International Journal of Adhesion & Adhesives 68 (2016) 115–123

Contents lists available at ScienceDirect

International Journal of Adhesion & Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

Investigation and neural network prediction of wood bonding quality based on pressing conditions

Selahattin Bardak [a,*], Sebahattin Tiryaki [b], Gökay Nemli [b], Aytaç Aydın [b]

[a] Department of Industrial Engineering, Faculty of Engineering and Architecture, Sinop University, 57000 Sinop, Turkey
[b] Department of Forest Industry Engineering, Faculty of Forestry, Karadeniz Technical University, 61080 Trabzon, Turkey

ARTICLE INFO

Article history:
Accepted 19 February 2016

Keywords:
Neural network
Bonding strength
Prediction
Pressing conditions
PVAc
Wood

ABSTRACT

This paper presents an application of artificial neural network (ANN) to predict the bonding strength of the wood joints pressed under different conditions. An experimental investigation firstly was carried out and then an ANN model was developed based on the experimental data. In the experimental investigation, Oriental beech (*Fagus orientalis* L.) and Oriental spruce (*Picea orientalis* (L.) Link.) samples bonded with polyvinyl acetate (PVAc) adhesive were pressed at four different temperatures (20, 40, 60 and 80 °C) for four different durations (2, 8, 14 and 20 min). The experimental results showed that higher values of bonding strength were obtained when high temperatures were combined with short pressing duration. Similar findings could be also obtained with longer pressing time for lower temperatures. The first case may be recommended to increase the efficiency of the production process, allowing a greater quantity of production per unit time. The ANN results showed a good agreement with the experimental results. It was shown that prediction error was within acceptable limits. The results revealed that the developed ANN model is capable of giving adequate prediction for bonding strength with an acceptable accuracy level. The desired outputs of bonding strength can be thus obtained by conducting less number of time-consuming and costly experimental investigations using the proposed model.

1. Introduction

Wood products are generally constructed by combining a few pieces of wood and these pieces are held together by various joining techniques [1]. Adhesive bonding is a joining technique that enables us to hold together such a few pieces of materials. This is an important advantage of adhesive bonding [2,3]. In this content, it is possible to say that adhesives play a prominent role in the production of many wood products, such as furniture and furnishings, musical instruments and gift items. Moreover, adhesives are widely used as binders in the production of wood-based composite products, such as particleboard, fiberboard and plywood [1]. In light of this information, it can be said that they are among the main inputs of wood products industry and account for a substantial part of production costs [4].

Nowadays, PVAc, a thermoplastic polymer, is widely used in bonding wood samples [5,6]. PVAc is usually known as the "white glue". The bonding principle of this adhesive is based on the removal of the water from the adhesive dispersion [7]. It is an odorless, nonflammable adhesive. PVAc can be used in cold temperatures and solidifies quickly. It is also easy to apply and has a low cost. However, it loses adhesion force at high temperatures [8].

It may be said that the bonding strength of wood joints is the main indicator of the quality of adhesion [9]. However, it is strongly influenced by the factors related to the wood such as species, density, anatomical structure, adhesive factors such as type of adhesive or viscosity, and process factors such as pressing temperature and pressing time [10]. Dunky and Pizzi [7] reported that good-quality bonding can be attained if each of these factors is considered sufficiently in the bonding process. Hence, evaluating the factors affecting the performance of the bond between wood and adhesive is very important in terms of the success of bonding applications. Burdurlu et al. [1] stated that the type of adhesive used influences significantly the mechanical behavior of the bonded wood joints. Furthermore, as mentioned above, the factors related to the wood such as density and species are among the main factors affecting the bonding strength of wood joints. There are some attempts on understanding how these factors influence the bonding strength of wood joints. Custodio et al. [11] reported that wood is a porous, permeable and heterogeneous material that has extreme chemical diversity and physical complexity. Therefore, its properties vary between species, within a

* Corresponding author. Tel.: +90 368 2714152; fax: +90 368 2714374.
E-mail addresses: sbardak@sinop.edu.tr (S. Bardak), sebahattintiryaki@hotmail.com (S. Tiryaki), nemli@ktu.edu.tr (G. Nemli), aytac@ktu.edu.tr (A. Aydın).

http://dx.doi.org/10.1016/j.ijadhadh.2016.02.010
0143-7496/

species, and even within a tree [11]. This makes it difficult to assess the interaction between adhesive and wood [5]. As a result, a difference in terms of bonding performance amongst wood species emerges [11]. With regard to the wood density, Dunky and Pizzi [7] stated that the strength of an adhesive bond increases with the wood density in the region of 0.7 to 0.8 g/cm^3. In another study, similar findings were also reported by Burdurlu et al. [1].

The pressing conditions have also a considerable influence on the performance of the wood joints bonded with an adhesive. It is possible to say that the pressing temperature is a critical part of the bonding process since it helps the adhesive to solidify during the joining. Raising the temperature may contribute to the development of the bonding strength and the increase of the production capacity because of reducing the time required to complete the solidification. However, it is well known that high temperatures affect negatively the bonding strength of wood. Especially, PVAc softens and loses a portion of its strength under high temperatures. Hence, high-quality adhesive bonds can ensure if pressing temperature is controlled within a reasonable range [12].

In addition to the pressing temperature, another parameter is pressing time, which is highly important for the development of adequate bonding strength. The prolongation of the pressing time up to a certain limit generally results in a higher degree of solidification for adhesive and a higher bonding strength. However, such a situation increase significantly the cost of heat energy required for the pressing operation, and reduce the production volume. Hence, wood products manufacturers have continually been trying to find optimal pressing conditions, which provide a balance between product performance and manufacturing cost [13]. However, achieving this through experimental investigations are time consuming, expensive, and consume a large number of experimental materials. Thus, the most recent studies have focused on predicting the bonding strength by modeling tools rather than comprehensive experimental procedures. Artificial neural network (ANN) can provide an opportunity to obtain the desired values of bonding strength by performing less number of experimental studies because of its ability to uncover complex and non-linear relationship in the data structure [14,15]. In this context, it can be said that ANN models are of critical importance to help improve the economics of bonding process. Due to such advantages, the ANN technique has been used in several studies for predicting bonding strength in the field of wood science. However, the majority of these studies involve the bonding strength prediction of wood based composites. For instance; Cook and Chiu [16], Fernandez et al. [17] and Watanabe et al. [18] used the ANN approach for modeling the internal bond strength of particleboard. Demirkir et al. [19] employed the same approach for modeling the plywood bonding strength. On the other hand, the information on the prediction of the bonding strength of solid wood by means of the ANN is very limited. In a previous study, Tiryaki et al. [20] employed the ANN for predicting the optimum bonding strength of the wood subjected to heat treatment and different machining conditions.

In the relevant literature, the effects of various process variables on the bonding strength of wood were discussed in detail. Moreover, ANN attempts on predicting the bonding strength of solid wood and wood based composites were referred. It was shown that little information is available on investigating and predicting the effects of different pressing temperatures and durations on the bonding strength of solid wood. In the present study, we therefore aimed to investigate and predict the bonding strength of wood joints subjected to different pressing conditions, differing from previous studies reported.

2. Artificial neural networks

ANNs are among the fastest developing information processing techniques in the field of the artificial intelligence. ANNs are increasingly used in solving complex problems due to their proven success [21,22]. They have the ability to work without having a detailed knowledge about the investigated system. Instead of having this information, they learn the relationship between input and output variables by the previously recorded data [15]. To achieve this, the network is trained with the data related to the problem under consideration using a training algorithm. The training is a process of adjusting the connection weights that allow the ANN to produce outputs that are equal or close to targets [23]. Zhang et al. [14] reported that the feed forward and back propagation is the most popular learning algorithm for ANN training.

The multilayer perceptron (MLP) feed forward neural network is the most commonly used architecture for prediction. The MLP architecture consists of an input layer, an output layer and one or more hidden layer(s) depending on the degree of the complexity of the problem in hand [24,25]. Each layer in the MLP is made up of a collection of interconnected elements called neurons that allow the network to produce a specific output from input variables. A simple example of the MLP, which consists of one input layer, one hidden layer and one output layer, is shown in Fig. 1 [25]. Eq. (1) calculates the output of the MLP given in Fig. 1.

$$Y = g\left(\theta + \sum_{j=1}^{m} v_j \left[\sum_{i=1}^{n} f\left(w_{ij}X_i + \beta_j\right)\right]\right) \tag{1}$$

In Eq. (1), Y is the prediction value of dependent variable; X_i is the input value of ith independent variable; w_{ij} is the weight of connection between the ith input neuron and jth hidden neuron; β_j is the bias value of the jth hidden neuron; v_j is the weight of connection between the jth hidden neuron and output neuron; θ is the bias value of output neuron; g(.) and f(.) are the activation functions of output and hidden neurons respectively.

In the ANN architecture, the first layer and last layer are input layer and output layer, respectively. The layer between the input layer and output layer is known as the hidden layer. The hidden layer receives data from the input layer, and then it processes the data, and next sends a response to the output layer. The output layer receives the response coming from the hidden layer and produces output data for the input layer of the network, and hereby it sends output data to the outside world [26].

3. Materials and method

3.1. Wood

In the present study, we chose beech (*Fagus orientalis* L.) from hardwood and spruce (*Picea orientalis* (L.) Link.) from softwood, which are widely used in the woodworking industries, for the materials of the experiment. Although these species indigenously grow in a wide scope from Bulgaria to the Caucasia, there are abundant forest areas of them along the Black Sea Region in Turkey [27]. Experimental samples were all randomly selected from naturally grown woods in Artvin, Turkey. The average densities of beech and spruce samples were found as 0.680 g/cm^3 and 0.430 g/cm^3, respectively. Special emphasis was paid to the preparation of the samples from the logs without any defect. The samples with dimensions of $150 \times 20 \times 10$ mm^3 were thus prepared flawlessly. The samples were then conditioned at a temperature of $20 \pm$ °C and $65 \pm 5\%$ relative humidity to the moisture content of about 12%.