Adaptive Neuro Fuzzy Inference System Based Modeling for the Effect of Natural and Steel fibers On the Performance of High Strength Concrete

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***Abstract*— High Strength Concrete is an improved construction material in high rise buildings, bridges and off shore structures because it offers greater compressive strength. The increase in compressive strength of High Strength Concrete (HSC) not only increases brittleness but also reduces the ductility of the concrete. To improve the ductility of HSC, the strategy is to introduce fibers in HSC which results in development of near isotropic material with reasonable tensile strength, reduced shrinkage effect and greater toughness. Hence this paper aims to determine the basic characteristics of hybrid fiber-reinforced high strength concrete containing silica fume mixed with different types of fiber s; steel, palm, sisal and coir fibers in terms of compressive strength, splitting-tensile strength, flexural strength and modulus of elasticity as 1% volumetric fraction. Silica fume replacement was 10%. The specimens are tested at 28 days. Following this experimental effort, Adaptive Neuro - Fuzzy Inference System (ANFIS) modeling has been proposed for predicting the strength parameters. A better correlation has been observed between the test results and those predicted through the proposed modeling.**

***IndexTerms*— High strength concrete (HSC), fiber reinforced concrete (FRC), Adaptive Neuro - Fuzzy Inference System (ANFIS). Aritificial neural network (ANN)**

I. INTRODUCTION

A. General

The engineering characteristics and economic advantages of high-strength concrete (HSC) are distinct from conventional concrete, thereby popularizing the HSC concrete in a large variety of applications in the construction industry. Used for high-rise buildings, HSC avoids the unacceptable oversized columns on the lower floors, allowing large column spacing and usable floor space, or increasing the number of possible stories without detracting from lower floors. Used for long span bridges, HSC reduces the dead load of bridge girders for fewer and lighter bridge piers and thus enables greater underpass clearance widths. HSC inspires substantial savings in expenditure on bridge maintenance, while prolonging the serviceable life of the bridges. Further, HSC possesses uniform high density and very low impermeability, endowing itself with excellent resistance to aggressive environments and disintegrating agencies, and benefiting the durability of concrete buildings and structures. The comparatively higher compressive strength of HSC is an attractive profit; whereas, the strength behaves against the ductility of the concrete by welcoming brittleness pronouncedly. The HSC always possesses a steeper descending stress–strain curve in compression than does the normal strength concrete. The rapid decrease in compressive strength in the post-peak load region brings about a pronouncedly brittle mode of failure. To foster the compressive strength without sacrificing the ductility is to incorporate fibers into cementitious materials which has been proven to improve both their flexural toughness and resistance to cracks development. Thus, the inclusion of fibers into concrete not only provides considerably more ductile structure but also improves such structural properties as tensile strength, static flexural strength, impact strength, flexural toughness and the energy absorption capacity of the high strength concrete.

The performance of fiber reinforced concrete (FRC) depends on the properties of concrete and the fibers. The properties of fiber s that are usually of interest are fiber concentration, fiber geometry, fiber orientation, and fiber distribution. Moreover, the use of a single type of fiber may improve the properties of FRC to a limited level. However the concept of hybridization, which is the process of adding two or more types of fiber into concrete, can offer more attractive engineering properties as the presence of one fiber enables the more efficient utilization of the potential properties of the other fiber. It has been shown from previous studies (Eether Thanon Dawood et al 2012) that the concept of hybridization with two or three different fibers incorporated in a common cement matrix can offer more attractive engineering properties because the presence of one fiber enables the more effective utilization of the potential properties for the other fiber. Steel fiber has a considerably larger length and higher Young's modulus of elasticity as compared to the other fiber-types. This leads to an improved flexural rigidity and has great potential for crack control, although the volumetric density is high. It is also important to note that steel is conductive in both electric and magnetic fields and hence, the steel fiber content has to be reduced to a certain level. Optimization of mechanical and conductivity properties can be achieved by combining different types of fiber s, such as in the case of natural fibers (coir, sisal, and palm fiber and steel fiber). The attractive advantage of hybrid fibers system is that it provides a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and ultimate strength, where the second type of fiber , which is more flexible and ductile, leads to the improved toughness and strain capacity in the post-cracking zone. It also contributes to a hybrid reinforcement, in which the smaller fiber bridges microcracks and reduce crack widths. This leads to a higher tensile strength of the composite. The second type of fiber is larger, so that it can arrest the propagating macrocracks and can substantially improve the toughness of the composite. However, most of the research work and utilization of fiber reinforcement are about monotype fiber. Using hybrid fibers as reinforcement to improve the performance of concrete are not frequently reported. Therefore, the research would present the results of some properties of high strength concrete added with hybrid fibers.

On the other hand, in the recent years, the soft computing tools are used in modeling as well as predicting many engineering systems as they differ from conventional hard computing in many ways like their tolerance to imprecision, robustness and being low in solution cost. In fact, soft computing is an emerging approach to computing which parallels the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision (Jang el at., 1997). It consists of many complementary tools such as artificial neural network (ANN), fuzzy logic (FL), and adaptive neuro-fuzzy inference system (ANFIS). Amongst the various soft computing tools ANFIS models can serve as reliable and simple predictive tools for the prediction of strength parameters of concrete. The fuzzy logic concept provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria rather than the presence of random variables. The fuzzy approach considers the cases where linguistic uncertainties play some role in the control mechanism of the phenomena concerned. It can be applied to solve most of civil engineering problems as a future research.

Many research works can be found in the literature that focused on the prediction of the various properties of concrete. Raikar R.V et al. [1] proposed ANN and ANFIS models to predict the mechanical and chloride permeability properties of concrete containing GGBFS and CNI. In total, 162 tests were administered for compressive strength, splitting tensile strength, and chloride ion permeability (54 tests each). In addition, the formulated four-layered artificial neural network method (ANN) and the adaptive neuro-fuzzy inference system (ANFIS) were trained using 120 of the 162 specimens. The methods were tested with the other 42 specimens for each parameter. J.Saravanan et al. [2] has proposed Adaptive Neuro - Fuzzy Inference System (ANFIS) modeling on the performance of Glass fiber Reinforced Polymer (GFRP) wrapped high strength concrete columns under uni-axial compression. A better correlation has been observed between the test results and those predicted through the proposed modeling. Jafar Sobhani et al. [6] considered concrete constituents as input variables; several regression, neural networks (NNT) and ANFIS models are constructed, trained and tested to predict the 28-days compressive strength of no-slump concrete (28-CSNSC). Comparing the results indicate that NNT and ANFIS models are more feasible in predicting the 28-CSNSC than the proposed traditional regression models. A data set of a laboratory work, in which a total of 48 concretes were produced, was utilized in the ANNs and FL study. The concrete mixture parameters were four different water–cement ratios, three different cement dosages and three partial silica fume replacement ratios. The obtained results with the experimental methods were compared with ANN and FL results. The results showed that ANN and FL can be alternative approaches for the predicting of compressive strength of silica fume concrete. Ilker Bekir Topc, u et al. [12] predicted the rubberized concrete properties using artificial neural network and fuzzy logic. During the tests similar results were observed for experimental results with those of ANN and FL models. Osman Unal et al [15] presented a fuzzy logic approach to predict stress–strain curves of steel fiber-reinforced concretes in compression. The stress–strain curves for SFRC were modeled by use of fuzzy logic approach, and the results that were obtained from experiments and modeling were compared. As a result close relationship between both results was seen. Fuat Demir et al [13] predicted the elastic modulus of normal and high strength concrete using fuzzy logic. A fuzzy logic algorithm has been devised for estimating elastic modulus from compressive strength of concrete. The main advantage of fuzzy models is their ability to describe knowledge in a descriptive human-like manner in the form of simple rules using linguistic variables only. Adaptive neuro fuzzy inference system architecture is shown in Figure 1.

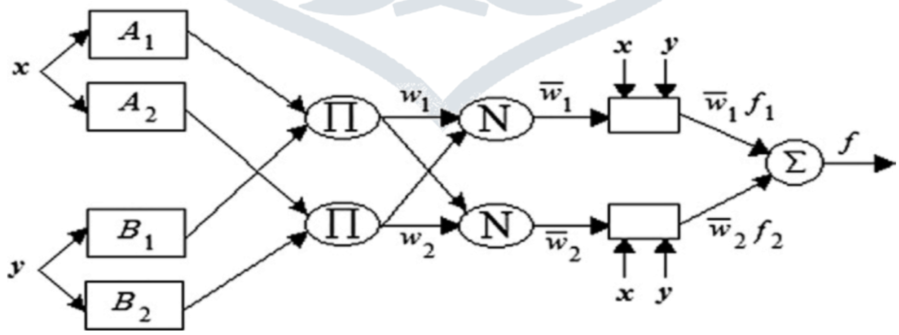

Figure 1: Architecture of ANFIS

The focus of this paper is on the prediction of strength parameters of HSC with steel and natural fiber reinforcement up to 1%. The strength parameters considered were compressive strength, split tensile strength and flexural strength and modulus of elasticity. The experimental results are used to develop ANFIS model.

II EXPERIMENTAL PROGRAM

A. Materials

1) Cement:

Strength development of concrete will depend on both cement characteristic and cement content. 53 grade Ordinary Portland Cement conforming to IS 12269 (Indian Standard Designation, IS 12269-1987) was used for the concrete mixtures.

2) Silica Fume:

Microsilica is obtained from Astrra chemicals, chennai

3) fibers Used:

fibers used in the study where hooked steel, coir, sisal and palm fibers from local manufacturers

3.1 Hooked steel fibers: Steel fiber of length 50mm is used . and the characteristics are given in table 1

Table 1: Characteristics of steel fiber

Average fiber length	50
Diameter	1
Aspect ratio	50
Tensile strength (Mpa)	532
Specific gravity	7.85
Water Absorption (%)	33.33
Density in kg/m3	7850

3.2) Coir fiber: Coir fiber is cut into length of 50mm. The characteristics are listed in table 2.

Table 2: Characteristics of coir fiber

Average fiber length (mm)	50
Average fiber diameter(mm)	0.48
Aspect ratio	104.2
Tensile strength (Mpa)	160
Specific gravity	.87
Water Absorption (%)	210
Density in kg/m3	2057

3.3) Sisal fiber: It is taken as 50 mm length. The characteristics are given in table 3.

Table 3: Characteristics of sisal fiber

Average fiber length (mm)	50
Average fiber diameter(mm)	0.75
Aspect ratio	66.67
Tensile strength (Mpa)	297.83
Specific gravity	.69
Modulus of elasticity (Mpa)	11.37
Water Absorption (%)	119

3.4)Palm fiber: Palm fiber of 50 mm length used in the experiment work. The characteristics are depicted in table 4.

Table 4: Characteristics of palm fiber

Average fiber length (mm)	50
fiber diameter (mm)	1
Aspect ratio	50
Tensile strength (Mpa)	21.2
Specific gravity	1.24
Water Absorption (%) 24/48 hrs	.6

4) Super plasticizer:

Enfiq Superplast-400 is used as super plasticizer which is a high range water reducing admixture with set regarding effect to produce free flowing concrete. It complies with IS 9103-79, ASTM C 494 type D.

5). Fine Aggregates:

River sand with a specific gravity of 2.86 and fineness modulus of 2.78 which confirms to the Zone III grading of IS383:1970 was used as the fine aggregate for the experimental work. .

6) Coarse Aggregates:

Crushed gravel with maximum size of 20mmmm and with a specific gravity of 6.9 also confirming to IS383:1970 were used as coarse aggregate.

B. Mix proportions

The mix proportion adopted was 1: 1.356: 2.767 with a water-cement ratio of 0.318. Table5 presents the control concrete mix proportions used in the testing program. The mix proportion for different fiber combinations as total of 1% is shown in table 6.

Table 5: Concrete Mix Proportion

Cement (kg/m^3)	450.95
Sand (kg/m^3)	611.52
Coarse aggregate (kg/m^3)	1247.58
Water (kg/m^3)	145

Table 6: Mix proportion for different fiber combinations

Mix ID	Steel	Sisal	Palm	Coir
C0	-	-	-	-
C1	1	-	-	-
C2	.5		.5	-
C3	.5			.5
C4	.5	.5	-	-
C5	.5	-	.25	.25
C6	.25	-	.5	.25
C7	.25	-	.25	.5
C8	.25	.25	.25	.25
C9	-	1	-	-
C10	-	.5	.5	-
C11	-	.5	-	.5
C12	-	.5	.25	.25
C13	-	.25	.5	.25
C14	-	.25	.25	.5
C15	.25	.25	.5	-
C16	.25	.5	.25	-
C17	.5	.25	.25	-
C18	.25	.25	-	.5
C19	.25	.5	-	.25
C20	.5	.25	-	.25

c. Test Methods

1. Compressive strength is determined as per IS 516-1959. Three cube samples of 150 mm are used for each mix to test the compressive strength
2. The test for split tensile strength was carried out according to IS 5816- 1999 to obtain the splitting tensile strength using the average of three concrete cylinders (150 X 300 mm)
3. Determination of Flexural strength is as per IS 5816-1999. The specimens of 10 x 10 x 50 cm are used and two point loading is used to determine the modulus of rupture.
4. Modulus of elasticity is determined as per ASTM C469 using a longitudinal Compressometer in a CTM. The specimens were tested as per clause 9 of IS: 516 – 1959

d. Test Results

Table 7: Test results

Mix ID	Compressive strength	Split tensile strength	Flexural strength	Modulus of Elasticity
CO	57.92	4.86	6.85	35.77
C1	62.25	5.28	7.46	37.20
C2	61.28	4.98	7.25	36.85
C3	57.48	5.16	7.16	32.93
C4	60.36	5.62	7.2	34.1
C5	64.03	5.3	7.51	36.96

C6	63.5	5	7.27	36.26
C7	60.04	5.37	7.21	33.93
C8	59.49	5.01	7.14	34.29
C9	57.71	5.64	7	34.87
C10	58.89	5.34	7.04	35.07
C11	56.1	5.58	6.57	33.24
C12	56.88	5.45	6.68	35.12
C13	60.45	5.18	7.04	35.94
C14	55.93	5.39	6.9	34.52
C15	62.5	5.43	7.53	36.8
C16	61.32	5.76	7.46	38.01
C17	65.88	5.98	7.95	39.73
C18	59.25	6.12	7.22	37.39
C19	60.02	6.42	7.45	38.88
C20	62.21	6.36	7.7	39.27

III ANFIS

The fuzzy set theory developed by (Zadeh, 1965) provides as a mathematical framework to deal with vagueness associated with the description of a variable. The commonly used Fuzzy Inference System – Theory 478 and Applications fuzzy inference system (FIS) is the actual process of mapping from a given input to output using fuzzy logic. Fuzzy logic is particularly useful in the development of expert systems. Expert systems are built by capturing the knowledge of humans: however, such knowledge is known to be qualitative and inexact. Experts may be only partially knowledgeable about the problem domain, or data may not be fully available, but decisions are still expected. In these situations, educated guesses need to be made to provide solutions to problems. This is where fuzzy logic can be employed as a tool to deal with imprecision and qualitative aspects that are associated with problem solving (Jang, 1993). A fuzzy set is a set without clear or sharp boundaries or without binary membership characteristics. Unlike a conventional set where object either belongs or do not belong to the set, partial membership in a fuzzy set is possible. In other words, there is a softness associated with the membership of elements in a fuzzy set (Jang, 1993).A fuzzy set may be represented by a membership function. This function gives the grade (degree) of membership within the set. The membership function maps the elements of the universe on to numerical values in the interval [0, 1]. The membership functions most commonly used in control theory are triangular, trapezoidal, Gaussian, generalized bell, sigmoidal and difference sigmoidal membership functions (Jang et al., 1997; Matlab toolbox, 2009; Zaho & Bose, 2002). As mentioned previously, the fuzzy inference system is the process of formulating the mapping from a given input to an output using fuzzy logic. The dynamic behavior of an FIS is characterized by a set of linguistic description rules based on expert knowledge.

The fuzzy system and neural networks are complementary technologies.The most important reason for combining fuzzy systems with neural networks is to use the learning capability of neural network. While the learning capability is an advantage from the view point of a fuzzy system, from the viewpoint of a neural network there are additional advantages to a combined system. Because a neuro-fuzzy system is based on linguistic rules, we can easily integrate prior knowledge in to the system, and this can substantially shorten the learning process. One of the popular integrated systems is an ANFIS, which is an integration of a fuzzy inference system with a back-propagation algorithm (Jang et al., 1997; Lin & Lee 1996).

There are two types of fuzzy inference systems that can be implemented: Mamdani-type and Sugeno-type (Mamdani & Assilian, 1975; Sugeno, 1985). Because the Sugeno system is more compact and computationally more efficient than a Mamdani system, it lends itself to the use of adaptive techniques for constructing the fuzzy models. These adaptive techniques can be used to customize the membership functions so that the fuzzy system best models the data. The fuzzy inference system based on neuro-adaptive learning techniques is termed adaptive neuro-fuzzy inference system (Hamidian & Seyedpoor, 2009). In order for an FIS to be mature and well established so that it can work appropriately in prediction mode, its initial structure and parameters (linear and non-linear) need to be tuned or adapted through a learning process using a sufficient input-output pattern of data. One of the most commonly used learning systems for adapting the linear and nonlinear parameters of an FIS, particularly the first order Sugeno fuzzy model, is the ANFIS. ANFIS is a class of adaptive networks that are functionally equivalent to fuzzy inference systems (Jang, 1993).

A. Model Construction

ANFIS requires generation of individual fuzzy inference system object for each parameter taken up for prediction. Prediction system is developed for Modulus of rupture, compressive strength , split tensile strength and modulus of elasticity . All the fuzzy Inference systems take percentage of steel, sisal, palm and coir fibers as input parameters.

The fuzzy inference systems were generated on MATLAB software using fuzzy logic toolbox. The ANFIS models for the above work were developed using *anfisedit* command available in the fuzzy logic toolbox of Matlab software. We can create, train, and test Sugeno-type fuzzy systems using the ANFIS Editor GUI. The following table 8 shows the Rms and Average Testing Error of various mechanical properties while designing the ANFIS model.

Table 8 : Rms error and average testing error of Anfis models

Anfis Model	Rms Error	Average Testing Error
Compressive strength	.0009322	2.278
Split tensile strength	.01238	2.9463
Flexural strength	.042958	3.043
Modulus of Elasticity	.016925	12.8301

IV CONCLUSIONS

1. The marked brittleness with low tensile strength and strain capacities of high-strength concrete (HSC) can be overcomed by the addition of hybrid fibers

2. Among all hybrid fiber combinations C17 (.5% steel + .25%palm + .25% sisal) mix has performed better in all respects compared to the mono steel fiber concrete and concrete without fibers with the strength effectiveness of 13% in compressive strength, 5.12% in split tensile, 16% in flexural and 11% improvement for Modulus of Elasticity.

3. The mix C19 (.25% steel + .5% sisal + .25% coir) has the highest split tensile strength. It can be seen that sisal fiber and its combination with other fibers gives the best performance of split tensile strength

4. The influence of steel fibers on flexural strength of concrete is much greater than for direct tension and compression. Inclusion of steel fibers increases by 8.9% compared to plain HSC. Steel fibers provide reasonable first crack strength.

5. The test results of Elastic Modulus shows that the modulus increases with the incorporation of hybrid fibers.

6. A remarkable significance of these findings is that steel fibers in concrete could be replaced to smaller extent natural fibers to provide a similar strength of steel fiber high strength concrete.

7. All of the proposed ANFIS models exhibit acceptable performance. Of these models, FL Model for Split Tensile Strength with Gaussian membership functions in its layers presents the best prediction performance.

8. Strength models gave the predictions matching the measurements. Therefore the application of the proposed fuzzy model is straightforward for any mechanical properties of HSC added with steel and natural fibers such as sisal, palm and coir.

9. The strength values can be predicted in the models of fuzzy logic without attempting many experiments and also in a quite short period of time with tiny error rates.

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