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Development of Genetic Algorithm Based Macro Mechanical Model for Steel Fibre Reinforced Concrete

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ABSTRACT
This paper presents the applicability of hybrid networks that combine Artificial Neural Network (ANN) and Genetic Algorithm (GA) for predicting the strength properties of Steel Fibre Reinforced concrete (SFRC) with different water-cement ratio (0.4,0.45,0.5,0.55), aggregate-cement ratio (3,4,5), % of fibres (0.75,1.0,1.5) and aspect ratio of fibres (40,50,60) as input vectors. Strength properties of SFRC such as compressive strength, flexural strength, split tensile strength and compaction factor are considered as output vector. The network has been trained with data obtained from experimental work. The hybrid neural network model learned the relation between input and output vectors in 1900 iterations. After successful learning GA based BPN model predicted the strength characteristics satisfying all the constrains with an accuracy of about 95%.The various stages involved in the development of genetic algorithm based neural network model are addressed at length in this paper.

Keywords: Aggregate-Cement ratio(A/C), Aspect ratio(AR**),** Back propagation network(BPN),Genetic Algorithm(GA),Steel Fibre Reinforced Concrete(SFRC),

I. Introduction

The inherent deficiency of concrete is to resist tension. The inherent weakness of concrete to resist tension can be overcome to some extent by mixing the steel fibres in the concrete. This concept was first introduced by Romualdi and Batson [1963], Romualdi and Mandel [1964]. They and many other investigators [1988] have established that inclusion of high strength, high elastic modulus steel fibres of short length and small diameter improve the tensile strength.It is proved by the investigations of Singhal et.al. [1993] and Mangat et.al.[1988] that the corrosion resistance of steel fibre reinforced concrete is better than that of conventional concrete. Rheological parameter of SFRC may also decreases at low fibre volume concentration and increases with increasing aspect ratio through the experimental study conducted by Laskar and Talukdar et.al.[2008]. The advantage of steel fibre reinforced concrete (SFRC) over plain concrete is improvement of various properties such as tensile strength, flexural strength, ductility, imperviousness etc. However the gains have to be optimized through a proper mix design procedure. In spite of extensive research on SFRC, no standard procedure evolved in SFRC mixes. It is felt that the conventional method of design of concrete may not be suitable for SFRC mixes, because with the addition of fibres more water content is needed for achieving the same workability. Further, the strength and workability properties of are greatly influenced by several parameters viz. fibre material, volume percentage of fibres, aggregate –cement ratio, fibre aspect ratio, ratio of fine aggregate to coarse aggregate and water-cement ratio etc., Consequently development of a macro mechanical model for SFRC mixes requires an extensive understanding of the relation between these parameters and the properties of the resulting mix. Developing empirical or semi-empirical formula for macro mechanical modeling of SFRC is rather difficult due to highly non-linear interaction among the above mentioned parameters. Further, the degree of non-linearity and the extent of interaction of the constituent parameters is also not clearly known.

An Artificial Neural Network is defined as a data processing system consisting of a large number of simple highly processing elements (artificial neurons) in an architecture inspired by the structure of the cerebral cortex of the brain. ANNs are highly nonlinear and can capture complex interaction among input/output variables in a system without any prior knowledge about the nature of these interactions. In recent years ANNs have gaining momentum as effective strategies to provide control action for wide diversity applications. The main advantage is that, one does not have to explicitly assume a model from which relationship of possibly complicated shape between input variables is generated between input or output variables is generated by data points themselves. ANNs with this remarkable ability to derive meaning from complicated or imprecise data can be used to extract patrons and detect trends that are too complex, to be noticed by either humans or other computer techniques. ANNs are highly parallel, i.e., their numerous independent operations can be executed simultaneously. Among all kinds of neural network algorithms, error back propagation (BP) network is the most typical delegate. But there are some intrinsic drawbacks for the BP algorithm due to its slow convergence rate and tapping in the local optimization. Furthermore, it needs plenty of training samples in model establishments.

Genetic Algorithm (GA) on the other hand is a stochastic global searching and optimization algorithm that based on Darwin's biological theory of evolution and the Mendel's Genetic principle of genes.GA is used to solve complicated problems by simulating the evolutionary course of natural selection and natural inheritance of biological circles, featured by many advantages such as simple searching method, strong robustness, global parallel searching and is suitable to solve the complex problems of large scale. GA optimize the encoding which composed by parameters, according to a certain fitness function and genetic operations (selection, cross over and mutation) on the individual implementations of the evolution, so that high fitness value individual has been preserved and form a new group. While the individual of a new group is evolving, fitness value is increasing continually until the limit meets certain conditions. At this point the highest fitness value of the individual shall be the optimum solution. However GA also has its own shortages such as lower local convergence speed inkling to premature convergence etc.

It is evident that there is a strong complementarity between BP and GA. Based on that complementarity a new hybrid evolution mode can be established. i.e., the relationship model is established by BP network, the connection weights and thresholds of BP are optimized by GA and then the precision of model is increased by BP. The GA is accomplished by the BP techniques such as training repetition; early stopping and complex regulation are employed to improve evolutionary process results. It accelerates the convergence speed of algorithms and overcomes the drawbacks of BP network is difficult to achieve a satisfactory model with few trainings. Recently, it is established that, hybrid networks which combines genetic algorithm and neural network have the ability to map this type of multi parametric interaction.

Hence in this paper genetic algorithm and back propagation neural network model is presented to predict the strength properties of steel fibre reinforced concrete.

II. Literature survey

Serio Lai and Marzouk [1997] presented an ANN model predicting strength of building materials. Yeh [1998] adopted ANN methods for modeling the strength of high performance concrete. Wang [1999] developed Neural Networks to the design of concrete mix. Savic et.al., [1999] developed software for the optimal design of general and symmetric bar balanced laminates (or sandwich panels) with specified mechanical properties. Guang et.al., [2000] developed ANN model for compressive strength of concrete using multi layer feed forward networks. Saka et.al., [2001] developed a genetic algorithm based method for the optimum design of grillage systems. Nehdi et.al., [2001] have developed model for performance of self compacting concrete mixtures. Raghunath Reddy [2001] has developed macro mechanical model for steel fibre reinforced concrete by ANN. Cengiz Toklu [2005] formulated an aggregate-blending as a multi objective optimization problem and solved by using genetic algorithms. Kong [2006] developed preliminary design of concrete structures using genetic algorithms and spread sheets. Govindraj and Ramasamy [2006] have developed optimum design of reinforced rectangular columns using genetic algorithms. Bhattacharya et.al. [2008] developed optimal design of precast pipe racks using genetic algorithm. Sivakumar and Vaidyanathan [2007] have developed logical penalty functions for efficient search in optimization of discrete structures using genetic algorithms. Sudarshana Rao and Ramesh Babu [2007] developed ANN model for the design of beam subjected to bending and shear. Sudarshana Rao and Chandrasekhara Reddy have developed ANN based macro mechanical model for slurry infiltrated fibrous concrete. Sudarshaha Rao et.al.,[2012] developed genetic algorithm based hybrid neural network model for predicting the ultimate flexural strength of ferrocement elements. Vaishali et.al., [2013] developed Neural Network model for predicting strength of high performance concrete.

III. Experimental work

Experiments on SFRC mixes were conducted to determine the properties such as compressive strength, split tensile strength, flexural strength and workability (compaction factor) for different water-cement ratios(0.4,0.45,0.5,0.55), aggregate-cement ratios(3,4,5), fibre Aspect ratios(0.75,1.0,1.5) and % of fibres (0.75,1.0,1.5) as variables. A total of 108 sets of SFRC mixes were casted and tested in the laboratory for compressive strength, split tensile strength, flexural strength and compaction factor . Out of these 108 data sets ,87 data sets (80%) were used for training the network and 21 data sets were used for validation of GANN model. Steel fibres used in the present study were a black binding wire (mild steel)of diameter of 0.944mm with tensile strength of 364.42 N/mm^2.A part of training set data is presented in Table.1

Table.1 part of training data

	INPUTS				OUTPUTS			
Sl.no.	W/C	A/C	% of f	Asp. ratio	Comp factor	comp. str.	Split ten.str.	Flex. Str.
1	0.4	3	0.75	40	0.95	35.7	3.03	3.9
2	0.4	3	1	40	0.93	37.3	3.2	4.07
3	0.45	3	0.75	40	0.96	31.1	2.97	3.81
4	0.45	3	1.5	40	0.92	35.8	3.34	3.99
5	0.5	3	0.75	40	0.963	30.5	2.83	3.72
6	0.5	3	1	40	0.95	31.6	3	3.8
7	0.4	4	0.75	40	0.836	34.93	2.9	3.75
8	0.4	4	1	40	0.825	36.2	3.15	3.86
9	0.4	4	1.5	40	0.813	37.33	3.45	3.9
10	0.45	4	1	40	0.873	31.9	3.06	3.65
11	0.45	4	1.5	40	0.86	34.8	3.3	3.8
12	0.5	4	0.75	40	0.9	29.8	2.75	3.35
13	0.5	4	1.5	40	0.87	32.5	3.16	3.69
14	0.55	5	0.75	40	0.88	26.3	2.54	3.09
15	0.55	5	1	40	0.87	28.3	2.7	3.18
16	0.4	5	0.75	50	0.807	36.44	2.9	3.765
17	0.4	5	1	50	0.79	37.25	3.11	3.82
18	0.4	5	1.5	50	0.781	38.44	3.46	4.08
19	0.45	5	1	50	0.85	33.1	3.03	3.67
20	0.45	5	1.5	50	0.82	34.6	3.32	3.92

IV. Development of Hybrid Neural Network

In the present work, it is required to development of GANN model for predicting strength properties of SFRC such as compressive strength, split tensile strength, flexural strength and compaction factor. This means, the model should be able to predict the above properties for a given input vectors of Water-cement ratio (W/C), Aggregate-cement ratio(A/C), % of fibres (%fib) and Aspect ratio of fibre (A/R). Hence input to the network is selected as above, similarly the output vector for the neural network is compaction factor, compressive strength, split tensile strength and of flexural strength of SFRC. MATLAB was used to develop GANN model.

4.1 Selection of suitable Network configuration:

The network configuration is defined in terms of the number, size, nodal properties etc. of the Input / Output vectors and intermediate hidden layers. Once input and output vectors are decided to cater the present investigation requirements, the task of selection a suitable configuration has been taken up. There is no direct method to select number of nodes in hidden layers. Usually a trial and error method is adopted for arriving at the network configuration. After doing many trials, it is observed that the network with 10 neurons in one hidden layers is behaving well. Accordingly a configuration of (4-10-4) has been selected for this network model. The architecture is depicted in Fig.1

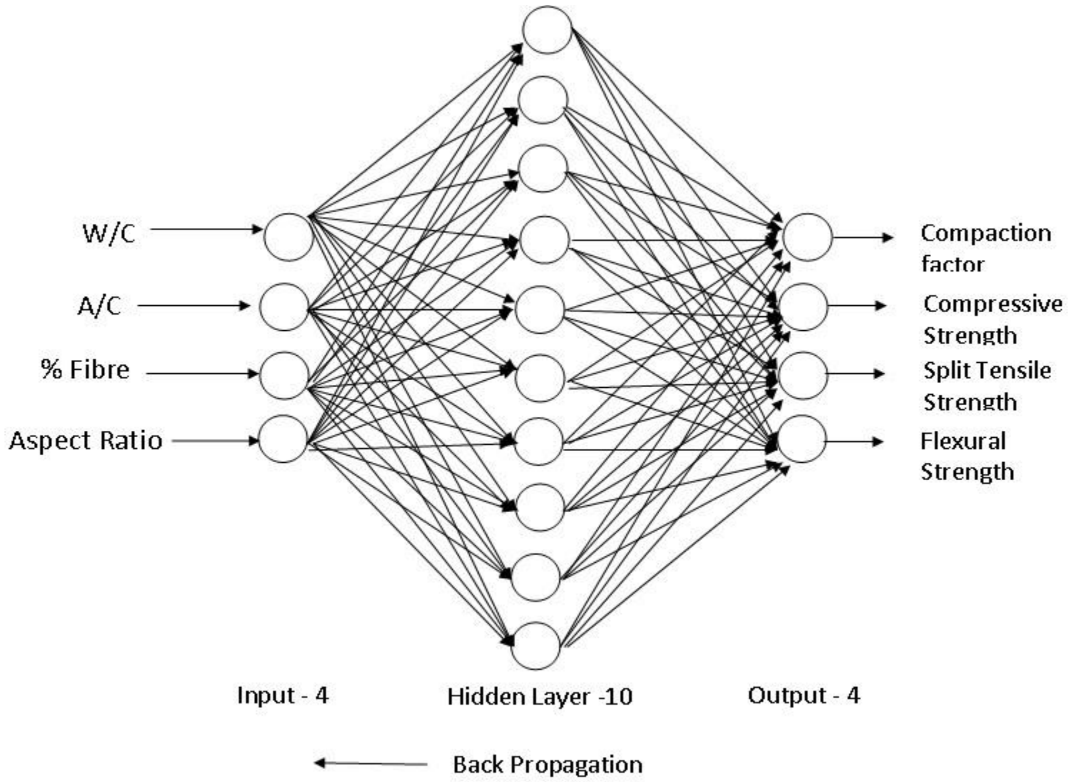

Fig. 1 Configuration of GANN Model.

4.2Training of network

Conventionally Back propagation network makes use of a weight updating rule based kind of gradient descent technique to determine their weights and therefore runs the risk of encountering the local minima problem. On the other hand Genetic Algorithm (GAs) which are adoptive search and optimization algorithms that mimic the principle of natural genetics. Genetic Algorithms are quite different from traditional search and optimization techniques used in engineering design problems but at the same time exhibit simplicity, ease of operation, minimum requirements and global perspective.

In the present work MATLAB was used to develop the model. The neural network which was developed consists of three layers input, hidden and output with 4,10,4 neurons respectively. The activation function used is "atan(x).The weights of network are obtained by minimizing the error between neural net output and actual output. To minimize the error and determine the weights, the optimization procedure was carried in two steps. First Genetic Algorithm was used to minimize the error to avoid the solution to be trapped in local minima and then optimization is shifted to sequential quadratic programming to hasten up the optimization process to complete the solution fast. Genetic Algorithm which use a direct analogy of natural behavior, work with a population of individual strings, each representing a possible solution to the problem concerned. Each individual string is assigned a fitness function which is an assessment of how good a solution is to a problem. The high fit individuals participate in reproduction by cross breeding. This yields new individual strings as off springs which share some features with each parent. The least fit individual are kept out from reproduction and so they die out. A whole new population of possible solutions to the problem is generated by selecting the high fit individuals from the current generation. This new generation contains characteristics which are better than their ancestors. A constant rate of crossover factor of 0.8 and population 200 has been adopted during training. Satisfactory training has been obtained after 1900 iterations. After successful learning of network maximum error calculation between NN output and actual output was 0.018819. During training of model develops function value vs. iteration is as shown in Fig.2.The Learning of GANN network for split tensile strength and flexural strength are shown in Fig. 3 and Fig.4

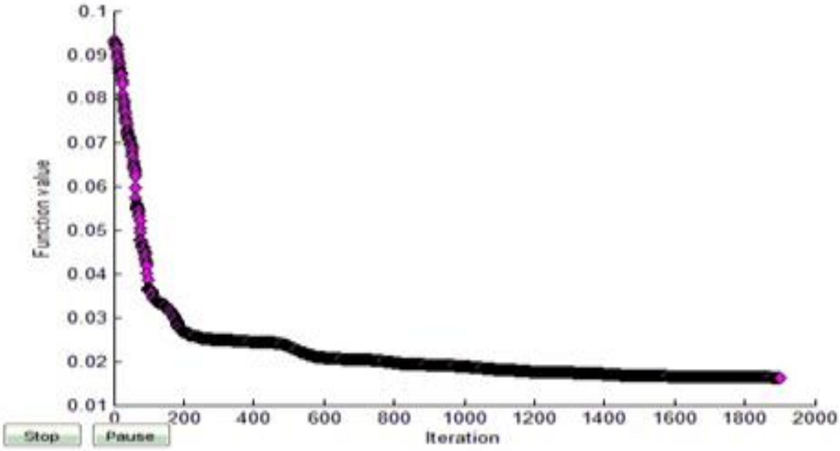

Fig.2 Function value vs iterations

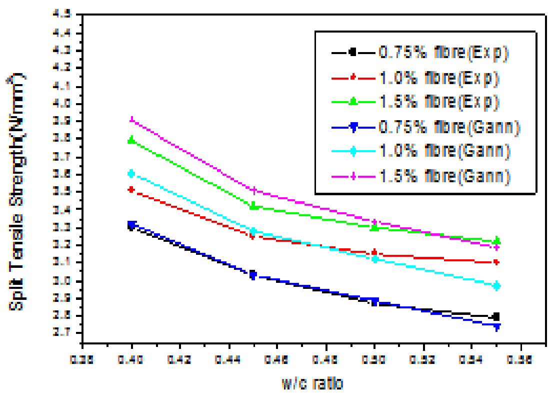

Fig.3 Learning of GANN for Split tensile strength

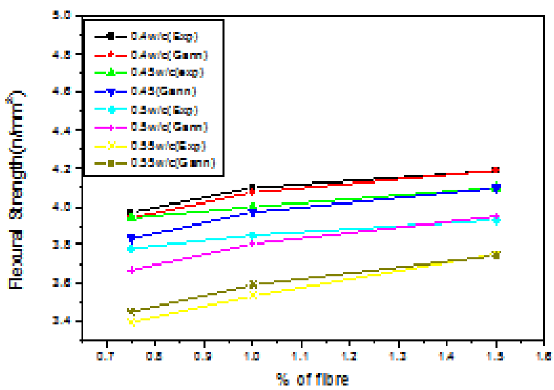

Fig.4 Learning of Gann for Flexural Strength

V. Results and Discussion

Validation of network is to test the network for parameters that not used in the training of the network. The network was asked to predict the compaction factor, compressive strength, split tensile strength and flexural strength of SFRC mixes for 21 data sets which are not included in training sets. It can be observed that from Fig.5,6,7,8, the values predicted by GA/ANN model for new set matches satisfactory with the experimental results. Hence GA/ANN model can be used for the prediction of strength properties of SFRC mixes**.**

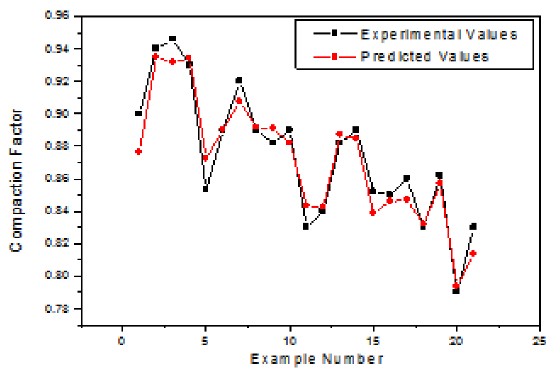

fig.5 Validation of GANN Model for Compaction Factor

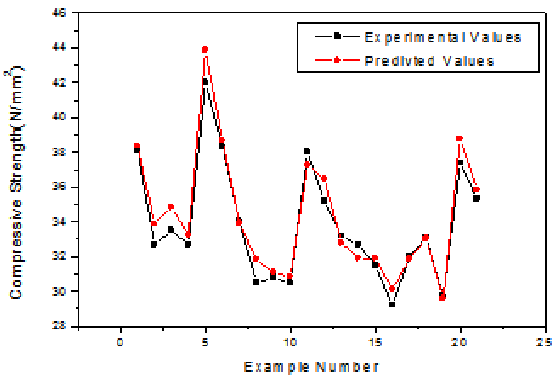

fig.6 Validation of GA ANN for Compressive Strength

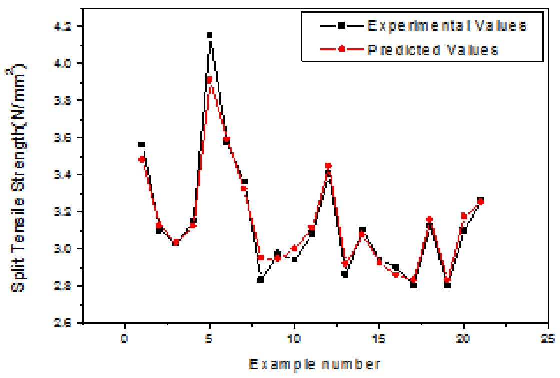

fig.7 Validation of GAANN for Split Tensile Strength

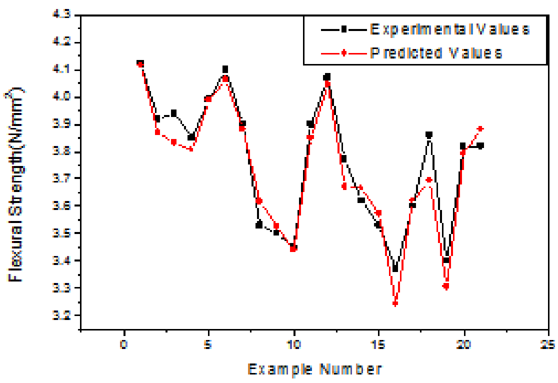

fig.8 Validation of GAANN for Flexural Strength

VI. Conclusions

In this paper, the application of GA/ANN model for predicting the strength properties of SFRC mixes such as compressive strength, split tensile strength, flexural strength and compaction factor has been demonstrated. The network model has been trained using 87 sets of examples obtained from the experimental results. The training examples are so chosen that they will cover all variables involved in the problem. The weights for network has been obtained using genetic algorithm. The network could learn the prediction of strength properties with just 1900 iterations. After successful training GANN model is able to predict compaction factor, compressive strength, split tensile strength, flexural strength and of SFRC satisfactorily for new problems with an accuracy of about 95%.Thus it is concluded the neural network model can serve as macro mechanical model for predicting strength properties of SFRC .

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