Effects of Heat Treatment on Some Physical and Acoustic Properties of Wood Species

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The objective of the study was to investigate the influence of heat treatment on air-dried density, equilibrium moisture content (EMC), porosity, average surface roughness (R_a), sound transmission loss, and sound absorption coefficient of poplar (*Populus nigra* L.) and beech (*Fagus orientalis* Lipsky) woods. Specimens were exposed to four different temperature levels, namely 150 °C, 170 °C, 190 °C, and 210 °C, for 3 h. The sound absorption coefficient and sound transmission loss of test samples were determined in the frequency range of 63 Hz to 6300 Hz using an impedance tube. It was found that the density, EMC, and average surface roughness values of samples decreased with the heat treatment temperature. In contrast, as the heat treatment temperature increased, porosity of samples increased. The sound absorption coefficient and sound transmission loss of both wood species increased with the heat treatment temperature. The average sound absorption coefficients of untreated and heat-treated poplar samples were approximately 0.16 and 0.18; whereas for beech wood the corresponding values were approximately 0.15 and 0.16. The average sound transmission losses of untreated and treated poplar were approximately 22.7 and 24.0 dB, for the untreated and treated beech samples were 17.3 and 20.7 dB respectively.

DOI: 10.15376/biores.21.1.1329-1346

Keywords: Heat treatment; Physical properties; Acoustic properties; Poplar; Beech

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INTRODUCTION

Noise is one of the most common environmental pollutants, according to reports by the World Health Organization (WHO) and the European Environment Agency (EEA). Exposure to noise is a significant public health threat that affects both physical and mental health (Hahad *et al.* 2025). Noise causes restlessness, stress, and hearing difficulties in indoor and outdoor areas. Noise and unwanted sounds disrupt the natural characteristics and quality of the living environment and pollute living spaces and the environment (Toprak and Aktürk 2004). In daily life, the adverse effect of sound and noise on human health is gradually increasing with developing urbanization and technological developments and it is currently becoming a serious problem. In this respect, there has been increasing attention paid to noise control in living spaces, as well as closed areas. Depending on the developing technology, efforts to reduce or eliminate noise have gained importance (Muslu 2025).

Noise has many different effects on people. However, there are no objective criteria for determining which sounds are "noise" and which sounds are normal. In fact, while one of the two people in the same environment may be satisfied with the sounds they perceive, the other may be extremely disturbed by it and consider it as noise. Therefore, it can be difficult to determine when a sound is noise and when it is normal (Sezgin and Mutlu 2017). When hearing sounds, some of them have a relaxing effect on the user, while others can cause discomfort. In general, the higher the decibel value of a sound, the more damaging it is. In recent years, various acoustic materials are preferred to reduce noise. These acoustic materials can be in different forms, such as sponge, rubber, melamine, *etc*. A better-quality environment can be provided with acoustic materials used for sound insulation (Öz and Köse 2020). Materials having good sound aborbing ability are needed to protect people against the adverse effects of noise present in the affected areas. Success depends on the acoustic performance of building materials and building elements (Fiala *et al.* 2019; Tao *et al.* 2021).

Wood is a naturally renewable raw material that can be used in construction with minimum damage to the environment. The physical and mechanical properties of wood, its anatomical structure, physical and mechanical properties, and chemical composition allow wood material to be used in many different products (Bozkurt and Göker 1996). Wood material is an organic, hygroscopic, and anisotropic material with unique advantages and applications. It has been commonly used in the building and construction industries for a long time due to its low density, excellent mechanical performance, good insulation properties, environmentally friendly material, sustainability, easy availability, and aesthetic appeal (Bal and Bektaş 2013). Because of these positive features, it has been used as indoor and outdoor decoration material and most used in the construction and furniture industry since ancient times (Chung *et al.* 2017; Auriga *et al.* 2020). Moreover, wood and wood-based materials can be used as an acoustic material because of the sound absorption ability and transmission loss. Çavuş and Kara (2020) examined the relationship between sound transmission loss values and density in 16 wood species. While no clear relationship was determined between average sound transmission loss and density, it was found that higher sound transmission loss was observed in wood species with lower density as frequency increased. Kang *et al.* (2019a) studied the sound absorption and sound transmission loss of six types of wood bark particles; they found that the noise reduction coefficient ranged from 0.24 to 0.82 depending on the particle density and thickness properties. In addition, Smardzewski *et al.* (2015) determined 17 types of wood-based materials commonly employed in furniture design and manufacture. They reported that for frequencies between 125 and 500 Hz, the highest capability of sound absorption was associated with low surface layer density and high porosity. In the woodworking and furniture industries, the surface roughness properties of wood material are paramount in terms of the quality of the manufactured product.

Additionally, wood as a natural composite material, is considered a construction material with remarkable properties such as high porosity, low density, high strength, and excellent resistance to UV radiation (Lashgari *et al*. 2024). In this regard porosity and density of wood are important parameters that significantly affect various properties, such as adsorption, and impregnability, but also heat conductivity and tensile and bending strength (Plötze and Niemz 2011). In addition, porosity is a main parameter in insulation materials and it is an important factor to the thermal insulating performance of the material.

Wood has several superior qualities that contribute to its prominence as an indispensable building and furniture material. One of these is its surface characteristics. The surface roughness of wood is an important quality parameter because it affects the tactile and visual perception of the wood surface (Kang *et al*. 2023). The surface roughness of wood material has a great influence on its performance and is an important indicator in the processing and manufacturing processes (Yang *et al.* 2023). Surface quality of solid wood is also one of the most important properties influencing further manufacturing surface processes such as varnishing, painting, coloring, and coating of products. The surface roughness of wood material is influenced by wood species, density, hardness, moisture content, cutter blade diameter, cutter shape, spindle speed, cutting speed, and cutting depth (Aydın and Çolakoğlu 2003; Sofuoglu 2017). Roughness is influenced by impregnation (Söğütlü and Döngel 2009) and heat treatment processes (Budakçı *et al.* 2011).

Although wood continues to be used for many applications because of its many excellent material properties, due to wood being a natural material, according to its composition and exposure wood can be damaged by abiotic factors as well as biotic factors and it also suffers from several disadvantages. It is necessary to treat the wood material with appropriate methods to protect it against biotic and abiotic factors that damage the wood material. Coatings and other treatments can prolong wood's service life, widen its application areas, and achieve the desired functionality of the wood material. Wood modification methods are widely used to improve the desirable properties and reduce the poor properties of wood material (Hill 2006). Heat treatment is one of the most used wood modification methods for improving wood properties, such as dimensional stability, water resistance, and biological durability, without using harmful chemical agents (Jirouš-Rajković and Miklečić 2019). Wood heat treatment has increased significantly in the last few years and is still growing as an industrial process to improve some wood properties (Esteves and Pereira 2009). The most important properties of heat-treated wood material are increased dimensional stability, reduced equilibrium moisture content, and higher resistance to biological attack (Gunduz *et al.* 2009). Heat-treated wood is used for a variety of outdoor and indoor decorative uses. There is a great market for different applications, including outdoor paneling, wooden decks, sauna construction, fences, outdoor furniture, garden elements, windows, and doors frames (Esteves and Pereira 2009). In addition, heat treatment influences the chemical composition of wood. There are significant changes in the permeability values of wood materials that have been heat-treated or dried at high temperatures. Depending on the condition of heat applied, the permeability properties of wood increase due to the loss of bound water, shrinkage at low temperatures, and physicochemical changes in cell walls at high temperatures (Taghiyari and Malek 2014). Therefore, improving the permeability of heat-treated wood material has some positive consequences, as well as advantages, such as increasing sound absorption performance (Jang *et al.* 2020). The acoustic properties of different wood materials have been studied by many researchers (Jiang *et al.* 2004; Fukuta *et al.* 2012; Obataya 2017); however, there has been limited research about the sound transmission loss and sound absorption coefficient of heat-treated wood materials.

This study aimed to provide more information on the properties of heat-treated poplar (*Populus nigra* L.) and beech (*Fagus orientalis* Lipsky) wood materials including air-dried density, equilibrium moisture content (EMC), porosity, average surface roughness (R_a), sound transmission loss, and sound absorption coefficient.

EXPERIMENTAL

Material

In this study, poplar (*Populus nigra* L.) and beech (*Fagus orientalis* Lipsky) woods were used as test materials. Test samples were obtained from sapwood parts poplar and beech logs (1.3 m above ground). Wood materials were selected randomly from a forest products company in Kütahya, Türkiye. In the selection of both wood materials, special emphasis was on the properties of non-deficient, proper, knotless, normally grown wood (without zone line, reaction wood, decay, insect, and mushroom damages). Both poplar and beech woods, having superior technological properties and having high usage potential, are important species in the woodworking industry. Two different boards of the same batch were used for the wood material of each species. Specimens were cut in rough sizes from sapwood of boards in accordance with ISO 3129 (2019).

Methods

Prior to the heat treatment process, the initial dimensions of wood planks were cut to 450 mm x 120 mm x 25 mm (longitudinal x radial x tangential), and then the samples were kept in the air conditioning cabin at 20 ± 2 °C with relative humidity of 65% ± 5 until they attained a relative humidity of 12%. Afterwards heat treatment was carried out at 150, 170, 190, and 210 °C for 3 h in a laboratory-type (Nüve FN 120) heating chamber controlled at an accuracy of ± 1 °C under atmospheric pressure. Heat-treated materials were conditioned at room conditions for three weeks. The dimensions of the samples were as follows: 30 mm x 20 mm x 20 mm (longitudinal x radial x tangential) for air-dried density, 99 mm x 18 mm (diameter x thickness) for EMC, and 29 mm x 18 mm (diameter x thickness) for acoustic properties (Fig. 1).

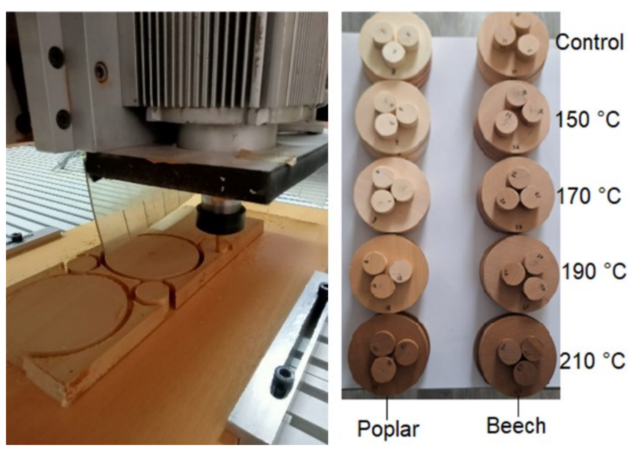

Fig. 1. Preparation of test samples for acoustic parameters

The test specimens were prepared in a sufficient number to accommodate ten repetitions for density, EMC, and three repetitions for acoustic properties in the study. The acoustic properties of the samples were evaluated based on the ISO 10534-2 (1998) standard, the EMC and density of the sample were calculated based on the ISO 3130 (1975) and ISO 3131 (1975) standards, respectively. The density and EMC tests were conducted on the same samples. Prior to the tests, the samples were conditioned in a cabinet at 20 ± 3 °C and 65 ± 5% relative humidity until they reached a constant weight. The sound absorption properties of the samples were measured using the transfer function method of the heat-treated and untreated samples in type SW 422 and type SW 477 impedance tubes (BSWA Technology Co., Ltd., China) (Fig. 2).

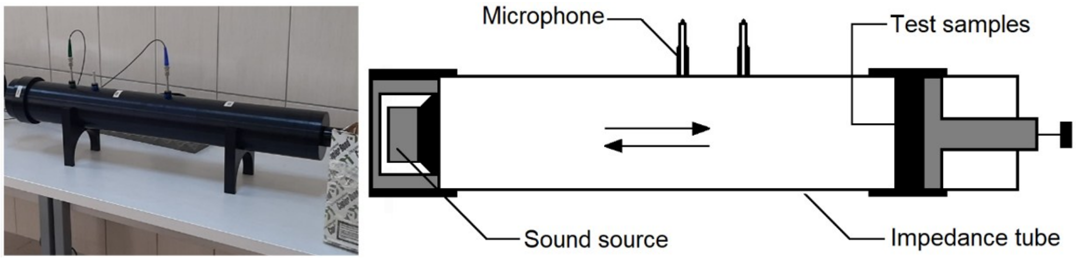

Fig. 2. Schematic diagram of impedance tube

According to the relevant standard, sound absorption properties were tested with a large tube (99 mm) for low frequencies (63 to 1600 Hz) and with a small tube (29 mm) for high frequencies (1600 to 6300 Hz).

The porosity is a prominent factor affecting the sound-absorbing properties of the sound-absorbing materials (Mao *et al.* 2024). Wood porosity is defined as the relative volume of emptiness in oven-dry wood and it is calculated according to Eq. 1 (Varivodina *et al.* (2010),

$$P = [1-(P_0 / P_{w.s}) \times 100] \tag{1}$$

where P is the porosity of wood (%) and P_0 is density of the oven-dry samples (g/cm^3), and $P_{w.s}$ is density of wood substance (assumed to be 1.53 g/cm^3).

The measurement of test samples surface roughness was performed using a digital display surface roughness measuring instrument TIME TR200 (Beijing Time Raguang Technologies Co., Ltd., China) (Fig. 3), according to ISO 4287 (1997) standard.

Fig. 3. TIME TR200 surface roughness device

Test samples used in surface roughness measurements were processed with a planing machine using a four fixed-knife format with a 6000-rpm spindle speed, a feed speed of 4 m/min, and 1 mm cutting depth. After the planing process, the test samples were sanded with grit 120 and then 180 grit sandpaper.

The device had diamond stylus with a 5-μm radius and 90° of tip angle. Surface roughness measurements were determined in the direction parallel to the grain. In the evaluation of surface roughness, average roughness values are the most used parameter in surface roughness measurements and it represents the arithmetic mean of the absolute deviations of the roughness profile related to the average line (Aydın and Çolakoğlu 2003). For this purpose, the average surface roughness parameters (R_a) were evaluated based on the ISO 4287 (1997) standard.

Statistical Analyses

To determine the effects of the heat treatment on properties of wood material, analyses of variance (ANOVA) were conducted using the MSTAT-C software, a computer-based statistical package (Version 1.42, Michigan State University, USA). When the differences emerged as statistically significant according to the level of $P < 0.05$, the importance was determined amongst groups with the Duncan test.

RESULTS AND DISCUSSION

The mean values of the measured properties of untreated and heat-treated wood species at different treatment levels and the differences between them are shown in Table 1.

Table 1. Mean Values of Density and EMC of Test Samples

Wood Type	Treatment Temperature	Density (g/cm^3)	EMC (%)
Poplar	Untreated	0.381^F ± (0.013)	12.93^B ± (0.670)
	150 °C	0.371^G ± (0.016)	11.83^C ± (0.990)
	170 °C	0.362^H ± (0.012)	11.09^D ± (0.667)
	190 °C	0.353^I ± (0.016)	9.98^E ± (0.585)
	210 °C	0.344^J ± (0.020)	9.16^F ± (0.506)
Beech	Untreated	0.695^A ± (0.012)	13.81^A ± (0.703)
	150 °C	0.677^B ± (0.015)	12.09^C ± (0.721)
	170 °C	0.662^C ± (0.019)	10.97^D ± (0.569)
	190 °C	0.649^D± (0.018)	9.77^E ± (0.546)
	210 °C	0.621^E ± (0.016)	8.98^F ± (0.573)
Values within the same group followed by dissimilar letters are significantly different to each other using the Duncan comparison test at P < 0.05 level. Values in parentheses are standard deviation.			

The density and EMC of the heat-treated samples were reduced, as shown in Table 1. The density values were evaluated in the range of 0.344 to 0.381 g/cm^3 for poplar and 0.621 to 0.695 g/cm^3 for beech, and EMC values were determined in the range of 9.16 to 12.93% for poplar and 8.98 to 13.81% for beech samples.

Density following heat treatment at the high temperature was lower than heat treatment at the low temperature. As the heat treatment temperature increased, the density of wood was decreased (Table 1). The densities of specimens that were heat-treated at 150, 170, 190, and 210 °C presented a decrease of 2.6%, 4.99%, 7.35%, and 9.71% compared to untreated (control) poplar specimens, whereas regarding beech specimens these decreases were 2.6%, 4.45%, 7.75%, and 10.8%, respectively, compared to the untreated (control) group. Based on statistical analysis, a significant difference was found between the density of the untreated samples and those exposed to heat treatment for poplar and beech woods. There was limited change in wood density after heat treatment at mild conditions (at 150 °C and 170 °C), and it was accompanied by a larger decrease in higher heat treatment conditions (at 190 °C and 210 °C). These effects can be explained by more decomposition and degradation of wood chemical components during the thermal modification at higher temperatures (Hill 2006; Bektas *et al.* 2017; Gašparík *et al.* 2024). In similar research by Gao *et al.* (2016), heat-treated poplar showed a decrease in oven-dry density, while Yılmaz Aydın *et al.* (2025) recorded similar findings as well for poplar samples. With respect to beech wood, similar results have been reported by other researchers in previous studies (Kol and Sefil 2011; Perçin *et al.* 2016).

Table 1 displays the average EMC values of untreated samples and samples treated at various temperatures. As shown, the values of EMC decreased with increasing heat treatment temperature. Data obtained from Table 1 showed that heat treatment had a significant influence on the EMC of poplar and beech samples. Regarding equilibrium moisture content, there was a significant difference ($p \leq 0.05$) between heat-treated and untreated wood specimens. In the case of poplar, compared to untreated samples, while average EMC values in samples subjected to 150 °C decreased 8%, those subjected to 170, 190, and 210 °C decreased 14%, 22%, and 28%, respectively. For beech wood, a behavior similar to poplar was observed, though differences between heat-treated and untreated samples were more evident. Regarding beech wood, compared to untreated groups, while average EMC values in samples subjected to 150 °C decreased 12%, those treated at 170, 190, and 210 °C decreased 20%, 29%, and 34%, respectively. A significant difference was found between the EMC of the untreated samples and those exposed to heat treatment for poplar and beech woods. Generally, the properties of EMC change found in this work were like those reported in the literature. Thus, the heat treatment process can effectually decrease wood material hygroscopicity by thermally degrading hemicellulose considerably, and sometimes cellulose at higher temperatures than 200 °C (Li *et al.* 2017). Tjeerdsma and Militz (2005) explained that reduction of free accessible hydroxyl groups results in decreased moisture uptake. Additionally, in the literature, it has been seen that the heat treatment strongly affected the chemical composition and structure of wood material. The degradation of hemicelluloses reduces the water absorption by wood material. There are also changes in lignin and cellulose at higher heat treatment temperatures. Lignin softens and blocks the cell pores, contributing to the reduction in water absorption. As explained above, the hygroscopicity of heat-treated wood is reduced and the heat-treated wood becomes more hydrophobic compared to the untreated wood (Kocaefe *et al.* 2008). This may be the main reason contributing to the reduction in water absorption of heat-treated wood. Moreover, the esterification of hydroxyl groups and cross-linking reactions occur during the thermal treatment of wood. Based on the combined effect of the above factors, the -OH groups available for moisture adsorption are significantly reduced by the heat treatment, which in turn decreases the hygroscopicity and EMC of wood (Li *et al.* 2011). Similar results were obtained by Bekhta and Niemz (2003) with spruce wood, and they reported that the wood EMC decreases by approximately 30 to 45% in the course of heat treatment. In addition, Zhou *et al.* (2013) reported that the EMC of heat-treated specimens decreased 23.4% to 37.4% compared to untreated specimens.

The total porosity and average surface roughness values of untreated and heat-treated wood samples are presented in Table 2.

Table 2. Porosity and Average Surface Roughness of Test Samples

Wood Type	Treatment Temperature	Porosity (%)	Average Surface Roughness (*Ra*) (μm)
Poplar	Untreated	75.1^{D} ± (0.842)	6.16^{A} ± (0.548)
	150 °C	75.7^{CD} ± (0.821)	5.82^{A} ± (0.438)
	170 °C	76.3^{BC} ± (0.641)	5.28^{B} ± (0.395)
	190 °C	76.9^{AB} ± (0.879)	4.97^{BC} ± (0.479)
	210 °C	77.5^{A} ± (1.278)	4.71^{CD} ± (0.331)
Beech	Untreated	54.5^{I} ± (0.742)	5.25^{B} ± (0.383)
	150 °C	55.7^{H} ± (0.949)	4.86^{C} ± (0.363)
	170 °C	56.7^{G} ± (1.194)	4.39^{DE} ± (0.429)
	190 °C	57.5^{F} ± (0.718)	4.18^{E} ± (0.496)
	210 °C	59.4^{E} ± (0.674)	3.68^{F} ± (0.456)
Values within the same group followed by dissimilar letters are significantly different to each other using the Duncan comparison test at P < 0.05 level. Values in parentheses are standard deviations.			

According to Table 2, with the increase of heat treatment temperature, the porosity of both wood samples increased continuously.

The total porosity of poplar was increased from 75.1% to 75.7%, 76.4%, 77.0%, and 77.5% as the heat treatment temperature increased from the untreated group (control) to 150, 170, 190, and 210 °C, respectively. Additionally, the total porosity of beech increased from 54.6% to 55.8%, 56.7%, 57.6%, and 59.4% as the heat treatment temperature increased from the untreated group (control) to 150, 170, 190, and 210 °C, respectively. Porosity of specimens presented an increase of about 1%, 1.7%, 2.4% and 3.2% compared to untreated (control) poplar specimens, whereas regarding beech specimens these increases were 2.1%, 3.9%, 5.4%, and 8.8%, respectively, compared to the untreated (control) group. Based on statistical analysis, a significant difference was found between the porosity of the untreated samples and those exposed to heat treatment. In contrast, based on statistical analysis, no significant difference between porosity of untreated samples and those exposed to a temperature of 150 °C was found for poplar wood. Kaya (2023) conducted a similar study of heat treatment on the porosity of Mediterranean cypress (*Cupressus sempervirens* L.) and field maple (*Acer campestre* L.) wood samples. It was reported that heat treatment affected porosity of samples and as the heat treatment temperature increased, porosity increased in both wood species depending on degradation of hemicellulose. Heat treatment causes significant changes in the cell walls and degradation of the main chemical components of the wood cell wall (cellulose, hemicelluloses, lignin) and extractives (Barlović *et al.* 2022). During the heat treatment, the components and microstructure of the wood are changed, and the cell wall of the internal pores became rough (Chung *et al.* 2017). In another study, it is reported that in wood materials and wood-based composites, porosity started to increase rapidly above 300 °C, which corresponded with the onset of material decomposition (Li *et al.* 2021). In another study, pore structure of wood was analyzed after heat treatment ranging from 190 to 230 °C for 6 h for both yellow poplar (*Liriodendron tulipifera*) and red pine (*Pinus densiflora*) woods. It is reported as heat treatment conditions become severe, though pore porosity increases (Jang and Kang 2019).

Table 2 displays surface roughness values of all samples exposed to different heat treatment temperatures. According to average roughness measurements, surface quality of all species improved with increasing heat treatment temperature. Poplar samples exposed to a temperature of 150, 170, 190, and 210 °C had 5.82, 5.28, 4.97, and 4.71 µm average roughness values, which was 6%, 14%, 19%, and 24% lower, respectively, than that of control samples, as shown in Table 2. Regarding to beech samples, the average surface roughness measurements for heat-treated samples at untreated, 150, 170, 190, and 210 °C were 5.25, 4.86, 4.39, 4.18, and 3.68 µm, respectively. Based on statistical analysis, different heat treatment temperatures resulted in a significant effect on the surface roughness of the specimens, as shown in Table 2. Furthermore, the decreases in average surface roughness of heat-treated samples were found to be 7%, 16%, 20%, and 30%, respectively, compared to those of the untreated samples. These findings agreed with those determined in various earlier studies (Kasemsiri *et al.* 2012; Bakar *et al.* 2013; Korkut *et al.* 2013). In another heat treatment study, it was found that for Oriental beech (*Fagus orientalis*) wood specimens exposed to three different temperatures (140, 170, and 200 °C) and three treatment durations (2, 4, and 8 h), surface roughness of heat-treated beech samples decreased with increasing heat treatment temperature (Baysal *et al.* 2014).

In the literature, it is suggested that the improvement of surface quality, such as smoothness with heat treatment, may be due to biochemical changes in the cell wall, possibly at elevated temperatures (Bakar *et al.* 2013). Additionally, high temperature causes the conversion of lignin into a thermoplastic condition, resulting in densification and compaction of the surface roughness of the samples (Kasemsiri *et al.* 2012). The surface roughness of wood products depends on many factors such as wood anatomical features (vessels, cell lumen, annual ring width, hardness, *etc.*), machine conditions (feed rate, spindle speed, *etc.*), and cutting properties (Karagoz *et al.* 2011).

The measured sound absorption coefficients of the specimens are presented in Fig. 4 for poplar and in Fig. 5 for beech.

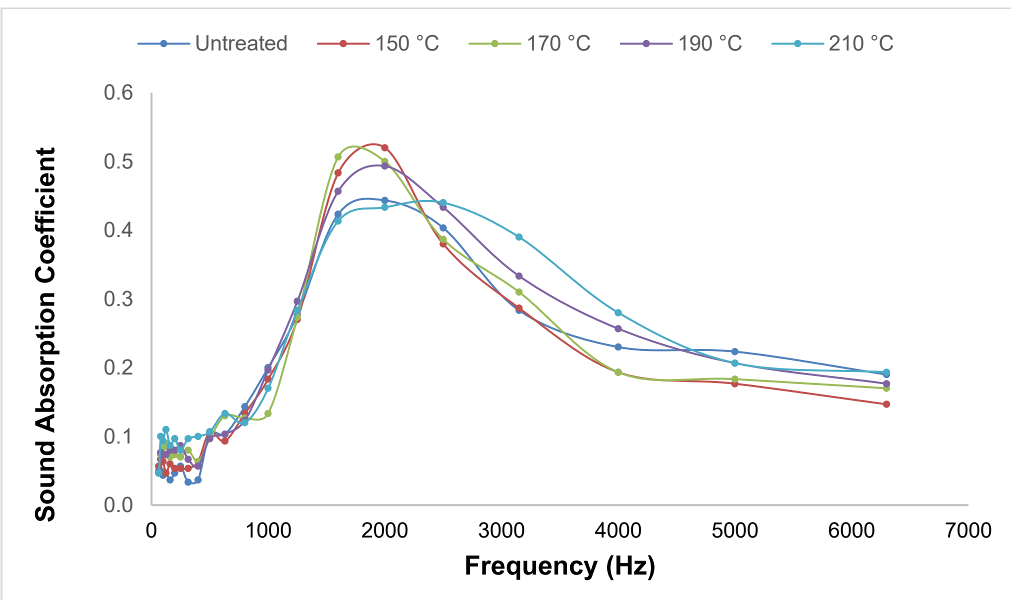

Fig. 4. Sound absorption coefficient of poplar wood

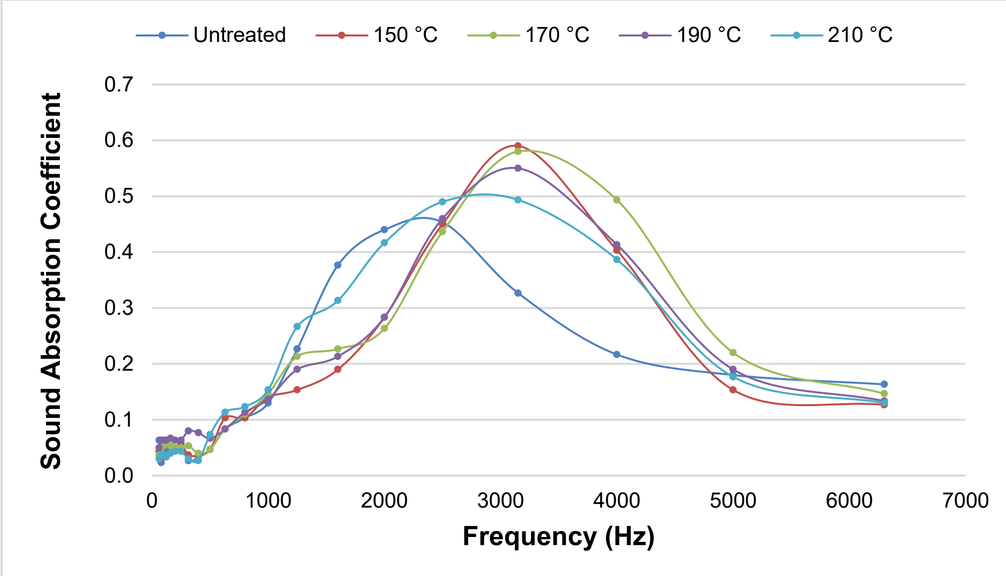

Fig. 5. Sound absorption coefficient of beech wood

Figures 4 and 5 show the rapid increase in the measured sound absorption coefficients above 1000 Hz for both species. According to Fig. 4, in the 1600 to 2500 Hz frequency range, poplar samples are characterized by the highest value of the analyzed parameter. Regarding the beech samples, the highest sound absorption coefficients were measured in the 2000 to 3500 Hz frequency range (Fig. 5). For poplar wood, among all samples, the highest value of the measured sound absorption coefficient, which was 0.52, was observed at 2000 Hz and at 150 °C (Fig. 4). In addition, regarding the beech wood, the highest sound absorption coefficient value was measured as 0.59 at 3150 Hz and at 150 °C (Fig. 5). In both wood species, the sound absorption coefficient decreased as the frequency value increased. At 6300 Hz, unheated poplar and beech samples had higher sound absorption coefficients compared to other heat-treated samples in their respective wood species. Generally, as shown in the figures, the sound absorption coefficient increased with the heat treatment temperature. This situation may have resulted from a slight increase in the porosity of the experimental samples after the heat treatment application (Table 2). Regarding the poplar wood, when the specimens that were heat-treated at 150, 170, 190, 210 °C, and the control specimens were compared, the increase rate of the average sound absorption coefficient was approximately 2%, 6%, 11%, and 15%, respectively. In addition, regarding the beech wood, when the specimens that were heat-treated at 150, 170, 190, 210 °C, and the control specimens were compared, the increase rate of the average sound absorption coefficient of beech samples was approximately 1%, 8%, 9%, and 10%, respectively. These results are in agreement with an earlier study obtained by Mania *et al.* (2023) for Scots pine (*Pinus sylvestris* L.), beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), and red oak (*Quercus rubra* L.) woods treated at temperatures 190 to 213 °C. They stated that as the heat treatment temperature increased, the sound absorption coefficients of test samples increased, and this situation was due to the increase in porosity due to the increase in heat treatment temperature. In another study, Kaya (2023) studied effect of impregnation with linseed oil and heat treatment on sound absorption coefficient of Mediterranean cypress (*Cupressus sempervirens* L.) and field maple (*Acer campestre* L.) wood samples. It is reported that the porosity increased in both wood samples due to heat treatment and the sound absorption coefficient also increased after heat treatment. In this study, in both beech and poplar samples, the sound absorption coefficient tends to decrease in the high frequency range. Chung *et al.* (2017) analyzed sound absorption coefficients of heat-treated *Larix kaempferi* wood at 200, 220, and 240 °C for 9, 12, 15, and 18 h at 250, 500, 1000, 2000, and 4000 Hz. They reported that the increase of the sound absorption coefficient in a low-frequency band range is due to the increased roughness of the internal pore wall and increase of the sound absorption coefficient by heat treatment in the high-frequency band range is due to the increase of porosity.

Sound transmission refers to the propagation of sound waves from one space to another through building materials. When sound waves strike a material surface, some of the wave is reflected by the surface, some is absorbed, and the remainder is transmitted. Sound transmission loss indicates a sound-blocking effect of the material. Furthermore, depending on the frequency, a higher transmission loss results in a greater sound insulation effect of the material (Kang *et al.* 2019b; Özdil *et al.* 2020); consequently, less noise is heard. Acoustic parameters of a material, such as sound absorption and sound transmission loss, are affected by its technological properties (macrostructure-related properties, mechanical properties, air properties within the porous structure, and physical properties of the material) (Arslan and Aktaş 2018).

The sound transmissions losses of poplar and beech samples depending on frequency are shown in Fig. 6 and Fig. 7, respectively.

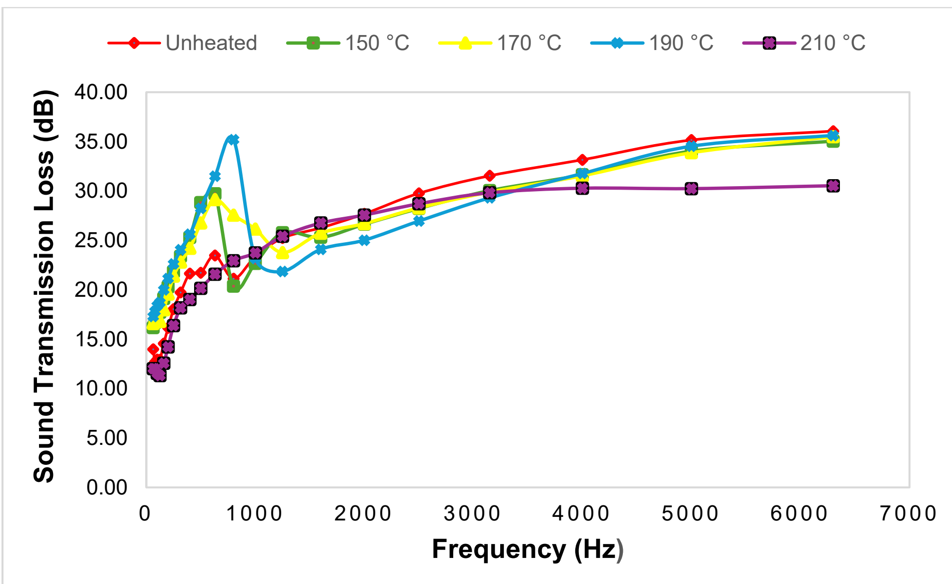

Fig. 6. Sound transmission loss of poplar

According to Fig. 6, average sound transmission loss of the untreated poplar wood samples was 22.7 dB and the highest sound transmission loss at 6300 Hz was 36.1 dB. For the heat-treated samples at 150 °C, the average sound transmission loss of samples was 24.6 dB, the highest sound transmission loss at 6300 Hz was 35.0 dB, and for heat-treated samples at 170 °C, average sound transmission loss of samples was 24.7 dB, and the highest sound transmission loss at 6300 Hz was 35.5 dB. Regarding the test samples that were heat-treated at 190 °C, the highest sound transmission loss, which was 35.6 dB, was found at 6300 Hz, and the average value was 25.4 dB. Additionally, regarding the test samples that were heat-treated at 210 °C, the highest sound transmission loss, which was

30.5 dB, was found at 6300 Hz, and the average value was 21.2 dB. As shown in Fig. 6, compared to the untreated (control) group, sound transmission loss of poplar samples increased as heat treatment conditions became more severe, but decreased a little in the test samples heat-treated at 210 °C.

In terms of sound transmission loss, beech samples have shown slightly different measurements compared to poplar samples.

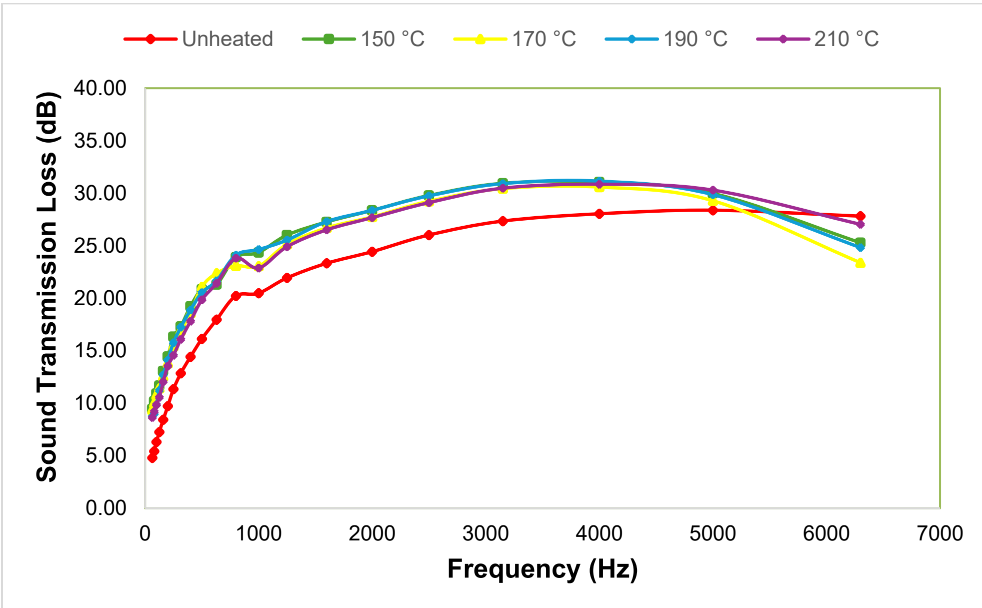

Fig. 7. Sound transmission loss of beech

According to Fig. 7, the average sound transmission loss of the untreated beech samples was 17.3 dB, and the highest sound transmission loss at 5000 Hz was 28.4 dB. For heat-treated samples at 150 °C, the average sound transmission loss of samples was 21.0 dB and the highest sound transmission loss at this temperature at 4000 Hz was 31.1 dB. The average sound transmission loss of heat-treated samples at 170 °C was 20.5 dB and the highest sound transmission loss at 4000 Hz was 30.6 dB. Regarding the test samples that were heat-treated at 190 °C, the average value was 20.8 dB, and the highest sound transmission loss, which was 31.2 dB, was found at 4000 Hz. In addition, regarding the test samples that were heat-treated at 210 °C, the average sound transmission loss was 20.3 dB, the highest sound transmission loss, which was 30.8 dB, was found at 4000 Hz. An increase in temperature was observed to have a significant effect on the sound transmission loss of the heat-treated beech samples. As shown in Fig. 7, compared to the untreated (control) group, the sound transmission loss values of the heat-treated wood increased as the temperature of the heat treatment process increased.

According to Figs. 6 and 7, a generally similar relationship was observed between frequency and sound transmission loss value in the samples. For the untreated poplar samples, as the Hz increased, the sound transmission loss of the test samples gradually increased especially after 2000 Hz. In addition, sound absorption coefficient of the heat-treated poplar samples slightly decreased depending on the heat treatment temperature after 2000 Hz. The sound transmission loss trends at frequencies greater than 2000 Hz for poplar test samples untreated and heat-treated at 150, 170, and 190 °C were similar over the full frequency range. These test samples also yielded similar results at frequencies less than 1000 Hz (Fig. 6).

The sound transmission loss of heat-treated beech samples increased depending on the heat treatment temperature. Compared to the unheated samples, the sound transmission loss values of all heat-treated test samples were higher, based on the change in frequency from 63 to 5000 Hz. Sound transmission loss was higher only at 6300 Hz in the unheated samples. In a previous study, Kang *et al.* (2018a) reported that the sound transmission loss samples increased as the density increased and as the frequency increased.

The main objective of this study was to investigate the effect of heat treatment temperature on some physical and acoustic parameters of wood materials. The heat treatment changed the density, EMC, and porosity of both poplar and beech woods. Changes in these properties were not stable in both wood species. The acoustic parameters (sound absorption coefficient and sound transmission loss) differed in both tree species depending on the rate of change in properties and the frequency range.

In both tree species, the sound transmission loss values changed at different rates with increasing heat treatment temperature and frequency. Several researchers have found an important effect of heat treatment on sound absorption coefficient and sound transmission loss in different heat-treated wood samples (Kang *et al.* 2018b; Uzun *et al.* 2024). In Kang *et al.* (2019b), they reported that the anatomical structure of wood material, as well as low density and high porosity values resulting from heat treatment, are effective in sound transmission loss of wood samples.

CONCLUSIONS

The experimental results of density, equilibrium moisture content, porosity, average surface roughness, sound transmission loss, and sound absorption coefficient depending on the heat treatment temperature conditions for poplar (*Populus nigra* L.) and beech (*Fagus orientalis* Lipsky) woods are summarized as follows.

1. In both wood species, density values decreased with increasing heat treatment temperature. As heat treating temperature increased, the degree of decrease in density of beech was greater than that of poplar.
2. As the intensity of the treatment increased, the equilibrium moisture content (EMC) values were decreased. At the highest treatment temperature, EMC decreased 28% for poplar and 34% for beech.
3. Porosity increased after heat treatment process for both wood species.
4. The surface roughness values of the heat-treated poplar and beech samples increased with increasing heat treatment temperature. Increasing the conditions of heat treatment resulted in smoother surfaces.
5. The sound absorption coefficient increased with the treatment temperature for both wood samples. Generally, as heat treatment temperature increased, the degree of increase in sound absorption coefficient of poplar was greater than that of beech.

6. Poplar and beech samples exhibited different behaviors against the heat treatment process. The sound transmission loss increased in both the poplar and the beech samples with increased heat treatment temperature, and the sound transmission loss of poplar wood was higher than beech wood.

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Article submitted: November 14, 2025; Peer review completed: December 13, 2025; Revised version received and accepted: December 14, 2025; Published: December 26, 2025.
DOI: 10.15376/biores.21.1.1329-1346