Construction and Building Materials 62 (2014) 102–108

Contents lists available at ScienceDirect

Construction and Building Materials

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

An artificial neural network model for predicting compression strength of heat treated woods and comparison with a multiple linear regression model

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HIGHLIGHTS

- Effects of heat treatment temperature and duration on CS were studied.
- CS values were predicted with the ANN and MLR models using the experimental data.
- CS values decreased with increasing heat treatment temperature and duration.
- ANN showed a better prediction performance compared to MLR.
- It was shown that the ANN model save time, and decrease the experimental costs.

ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 26 March 2014
Accepted 26 March 2014
Available online 17 April 2014

Keywords:
Artificial neural network
Heat treatment
Compression strength
Multiple linear regression

ABSTRACT

This paper aims to design an artificial neural network model to predict compression strength parallel to grain of heat treated woods, without doing comprehensive experiments. In this study, the artificial neural network results were also compared with multiple linear regression results. The results indicated that artificial neural network model provided better prediction results compared to the multiple linear regression model. Thanks to the results of this study, strength properties of heat treated woods can be determined in a short period of time with low error rates so that usability of such wood species for structural purposes can be better understood.

1. Introduction

Heat treatment is one of the processes used to improve the various properties of wood [1]. It was reported that heat treatment improves wood properties such as wood durability, dimensional stability and resistance to fungi [2,3]. However, it is a fact that increased temperature and duration during heat treatment adversely influence most of mechanical characteristics of wood [4–6]. The temperature and duration of heat treatment generally varies from 120 °C to 250 °C and 15 min to 24 h, respectively depending on wood species, sample dimensions, moisture content of the sample and intended use [7]. Especially, temperatures over 150 °C applied to wood modify the mechanical, chemical and physical properties of wood gradually [8]. Wood becomes more brittle due to heat treatment and its strength characteristics are decreased by 10–30% [2]. It was claimed that degradation of the hemicelluloses between microfibrils in cell wall is the main reason of strength loss in wood [9]. This case especially reveals the importance of determining the strength properties of heat treated woods in terms of structural constructions.

Several studies were conducted to determine the effects of heat treatment temperature and duration on compression strength (CS) of wood. Unsal and Ayrilmis [10] found that CS parallel to grain of river red gum (*Eucalyptus camaldulensis* Dehn.) samples decreased about 19.0% as a result of heat treatment at 180 °C for 10 h. Yıldız et al. [11] investigated the mechanical behavior of spruce wood modified by heat. They observed that the CS losses due to heat treatment were 32.44% at 200 °C for 10 h. Korkut [12] detected a reduction of 29.41% for CS of Uludag fir (*Abies bornmuellerinana* Mattf.) wood at 180 °C for 10 h. Korkut and Budakçı [13] studied on the mechanical properties of rowan (*Sorbus aucuparia* L.) wood. They determined a reduction of 24.33% for CS of the samples

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http://dx.doi.org/10.1016/j.conbuildmat.2014.03.041
0950-0618/

exposed to the same treatment time and temperature. Similarly, heat treatment causes varying amounts of weight loss (WL) depending on exposure temperature and time. Zaman et al. [14] reported WL of 6.4%, 7.1% and 10.2% for birch (*Betula pendula*) treated at 205 °C for 4, 6 and 8 h, respectively.

It is a fact that a great number of temperature and duration values need to be tested to determine a change in the mechanical behavior of wood caused by heat treatment. However, conducting comprehensive experiments causes the loss of much time and high costs. Therefore, it is very important to find more economic methods providing desirable results concerning CS of heat treated wood without needing the more experiments requiring much time and costs. For this purpose, artificial neural networks (ANNs) have been widely used in the field of wood science, such as calculating wood thermal conductivity [15], moisture analysis in wood [16], predicting fracture toughness of wood [17], wood recognition system [18], forecasting wood quality [19], drying process of wood [20], and wood veneer classification [21].

ANNs have been also used for predicting some mechanical properties of solid wood and wood composites. Cook and Chui [22] predicted the internal bond strength of particleboard using a radial basis function neural network with an accuracy level of 87.5%. Fernández et al. [23] predicted MOR and MOE values of particleboard by ANN at the accuracy levels of 86% and 87%, respectively. Esteban et al. [24] predicted the MOE of *Abies pinsapo* Boiss. wood by using ANN with 75.0% accuracy. Esteban et al. [25] predicted bonding strength of plywood using an ANN with 93% accuracy. Demirkır et al. [26] predicted the bonding strength of plywood using an ANN at the accuracy level of 98.0%.

Studies on predicting some mechanical properties of wood and wood composites were expressed above. However, there is very limited information on predicting CS of heat treated wood. Ulucan [27] predicted CS of heat treated pine and chestnut woods by ANN at the accuracy levels of 92.59% and 92.04%, respectively. Therefore, the main aim of this study was to design the models having capable of predicting CS in heat treated woods by using the values obtained from the experimental study and thus to obtain more economic and safe results without doing comprehensive tests.

2. Materials and methods

2.1. Materials

Oriental spruce (*Picea orientalis* (L.) Link.), Scots pine (*Pinus sylvestris* L.), Anatolian chestnut (*Castenea sativa* Mill.) and Oriental beech (*Fagus orientalis* Lipsky.), which are commonly utilized in the forest industry sector, were chosen for the materials of the experiment. The samples used in the experiments were all randomly selected from naturally grown woods in the Black Sea region of Turkey. Sample logs obtained from each wood species were allowed to dry naturally to reduce the moisture. Then, the sample dimensions were trimmed to the appropriate dimensions (20 × 20 × 30 mm) for CS experiments. The samples were randomly divided into 48 treatment groups, each having 10 wood samples. Thus, a total of 480 (48 × 10) experimental samples were used for CS experiments. The samples were conditioned at a temperature of 20 ± 2 °C and 65 ± 5% relative humidity to the moisture content of about 12%.

2.2. Experimental details

2.2.1. Application of heat treatment

Heat treatment was applied to the experimental samples in a laboratory type heating oven controlled at an accuracy of ±1 °C under atmospheric pressure. The temperature reached to 130 °C, 150 °C, 170 °C, and 190 °C at a heating rate of 10 °C/min. Once the target temperature had been reached, the temperature was held constant for 2 h, 6 h, and 10 h. After heat treatment process, the samples were conditioned to constant weight at 65 ± 5% relative humidity and at a temperature of 20 ± 2 °C until they reached stable weight according to TS 642 [28]. Prior to the experiments, the dimensions of the samples were measured to the nearest 0.001 mm and their weights were recorded at an accuracy of 0.01 g.

2.2.2. Determination of weight loss (WL)

Prior to heat treatment, samples prepared for the experiments were dried in a heating oven at 103 ± 2 °C. Then, oven-dry weight of samples was determined with ±0.01 g sensitivity. After heat treatment, oven-dry weight of the same samples was measured again. WL of samples due to heat treatment was calculated according to Eq. (1). Table 1 gives WL of samples.

$$\mathrm{WL}\ (\%) = 100(m_b - m_a)/m_b \tag{1}$$

where m_b is the initial oven-dry weight of the sample prior to heat treatment and m_a is the oven-dry weight of the same sample after heat treatment.

2.2.3. Determination of compression strength (CS)

The universal test device (Mohr + Federhaff + Losenhausen) was used to determine CS values parallel to grain of the wood samples. Determination of CS values was carried out using the samples prepared according to TS 2595 [29] standards. For this purpose, the samples having 20 × 20 × 30 mm dimensions were used in CS experiments. The speed of the test machine in the experiments was adjusted to 1.5–2 min for crushing. Then, the force (F_{max}) applied on wood samples during crushing was recorded. CS values parallel to grain of samples were calculated by Eq. (2).

$$\sigma_{c//} = F_{max}/a.b(N/mm^2) \tag{2}$$

where F_{max} is the force applied on wood samples (N), a is the cross-sectional width of test sample (mm), b is the cross-sectional thickness of the test sample (mm).

After determining CS, the moisture content of each sample was measured according to TS 2471 [30]. Then, in the event of deviation from 12% moisture content, strength values were corrected (transformed to 12% moisture content) using the following conversion equation:

$$\sigma_{c//(12)} = \sigma_{cm//}[1 + \alpha(M_2 - 12)] \tag{3}$$

where $\sigma_{c//(12)}$ is the strength at 12% moisture content (N/mm^2), $\sigma_{cm//}$ is the strength at moisture content deviated from 12% (N/mm^2), α is the constant value showing relationship between strength and moisture content ($\alpha = 0.05$ for $\sigma_{c//}$) and M_2 is the moisture content as percentage during the experiment.

Table 1
The experimental (measured) values of CS and WL of samples due to heat treatment.

Temperature (°C)	Time (h)	N	Oriental spruce		Scots pine		Anatolian chestnut		Oriental beech	
			CS (N/mm^2)	WL (%)	CS (N/mm^2)	WL (%)	CS (N/mm^2)	WL (%)	CS (N/mm^2)	WL (%)
130	2	40	**37.18**	2.92	*58.02*	3.36	*58.81*	3.36	**67.68**	4.05
130	6	40	***36.13***	3.84	*59.20*	3.95	*59.08*	4.72	***68.60***	4.89
130	10	40	*37.76*	4.61	*58.08*	4.96	**57.05**	5.64	***65.23***	5.71
150	2	40	*38.64*	3.77	*58.30*	4.30	*56.83*	4.17	*65.80*	4.87
150	6	40	*37.05*	4.93	*58.29*	5.74	**54.97**	5.56	*65.81*	5.67
150	10	40	***35.70***	6.07	*56.07*	6.87	*54.17*	6.83	*64.46*	7.32
170	2	40	**35.41**	4.71	***55.70***	5.50	*54.47*	5.48	*65.35*	5.76
170	6	40	*36.07*	5.90	*54.44*	6.97	*55.45*	6.85	**64.45**	6.93
170	10	40	**33.43**	7.89	*53.94*	8.56	*53.69*	8.13	*61.98*	8.63
190	2	40	***33.79***	6.27	*54.24*	7.17	*53.40*	7.01	*63.04*	7.08
190	6	40	*32.93*	8.59	*52.11*	9.04	*51.65*	9.88	*61.14*	9.18
190	10	40	*30.08*	10.80	*48.76*	11.35	*49.83*	12.46	***58.66***	11.93

Note: training values: italics, validation values: bold, testing values: bold italics, N: number of samples.