International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:9, No:1, 2015

Determining Fire Resistance of Wooden Construction Elements through Experimental Studies and Artificial Neural Network

Sakir Tasdemir, Mustafa Altin, Gamze Fahriye Pehlivan, Ismail Saritas, Sadiye Didem Boztepe Erkis, Selma Tasdemir

***Abstract*—**Artificial intelligence applications are commonly used in industry in many fields in parallel with the developments in the computer technology. In this study, a fire room was prepared for the resistance of wooden construction elements and with the mechanism here, the experiments of polished materials were carried out. By utilizing from the experimental data, an artificial neural network (ANN) was modelled in order to evaluate the final cross sections of the wooden samples remaining from the fire. In modelling, experimental data obtained from the fire room were used. In the developed system, the first weight of samples (ws-gr), preliminary cross-section (pcs-mm^2), fire time (ft-minute), and fire temperature (t-^{o}C) as input parameters and final cross-section (fcs-mm^2) as output parameter were taken. When the results obtained from ANN and experimental data are compared after making statistical analyses, the data of two groups are determined to be coherent and seen to have no meaning difference between them. As a result, it is seen that ANN can be safely used in determining cross sections of wooden materials after fire and it prevents many disadvantages.

***Keywords*—**Artificial neural network, final cross-section, fire retardant polishes, fire safety, wood resistance.

I. Introduction

COATING is made with many kinds of construction materials on the surfaces of construction elements such as wall, column, joist, flooring and stairs constituting the essential of the construction and carrying the loads. The type, shape and the way of being made of coating material change according to the aim of being made of the coating. Coating is made in order to protect the construction elements from the external factors, embellish the physical appearances of the rough construction elements, increase the strength of the element surfaces against corruption and enable using the construction in an easy, a comfortable and a healthy way. Many different kinds of materials are used in the coating [1], [2].

Fire is a chemical dynamical event and it is seen that as a result of different experiments, it spreads very quickly if there are no obstacles. Fire spreading depends upon many factors. These factors are the quantity and kind of inflammable material, oxygen quantity and temperature. In order to determine the danger of collapsing in the fire, the behaviors of construction materials against fire, construction types of buildings and the features of building part need to be known well.

Because of some advantages, it is commonly seen that wood is used as the construction material. Wood is resistant to high pressure and its tensile strength and flexibility power are good. The thermal conductivity coefficient of it is small. When it burns, wood coal shell occurs in the upper surface. Because the thermal conductivity coefficient of this shell is very small, it prevents the lower parts from evaporating and charring. However, coal shell cannot protect at the high temperatures and it burns [3], [4].

There are different fire retardants reducing the speed of fire spreading and giving off very little toxic smoke and preventing wood from immediately burning in case of any fire. Polished systems that are one of these materials are commonly used in wood. These kinds of materials enables extra safety against fire in the places where there are crowded people and which are risky. What is more, fire retardant polishes enable enough time for evacuation at the moment when the fire begins in the indoor places where there are crowded of people [5].

Nowadays, computers both decide upon events and realize the relationships among events. Artificial intelligence applications are commonly used in many fields in industry in parallel with the developments of computer technology. It is necessary for creating the experiment environment. Furthermore, a specialist and special equipment are needed in this matter. However, pretty much time and costs are needed. Artificial intelligence methods easily solve problems that are not linear, can be solved in a difficult way with especially ANN classical methods, cannot be modelled mathematically or are impossible to solve and they are successfully used by removing the limitations and insufficiencies. ANN are smart computer software imitating neural network of human brain, connecting each other through weighting connections, having the ability of creating new information, discovering and producing with the learning method of making generalizations from samples. ANN's are used in many application fields such as industry, financial, military, health, communication and engineering by realizing functions like prediction, classification, pattern recognition, diagnosing, interpretation, data filtering and association [6]-[8].

S. Tasdemir is with the Higher School of Vocational and Technical Sciences, Selcuk University, Konya 42003 Turkey (e-mail: stasdemir@selcuk.edu.tr).

M. Altin is with Selcuk University, Turkey (corresponding author to provide phone: +903322232380; fax: +903322410185; e-mail: maltin@selcuk.edu.tr),

G. F. Pehlivan, S. D. B. Erkis, I. Saritas, and S. Tasdemir are with Selcuk University, Turkey (e-mail: geraybat@selcuk.edu.tr, didemboztepe@hotmail.com, isaritas@selcuk.edu.tr, sakir_burak@hotmail.com).

ISSN: 2415-6620
Vol:9, No:1, 2015

A number of studies are reported in the literature concerning the use of ANNs for fire model. Some of these studies are a primitive study of a fire detection method controlled by artificial neural net [9], multi-criteria fire detection systems using a probabilistic neural network [10], generalized integrate-and-fire models of neuronal activity approximate spike trains of a detailed model to a high degree of accuracy [11], development of neural network committee machines for forest fire detection using lidar [12], a novel artificial neural network fire model for prediction of thermal interface location in single compartment fire [13], influence of feature extraction duration and step size on ANN based multisensor fire detection performance [14].

In this study, pine, fir and poplar were taken and polished and they were kept until they completely dried. Then, these elements were exposed to a fire environment in a fire room at different durations and temperature values. Fire resistance of these elements was experimentally examined after they were covered by polish and final cross-sections were recorded. By using these experimental data that are not linear, artificial neural network with 4 inputs and 1 output which is an artificial intelligence technique was modeled and their final cross-sections were predicted as a result of the fire.

II. Experimental Study

For the experimental studies, firstly, the material types of fire retardants that are the most frequently seen in the market were searched and the most appropriate fire retardant polish for wood was decided. Fire retardant polishes were produced according to the standards, UNI EN ISO 14001: 2004 (ISO 14001: 2004) and an imported material whose franchise exists in Turkey was chosen. Experimental study was decided to be carried out in the classes of F30 and F60 as the fire resistant classes [15], [16].

3 kinds of wood were chosen in order to be used in the experimental studies. First one of them is pine (*Pinus silvestris* L.) whose density is between 620 and 780 kg/ m³ and the others are fir (*Abies* sp.) whose density is between 430 and 520 kg/m³ and poplar whose density is between 310 and 400 kg/m³ (*Populus* sp.). These kinds of wooden materials were chosen from the ones that are knotless and smooth trunks and do not have mold, mushrooms and bugs. The wooden samples were at three different lengths and were prepared in the measurements of 100x100x300 mm, 140x140x300 mm and 160x160x300 mm that are demanded according to their usage, place and objectives. The wooden samples were kept (1 year) until the moisture content was 7% in the laboratory environment where relative humidity was 30 ± 3% and temperature was 27 ± 2°C. All the wooden samples coming from the cutting workshop were coded. After they reached stable weight and size, they were weighted on the analytical balance whose sensitivity was 0.001 g and their sizes were measured with the caliper of 0.01 sensitivity and determined. All of the surfaces of wooden materials were rubbed and they became smooth, and polish applications were made with the application techniques used in everyday life. Then, wooden samples were kept in order to dry. After the wooden samples were completely dried, their net weights and cross-sections were taken and data were recorded. The photograph belonging to their preparation in the laboratory environment is given in Fig. 1 [15], [16].

Fig. 1 Preparations of wooden samples in the laboratory environment

For the experimental study, 27 samples which are from pine, fir and poplar separately in the sizes of 100x100x300 mm, 140x140x300 mm and 160x160x300 mm as three from each size were prepared for F30 experiment. In the same way, 27 samples from each sizes as three were prepared for F60 experiment.

27 samples prepared for F30 experiment were experimented for 31 minutes and all the measurements of the burned samples were taken and recorded at the end of the experiment. In a similar way, F60 experiment was continued for 62 minutes and the data obtained from the burnt samples at the end of the experiment were recorded. In Fig. 2, there are images where placements of the samples in the fire room, the moment of fire and after fire exist.

Fig. 2 The image where placements of wooden samples, the moment of fire and after fire exist

In the F30 experiment, the maximum temperature value reached to 758°C and 744°C in F60 experiment. The temperature-time chart was given in Fig. 3.

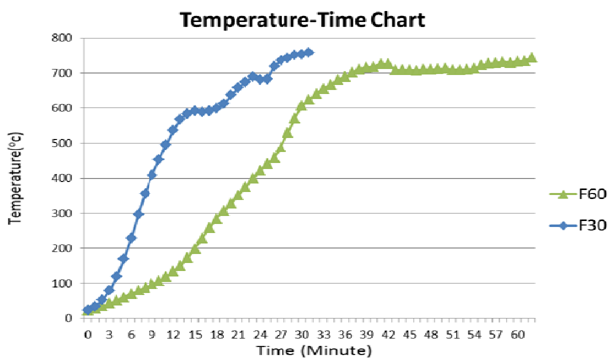

Fig. 3 Temperature-Time chart for F30 and F60 fire resistance class

The fire resistance of all the prepared samples was separately tested for F30 and F60 classes. As a result of polishing these elements, their fire resistance was experimentally examined. By using experimental data in the polished materials, an artificial neural network that is an artificial intelligence technique was modeled and the final cross-section as a result of fire was predicted.

III. ANN and Developed System

Artificial neural networks are intelligence systems created by imitating the structure and the function of biological neural network model. The structure of ANN basically consists of input, hidden and output layers (Fig. 4). In these layers, there are components that are neurons, connections and weights. These three components are used in the mathematical process known as the stage of education and test after they form the structure of the network. The artificial neural network utilizes from the data and results related to the problem field in life, in other words from the samples in learning process. The variances related to the problem field in real life constitutes artificial neural network input array and the results related to the real life and that are obtained with these variances the sequence of target outputs that the artificial neural network needs to reach. Many inputs and output sequence related to the inputs are needed in order for ANN to be educated and to reach target outputs. These data sequences are called as the set of education and test. In order to see what results the network designed using test data after learning process gives, test process is carried out. There are many types of ANN architectures in the literature. A feed-forward back-propagation network is the most widely used for prediction, and in engineering applications. Architecture typically has an input layer, an output layer, and one or more hidden layers [7]. The mechanism enabling weights inside the network in a way that artificial neural network will produce desired outputs in the learning process is called as learning algorithm. The difference calculated between the ANN outputs and target outputs is called as error. This error is used to remove the difference between the weights of artificial neural network and desired outputs inside the network.

The aim of the present study is to predict the final cross-section (mm^2). With this purpose, an ANN structure with 4 inputs and 1 output was designed and application was performed using the designed structure (Fig. 4). As input parameters, the first weight of samples (ws-gr), preliminary cross-section (pcs-mm^2), fire time (ft-minute), fire temperature (t-^oC), as output parameter, final cross-section (fcs-mm^2) were taken. The performance of the ANN was presented by examining the consistency between the values obtained through the ANN approach and the experimental data.

The data obtained from experimental study and were used in the present study. The ANN created for this study has 4 inputs and 1 output (Fig. 4). A total of 150 data sets were used for training and 30 data sets were used for testing in the ANN application.

Each variable is min-max normalized within the range of 0-1 for ANN modeling. Since, the transfer functions generally modulate (1) the output to values between 0 and 1.

$$V_N = \frac{V - V_{\min}}{V_{\max} - V_{\min}} \tag{1}$$

where V_N is the normalized value of a variable V (real value in a parameter), V_{max} and V_{min} are the maximum and minimum values of V, respectively.

Table I gives the statistical investigation including the minimum value, maximum value, mean value of attributes used in dataset.

TABLE I
STATISTICAL MEASURES (DESCRIPTIVE STATISTICS) OF EXPERIMENT DATASET

Parameters	Unit	Mean	Maximum	Minimum
first weight of samples	gr	2672.17	4918.10	911.00
preliminary cross-section	mm^2	17116.64	26082.00	8099.00
fire time	min.	46.50	62.00	31.00
fire temperature	^oC	751.00	758.00	744.00
final cross-section	mm^2	9717.97	22797.00	500.00

Feed-forward back-propagation algorithm was used in feed forward single hidden layers. It was aimed to find the most appropriate network model by changing certain parameters such as the number of hidden layers, the number of neurons used in hidden layers, epoch number, training functions and transfer functions. Training algorithm and activation functions were tested using the software developed and results were obtained in the Matlab environment.

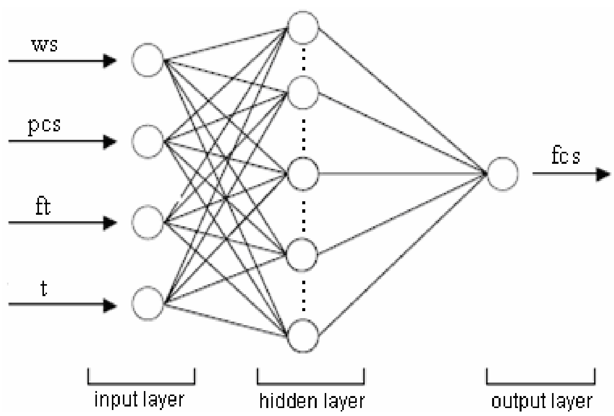

Fig. 4 Proposed Neural Network model

IV. Results and Discussion

The first procedure carried out in the study was to determine which training algorithm could provide more successful results. With this purpose, the software developed in Matlab was run in order to determine the training algorithm that yielded the training and testing data which was found to be closest to actual experimental values. The training algorithm that yielded the best result in consequence of the training and testing procedures was determined based on mean square error (MSE) (2) error rate. Epoch and the number of neurons in the hidden layer and also the period of training were also taken into consideration while determining the best algorithm structure. The training algorithm that yielded the smallest error rate was chosen.

$$MSE\frac{1}{n}\sum_{i=1}^{n}(d_i - O_i)^2 \tag{2}$$

Here, di is targeted or real value, Oi is network output or predicted value, and n is the output data number.

The back-propagation learning algorithm has been used in feed forward single hidden layers. The 150 data sets selected for training and the 30 data sets selected for testing were trained using Levenberg-Marquardt (trainlm) algorithm respectively and the results were obtained. The back-propagation algorithm was implemented to calculate errors and adjust weights of the hidden layer neurons. Log-sigmoid (logsig) transfer function was used in this study. Here for equation NETj was given as attached to X_1, X_2, X_3 and X_4 in (3) and (4)

$$NET_j = (W)_{i,1} * X_1 + (W)_{i,2} * X_2 + (W)_{i,3} * X_3 + (W)_{i,4} * X_4 + (W)_{i,5} * X_5 + (W)_{i,6} * X_6 + (W_b)_{i,7} * b \tag{3}$$

$$F_j = \frac{1}{(1+\exp^{(-NETj)})} \tag{4}$$

In the single hidden layer network structure, number of neurons in the hidden layer values respectively 2, 4, 5, 7, 9, 15, 20, 40 and epoch number 2, 5, 10, 15, 20, 25, 100 were used for all training algorithms and the results were observed. The data used in ANN system were taken as 6 fold and chosen according to training and testing. What is more, considering the smallest values in MSE and the biggest values in R^2, their averages were calculated. Then, the best models were found according to this. Among all the circumstances, the trainlm training algorithm and logsis transfer function gave the best result. Also the (4-7-1 (20 epochs)) model was used, which had the lowest error values and the highest R^2 values.

MSE errors (0.000120432) for training (Fig. 5) that were obtained through the trainlm for model 4-7-1 (20 epoch) and the graphs that show the comparative results are presented below.

MSE errors (0.00553244) for testing (Fig. 6) that were obtained through the trainlm for model 4-7-1 (20 epochs) and the graphs that show the comparative results are presented below. As comparative graphics in Figs. 5 and 6 are examined, obtained data are seen to be very similar to the results in ANN.

It was observed that the estimated final cross-section values (by ANN) were close to measured final cross-section and there was a strong concordance between them.

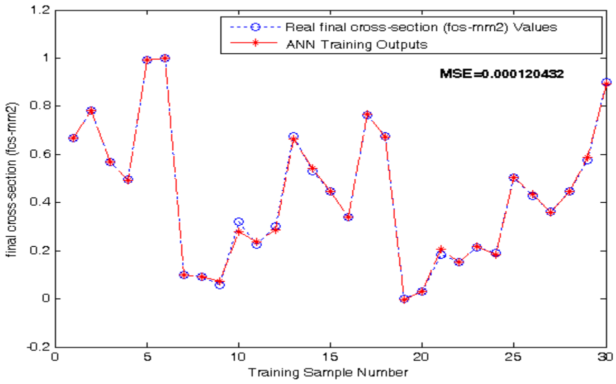

Fig. 5 Levenberg-Marquardt 4-7-1 model training results for 20 epochs

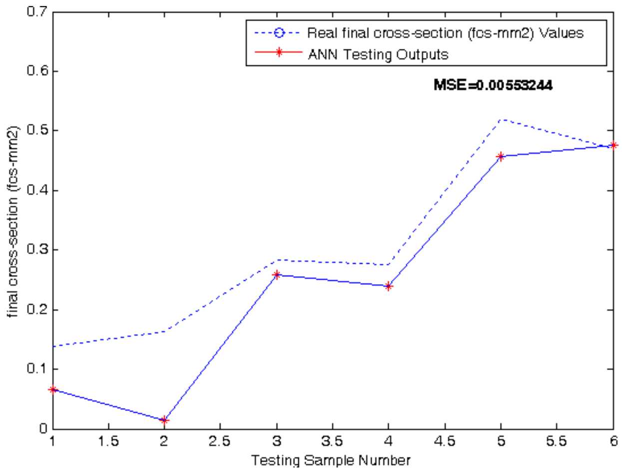

Fig. 6 Levenberg-Marquardt 4-7-1 model testing results for 20 epochs

V. Conclusion

When the analysis was assessed, the final cross-section obtained from the ANN was very close to the experimental results. Therefore, it was seen that the ANN might be used safely.

In the present study, the final cross-section (fcs-mm^2) was successfully predicted using an ANN model with 4 inputs and 1 output. Accuracy rates that were obtained during the training and testing stages and MSE show that the model created in the study can be used for predicting final cross-section (fcs-mm^2).

A number of further parameters can also be estimate final cross-section. Predicts can be made by creating respective ANN structures for all other parameters. Quite close results can be obtained by either increasing number of input, output parameters or using double or multiple hidden layers.

ANN can be used for prediction cutting force as an alternative and effective method to experimental measurements. ANN model might turn disadvantages (time loss, etc.) in experimental researches into advantages.

ACKNOWLEDGMENT

This study has been supported by Selcuk University's Scientific Research Unit.

REFERENCES

[1] G. Koca, N. As and N. Arıoğlu, "Ahşap Dış Cephe Kaplama Elemanları", *7. Ulusal Çatı & Cephe Sempozyumu*, Yıldız Teknik Üniversitesi İstanbul, Turkey, 2013.
[2] A. Kılıç, http://www.yangin.org/, 12 May 2014.
[3] Ahşap Kaplamalar ve Uygulama Esasları, http://www.cs.sakarya.edu.tr/sites/ivural/file/AHSAP-KAPLAMALAR.pdf, 15 May 2014.
[4] R. Stevens, S.D. Es van, R. Bezemer and A. Kranenbarg, "The Structure Activity Relationship of Fire Retardant Phosphorus Compounds in Wood", *Polymer Degradation and Stability*, 91, 832-841, 2006.
[5] Yangın Geciktirici Cila Sistemleri, http://www.hemel.com.tr/tr/urunler/default.aspx?lsn=1&KatID=1020501&UAd=Yangin-Geciktirici-Cila-Sistemleri, 15 May 2014.
[6] Ş. Tasdemir, S. Neşeli and S. Yaldız, "Prediction of surface roughness on turning with Artificial Neural Network", *Journal of Engineering and Architecture Faculty of Eskişehir* Osmangazi University 22(9), 65-75, 2009
[7] S. Tasdemir, S. Neseli, I. Saritas and S. Yaldiz, "Prediction of Surface Roughness Using Artificial Neural Network in Lathe", *CompSysTech'08*, IIIB.6-1- IIIB.6-8 pp., Gabrovo, Bulgaria, Haziran 2008.
[8] S. Tasdemir, I. Saritas, M. Ciniviz, C. Cinar, and N. Allahverdi, "Application of artificial neural network for definition of a gasoline engine performance", *4th International Advanced Technologies Symposium*, Konya, Turkey, 28–30 September, pp. 1030–1034, 2005.
[9] Y. Okayama, "A primitive study of a fire detection method controlled by artificial neural net", *Fire Saf J*, 17, 535-553, 1991.
[10] S.L. Rose-Peherson, R.E. Shaffer, S.J. Hart, F.W. Williams, D.T. Gottuk, B.D. Strehlen and A. Hill, "Multi-criteria fire detection systems using a probabilistic neural network", *Sensors and Actuators*, B: Chemical, 69, 325-335, 2000.
[11] R. Jolivet, T. J. Lewis, and W. Gerstner, "Generalized integrate-and-fire models of neuronal activity approximate spike trains of a detailed model to a high degree of accuracy", *J Neurophysiol* 92, 959-976, 2004.
[12] A. M. Fernandes, A. B. Utkin, A. V. Lavrov and R. M. Vilar, "Development of Neural Network Committee Machines for Forest Fire Detection Using Lidar," *Pattern Recognition*, 37, 10, 2039-2047, 2004.
[13] W.M. Lee, K.K. Yuen, S.M. Lo, K.C. Lam and G.H. Yeoh, "A novel artificial neural network fire model for prediction of thermal interface location in single compartment fire", *Fire Safety Journal*, 39, 67-87, 2004.
[14] W, Xue-gui, L. Siu-ming and Z. He-ping, "Influence of Feature Extraction Duration and Step Size on ANN based Multisensor Fire Detection Performance", *Procedia Engineering* 52, 413-421, 2013.
[15] ISO 14001, "Environmental management systems-Requirements with guidance for use", 2004.
[16] M. Altin, "Determining behaviors of fire doors with thermal camera and traditional methods comparatively", *Energy Education Science and Technology Part A: Energy Science and Research*, 30(1), 465-474, 2012.