Stalin Jose

Abstract: *Strengthening and enhancing of Reinforced Concrete (RC) structural components are important to broaden its administration period, overcoming the first structure limits and to limit the impact of construction defects as well as the design defects. In this work, Fiber Reinforced Polymers (FRPs) is utilized as to strengthen RC structures. In this paper, the utilization of FRP such as Sisal, Jute, and Coir in concrete structures is being examined for its viability in upgrading structural execution both regarding strength and ductility. The structural behavior of FRP specimen is examined by experimental and numerical examination by estimating the parameters, for example, compressive strength, tensile strength, ductility, and deflection. Here, we utilized the Fuzzy Neural Network (FNN) procedure to test the strength of specimen. At the point, when compared with existing work, the proposed FNN model achieves the greatest performance in terms of all parameters for the fiber reinforced specimen under various loaded condition.*

Keywords: *Reinforced Concrete, FRP, FNN, compressive strength, tensile strength, ductility, deflection.*

I. INTRODUCTION

Nowadays utilization of fiber reinforced concretes for the retrofitting of existing structures has turned out to be increasing across the board. Retrofitting is the adjustment of existing structures to improve the execution as well as the durability of the structure [1-2]. Conventional retrofit procedures, for example, concrete segment expansion and covering outside with steel plates, are broadly utilized in practical life [3]. The utilization of fiber reinforced composites to fix RC structures has developed as another and suitable decision [4]. The FRPs are lighter, progressively sturdy and have higher strength-to-weight proportions than customary fortifying materials, for example, steel, and can result in less work escalated and less gear concentrated retrofitting work [5-6].

FRP composites have some extraordinary properties, for example, protection from erosion, great weariness and resistance to damping, high strength to weight proportion and electromagnetic straight forwardness [7].

As of late, natural fibers have turned into an appealing territory for researchers, designers, and scientists as elective support for FRP composites because of their ease, genuinely great mechanical properties, high explicit strength, non-rough and eco-kind disposition [8-10].

When all is said in done, Sisal fiber is incredibly durable and low upkeep with apparent mileage, SF is too much except for materials and surfaces. In addition, retrofitting with FRP may give a progressively conservative and in fact better option than the conventional techniques much of the time. The FRPs is durable one, lighter in weight and furthermore higher strength-to-weight proportions than customary fortifying materials, for example, steel and which can result in less work escalated and less gear serious retrofitting work [11-12]. In any case, such experimental methods have a few issues, for example, long development periods because of the relieving necessities and generally staggering expenses because of the intricacy of the development and establishment forms. To approve these systems, improvement procedures are utilized to discover the execution of the structure and predict the strength of fiber reinforced specimens [13-14].

The utilization of Neural Networks (NNs) for prediction as well as the optimization of the concrete properties is generally another research territory and from the exhibited examination the NN stands out amongst machine learning devices for this reason [15-17]. By the guide of such algorithms, masses can be diminished, and the solidness or strength of such structures will be expanded. In this Inquisition presents the experimental and simulation modeling for accomplishing the elite of fiber concrete structures. Here, we used common fibers for performing superior concrete structures to discover the behavior of the structures. For approval reason, Optimal Fuzzy Neural Network (OFNN) is utilized to anticipate the mechanical properties optimally when compared with experimental and existing systems.

II. SURVEY ON FRP CONCRETE STRUCTURES RELATED TO RECENT LITERATURE

Aramid was used as Fiber Reinforced Polymers (AFRP) for retrofitting RC structures and the probabilistic seismic is appraised by Saeid Tarfan et al.

in 2018. Using finite element methods are created in Open

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Sees utilizing concentrated plastic pivot models that can catch shear shortcoming of unique segments and deterioration of beams' stiffness and strength. Using finite element methods based on plastic pivot models the shear and deterioration of beam stiffness and its strength are determined using Open Sees.

The creators Raju Sharma and Prem Pal Bansal [19] proposed an experimental interpretation to find the viability of ultra high-performance hybrid fiber reinforced concrete for retrofitting, the impact of starting damage using UHP-HFRC retrofitted outside beam-column joint. Francisco J. Rescalvo et al. [20] in 2018 had exhibited a philosophy for the checking of timber bars for retrofitting with Carbon Fiber Reinforced Polymer by using Acoustic Emission system (AE). This outcome was exceptionally encouraging for safety observing of retrofitted timber components in genuine situations. Aditya Singh Rajput et al. [21] had inspected to reestablish the seismic execution of corroded Reinforced Concrete (RC) sections. Retrofitting materials involved High-Performance Fiber Reinforced Concrete and Glass Fiber Reinforced Polymer wraps. Executing the column specimens was studied based on the strength and ductility. The decently steep post-top reaction was the main weaknesses of these retrofitting methodologies. Xiaoshuang Xiong et al. [22] had assessed the multi-scale constitutive models to interpretation the mechanical properties of the woven composites. The anticipated outcomes of multi-scale constitutive model demonstrated great concurrences with compared with finite element methods of analysis and experiments. Tara Sen and H. N. Jagannatha Reddy [23] studied the Finite Element Simulation for retrofitting RCC Beam with Sisal Fiber as composite. To assess the execution of sisal fibers in basic retrofitting, a Plain Concrete Block is utilizing with sisal FRP. Madhavan K Mini et al. [24] had studied artificial neural network models for finding the fatigue life of glass fiber-reinforced epoxy composites. The combination of neural network and the fuzzy system is utilized in the present examination, and a similar report was done to get the ideal network.

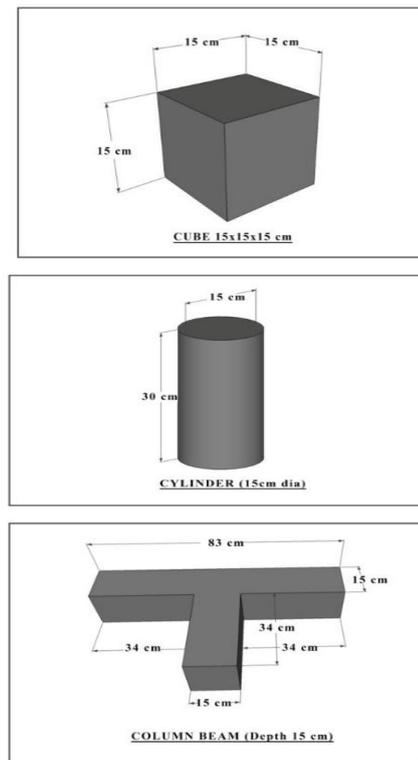
2.1 Research Gap

Existing literature and Inquisitions were led to get the thought regarding the modeling procedure and the portrayal of fibers in the structure design. Any innovation or material has its restrictions and to meet the new necessities must be created and utilized. As of late, structures may not fit the bill to current heavy load prerequisites and in this manner, retrofitting of these structures is essential. The retrofitting is a standout amongst the best alternatives to make a current deficient structure safe against future probable earthquake or other environmental forces. The simplest stratagem to strengthen the structures is to wrap fiber by two symmetrical headings. Current techniques for retrofitting steel bridges and structures normally use steel plates that are shot or welded to the structure. In any case, constructability, as well as durability disadvantages, is related to this technique. Steel plates need heavy lifting hardware and can add significantly increasingly dead load to the structure, which lessens their strengthening adequacy. To beat the issues, the utilization of

FRP frameworks for retrofit of concrete structures has been successful.

III. METHODOLOGY: HIGH PERFORMANCE FIBER REINFORCED CONCRETE

The methodology presents the experimental interpretation for analyzing the behavior of high-performance fiber reinforced concrete structures (cubes, cylinder, and beam-column) the used natural fibers like sisal, coir, and jute. The high-performance fiber reinforced concrete is made of M20 grade which has the mixing proportion of OPC 53 grade, coarse aggregate, and some admixtures with a specific rate. The reinforced concrete was tested according to IS 456 – 2000 standard. The three types of specimens are demonstrated in figure 1.



(a) Cube (b) Cylinder (c) Beam-column joint

Figure 1: Dimensions of Reinforced Concrete Structures (a) cube (b) cylinder (c) Beam-column

4.1 Materials Used For Experimentation

In the proposed interpretation, the materials used for making specimen are depicted as M20 concrete (cement, fine aggregate, coarse aggregate, water) along with FRP material. A mix design of M20 concrete is 1:1.5:3, which is clumped for blending. Concrete was prepared based on the mix proportion using volume batching and set in the respective segments. FRPs are thought to be directed flexible until the strain pressure achieves its definitive strength which makes weak crack and afterward reduced as zero. In the proposed work, the analyzed characteristic FRP materials are sisal, jute, and coir. The fibers are shown in figure 2 and the properties of fiber materials are shown in figure 2.



Table 1: Mixing Proportion of Concrete

Mixing Proportion	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Water (kg/m ³)
M20	400	693	1377	180

i) Sisal Fiber

Currently, a lot of research concentrated on the capability of sisal fibers reinforced composites. For utilizing the fiber composites in numerous applications it is vital that it had some mechanical properties like it ought to have adaptability, great tensile strength, and should have less wear property.

ii) Jute Fiber

It is one of the minimal effort natural fibers and is by and by the bast fiber with the most extreme generation volume. Jute fibers have less protection from dampness, corrosive and UV light. On the other hand, their fine texture, as well as their protection from heat as well as fire, is giving a boundless scope of uses in enterprises, for example, material, development, and car.

iii) Coir Fiber

Coir fiber contains the practically equivalent level of lignin and cellulose. In the bio-softening procedure, lignin gets expelled and cellulose is held. This gives the fiber increasingly white shading and expanded elasticity and lengthening properties



(a) (b) (c)

Figure 2: Fiber Materials (a) Sisal, (b) Jute, (c) Coir

Table 2: Properties of Fibers

Type of FRP Material	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation at failure (%)	Density g/m ³
SFRP	126-860	Sep-22	02-Jul	1.28-1.42
JFRP	410-780	Oct-30	1.5-1.8	1.48
CFRP	500	16-26	17	1.25-1.5

4.2 TEST

4.2 SPECIMEN DETAILS

Tested specimens were divided into two groups: control, FRP (sisal, jute, and coir).

Group 1: Control Specimen: contains threespecimens of M20 grade i.e. CS1, CS2 and CS3 in three different shapes such as a cube, cylinder, and beam column.

Group 2 (FRP strengthened Specimen): contains nine specimens of M20 grade with fiber material in three different shapes such as cube, cylinder, and beam column. For each shape HPC, the specimens are M20 grade reinforced with Sisal FRP, M20 grade reinforced with Jute FRP, M20 grade reinforced with Coir FRP.

Table 3: Specimen Details

S. No.	Specimen	Specimen Notation		
		For Cube	For Cylinder	For Column
1	Control Specimen	CS1	CS2	CS3
2	FRP Specimen	SFRP	SFRP	SFRP
3		JFRP	JFRP	JFRP
4		CFRP	CFRP	CFRP

4.3 PREPARING SPECIMEN



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(a) (b) (c)
(d) (e) (f)

Figure 3: Specimen preparation (a) cylinder (b) Cube (c) Beam-Column Specimen (d) Curing specimens (e) Testing Specimens (f) Tested cylinder specimen

The specimens were subjected to cyclic loading until cracks developed. Every specimen is independently tested and obtains the deflection, load conveying limit and mechanical properties for each specimen. The performances of these experimental samples were approved by soft computing technique performed in MATLAB.

4.4 FNN Analysis based on Experimentation

Paradigms

With the use of experimental samples, the load carrying capacity and mechanical properties of every specimen with varying conditions are investigated by simulation analysis i.e. Fuzzy Neural Network (FNN). The utilization of FNN structure is to accomplish the best solution and the input parameters (for example the membership functions) are initialized as the issue of evaluation.

4.4.1 Implementation of FNN

A Fuzzy NN (FNN) comprises 4 layers as pursues: 1) the first is the input layer as in a BPNN or RBFNN that just fans out the contributions to the following layer; 2) a hidden layer that fuzzifies the information sources, e.g., into LOW, MEDIUM, and HIGH etymological factors as standard predecessors with a fuzzy truth for each passing input esteem through a Fuzzy Set Membership Function (FSMF) for the linguistic variable. 3) Rule layer where bolts from certain fuzzifying nodes suggests a fuzzy variable in the layer; and 4) the defuzzification layer; its structure is shown in figure 4.

Input Layer: For examining the nature of high-performance fiber reinforced concrete structures (cubes, cylinder, and beam-column) prepared with natural fibers, we instate the input parameters, for example, load, Young's modulus, density, tensile strength and the fiber type for every specimen. Where C_i indicates the input parameters.

$$C_i = \{C_1, C_2, C_3, \dots, C_n\} \dots \dots \dots (1)$$

Membership function layer: Each node of the layer consists of a membership function that correlates with linguistic label of any one of the input variables in the input layer. The fuzzy membership grade of each crisp input is assessed by the accompanying condition.

$$f_2 = \mu_i = \exp\left[-\left(\frac{C_i - r_{ij}}{s_{ij}}\right)^2\right] \dots \dots \dots (2)$$

Layer a node represents one of the fuzzy logic rule and performs the precondition matching.

Rule 1: If (x is A1) and (y is B1) then $f_1 = (p_1x + q_1y + r_1)$

Rule 2: If (x is A2) and (y is B2) then $f_2 = (p_2x + q_2y + r_2)$

Likewise, the conditions are formed based on the initialized parameters. For these conditions, its was weight calculated as the product of the input membership values as:

$$f_3 = G_j = \prod_{i=1}^n \mu_i \dots \dots \dots (3)$$

Where G_j represents the weight of the condition generated in layer, n is the number of input parameters considered in the FRP specimen. The output of the node gives the firing strength for the fuzzy condition.

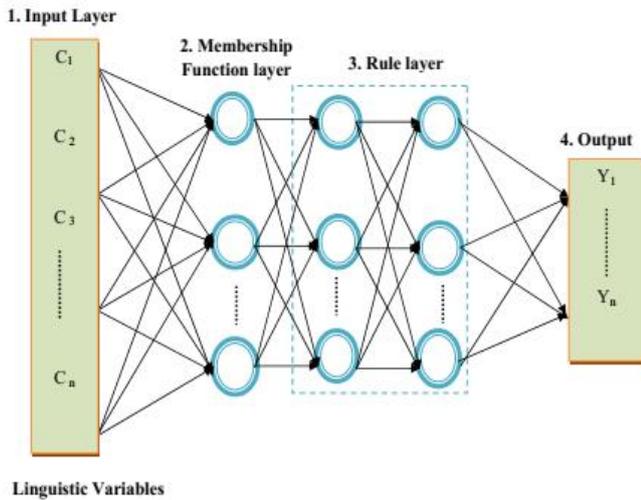


Figure 4: FNN Structure

Output layer:

The last layer is the clarification layer and is additionally called the defuzzification layer. The node in this layer is denoted as Σ , and the overall output is computed from the summation of all input signals.

$$f_4 = \sum_{i=1}^N O_i \times C_i + O_0 \dots \dots \dots (4)$$

Table 4: Results of Cube and Cylinder Specimen: Compressive Strength and Tensile Strength

Specimen	For Cube		For Cylinder	
	Compressive Strength test at 28 th day (N/mm ²)		Tensile Strength test at 28 th days (N/mm ²)	
	Experimental	FNN	Experimental	FNN
CS1	31.70	31.70	4.91	4.90
CS2	32.20	31.75	5.05	4.98
CS3	31.50	31.50	4.92	5.00
SFRP	32.86	33.10	6.25	6.24
JFRP	32.18	32.60	5.33	5.36
CFRP	35.40	35.42	6.80	6.82

Compressive Strength under Cyclic Loading

Where O_i is the connecting weight, the output of the Layer 4 associated with the Layer 3 and scalar O_0 is a bias. By executing those parameters in FNN, we can examine the compressive strength, tensile strength, deflection behavior of each specimen.

IV. EXPERIMENTAL RESULT ANALYSIS

The presented structural behavior analysis of FRP concrete with the distinctive specimen (for cube, cylinder and beam-column) is actualized in the working stage of having configuration of Intel (R) Core i5 processor and 4 GB RAM, and the properties are tested in the MATLAB program under the different loading condition.

Testing Parameters Compressive Strength (N/mm²)

Compressive strength for any material is characterized as the load connected at the point of failure to the cross-segment territory of the face on which load was connected.

Tensile Strength (N/mm²)

It is the material’s property to withstand a pulling (tensile) constraint. It is generally estimated in units of power per cross-sectional zone.

Deflection (mm)

The deflection distance of a section under a load is explicitly associated with the slope of the deflected shape of the part under the relative load.

Ductility (mm)

Ductility is the ratio of deflection at failure stage to the deflection at yield or at the primary crack.

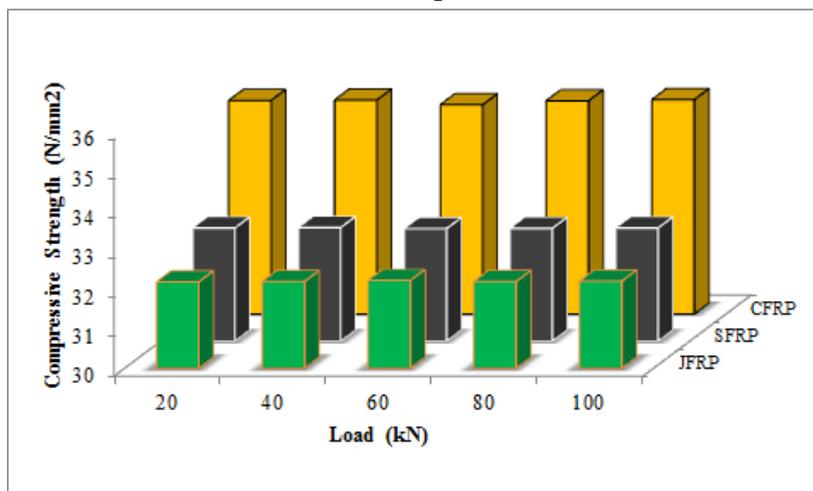


Figure 5: Compressive Strength for Cube Specimen

Concrete CS is typically acquired from testing concrete specimens of either cubic or cylindrical shapes with various sizes as proposed by various codes and principles. Compressive strength of the specimens using the techniques are identified and determined for 28 days. Figure 5 illustrates the CS behavior of FRP cube specimens SFRP, JFRP, and CFRP under different loaded condition. The graph clearly shows that CS increases with respect to the load condition. The graph clearly shows that fiber reinforced specimen attains high compressive strength compared to control specimen and JFRP, CFRP, SFRP.

Tensile Strength under Cyclic Loading

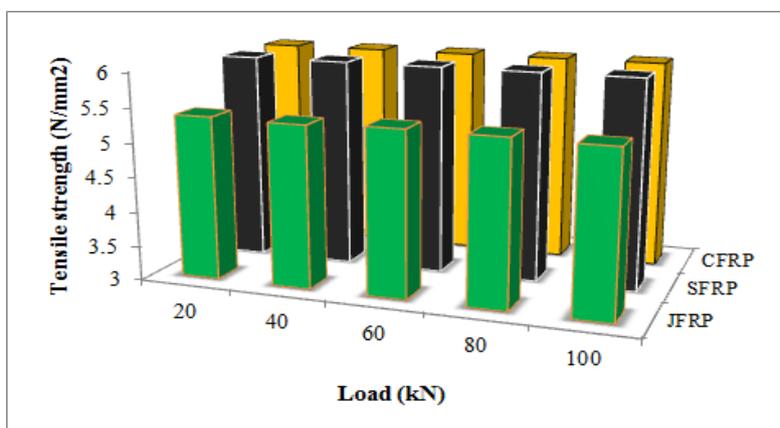


Figure 6: Tensile Strength for Cylinder Specimen

Figure 6 illustrates the tensile strength of the concrete mix proportion under the loaded condition for the cylinder specimens. The bar graph clearly explains only the TS behavior of FRP specimen SFRP, JFRP, and CFRP for 28 curing days. The graph clearly shows that the TS increase with respect to the load condition. On comparing the specimen curing days, the highest tensile strength is attained in the 28 days testing.

Table 5: Deflection Results of Column Specimen

Input (Load) (kN)	Deflection (mm)											
	CS		SFRP		JFRP		CFRP		R_GFRP		R_BFRP	
	Experime ntal	FNN										
0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.5	0.58	0.5	0.53	1.5	1.2	1.8	1.75	1.8	1.79	2.8	2.871
10	2.4	2.5	2.8	2.75	2.6	2.32	3.7	3.82	3.5	3.58	3.5	3.52

15	5.8	5.75	4	4.18	5.2	5.1	5.2	5.45	5.4	5.45	5.3	5.35
20	7.2	7.35	5.4	4.56	4.7	4.8	6.4	6.3	6.7	6.72	6.4	6.42
25	8.6	8.71	7.4	5.5	6.5	6.78	7.23	7.18	7.25	7.3	7.5	7.6
30	8.2	8.14	8.6	6.4	6.8	7.14	7.3	7.37	7.74	7.55	7.63	7.74

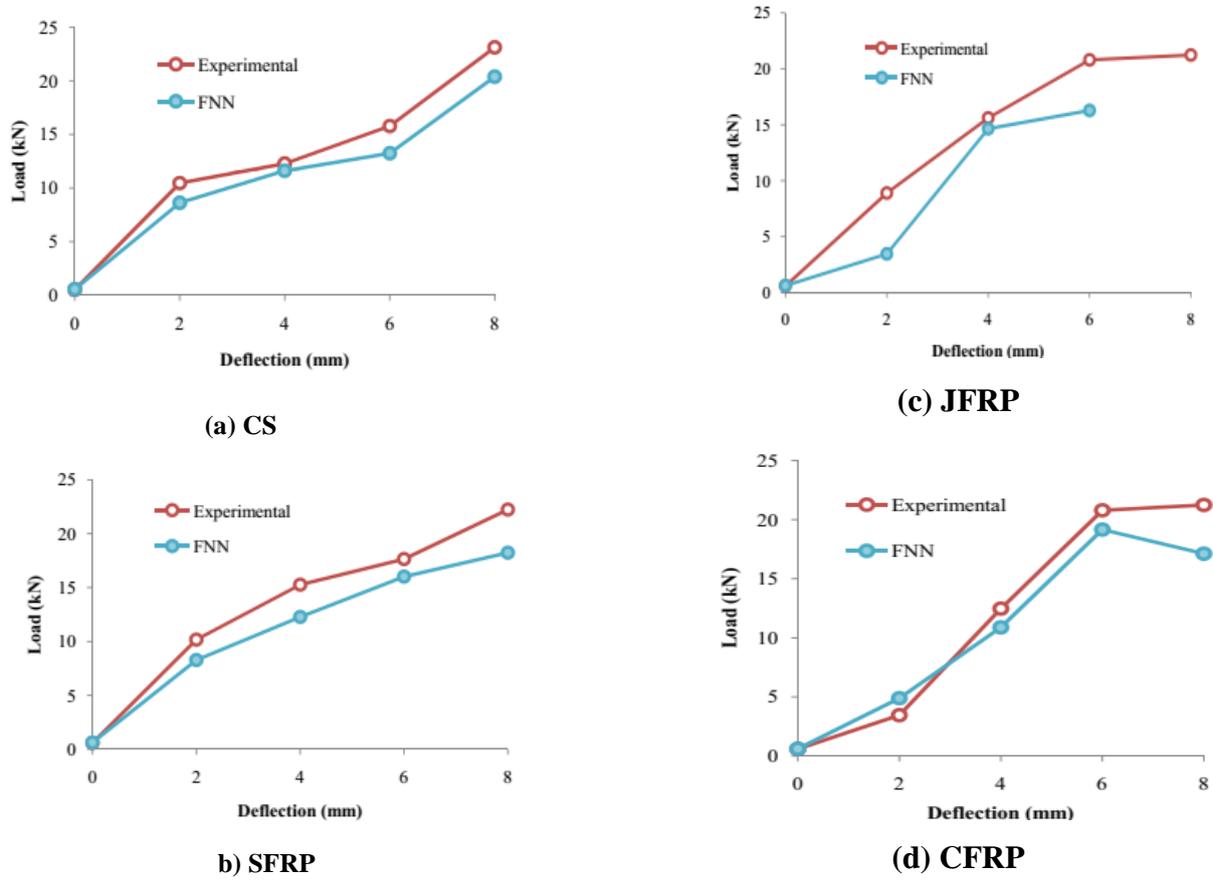


Figure 7: Deflection Analysis of Beam-Column Specimen (a) CS (b) SFRP (c) JFRP (d) CFRP

Table 5 describes the deflection value of three group specimens (control, FRP strengthened). The table compares the experimental and predicted values of deflection for the beam-column specimen. In the simulation analysis, the six beam-column specimens are tested by the proposed FNN stratagem. Figure 7 describes the load versus deflection curve of six different beam-column specimens such as CS, SFRP, JFRP, and CFRP.

Table 6: Ductility of Beam-Column

Input (Load) (kN)	Ductility (mm)											
	CS		SFRP		JFRP		CFRP		R_GFRP		R_BFRP	
	Actual	FNN	Actual	FNN	Actual	FNN	Actual	FNN	Actual	FNN	Actual	FNN
0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.25	3.32	4.12	4.14	5.2	5.24	5.76	5.78	5.82	5.86	5.92	5.93
10	4.23	4.26	4.86	4.88	5.22	5.23	5.78	5.75	5.83	5.88	5.95	5.97
15	5.12	5.19	5.63	5.67	5.17	5.46	5.82	5.89	6.02	6.04	6.22	6.3

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20	6.39	6.47	5.12	5.32	6.74	6.75	6.82	6.89	6.73	6.78	7.54	7.61
25	6.52	6.82	6.22	6.41	6.9	6.92	6.5	6.96	7.2	7.31	7.5	7.41
30	7.27	7.30	6.92	6.98	7.86	7.84	7.63	7.85	7.21	7.23	7.66	7.67

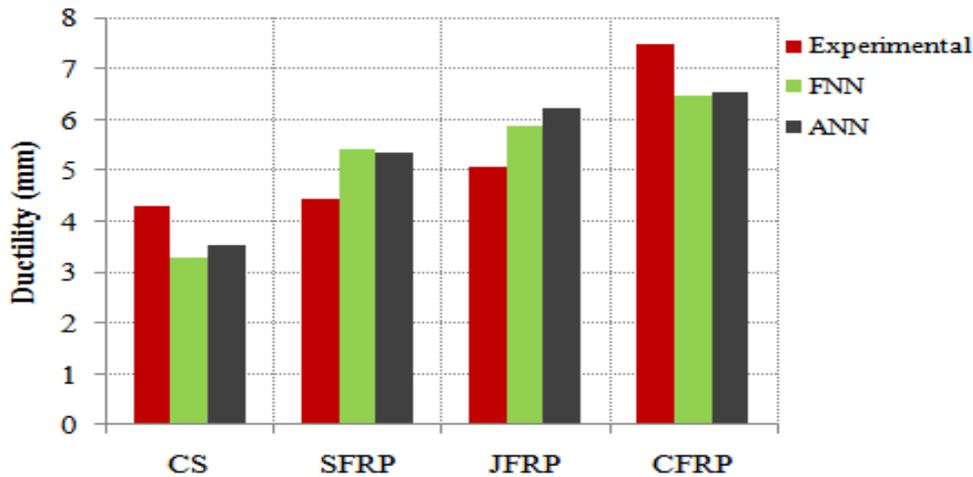


Figure 8: Ductility

Table 6 explains the ductility of beam-column specimens like CS, SFRP, JFRP, CFRP, R_GFRP and R_BFRP by varying load. Ductility can be termed as the structure's large deformation without losing its strength. Ductility can be justified based on the ductility factor. It is the ratio of deflection at the failure to the deflection at the yield point. It is compared with six different specimens is illustrated in

figure 8. Figure explains the ductility value of proposed FNN prediction model and its performance is compared to existing experimental values and one existing algorithm ANN. The results demonstrate that fiber reinforced specimen has high strength and ductility when compared to control specimen.

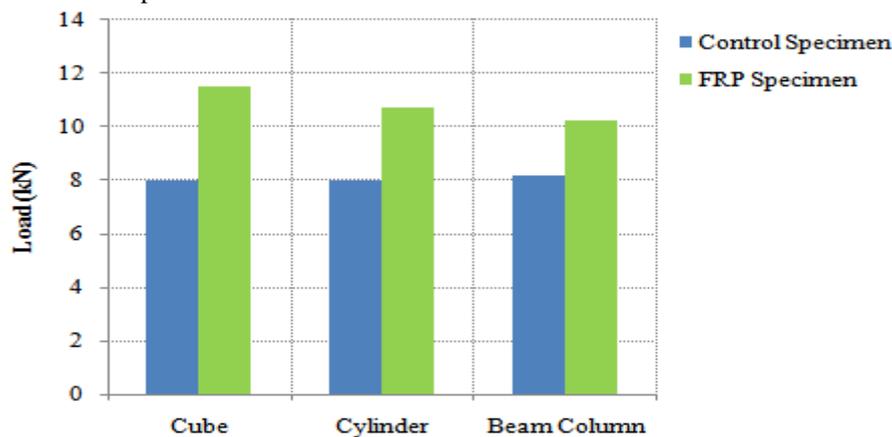


Figure 9: Load Carrying Capacity the Specimens

The load carrying capacity of test specimens such as control, FRP strengthened of the cube; cylinder and beam-column are analyzed and depicted in figure 9. The graph clearly shows that the concrete specimens with fiber having high load carrying capacity compared to control specimen.

analyzed under the cyclic loading, and furthermore, the impacts of FRPs on the concrete structures were also studied using the proposed component. The parameters such as compressive strength, tensile strength, deflection, and ductility were examined by the prediction analysis i.e. FNN stratagem.

V. CONCLUSION

The paper presented an experimental interpretation for investigating the physical behavior of high-performance fiber reinforced concrete structures (cubes, cylinder, and beam-column) prepared with natural fibers like sisal, coir, and jute. The behavior of developed eighteen specimens was

The optimal values are attained by the proposed FNN where the convincing output results are observed to be almost equivalent to the experimental data set with the

minimum error value. The proposed prediction FNN model achieves high accuracy in the strengthening analysis when compared to existing models. In future research work on strengthening of HPC structures, a hybrid combination of natural fibers is considered along with training algorithms is included in the prediction model.

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AUTHORS PROFILE

Biju C Thomas is a 3rd year PhD student at Noorul Islam University. He gained bachelor's degree in Civil Engineering from NMAMIT, Mangalore University and master's degree in Structural Engineering from REC Calicut presently know as NIT. Soon after completing his master's degree, he got placed in Indian Institute of Technology, Madras.. After leaving his job at IIT Madras, He is presently the Chief Consultant of Prime Builders & Architects. His main research interest centres on evaluation of various properties of RCC structures with the use of several type of fibres. He presented a thesis in "Strength and behaviour of Brick masonry confined with Ferro cement" during master's degree studies. His current research is "Retrofitting and evaluating Sisal Fibre reinforced high performance concrete structural elements". He is conducting various study programmes in the use of fibre's in concrete to enhance the structural properties and he is implementing these techniques in practical through his consultancy firm. Also he is interested in conducting training programmes to students in this field.



Dr Y Stalin Jose is a Research supervisor & Associate Professor Department of civil Engineering , Malla Reddy Institute of Technology and Science Maisammaguda, Secunderabad, Telangana- He was born in Kanyakumari, India in 1971. He did his basic schooling and pre degree at Kanyakumari, Tamil Nadu, India. He completed his BE degree in Civil Engineering from madurai Kamaraj University In 1995 and M E in Structural Engineering from Annamalai University , Chidambaram, Tamil Nadu in 2005. Also completed PhD in Noorul Islam University Kanyakumari in Tamil Nadu in 2016. He did his research in Investigation into flexural behavior of RC beams of varying strength. He has 14 years Teaching and 10 years industrial experience. Presently he is working in Associate professor at Telangana.

