Modelling Marshall Stability Of Fiber Reinforced Asphalt Mixtures With Anfis

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***Abstract*—In this study, an Adaptive Neural Fuzzy Inference System (ANFIS) model for predicting the Marshall Stability (MS) of basalt fiber reinforced asphalt concrete mixtures and various mix proportions has been developed. Experimental details were used to construct the model. The amounts of bitumen (%), Fiber (Basalt) Ratio (%) were used as input variables and Marshall Stability (kg) values were used as output variables. Statistical equations were used to evaluate the Developed ANFIS model.**

Results showed that developed ANFIS model has strong potential to predict Marshall Stability of asphalt concrete using related inputs in a short time. Also, the Marshall Stability of Fiber-Reinforced asphalt concrete and various mix proportions can be found without performing any experiments.

Keywords*—*Basalt Fiber; Asphalt Concrete; Marshall Stability; Adaptive Neural Fuzzy Inference System (ANFIS)

I. Introduction

The pavements are under the effect of traffic loads and natural circumstances. Traffic loads are composed of radial tensile and compressive stresses as well as vertical compressive stresses occurring due to axle loads during the movement of vehicles. The intensity and magnitude of traffic loads are directly proportional to the repetition of these stresses. The aim of the pavement design is to determine the thicknesses of the layers that are needed to bear safely the repetitive loads under environmental circumstances without large deformations or cracking, based on the characteristics of the materials to be used in these layers [1,2].

One of the most important characteristics of the materials to be used in road construction is the contribution to the achievement of project requirements in an economical manner. Besides, the parameters such as long economic life, low maintenance/repair costs, low construction and repair time, compatibility with the environment, use of waste materials, and adaptability to quality control procedures should also be taken into consideration [2,3].

Highways are rather high cost structures, and for that reason, it is obligatory that the materials to be used for their constructions should be appropriately designed. Flexible pavements are designed so as to have a 20 years project life. For that reason, the load distributions that would occur on these structures should also be calculated and included in the design

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process [4]. The current research subjects include the studies focusing on increasing the performance and lifetime of roads. It is aimed to increase the performance and lifetime of roads by using different additive materials.

The use of fibers alters the visco-elasticity characteristics of the mixture [8]; enhances its dynamic modulus [9], enhances sensibility against humidity [10], enhances flow coherence, and provides resistance against the rutting [11,12]; as well as decreases the amount of reflective cracks in asphalt mixtures and pavement [13-15].

Basalt Fibre, which was developed by Moscow Research Institute of Glass and Plastic in 1953-1954, is a high-tech fibers invented by the former Soviet Union after 30 years of research and development, and its first industrial production furnace that adopted 200 nozzles drain board combination oven bushing process was completed in 1985 at Ukraine fiber laboratory. It has a wide range of application and great prospects because of its high performance and cost-effective. Using a natural volcanic basalt rock as raw material, basalt fiber is a typical silicate fiber that were produced by putting raw material into furnace after their broken, and melted in the 1450-1500 ^{0}C, then made with platinum and rhodium alloy wire-drawing bushing.it has natural compatibility, superior mechanical properties, stable chemical properties and outstanding high temperature performance [16].

Nowadays Artificial Intelligent methods have been extensively used in civil engineering applications [17-18]. Fuzzy logic and neural networks are the widely used artificial inference systems. Each approach has its merits and drawbacks. To take advantage of both approaches, integration of these systems has been proposed by many researchers in recent years [19]. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a fuzzy system that uses ANN's theory to determine its properties (fuzzy sets and fuzzy rules) [20]. A Neuro Fuzzy model brings together the linguistic representation of a fuzzy system with the learning ability of Artificial Neural Networks (ANNs) [21].

In this study, an Adaptive Neural Fuzzy Inference System (ANFIS) model for predicting the Marshall Stability (MS) of basalt fiber reinforced asphalt concrete (BFAC) and various mix proportions has been developed.

II. Experimental Study

Asphalt mixtures were prepared in accordance with the technical specifications required by Highway General Directorate of Turkey [22]. A flowchart summarising the experimental study was given in Fig. 1.

Based on the obtained optimum bitumen content value, basalt fibers were added in tenthly different ratio in weights (0-0.25-0.50-0.75-1.0-1.5-2.0%) as three samples for each fiber rate (Fig. 2).

Crushed limestone aggregates were used in asphalt mixtures. Aggregate material tests were carried out based on American Standards, in order to obtain the physical and mechanical characteristics of the materials to be used in the mixtures. Aggregates ratios are used for binder respectively; 60% for 25-4.75 mm, 34% for 4.75-0.075 mm and 6% as filler. Crushed limestone was obtained from quarries around Isparta which are mainly used for highway construction. In the study, aggregate grading curves for asphalt mixtures were obtained from Turkish Highway Construction Specifications (Fig. 3) [22]. Sieve analyses were carried out and available grading curve for the aggregate used in the study was close to binder layer course [23].

To prepare the Marshall samples, 60-70 penetration asphalt cement was used. The physical characteristics of this selected bitumen are given in Table I [23].

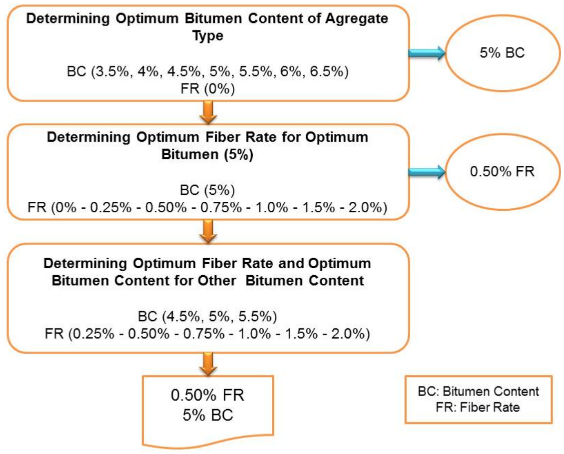

Fig. 1. Flow chart of laboratory works [23]

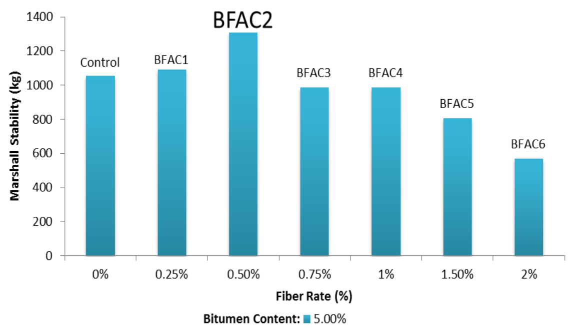

Fig. 2. Change in MS values for optimum bitumen content and different fiber rate (BFAC: Basalt Fiber Asphalt Concrete) [23]

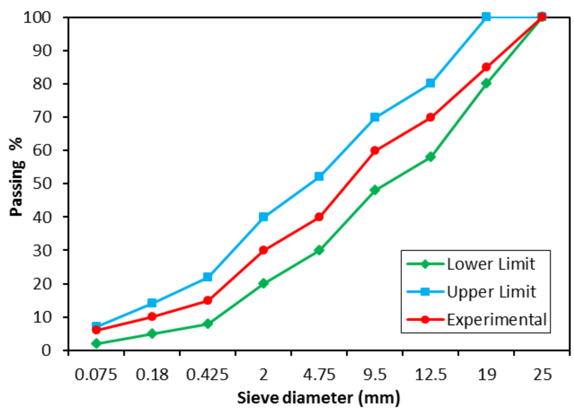

Fig.3. Gradation curve of the aggregates used in mixture

TABLE I. PHYSICAL CHARACTERISTICS OF THE BITUMEN

Test Name	Average Values	Standard
Penetration (25 ºC)	60-70	ASTM D5 [24]
Flash Point	180ºC	ASTM D92 [25]
Fire Point	230 ºC	ASTM D92 [25]
Softening Point	45.5°C	ASTM D36 [26]
Ductility (5 cm/minute)	>100 cm	ASTM D113 [27]
Specific Gravity	0.996 gr/cm³	ASTM D70 [28]

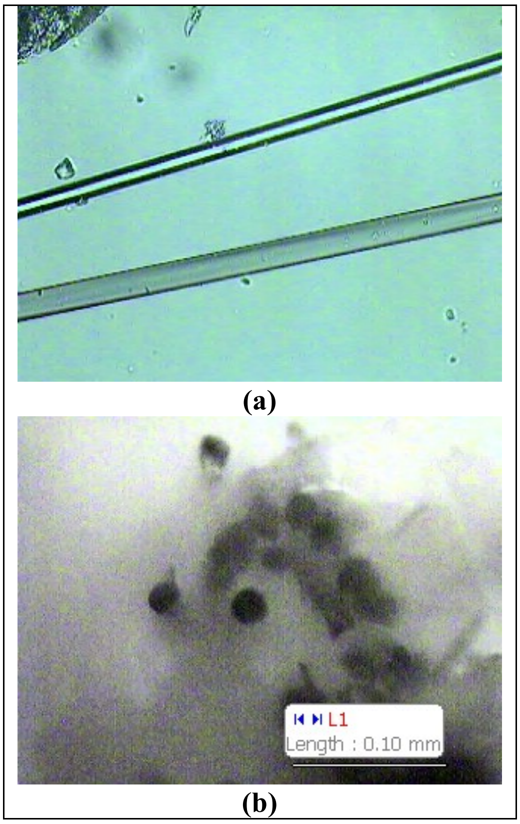

Fig. 4. The morphology of basalt fiber (a) longitudinal (b) cross section

Basalt fiber, which was used in the application, sample morphology was determined by using Motic light Microscopy and Motic image analysis software with 40x object lens and shown in the Fig. 4. As seen at morphological figures the cross section of the fibre was rounded shape. Basalt fibers (Fig. 5) provided by Spinteks Co, (Denizli, Turkey) [29].

The length of the 50 different basalt fiber which was selected at 50 different points in fiber bunch was measured with a digital calliper (Fig. 6). The diameter of the 50 different basalt fiber which was selected at 50 different points in fiber bunch was measured by using Motic light microscopy and Motic image analysis software with 40x object lens, the devices and results were shown in the Fig. 7.

As seen at graphics, the average of fiber length was calculated as 25.89 mm and the curve was so close to linear. After analysing the results of fiber diameter, three different fiber thickness has been determined as seen fiber diameter graphic and their diameter averages were calculated as avg.1=0.010 mm; avg.2= 0.017; avg.3= 0.021 mm.

Fig. 5. Basalt Fibers

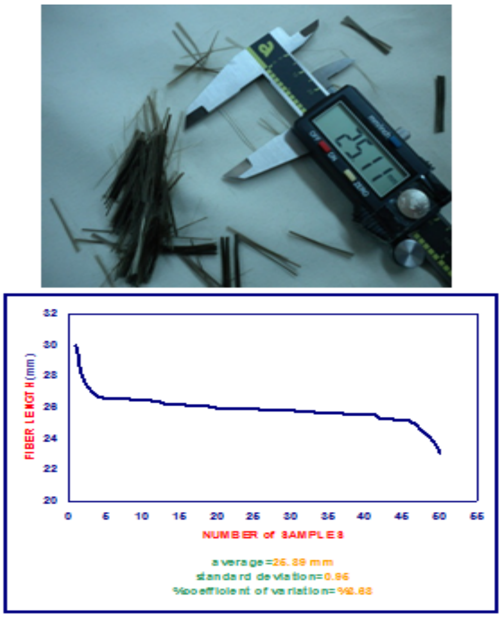

Fig. 6. Fiber Length

III. ARCHITECTURE OF ANFIS

ANFIS incorporates the human-like reasoning style of fuzzy systems through the use of fuzzy sets and a linguistic model consisting of a set of IF-THEN fuzzy rules [30-31].

In ANFIS, both the learning capabilities of a neural network and reasoning capabilities of fuzzy logic were combined in order to give enhanced prediction capabilities, as compared to using a single methodology alone. The goal of ANFIS is to find a model or mapping that will correctly associate the input values with the target values. The fuzzy inference system (FIS) is a knowledge representation where each fuzzy rule describes a local behaviour of the system. The network structure that implements FIS and employs hybrid-learning rules to train is called ANFIS [31].

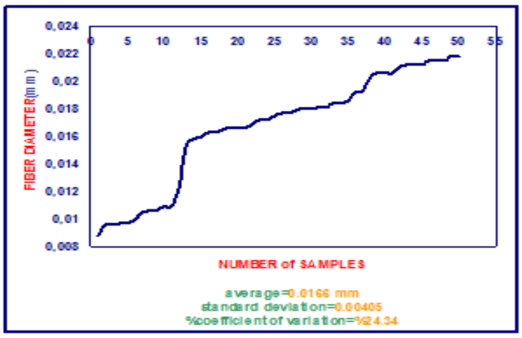

Fig. 7. Fiber Diameter

Fig. 8a and b illustrate the architecture of an ANFIS model with two input variables and the fuzzy-reasoning mechanism, respectively. Suppose that the rule base of ANFIS contains two fuzzy IF-THEN rules of Takagi and Sugeno's type as follows [30-32]:

Rule 1: IF x is A_1 and y is B_1, THEN $f_1 = p_1x + q_1y + r_1$.

Rule 2: IF x is A_2 and y is B_2, THEN $f_2 = p_2x + q_2y + r_2$.

The functions of each layer are described subsequently: Layer 1-Every node i in this layer is a square node with a node function:

$$O_i^1 = \mu_{Ai}(x) \quad (1)$$

where x is the input to node i and Ai is the linguistic label (fuzzy sets: small, large, etc.) associated with this node function.

Layer 2 -Every node in this layer is a circle node labelled Π which multiplies the incoming signals and sends the product out. For instance,

$$W_i = \mu_{Ai}(x) \times \mu_{Bi}(y), \ \ i = 1,2 \quad (2)$$

each node output represents the firing weight of a rule.

Layer 3 -Every node in this layer is a circle node labelled N. The ith node calculates the ratio of the ith rule's firing weight to the sum of all rule's firing weights:

$$W_i = W_i / (\frac{W_1}{W_2}) \quad i = 1,2 \quad (3)$$

Layer 4 -Every node in this layer is a square node with a node function:

$$O_i^4 = \overline{W_i} f_i = W_i(p_i x + q_i y + r_i), \quad i = 1,2 \quad (4)$$

Where $\overline{W_i}$ is the output of layer 3, and { p_i, q_i, r_i} is the parameter set.

Layer 5 -The signal node in this layer is a circle node labelled ∑ that computes the overall output as the summation of all incoming signals, i.e.

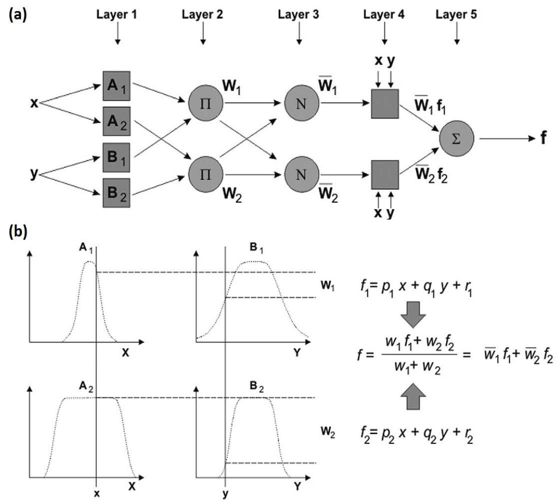

Fig. 8. (a) Architecture of ANFIS and (b) Fuzzy-reasoning scheme of ANFIS [30]

$$O_i^5 = \sum_i Wf_i = \frac{\sum_i W_i f_i}{\sum_i W_i} \quad (5)$$

The basic learning rule of ANFIS is the back-propagation gradient descent, which calculates error signals recursively from the output layer backwards to the input nodes. This learning rule is exactly the same as the back-propagation learning rule used in the common feed-forward neural networks. ANFIS adopted a rapid learning method named as hybrid-learning method, which utilises the gradient descent and the least-squares method to find a feasible set of antecedent and consequent parameters [30]. This latter method has been employed in the present study for developing the ANFIS model. MATLAB version 7.11.0 (R2010a) with using Fuzzy Logic Toolbox was employed for this method.

In this paper, an ANFIS model was developed to predict Marshall Stability (MS) of asphalt concrete using experimental variables. The model has two inputs and an output. Inputs were bitumen (%), Fiber ratio (%) and output were the Marshall stability (kg) of asphalt concrete.

While developing the model 29 (80% of all samples) experimental data used for training and 7 (about 20% of all samples) experimental data used for testing. After experimenting different learning algorithms with different epochs, best correlations was found through hybrid learning algorithm and 1000 epochs.

The general structure of model and membership functions for input and output parameters used for ANFIS modelling are given in Figure 9. as a diagram.

After training, the model was tested only using test input data by Defuzzification monitor (Fig. 10). Also Figs. 11 and 12 shows matching figure of the measured results with the results obtained from developed ANFIS model for training and testing stage.

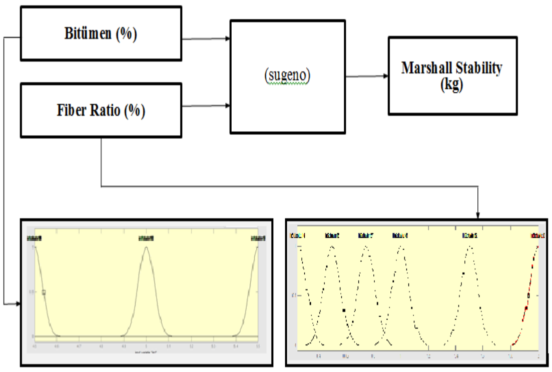

Fig. 9. General structure and membership functions of the model

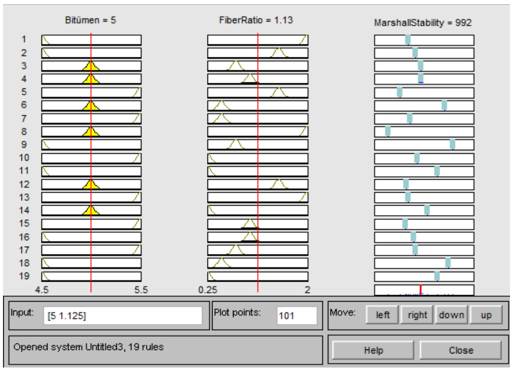

Fig. 10. Defuzzification monitor of the model

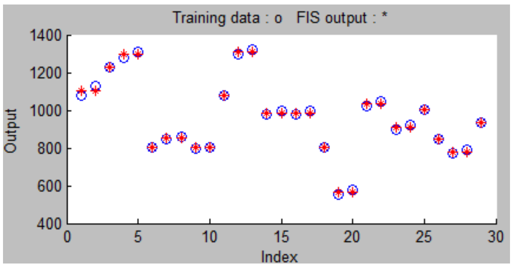

Fig. 11. Matching figure of results for training (ANFIS-exp).

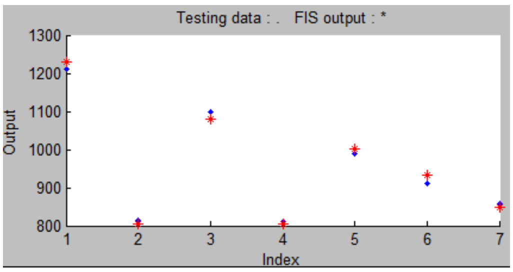

Fig. 12. Matching figure of results for testing (ANFIS-exp).

The MS from developed ANFIS model as a function of bitumen and fiber ratio is shown in Fig. 13.

IV. Developed ANFIS Model Structure, Parameters, and Results

The adequacy of the developed ANFIS model was evaluated by considering the coefficient of determination (R^2), root means squared error (RMSE) and Standard Error of the Estimate (SEE). Table II represent calculated R^2, RMSE, SSE and SEE values for training and test groups of developed ANFIS

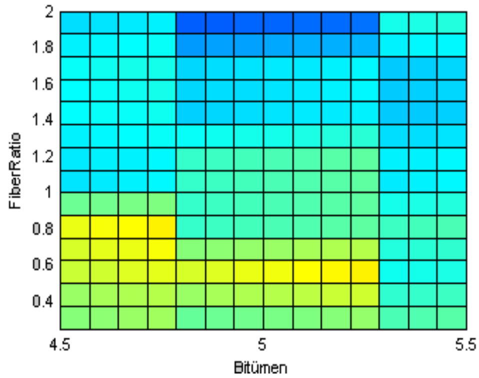

Figure 13. Relationship between inputs and outputs

TABLE II. Statistics of Marshall Stability Estimation Using ANFIS

	R^2	Adjusted R^2	SEE	RMSE
Testing Set	0.9907	0.9888	1400.0081	16.7332

As seen on the Table II, the R^2 and Adjusted R^2 is closely to one, which means that the results obtained from the ANFIS model have a correlation between each other. The SEE values is about 1400 which is a very big value. However, when the test results of the Marshall Stability test is thought, the SEE value is not as big as thought where the RMSE value supports that conclusion. So, the Marshall Stability values can be predicted easily by using this ANFIS model.

Fig. 14 show the model performances of the ANFIS modelling based on the 95% prediction bounds illustrated on the figures and linear curve fitting statistics summarised in Table II. Also matching figure of the values of experimental and ANFIS model for the testing set is given in Figure 15.

According to the comparison of the curve fitting statistics, as can be seen from Table II, the smallest prediction errors are observed in ANFIS model according to the curve fitting statistics. The RMSE values of the ANFIS model at the testing stage is 16.73. All of the statistical values in Table II show that the ANFIS model is suitable and predicted the Marshall Stability values very close to the experimental values.

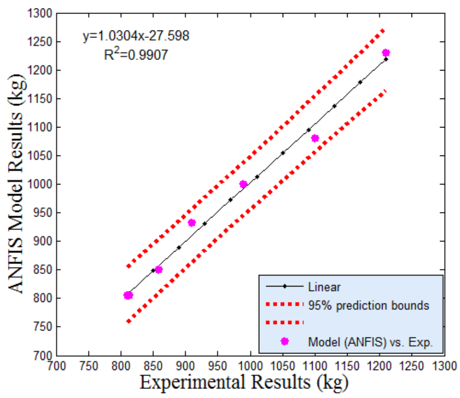

Fig. 14. Comparison of experimental and fuzzy logic results

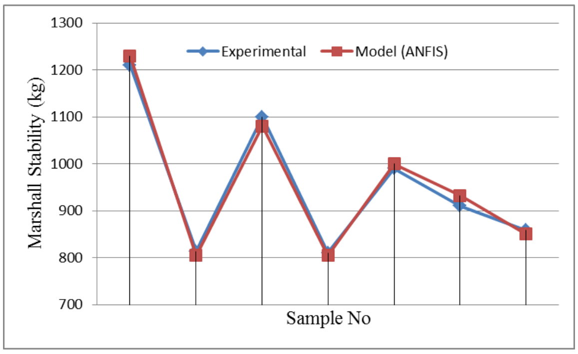

Fig. 15. Matching figure of the values of experimental and ANFIS model

V. CONCLUSIONS

In this study, an Adaptive Neural Fuzzy Inference System (ANFIS) model for predicting the Marshall Stability (MS) of basalt fiber reinforced asphalt concrete mixtures and various mix proportions has been developed.

While developing the ANFIS model, 29 randomly selected experimental data were used as training data and 7 data (residual) were used as testing data. Different approaches (learning algorithm) and iteration numbers were attempted while developing the model. The best correlation was found with hybrid learning algorithm and 1000 epochs. After finding the best closely ANFIS model, the results of ANFIS model were compared with the results from experiment. For comparing the results, coefficient of determination (R^2), Root mean square error (RMSE) and Standard Error of estimation (SEE) were used as comparison criteria. When predicted and measured MS values compared in the testing set, RMSE and R^2 were found as 16.73 and 0.9907 respectively.

As a result, stability values of basalt fiber reinforced asphalt concrete mixtures and various mix proportions can be predicted using the ANFIS model without any experiment.

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