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ANFIS MODEL for Performance Evaluation of Hybrid Fibre Reinforced Concrete

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ABSTRACT

This paper presents a study on the flexural performance of hybrid fibre reinforced concrete. The influence of fibre content on the flexural performance of hybrid fibre reinforced concrete specimens having different fibre volume fractions was investigated. The parameters of investigation included modulus of rupture, ultimate load, service load, ultimate and service load deflection, crack width, energy ductility and deflection ductility. A total of 27 specimens, 100 x 100 x 500 mm, were tested to study the above parameters. The specimens incorporated 0.0 to 2.0% volume fraction of polyolefin and steel fibres in different proportions. The flexural performance of hybrid fibre reinforced concrete specimens was compared with that of plain concrete. The test results show that addition of 2.0% by volume of hybrid fibres improves the overall performance appreciably. An adaptive Neuro-Fuzzy based model has been proposed to predict the flexural performance characteristics. A reasonably close agreement has been obtained between the experimental and predicted results.

Keywords: ANFIS; Ductility; Flexure; Fibres; Hybrid fibre reinforced concrete; MATLAB; Steel fibre reinforced concrete; Strength.

INTRODUCTION

Concrete is considered a brittle material, primarily because of its low tensile strain capacity and poor fracture toughness. Concrete can be modified to perform in a more ductile form by the addition of randomly distributed discrete fibres in the concrete matrix[1-4]. In fibre reinforced concrete (FRC), fibres can be effective in arresting cracks at both macro and micro levels. For an optimal response, different type of fibres may be suitably combined to produce hybrid fibre reinforced concrete (HFRC)[5]. The use of optimized combinations of two or more types of fibres in the same concrete mixture can produce a composite with better engineering properties than that of individual fibres. This includes combining fibres with different shapes, dimensions, tensile strength and young's modulus to concrete matrices[6].

This research work focuses on the polyolefin – steel hybrid fibre reinforced system. In this system, steel fibre, which is stronger and stiffer, improves the first crack strength and ultimate strength, while the polyolefin fibre, which is more flexible and ductile, leads to improved toughness and strain capacity in the post-cracking zone[7-8]. Information available on the flexural performance of hybrid fibre reinforced concrete is still limited. Hence an attempt has been made to study the flexural performance of steel fibre reinforced concrete and hybrid fibre reinforced concrete. An adaptive Neuro-Fuzzy based model has been proposed for predicting the flexural performance characteristics of hybrid fibre reinforced concrete.

EXPERIMENTAL PROGRAM

This study is part of the research program on evaluating the performance of hybrid fibre reinforced concrete. In this paper, flexural properties of steel fibre reinforced and hybrid fibre reinforced concrete are assessed and an adaptive Neuro-Fuzzy based model for predicting the above properties has been proposed.

Specimen Details

100 x100 x 500 mm prisms were tested in a loading frame. The test program was designed to study the flexural performance of concrete specimens with and without fibres. Table 1 shows the details of the specimens used for testing.

Table 1 Specimen Details

Sl. No.	Reference Code	V_f, (%)	Type of Fibre	
			Polyolefin	Steel
1	H0 – P0 S0	0	0	0
2	H0.5 – P0 S100	0.5	0	100
3	H0.5 – P30 S70	0.5	30	70
4	H1.0 – P0 S100	1.0	0	100
5	H1.0 – P30 S70	1.0	30	70
6	H1.5 – P0 S100	1.5	0	100
7	H1.5 – P30 S70	1.5	30	70
8	H2.0 – P0 S100	2.0	0	100
9	H2.0 – P30 S70	2.0	30	70

Note: H0-P0 S0 –Plain Concrete

Material Properties

Cement concrete having cube compressive strength of 26.65 MPa was used for casting the specimens. Properties of fibres used in the experimental work are shown in Table 2. For concrete with fibres, superplastizer (High range water reducing admixture-Conplast® SP337) was used in appropriate dosage to main the workability of concrete mix.

Table 2 Properties of Fibres

Sl. No.	Fibre Properties	Fibre details	
		Polyolefin	**Steel**
1	Length (mm)	48	30
2	Shape	Straight	Hooked at ends
3	Size/Diameter (mm)	1.22×0.732 mm	0.5 mm
4	Aspect Ratio	39.34	60
5	Density (kg/m^3)	920	7850
6	Specific Gravity	0.90-0.92	-
7	Young's Modulus (GPa)	6	210
8	Tensile strength (MPa)	550	532

Testing of Specimens

All the specimens were tested under four point-loading in a loading frame. Deflection measurements were made using dial gauges of 0.01 mm accuracy. The crack widths were measured using a crack detection microscope with a least count of 0.02 mm. The above measurements were taken at different load levels until failure.

TEST RESULTS AND DISCUSSION

The principal test results are presented in Table 3. The ductility indices of test beams are presented in Table 4. Each value presented is the average of three specimens. A total of 27 specimens were tested in this investigation. It is clear from Table 3, that increasing the fibre content from 0.0 to 2.0% increases the modulus of rupture. The increase in modulus of rupture was found to be 72.52% with 2.0% hybrid fibre content when compared to the plain concrete. The test results show that the load carrying capacity increases with increase in fibre content. The increase in ultimate load was found to be 72.42% with 2.0% hybrid fibre content when compared to that of plain concrete. From the test results furnished in Table 3, it can be observed that the hybrid fibre reinforced concrete specimens exhibit increase in deflection with increase of fibre content both at service and ultimate loads when compared to the plain concrete. The increase in ultimate and service load deflection was found to be 137.50% and 186.49% respectively with 2.0% hybrid fibre content when compared to the plain concrete. It is evident from Table 3 that the hybrid fibre reinforced concrete specimens exhibit more number of cracks with lesser widths when compared to the plain concrete. The percentage reduction was of the order of 80% when compared to the plain concrete. Table 4 indicates that the hybrid fibre reinforced concrete specimens exhibit enhanced ductility than that of plain concrete. It was noticed that for specimens with fibres the failure was not sudden. The randomly oriented fibres crossing the cracked section resisted the propagation of cracks and separation of the section. This caused an increase in the load carrying capacity beyond the first cracking[9-10]. The increase in energy and deflection ductility was found to be 98% and 83% respectively with 2.0% hybrid fibre content when compared to that of plain concrete.

Table 3 Principal Test Results of Specimens in Flexure

Sl. No.	Reference Code	Modulus of Rupture (MPa)	Ultimate Load (kN)	Service Load (kN)	Ultimate Deflection (mm)	Service Deflection (mm)	Average Crack Width (mm)
1	H0 – P0 S0	7.06	17.66	11.77	0.56	0.37	0.50
2	H0.5 – P0 S100	7.16	17.89	11.93	0.94	0.55	0.40
3	H0.5 – P30 S70	9.60	24.01	16.01	0.96	0.68	0.20
4	H1.0 – P0 S100	10.18	25.45	16.97	1.01	0.70	0.30
5	H1.0 – P30 S70	11.50	28.75	19.17	1.08	0.74	0.20
6	H1.5 – P0 S100	10.52	26.30	17.53	1.10	0.72	0.30
7	H1.5 – P30 S70	11.84	29.60	19.73	1.21	0.81	0.20
8	H2.0 – P0 S100	11.21	28.02	18.68	1.24	0.83	0.20
9	H2.0 – P30 S70	12.18	30.45	20.30	1.33	1.06	0.10

Table 4 Ductility Indices of Test Specimens

Sl. No.	Reference Code	Energy Ductility	Deflection Ductility
1	H0 – P0 S0	1.00	1.00
2	H0.5 – P0 S100	1.25	1.18
3	H0.5 – P30 S70	1.46	1.39
4	H1.0 – P0 S100	1.38	1.27
5	H1.0 – P30 S70	1.51	1.48
6	H1.5 – P0 S100	1.42	1.35
7	H1.5 – P30 S70	1.67	1.59
8	H2.0 – P0 S100	1.59	1.46
9	H2.0 – P30 S70	1.98	1.83

ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a tool for computational modeling of data obtained from experimental investigations. ANFIS is a hybrid system, which combines the decision-making abilities of fuzzy logic with the computational abilities of neural networks, and offers highly sophisticated platform for modelling/ prediction, where the input parameters and output values are known, but the mathematical relationship between them is not available, as in the case of experimental results. Fuzzy is essentially concerned with organizing input data into sets, determination of the membership value (which can be anything from 0 to 1), and taking decision on next action based on a series of rules and moving onto the next state. The Neuro-Fuzzy systems consists of the components of a conventional fuzzy system except that computations at each stage are performed by a layer of hidden neurons and neural network's learning capacity is provided to enhance the system knowledge. The schematic diagram of Neuro-Fuzzy system is shown in Fig.1.

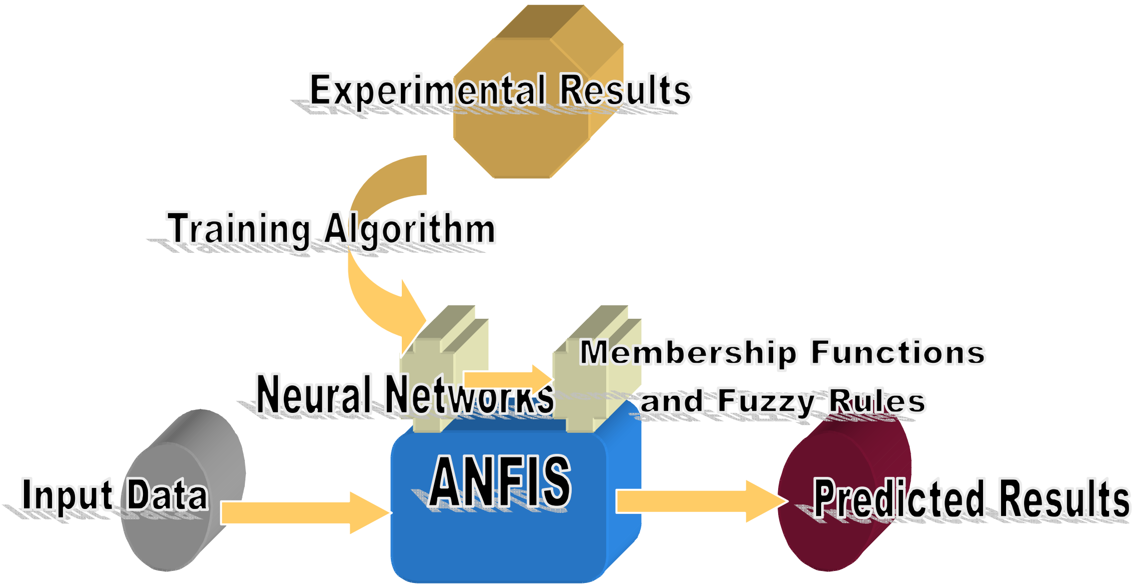

Fig.1 Schematic Diagram of Adaptive Neuro-Fuzzy Inference System

Neuro-Fuzzy Hybrid Systems

Neuro-fuzzy hybrid systems combine the advantages of fuzzy systems, which deal with explicit knowledge, which can be explained and understood, and neural networks, which deal with implicit knowledge which can be acquired by learning[11]. Neural network learning provides a good way to adjust the expert's knowledge and automatically generate additional fuzzy rules and membership functions, to meet certain specifications and reduce design time and costs. A typical Neuro-Fuzzy System is shown in Fig.2.

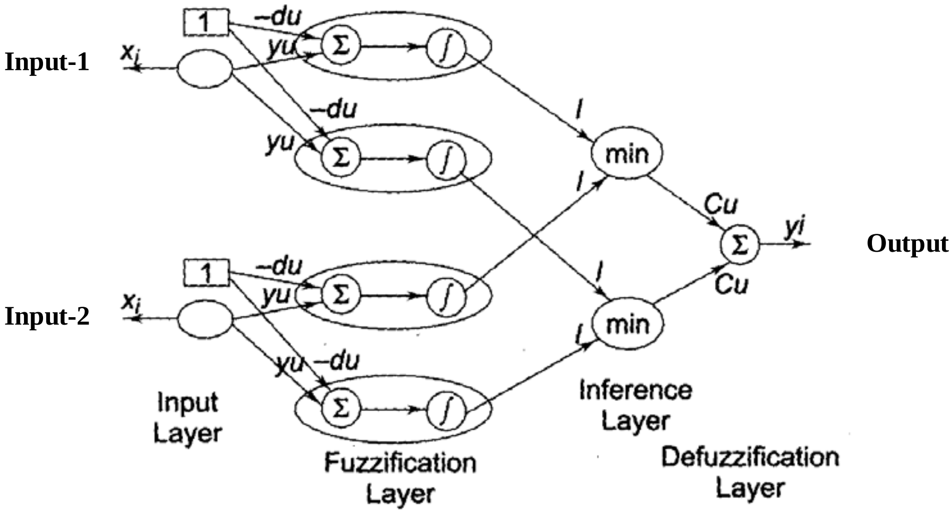

Fig. 2 Typical Neuro-Fuzzy System

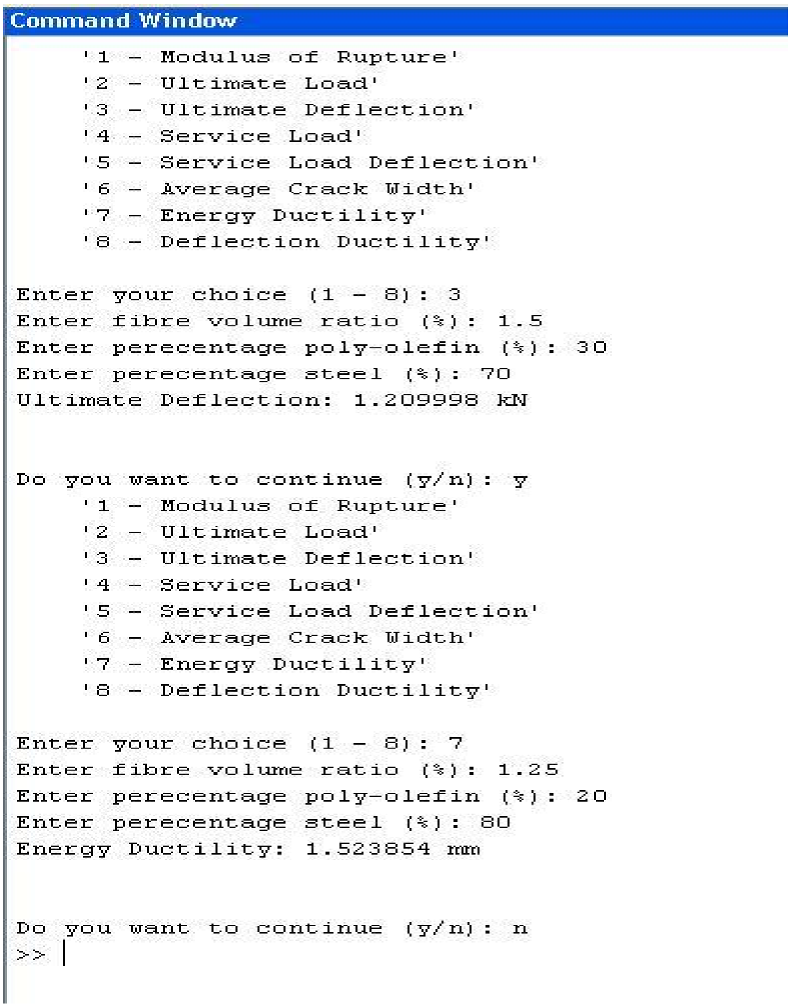

Fig.3 Graphical User Interface for Prediction

DEVELOPMENT OF ANFIS MODEL FOR PERFORMANCE PREDICTION

ANFIS model is capable of predicting only one parameter, although the input parameters may be many in number. Hence, each prediction parameter requires a separate ANFIS object to be generated. The input data for ANFIS modeling is given in Tables 3&4. The fuzzy inference systems were generated on MATLAB software using fuzzy logic toolbox[12]. The ANFIS models for the above work were developed using *anfisedit*command available in the fuzzy logic toolbox of Matlab software. All parameters required for ANFIS object generation were prepared in the matlab work environment. These parameters were imported to the '*anfisedit*' workspace and model generated. The performance of the ANFIS object was tested using data reserved for that purpose. After training and testing, the ANFIS object was exported to matlab workspace and saved in to suitably named disc file. After generating individual fuzzy inference system objects for each prediction parameter, all the *ANFIS* objects are saved into disk file, in order to make them available for client programs. ANFIS requires generation of individual fuzzy inference system object for each parameter taken up for prediction. Prediction system is developed for Modulus of rupture, ultimate load, ultimate deflection, service load, service load deflection, crack width, energy ductility and deflection ductility. All the fuzzy inference systems take fibre volume fraction, percentage of polyolefin fibre and percentage of steel fibre as input parameters. Graphical user interfaces were developed to take visual input and output from the user inMatlabcalled *HFRC_Specimen_Properties*for hybrid fibre reinforced concrete Specimen (Fig.3).This script can be run from Matlab environment by loading it on the Matlab script editor and pressing F5 to run the programme. This script requires fuzzy logic toolbox to be installed in the Matlab environment.

Table 4 Comparison of Results and Percentage Error for HFRC Specimens

Sl. No.	Parameters	Experimental Results	ANFIS Predicted	Percentage Error (%)
1	Compressive strength (MPa)	28.34	28.43	0.32
2	Modulus of Rupture (MPa)	9.20	9.40	2.17
3	Ultimate Load (kN)	23.00	26.78	16.43
4	Ultimate Deflection (mm)	0.95	0.96	1.05
5	Service Load (kN)	15.33	17.86	16.50
6	Service Load Deflection (mm)	0.62	0.66	6.45
7	Energy Ductility	1.38	1.44	4.35
8	Deflection Ductility	1.19	1.35	13.45

CONCLUSSIONS

1. A hybrid fibre volume fraction of 2.0% with 30–70 Polyolefin–Steel combine significantly improves the ductility performance of reinforced concrete specimens.

2. The hybrid fibre reinforced concrete specimens exhibit enhanced strength in flexure. The values of modulus of rupture increased up to 72.52% compared to their plain counterparts.
3. The hybrid fibre reinforced concrete specimensexhibit increase in deflection to the tune of 186.49% in comparison with plain concrete.
4. The hybrid fibre reinforced concrete specimensexhibit reduced crack width at all load levels, the maximum reduction in crack width was found to be 80% compared to that of plain concrete.
5. The hybrid fibre reinforcement appreciably enhances the ductility of concrete specimens. The increase in ductility was found to be 98% and 83% in terms of energy and deflection respectively.

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