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Research Article

Determination of Theoretical Fracture Criteria of Layered Elastic Composite Material by ANFIS Method from Artificial Intelligence

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Abstract:

The theoretical breaking boundary of the composite elastic composite material consisting of two is otropichomogeneous layers was investigated. Three-dimensional theory of elasticity and a fragment edhomogeneous body model were used to find the theoretical breaking limit. The defects of this material, which has local defects, are of the same length hand is changing with the angle β. The purpose of the articles was to examine the effect of theoretical refraction criterion limit values on the change of the angle β. It has been observed that the theoretical refraction limit values obtained for four different composite materials increase as the angle art increases. In this study, the change values with the β angle of the theoretical refraction limit obtained in other our article were recovered from the artificial intelligence of the MATLAB platform by ANFIS (Sugeno) method. It was seen that the values obtained with the Anfis method are the same with the theoretical results.

1. Introduction

Determination of the theoretical fracture limit as a result of compressing composite materials under pressure is of great importance in theoretical and practical terms [1-3]. In this study, researchers were conducted for the layered composite consisting of two materials with local folds in its structure [4,5]. The limit of the theoretical fracture limit is standard within the scope of various material properties of elastic layer composites in one-way compression [6,7]. It should be noted that one of the main reasons for the breakage of one-way composites under single-axis compression along the matrix elements of the composite material is the stabilization loss in the material structure [6-9]. It is assumed that the local imperfection region of each reinforcing layer of this material is sin-phase and covers the same range along the layers. However, it shows that the initial defect regions in its structure have a certain movement of all layers of the material according to each other. Therefore, in the article [10,11], research was developed for cases where the elastic layers that are supplements act according to each other in local initial defect regions. As a result of these procedures, the changes in the angle of the fracture criteria of different elastic materials obtained were created by artificial intelligence ANFIS method. As a result of this method, the accuracy and learning of the system has been tested.

2. Theoretical Method of The Problem

The structural form of the material, which has local curvature in its structure and is in the form of a sin-phase of the curved cellules between the layers, is given in Fig.1. It is seen in Fig.1 that composite material consisting of alternate layers of two materials is under pressure along equally dispersed infinity reinforcement layers [10]. It will be assumed that the reinforcing (matrix) layers are placed on the planes parallel to the Ox_1x_3 plane and the thickness of each filling layer is constant. Moreover, it is assumed that the local imperfection regions of the

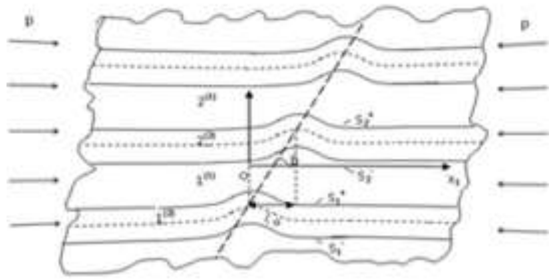

Figure.1 *A structure of the considered composite material with inclined local insignificant imperfection*

reinforcing layers move according to each other in the direction of the Ox_1 axis.
The moving length is

$$l_0 = 2H^{(1)} + H^{(2)}tg\beta \quad (1)$$

selected as. Where $2H^{(1)}$, $H^{(2)}$ is the thickness of the reinforcing (matrix) layer and the angle β is shown in Fig.1. β=0 is considered as in the articles [10,11]. The values related to the matrix layer are shown with the upper indices (1) and those related to the filler are shown with the upper indices (2). It is assumed that the material of the layers of filler layers is only elastic composites (1).
In the Solution Method and the finding of the Theoretical Fracture Criteria, nonlinear exact balance equations of elasticities theory were used, and a fragmented homogeneous body model was applied.
Thus, for each selected layer, we write the equilibrium equations, mechanical and geometrical relations as follows [7-9].

$$\frac{\partial}{\partial x_{jm}^{(k)}}\left[\sigma_{jn}^{m(k)}\left(\delta_i^n + \frac{\partial u_{im}^{(k)}}{\partial x_{nm}^{(k)}}\right)\right] = 0 \quad ; i, j, n = 1,2; k=1,2 \quad (2)$$

$$\sigma_{ij}^{m(k)} = \lambda^{(k)}\,\theta^{m(k)}\delta_i^j + 2\mu^{(k)}\varepsilon_{ij}^{m(k)}, \theta^{m(k)} = \varepsilon_{11}^{m(k)} + \varepsilon_{22}^{m(k)} \quad (2.a)$$

$$2\varepsilon_{ij}^{m(k)} = \frac{\partial u_j^{m(k)}}{\partial x_{jm}} + \frac{\partial u_j^{m(k)}}{\partial x_{im}} + \frac{\partial u_n^{m(k)}}{\partial x_{im}^{(k)}}\frac{\partial u_n^{m(k)}}{\partial x_{jm}^{(k)}} \quad (2.b)$$

Between each layer of the fill and matrix layers, the values for the zero and first approaches obtained before by using these equations and determining the contact conditions [6,7] are written [6,7] the values for the zero-approach given in [6.7] are shown to be determined from the non-linear equation. The linear equations obtained from the equation (2, 2a, 2b) are by determining the approach from the first order. Determining the values from the first approximation is reduced to solving the problem. For solution of this problem, we use the exponential Fourier transform,

$$f_F\ (s, x_2) = \int_{-\infty}^{+\infty} f(x_1, x_2)e^{-isx_1}dx_1 \quad (3)$$

After the expression of the Fourier transformation of the sought-after values is determined, the relationship between the problem parameters is given as follows.

$$det\|\alpha_{nm}\| = 0 \quad (4)$$

It is explained by determining the inverse Fourier transform.

$$f(x_1\ , x_2) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} f_F\ (s\ , x_2)\ e^{isx_1}\ ds \quad (5)$$

The roots of the equation coincide with the individual points of the appropriate function (3). As a result, the equation (4) is considered the order of the singuness of the function in (5). The integral defined here by (5) can be calculated using a well-known algorithm. Because the calculation of integral is done within the scope of Cauchy basic theory. In this case, (5) integral has no meaning and the corresponding force.

$$\frac{dp}{d(sH^2)} = 0 \quad (6)$$

The definition that is also satisfactory for the corral determined from the equation can be called "critical force" (4). According to equation (6), the critical force equation corresponds to the local minimum (or maximum) value of the function that provides it. The resulting critical force values are taken as "Theoretical Fracture Criteria" since these values are not linked to the initial local defect mode and wave generation shape parameter. Numerical results showing the fracture criteria using the equation (6) and the effect on the values of the angle and fracture criterion for various parameters of the problem were solved numerically using PC and by bisection method [11]. These results are given in Table-1. Table-1 shows the fracture criteria obtained according to the changing angle values when using different elastic layer materials. As a result, the aim of the study was to examine the effect of angle and varying length on the values of the theoretical fracture limit. According to these results, theoretical fracture limit values were found to increase with the length of movement. This length is expressed by the angle shown in Fig.1.

Table.1 *Fracture limit values according to β angle change of different materials*

β	β(rad)	$\eta^{(2)}=0.5$	$\eta^{(2)}=0.3$	$\eta^{(2)}=0.2$	$\eta^{(2)}=0.05$
0	0	0,3302	0,2368	0,2079	0,1458
5	0,0872	0,3451	0,248	0,2172	0,1462
10	0,1744	0,3909	0,2802	0,2457	0,147
15	0,2616	0,4705	0,3371	0,2954	0,148
20	0,3488	0,5898	0,4224	0,3699	0,149
25	0,4361	0,7577	0,5427	0,4707	0,149
30	0,5233	0,9885	0,7082	0,5774	0,149
35	0,6105	1,304	0,9354	0,681	0,148
40	0,6977	1,7415	1,2025	0,771	0,146
45	0,785	2,3591	1,4424	0,8329	0,146

3. Method

3.1 Fuzzy Logic

Fuzzy logic is to process the values obtained by using the data with certain algorithms and to remove the result values by using certain mathematical functions depending on each rule it will create as a result. It was developed because of very valuable logic studies against Aristotle's two valuable logic proposals. Fuzzy logic derives results by considering the values between these two valuable logics and expresses the sizes with variables that are less, very, slightly, medium, long, normal, as appropriate for the verbal language. Allows trading with intermediate values (such as 0.3, 0.92) instead of 0-1 values [12].

A blurry process (fuzzy process) consists of three separate units.

1. Fuzzification unit
2. Rule processing unit
3. Clarification unit

In the flowchart shown in Fig. 2, the data from the stream is changed by taking it into a scale here, and this scaling event can also be called blur. This process can also be explained as follows, each of the incoming information is assigned a membership value and converted into a linguistic structure and bound by the rules [13]. Thus, numerical values are obtained according to the structure of incoming data

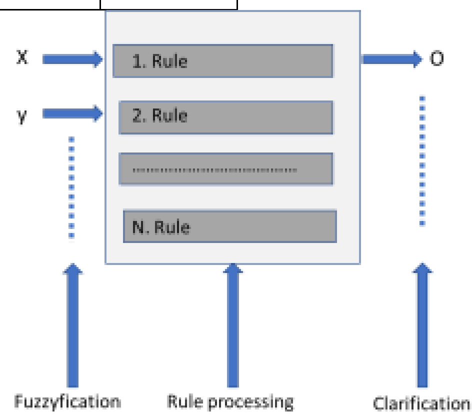

Figure.2 *General Representation of fuzzy system structure*

logical propositions and the results are sent to the rinser unit. In the rinser process, another scale change is performed in the fuzzy set, and the blurry information becomes real numbers [14,15].

3.2 Artificial Neural Network

Artificial neural networks are tools used in machine learning and are systems inspired by the learning of the human brain. It can obtain new data using the characteristics of the brain such as learning, remembering. The simulation between the biological nerve cell and the artificial neural network is given in Fig.3. According to this analogy, artificial neural networks can also be expressed as simulations of the biological nervous system. In the artificial neural networks cell seen in Fig.4, the input data and weights are multiplied in the artificial neural networks network, which has n inputs, creating bias

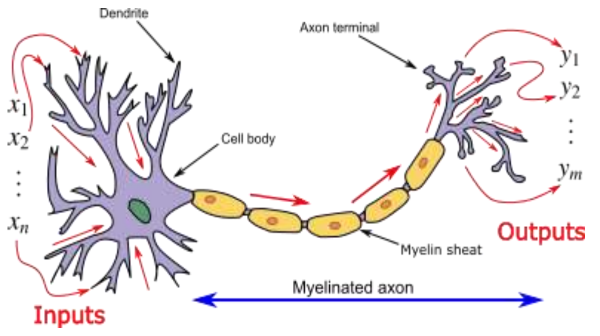

Figure.3 *Biological nerve cell and artificial neural network*

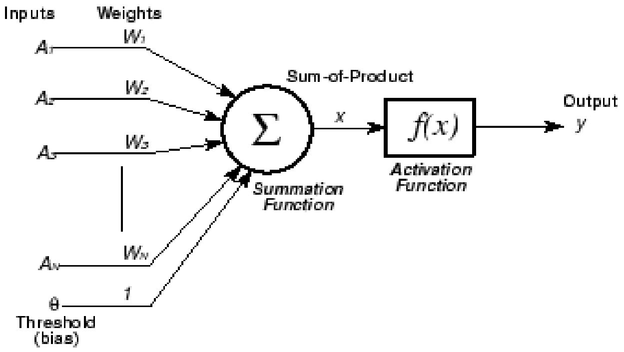

Figure.4 *Artificial neural network cell*

in its total function. The resulting net data is processed in the activation function. As a result of corrections in the Resulting Threshold value, activation is obtained.

3.3 Adaptive Neuro-Fuzzy Inference System – Anfis

Adaptive fuzzy neural networks system - Anfis (Adaptive Network Based Fuzzy Inference System) structure is a structure based on nerve layers formed because of its adaptation from the human brain, and they perform their duties with a certain function in the network on the given neurons. The structure of the ANFIS is fuzzy logic and artificial neural networks work as a hybrid [16]. Intuitive inferences of fuzzy logic and learning models of artificial neural networks work as a whole [17]. An ANFIS structure with two inputs in the first degree is shown in Fig.5. ANFIS has a five-layer structure, and these layers and their functions are as follows [18].

Layer 1: Node numbers are synchronized depending on the number of entries. In these nodes, the inputs are expressed as precursor parameters with a membership function.

Layer 2: The number of rules is created as much as the number of nodes in the structure. The rules of the outputs on the node show the degree of weight. The values entered the node express the values of the membership functions.

Layer 3: In this layer, the data coming to the nodes shows the degrees of weight, while the outputs express normalized weight grades. The main purpose of this layer is to normalize the rule weights.

Layer 4: All nodes are known to be adaptive, and the function of these nodes is a function in the Sugeno System. The functions functioning in this layer are of the first degree and perform the rinsing of the data.

Layer 5: In this layer, which is the last layer in our system, the values of non-blurred outputs are expressed.

Input and output parameters are the basic parameters of this five-tier system. First, the designated training data set is introduced to the designed artificial neural network. The system establishes a functional relationship between inputs and outputs with the best-tested training algorithm used and learning takes place. This process is done, optimization process. The sum of error squares is obtained by looking at the difference between the output of the system model and the output of the training data set. It is aimed to determine the optimum values of the parameters used by finding the cases where this total value, which is accepted as the error function, is minimum [16,19].

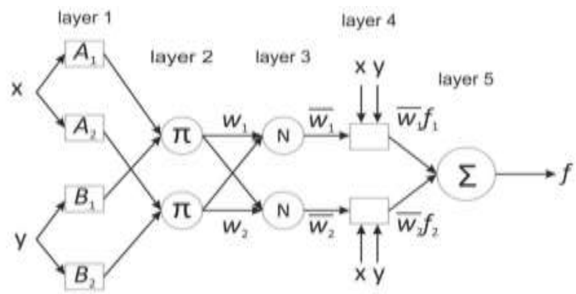

Figure.5 *An Anfis structure with two first-degree inputs and two rules*

3.4 Sugeno

Takagi – Sugeno fuzzy logic or Sugeno fuzzy logic was first used in 1985. The blurring of input variables and fuzzy logic operations are the same as Mamdani fuzzy modelling. The difference between the two methods is in the output membership functions. Output membership functions are linear or constant in Sugeno type fuzzy modelling as shown in Fig.6. When output membership functions are fixed, they are called zero degrees and when the first degree is in the form of the correct equation, they are called the first degree Sugeno fuzzy model.

Thus, the Sugeno-type fuzzy model is more complex and more impression-like than the Mamdani-type fuzzy model [20]. The advantages of the Sugeno-type blurred model are listed below; It is very suitable for calculation. Linear techniques can be used to control non-linear systems. It works well with optimization and adaptive techniques and improves results by optimizing output parameters. It has guaranteed continuity of the output surface. It is well suitable for mathematical analysis. Disadvantages of sugeno-type fuzzy model; When high sugeno fuzzy modelling is used, it has a very complex structure. Increasing the number of inputs and subsets make it difficult to train data, and the number of soncul parameters that must be determined to achieve the results increases. It's not very in accordance with human intuition [21].

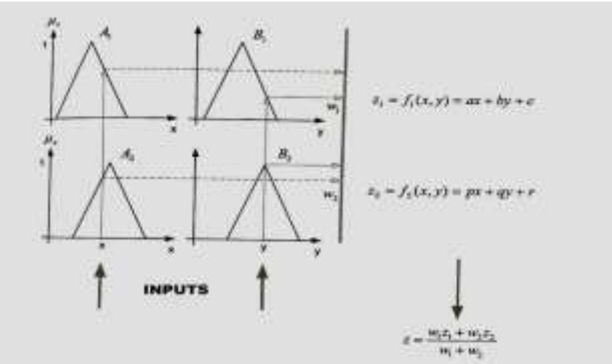

Figure.6 *Takagi-Sugeno Inference*

4. Results and Discussions

4.1 Applied of Anfis

A dataset based on input and output is generally needed to implement the ANFIS method. Depending on the number and type of membership function selected, the established model is created using a learning algorithm. The number of iterations during ANFIS applications is an important parameter. A value is determined that allows adequate and necessary improvements to be made. The error graph that occurs because of training the system with ANFIS is given in Fig.7. It is seen that the error value of the system during the training phase is 4.0119e-05. The resulting values resulting from the testing of the data with the control set were obtained as shown in Fig.8. The average error value of RMSE obtained by testing the network was determined as 4.0119e-05. Through the Fuzzy Logic Designer application, we can see how many inputs, outputs, and variables the system has and their names. There are 5 inputs in our system in Fig.9. These are β, β(radian), $\eta^{(2)}=0.5$, $\eta^{(2)}=0.3$, $\eta^{(2)}=0.2$

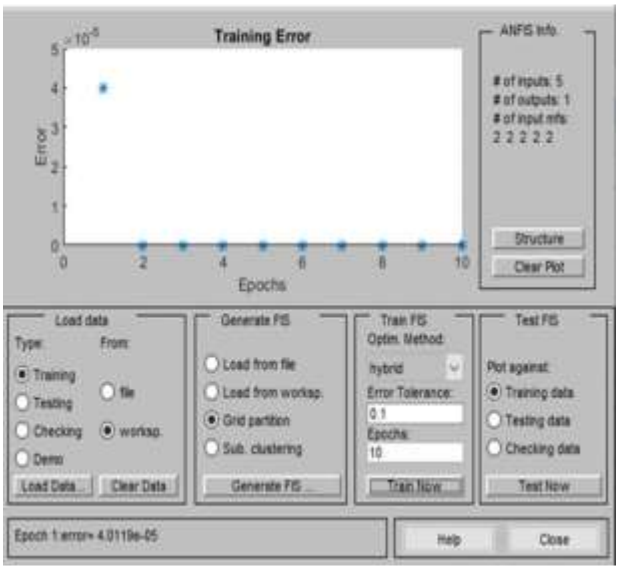

Figure.7 *Error chart caused by the training a network*

Figure.8 *Comparison of actual values and system-estimated values*

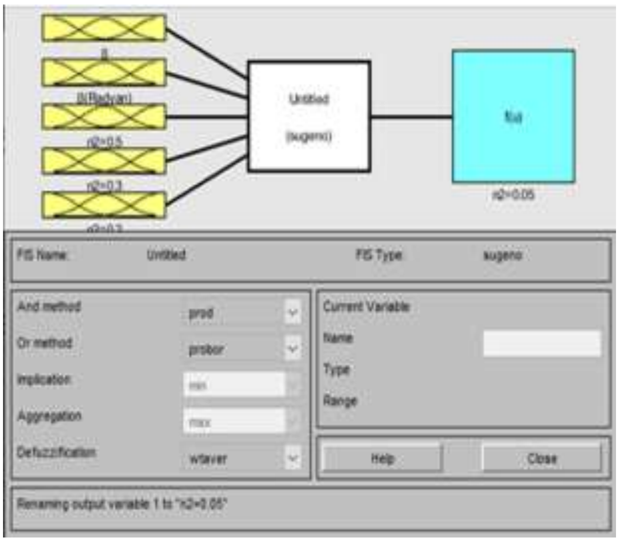

Figure.9 *Fuzzy Logic Designer*

When we test our system by experimenting through the rule table, we can see that the results we obtain are the same as the theoretically calculated results. This proves the accuracy of the result we obtained in ANFIS. When 3. and 8. lines are tried from our input data, the results and accuracy obtained are observed in the following ways as shown respectively in Fig.10 and Fig.11.

Table.2 *Data in line 3 in our entries*

β	β(rad)	$\eta^{(2)}=0.5$	$\eta^{(2)}=0.3$	$\eta^{(2)}=0.2$	$\eta^{(2)}=0.05$
10	0,1744	0,3909	0,2802	0,2457	0,147

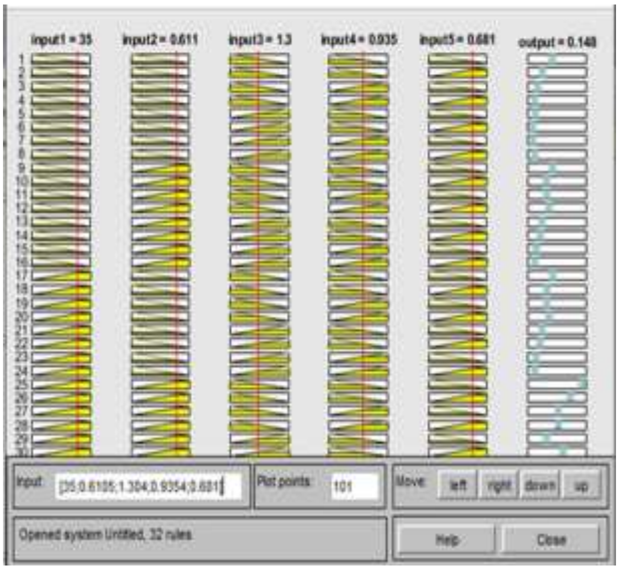

Figure.10 *Rule table that occurs when row 3 (table 2) is tried in the table where our input data is located*

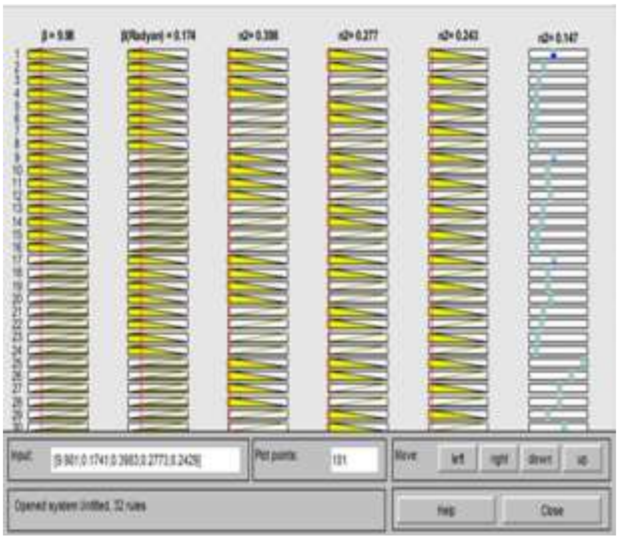

Figure.11 *Rule table that occurs when row 8 (table 3) is tried in the table where our input data is located*

Table.3 *Data in line 8 in our entries*

β	β(rad)	$\eta^{(2)}=0.5$	$\eta^{(2)}=0.3$	$\eta^{(2)}=0.2$	$\eta^{(2)}=0.05$
35	0,6105	1,304	0,9354	0,681	0,148

The ANFIS model structure formed as a result of the training is seen in Fig.12. According to this shape, a clear result is obtained by training 5 data inputs according to the rules.

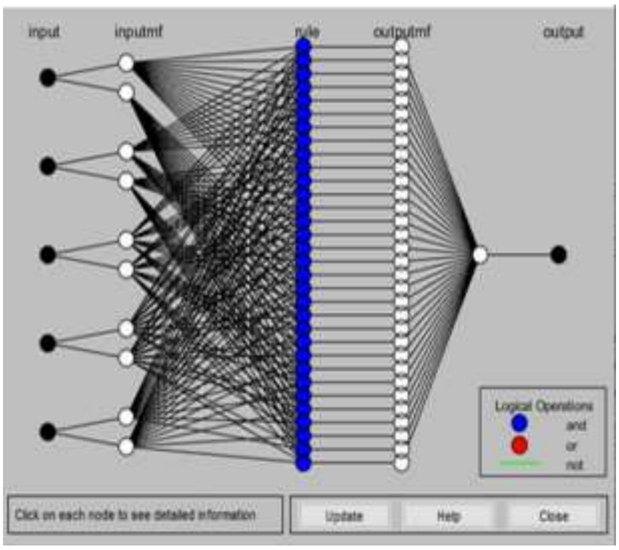

Figure.12 *Anfis Model Structure formed as a result of training*

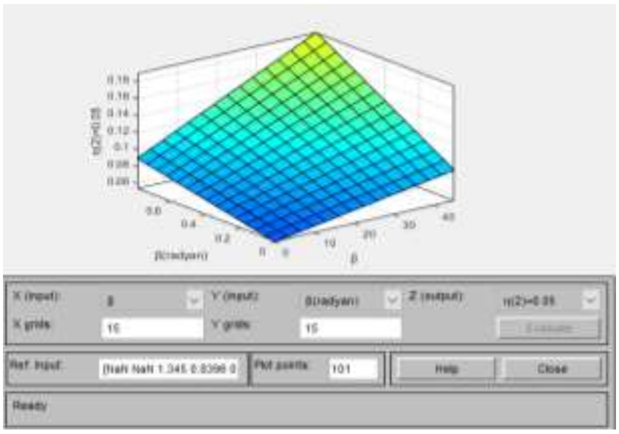

Figure.13 *Surface formed as a result of training*

5. Conclusions

The results of the simulation obtained were observed to be in harmony with the results obtained as a result of theoretical calculations. Thus, results were obtained by ANFIS method, which has a hybrid algorithm from artificial intelligence methods to predict the Theoretical Fracture Criteria of Layered Elastic Composite Material. At the same time, predictions were obtained for different situations. Accordingly, we can explain the results as follows. The data obtained as a result of training with ANFIS were found to be exactly the same as the theoretical results in Fig.13. As a result of training with ANFIS, the error value in the training phase of the system is 4.0119e-05. The RMSE error value obtained by testing the network is 4.0119e-05. Artificial intelligence algorithms to be selected in these and similar studies should be tested first with theoretical and experimental studies and their compliance should be shown and the prediction phase should be proceeded. Thus, the results will be obtained from more than one point of view and trust will be provided.

Our studies on obtaining the values that give the properties of the theoretically obtained composite materials by machine learning methods in artificial intelligence continue today. We think that the comparative results obtained in this study will be important in the future literature.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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