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Experimental and Analytical Study on Mechanical Properties of Concrete with Steel Fiber

S.Oviya¹, M.Anusiya²

Assistant Professor, Department of Civil Engineering, As Salam College of Engineering and Technology,
Aduthurai, India^{1,2}

ABSTRACT The new age structures are being built massive, taller and complicated in shape. These requirements cannot be fulfilled by conventional concrete, as it possess a very low tensile strength, limited ductility and little resistance to cracking, internal micro cracks are inherently present in the concrete and its poor tensile strength is due to propagation of such micro cracks. These effects can be removed by inclusion of steel or polymeric fibers. Here a study has been made on mechanical properties such as compressive strength, flexural strength and E for concrete of M40 and M50 grade of concrete with various percentages of steel fibers (Hooked end and Crimped steel fiber) such as 0.5% and 1% with conventional concrete by volume of concrete. The experimental data used to develop Artificial Neural Network (ANN) model for the analysis of strength parameters. Finally experimental results compared with the analysis results. Result shows the for same volume fraction the hook ended fiber shows improvement in all properties of concrete as compared to the crimped steel fiber. It can be observed that the experimental value satisfactorily matches with the ANN model value.

KEYWORDS: Steel fibers, Compressive strength, Flexural strength, E for concrete, Artificial Neural Network (ANN) model.

I. INTRODUCTION

Concrete is characterized by brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed fibers (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc. Steel fiber reinforced concrete (SFRC) has the ability of excellent tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest. Therefore, it has been applied abroad in various professional fields of construction, irrigation works and architecture. There are currently 300,000 metric tons of fibers used for concrete reinforcement. Steel fiber remains the most used fiber of all (50% of total tonnage used) followed by polypropylene (20%), glass (5%) and other fibers (25%).

There are numerous fibers types available for commercial experimental use. The basic fibers categories are steel, glass, synthetic and natural fibers material. Steel fiber reinforced concrete is a composite material consisting of mixtures of cement, mortar, concrete,

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discontinuous, discrete and uniformly dispersed suitable steel fibers. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed V_f . V_f typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a noncircular cross section use an equivalent diameter for the calculation of aspect ratio. Addition of steel fiber does not significantly increase compressive strength, but it increases the tensile toughness, and ductility. It also increases the ability to withstand stresses after significant cracking (damage tolerance) and shear resistance.

The following are the advantages of Steel Fiber Reinforced Concrete

- High structural strength
- Reduced crack width and control the crack width
- Improve durability
- Improve ductility.
- Increase the tensile strength
- Less steel reinforcement required
- Improve impact and abrasion resistance

II. EXPERIMENTAL PROGRAMME

A. MATERIALS USED

In this experimental study cement, sand, coarse aggregates, water and steel fibre are used.

Cement: The cement used in this experimental work is 53 grades Ordinary Portland Cement. The specific gravity of the cement is 3.13.

Fine aggregate: Locally available sand passed through 4.75mm IS sieve is used. The specific gravity of fine aggregate is 2.65. It conforming to Zone III as per IS 383-1970. The water absorption is 1%.

Coarse Aggregate: Crushed aggregate available from local sources has been used. The coarse aggregate with a maximum size of 20mm having the specific gravity value of 2.73. The water absorption is 0.5%.

Water: Potable water used for the experimentation.

Super plasticizer: Plasticizers help us to increase the workability of concrete without addition of extra quantity of water. It means that we can use less water without reducing the workability at the same cement content. This is added to avoid formation of flakes, due to less quantity of water. Use of plasticizers is economical as the cost incurred on them is less than the cost of cement saved.. Super plasticizer(Tec Mix550) is used in this study.

Steel Fiber (S.F) For improving the mechanical bond between the fiber and matrix, indented, crimped, machined and hook ended fibers are normally produced. The main variables used in this study are two different types of steel fibers i.e. hook ended steel fiber (HK) and crimped type steel fiber (CR) with aspect ratio of 50. 0.5 % and 1% constant dosages of fibers are used by weight of cement.

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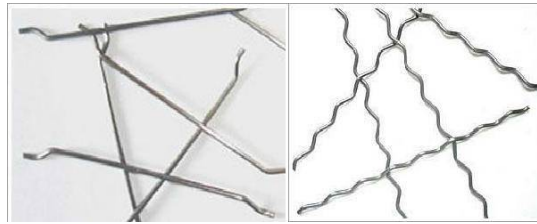


Fig1: Hooked End Steel Fiber Fig 2: Crimped Steel Fiber

I. Mix proportion

Table 1: Mix Proportions

Sl. No	Grade of concrete	Mix Ratio	Slump
1.	M40 Grade of Concrete	1 : 1.7 : 3.4 : 0.40	65 mm
2.	M50 Grade of Concrete	1: 1.41 :2.95:0.35	70mm

□ EXPERIMENTAL INVESTIGATION

Compressive strength test

For compressive strength test, cube specimens of dimensions 150 x 150 x 150 mm are cast for M40 and M50 grade of concrete. Super plasticized (0.6% to 0.8% by weight of cement) is added to this. The moulds are filled with concrete mix. Vibration is given to the moulds using table vibrator. The top surface of the specimen is leveled and finished. After 24 hours the specimens are demoulded and are transferred to curing tank wherein they are allowed to cure for 28 days. After 28 days curing, these cubes were tested on digital compression testing machine as per I.S. 516-1959. The failure load is noted. In each category three cubes are tested and their average value is reported. The compressive strength was calculated as follows.

Compressive strength =

Where, P=Failure Load, A=Area

Flexural strength test

For flexural strength test beam specimens of dimension 100x100x500 mm are cast. The specimens are demoulded after 24 hours of casting and are transferred to curing tank wherein they are allowed to cure for 28 days. These flexural strength specimens are tested under two point loading as per I.S. 516- 1959, over an effective span of 400 mm divide into three equal parts and rest on Flexural testing machine. The load is normally increased & failure load is noted at cracking of beam specimen. In each category three beams are tested and their average value is reported. The flexural strength is calculated as follows.

Flexural strength=—

Where, **P** - Failure load, **L** - Centre to Centre distance between the support = 400 mm, **b** -Width of Specimen=100 mm, **d** -Depth of specimen= 100 mm.

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As per IS code method the formula for flexural strength is $f_b = 0.7\sqrt{f_{ck}}$

Where, f_b - Flexural strength of beam, f_{ck} - Characteristic compressive strength of concrete

E for concrete

For elastic modulus test, cylinder specimens of dimensions 150 x 300 mm are cast for M40 and M50 grade of concrete. The moulds are filled with concrete mix. Vibration is given to the moulds using table vibrator. The top surface of the specimen is leveled and finished. After 24 hours, the specimen is remould from the mould and subjected to water curing for 28 days. After curing the specimen are tested using a calibrated universal testing machine. The specimen fitted on universal testing machine apparatus. The apparatus top side strain indicator is connected. The universal testing machine load for every increment of loading (1000N).The strain value is noted from the strain indicator. The testing continued to form a crack on concrete specimen. After having computed the recorded stress and strain values from the measured loads and deformations data by dividing the loads and deformations by the cross-sectional area of the cylindrical sample and by the initial length between the screws of the compressometer embedded into the sample, respectively, the resultant stress–strain relationship of each

sample was determined. As per IS code method the modulus of elasticity of concrete is

$$E_c = 5000\sqrt{f_{ck}}$$

Where, E_c - Modulus of Elasticity of concrete, f_{ck} - Characteristic compressive strength of concrete

Artificial neural network modeling

In the last years, artificial neural networks (ANN) approaches, a sub-field of intelligent systems, are being widely used to solve a wide variety of problems in civil engineering applications. The artificial neural networks solve very complex problems with the help of interconnected computing elements. Basically, the processing elements of a neural network are similar to the neurons in the brain. ANN can be defined as a data processing system consisting of a large number of simple, highly inter- connected processing elements (artificial neurons) arranged in three different layers: input layer, hidden layers and output layer. The fig 3 shows the schematic representation of artificial neural network modeling.

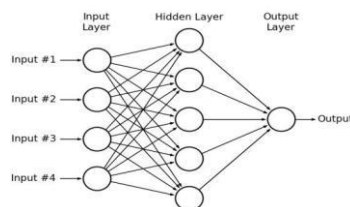


Figure 3: Schematic Representation of ANN Modeling

Data collection: Using this program, a neural network model with one hidden layer is constructed, trained and tested using the available test data. The data used in ANN model are arranged in a format of eight input parameters that covers the cement, F.A, C.A, water, super plasticizer, steel fiber, water- cement ratio and aspect ratio. The proposed ANN model predicts the 28 day compressive strength, flexural strength and elastic modulus.

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ANN training: In this work data are extracted from experimental tests gathered from literature. To train the ANN models, first the entire training data file is randomly divided into training and testing data sets. These data sets are used to train the different network architecture and they are used for testing to verify the prediction ability of each trained ANN model. Different training function available in MATLAB is experimented for the current application. The scaled conjugate gradient techniques built in MATLAB proved to be efficient training functions, and therefore, is used to construct the NN model. The network architecture or topology is obtained by identifying the number of hidden layers and the number of neurons in each hidden layers. There is no specific rule to determine the number of hidden layers and the number of neurons in each hidden layers. The network learns by comparing the output for each pattern with the target output for that pattern, then calculating the error and propagating an error function backward through the neural network. To use the trained neural network, new values for the input parameters are presented to the network. The network then calculates the neurons output using the existing weight values developed in the training process.

Validation performance: After testing and training level give the validation performance for input and output parameters. The multilayer feed forward back propagation technique is implemented to develop and train the neural network of the current study where the sigmoid transform functions are adopted. The validation performs should show on given graph plotation. The term ANN prediction is referred for ANN response for cases that are not used in the pre training stages. This is used in order to examine the ANN's ability to associate and generalize a true physical response that has not been previously seen. A good prediction for these cases is the ultimate verification test for the ANN models. These test have to be the applied for input and output response within the domain of training. It should expect that ANN would produce poor result for data that are outside the training domain. Preprocessing of data scaling is carried out to improve the training of the neural network.

IV. EXPERIMENTAL RESULTS

Compressive strength

The results of compressive strength for M40 and M50 grade of concrete are given in Table II.

Table II: Compressive Strength

Grade of Concrete	Mix Type	Compressive strength (N/mm ²)
M40	CC	49.70
	C HE _{0.5}	50.12
	C HE ₁	55.13
	C CR _{0.5}	49.97
	C CR ₁	52.37
M50	CC	57.78
	C HE _{0.5}	58.31
	C HE ₁	60.93
	C CR _{0.5}	58.00
	C CR ₁	58.84

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Flexural strength test

The results of flexural strength for M40 and M50 grade of concrete are shown in Table III.

Table III: Flexural Strength

Grade of Concrete	Mix Type	Flexural strength (N/mm ²)
M40	CC	4.6
	C HE _{0.5}	5.87
	C HE ₁	6.73
	C CR _{0.5}	5.6
	C CR ₁	6.07
M50	CC	5.47
	C HE _{0.5}	6.67
	C HE ₁	7.27
	C CR _{0.5}	6.53
	C CR ₁	7

Modulus of Elasticity for Concrete

The results of modulus of elasticity for M40 and M50 grade of concrete are given in Table IV.

Table IV: Modulus Of Elasticity For Concrete

Grade of Concrete	Mix Type	Modulus of Elasticity (N/mm ²)
M40	CC	30.95X10 ³
	C HE _{0.5}	33.5X10 ³
	C HE ₁	35.63X10 ³
	C CR _{0.5}	32.63X10 ³
	C CR ₁	34.59X10 ³
M50	CC	34.84X10 ³
	C HE _{0.5}	37.65X10 ³
	C HE ₁	40.67X10 ³
	C CR _{0.5}	36.67X10 ³
	C CR ₁	38.57X10 ³

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ANN Results

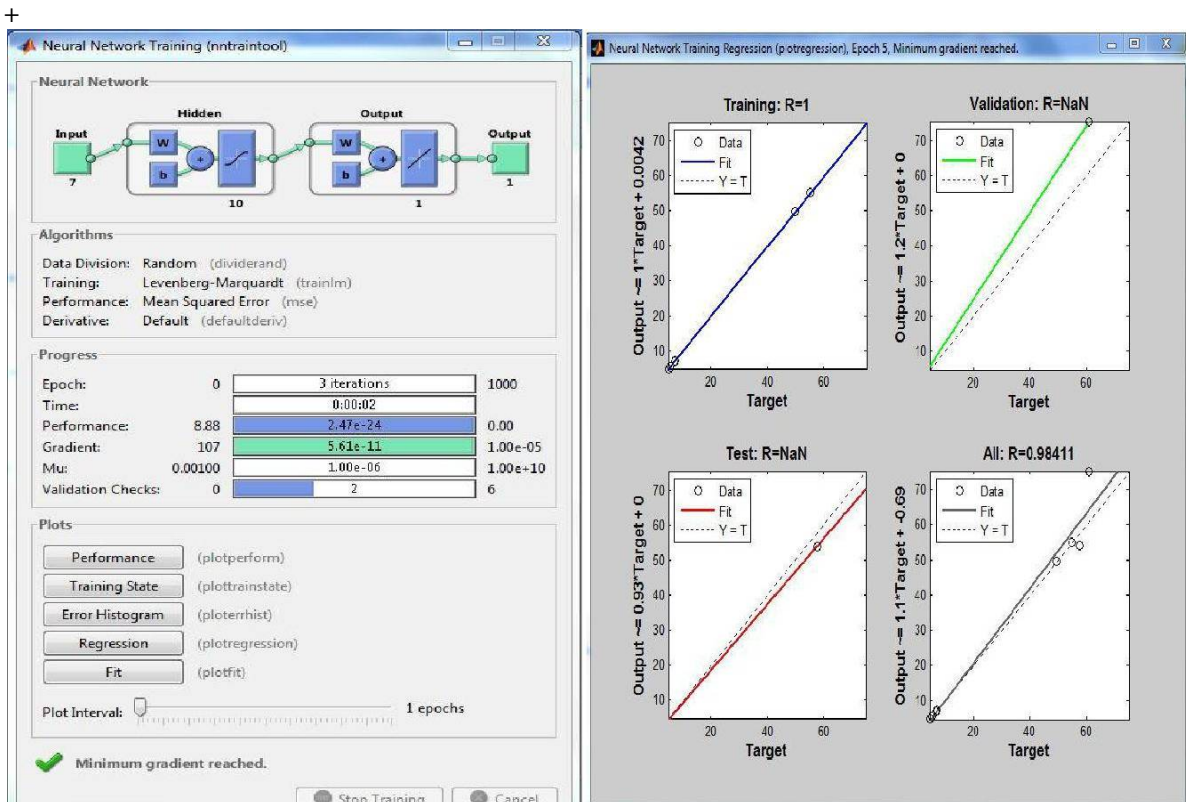


Fig 4: Neural Network Training

Fig 5: Validation of Network Performance

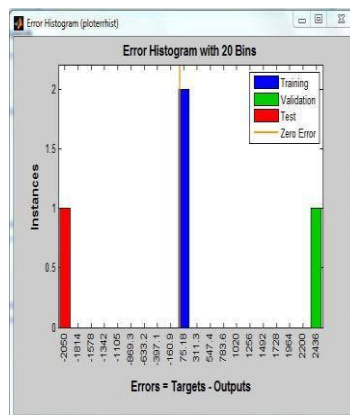


Figure 6: Neural Network Training Error Diagram

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Comparison of experimental and analytical results

Table V: Comparison of Experimental and Ann Results For Compressive Strength

Grade of Concrete	Mix Type	Experimental Result	Predicted Strength	% of Error
M40	C HE ₀	49.70	49.6893	0.022
	C HE _{0.5}	50.12	52.0246	-3.80
	C HE ₁	55.13	55.2027	-0.132
	C CR ₀	49.70	49.0808	1.260
	C CR _{0.5}	49.97	50.4458	-0.952
	C CR ₁	52.37	52.5419	-0.328
M50	C HE ₀	57.78	57.7430	0.064
	C HE _{0.5}	58.31	59.6864	-2.360
	C HE ₁	60.93	59.5490	2.320
	C CR ₀	57.78	57.6650	0.199
	C CR _{0.5}	58	58.9093	-1.568
	C CR ₁	58.84	58.6837	0.1266

Table VI: Comparison of Experimental And Ann Results For Flexural Strength

Grade of Concrete	Mix Type	Experimental Result	Predicted Strength	% of Error
M40	C HE ₀	4.6	4.7638	-3.560
	C HE _{0.5}	5.87	5.6273	4.31
	C HE ₁	6.73	6.73	0
	C CR ₀	4.6	4.4926	2.391
	C CR _{0.5}	5.6	5.1522	8.69
	C CR ₁	6.07	6.0765	-0.107
M50	C HE ₀	5.47	5.47	0
	C HE _{0.5}	6.53	6.1822	7.890
	C HE ₁	7.27	6.27	15.998
	C CR ₀	5.47	5.4637	0.115
	C CR _{0.5}	6.53	6.0881	7.258
	C CR ₁	7.00	6.1698	13.456

Table VII: Comparison of Experimental And Ann Results For Modulus Of Elasticity For Concrete

Grade of Concrete	Mix Type	Experimental Result	Predicted Strength	% of Error
M40	C HE ₀	30.95X10 ³	30.95X10 ³	0
	C HE _{0.5}	33.5X10 ³	34.023X10 ³	-1.561
	C HE ₁	35.63X10 ³	35.728X10 ³	-0.275
	C CR ₀	30.95X10 ³	30.95X10 ³	0
	C CR _{0.5}	32.63X10 ³	33.203X10 ³	-1.756
	C CR ₁	34.59X10 ³	34.551X10 ³	0.113
M50	C HE ₀	34.84X10 ³	34.84X10 ³	0
	C HE _{0.5}	37.65X10 ³	36.354X10 ³	3.565
	C HE ₁	40.67X10 ³	38.023X10 ³	6.962

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C CR ₀	34.84X10 ³	34.84X10 ³	0
C CR _{0.5}	36.67X10 ³	35.825X10 ³	2.359
C CR ₁	38.57 X10 ³	36.898X10 ³	4.531

V. CONCLUSION

The study on the effect of steel fibers with different types can still be a promising work as there is always a need to overcome the problem of brittleness of concrete.

The following conclusions could be drawn from the present investigation

It is observed that the compressive strength, flexural strength and elastic modulus for M40 and M50 grade of concrete from two different types of fibers at same volume fraction shows nearly same results with minor increase.

It is observed that for the same volume fraction the hook ended fiber shows improvement in all properties of concrete as compared to the crimped steel fiber.

It is observed that compressive strength, flexural strength and elastic modulus are on higher side for 1% fibers as compared to that produced from 0% and 0.5% fibers.

It has been noted that the compressive strength of M40 grade of concrete increases about 1% for an addition of 0.5% hooked end steel fiber and about 0.5% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete. Similarly the compressive strength of M50 grade of concrete increases about 1% for an addition of 0.5% hooked end steel fiber and about 0.4% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete.

- I. It has been noted that the compressive strength of M40 grade of concrete increases about 10% for an addition of 1% hooked end steel fiber and about 5% for an addition of 1% crimped steel fiber when compared to the conventional concrete. Similarly the compressive strength of M50 grade of concrete increases about 6% for an addition of 1% hooked end steel fiber and about 2%

for an addition of 1% crimped steel fiber when compared to the conventional concrete.

- II. It has been noted that the flexural strength of M40 grade of concrete increases about 28% for an addition of 0.5% hooked end steel fiber and about 22% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete. Similarly the flexural strength of M50 grade of concrete increases about 22% for an addition of 0.5% hooked end steel fiber and about 19% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete.

- JJ. It has been noted that the flexural strength of M40 grade of concrete increases about 46% for an addition of 1% hooked end steel fiber and about 32% for an addition of 1% crimped steel fiber when compared to the conventional concrete. Similarly the flexural strength of M50 grade of concrete increases about 33% for an addition of 1% hooked end steel fiber and about 28% for an addition of 1% crimped steel fiber when compared to the conventional concrete.

- III. It has been noted that the modulus of elasticity of M40 grade of concrete increases about 8% for an addition of 0.5% hooked end steel fiber and about 5.4% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete. Similarly the flexural strength of M50 grade of concrete increases about 8% for an addition of 0.5% hooked end steel fiber and about 5.2% for an addition of 0.5% crimped steel fiber when compared to the conventional concrete.

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JJJ. It has been noted that the modulus of elasticity of M40 grade of concrete increases about 15% for an addition of 1% hooked end steel fiber and about 12% for an addition of 1% crimped steel fiber when compared to the conventional concrete. Similarly the flexural strength of M50 grade of concrete increases about 17% for an addition of 1% hooked end steel fiber and about 11% for an addition of 1% crimped steel fiber when compared to the conventional concrete. Further, using the experimental results an ANN models have been developed. ANN model can be effectively used to predict all the three strength parameters of fiber reinforced concrete.

KKK. It can be observed that the experimental value satisfactorily matches with the ANN model value.

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