# DETERMINING THE SURFACE HARDNESS OF SOME DENSIFIED AND HEAT TREATED WOODS AFTER WATER-BASED VARNISHING

Hüseyin Pelit[1,*], Abdullah Sönmez[2], Erol Burdurlu[2], İlker Usta[3]

[1]*Duzce University, Faculty of Technology, Department of Wood Products Industrial Engineering, 81620-Konuralp, Duzce, Turkey*
[2]*Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering, 06500-Teknikokullar, Ankara, Turkey*
[3]*Hacettepe University, Department of Wood Products Industrial Engineering, 06532-Beytepe, Ankara, Turkey*

**Key words**

*Scots pine,*
*Eastern beech,*
*Densification,*
*Heat treatment,*
*Water-based varnish,*
*Surface hardness.*

**Abstract**

In this study was aimed at determining the surface hardness of scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) woods to which water-based varnishes were applied after thermo-mechanical densification and heat treatment. Samples; after densifying by compression in the radial direction at 20% and 40% compression ratios, and at 110 °C and 150 °C, samples were subjected to 2 hours of heat treatment at 190 °C, 200 °C, and 210 °C. Then, surface of the samples were varnished with one-component and two-component water-based varnishes. The changes occurring in surface hardness of the samples were determined according to the bases of TS EN ISO 1522. According to results of the study; surface hardness increased 5,1% and 4,9% in densified scots pine and Eastern beech samples, respectively. Decreases were observed in the surface hardness of the samples because of the increase in heat treatment temperature. After the water-based varnish applications, increases of 23% and 5% were obtained in the surface hardness of scots pine and Eastern beech samples, respectively. Moreover, no difference was observed between one and two-component water-based varnishes in terms of surface hardness.

Corresponding author: *huseyinpelit@duzce.edu.tr. Duzce University, Faculty of Technology, Department of Wood Products Industrial Engineering, 81620-Konuralp, Duzce, Turkey*

## 1. INTRODUCTION

Wood has been widely and popularly used as a decorative material because of its aesthetic appearance and characteristics properties. However, wood is much easier destroyed by environmental factors, including water, light, fire and living organisms, than many other man-made materials. Therefore, in recent years there has been a rapid increase in the application of different modification methods to wood and wood materials in order to improve their properties. In particular, thermal, thermo-mechanical and thermo-hydro-mechanical treatments of wood have been widely studied and applied to improve its properties (Bekhta et al. 2014). The usage of modification processes for wooden materials that involve the application of both heat and pressure are becoming more favorable; such processes are being used to extend the scope of use for various wood materials by enhancing some properties (Pelit et al. 2014). Heat treatment leads to permanent changes in molecular structure of the chemical compounds of wood. The fundamental idea underlying this application is to treat wooden material with heat above the temperatures of 150 °C where chemical reactions

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become accelerated (Cooper and Wang 2005; Boonstra 2008). The heat treatment process results in a slight modification in the molecular structure of the wooden material and thus improves its performance. The properties potentially improved by heat treatment are: biological resistance to fungi and insects, low equilibrium moisture content, increased dimensional stability with respect to the decrease in contraction and expansion, increased thermal insulation capacity, and increased resistance to weathering (Korkut and Kocaefe 2009; Pelit et al. 2015). However, an important disadvantage of heat treatment is the decrease in density and some mechanical resistance properties of wood (Yıldız 2002; Bekhta and Niemz 2003; Esteves and Pereira 2009; Aydemir and Gündüz 2009; Perçin 2012; Pelit 2014).

The density of wooden materials is an important factor that indicates their other properties and potential uses.

For example, the resistance, flexibility, and hardness of hardwoods are higher than those of softwoods. Additionally, hardwoods resist abrasives better (Örs and Keskin 2008). Densification makes it possible for low-density woods to be substituted for harder species so that low-density and commercially uninteresting wood species can be modified into high performance and high value products. In general, wood densification is the process by which wood density is increased by compression of the wood, the impregnation of cell lumens with a fluid substance, or a combination of compression and impregnation. Densification of wood can be achieved by impregnating its void volume with polymers, molten natural resins, waxes, sulphur, and even molten metals. Wood can also be densified by compressing it in a transverse direction under conditions that do not cause damage to the cell wall (Kutnar and Sernek 2007). An important disadvantage of densification by the compressing method is that the wood resumes its initial dimensions before compressing when soaked in water or exposed to high relative humidity (Seborg et al. 1956; Kultikova 1999; Morsing 2000; Pelit et al. 2014; Pelit and Sönmez 2015).

The wooden surface layers are commonly used for the protection of the furniture and decorative elements produced from wood and other structural elements. Protective liquid surface applications such as paints and varnishes are often used to extend the aesthetic and economic life of wooden material surfaces (Kurtoğlu 2000). The long-term durability of varnishes applied to wooden surfaces with respect to mechanical effects, such as friction, abrasion, and impact, depends on the resistance of the varnish layers to these effects. Varnished wooden surfaces are exposed to various effects, depending on the environments in which they are used. Therefore, in order to prevent economic losses, the use of varnish types that supply optimum efficiency according to the usage area is required (Sönmez et al. 2011a). At the present time, role and importance of water-based varnishes used to create the protective layer is great. The water-based systems are becoming more broadly used with the passage of time owing to their superior characteristics as being more environmentally friendly than solvent based systems and being less harmful for their user (Sönmez et al. 2011b). The objective of this study was to determine surface hardness properties of Scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) woods to which water-based varnishes were applied after thermo-mechanicall densification and heat treatment (ThermoWood® process).

## 2. MATERIAL AND METHOD

### *Wood material*

In this study, Scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) woods, widely used in woodworking industry in Turkey, were preferred. The Scots pine trees, from which the test samples were prepared, were obtained from Melet State Forestry Enterprise of the Mesudiye State Forestry Directorate in Ordu Province, Turkey, whereas the Eastern beech trees were obtained from Akkuş State Forestry Enterprise of Akkuş State Forestry Directorate. Round woods, having green moisture content, were cut from their sapwood with an automatically controlled band sawing machine. Cuts were determined by considering sample dimensions as annual rings parallel to the surface (tangent section) and these were transformed into timbers of rough scale. Attention was paid to ensure that no rot, knot, crack, color, or density differences were present in the samples (TS 2470 1976). Samples were initially dried to 12% moisture in an automatically controlled conventional drying furnace, and afterwards they were brought to the dimensions given in Table 1.

Table 1. Before densification dimensions of samples

| Compression ratio (%) | Length - longitudinal direction (mm) | Width - tangential direction (mm) | Thickness - radial direction (mm) |
|---|---|---|---|
| Control | 450 | 95 | 10 |
| 20 | 450 | 95 | 12.5 |
| 40 | 450 | 95 | 16.7 |

Before the densification process, samples were kept on hold in a conditioning cabin until they reached a stable weight with a relative humidity of 65±3%, and temperature of 20±2 °C. To prevent possible moisture changes that could occur after conditioning, samples were preserved in plastic bags until the time of densification (TS 2471 1976).

### *Densification and heat treatment*

Densification of the samples with the thermo-mechanical method was performed with a specially designed hydraulic press machine which can achieve pressure and temperature control and whose pressing tray dimensions are 60 × 60 $cm^2$ (Pelit et al. 2015). Densification process was done by forming four different variations at target compression ratios of 20% and 40%, with temperatures of 110±5 and 150±5 °C. Densification variations are given in Table 2.

Table 2. Densification Variations of the Treatments

| Pressing temperature (°C) | Compression ratio (%) | Duration (min.) | Research code |
|---|---|---|---|
| 110 | 20 | Heating + 10 | A1 |
| 110 | 40 | Heating + 10 | A2 |
| 150 | 20 | Heating + 10 | B1 |
| 150 | 40 | Heating + 10 | B2 |

The samples were placed onto the bottom tray of the pressing machine and held under a slight pressure by getting them in contact with the heated bottom and top press tray to provide heat transfer. The samples were kept in this position for a while until their internal temperature reached the target temperature, by checking with a thermometer. Temperature control samples, which were separately located on the pressing tray, were used for controlling internal temperature of the samples. Afterwards, a compression process in radial direction with automatic control at 30 mm/min loading speed was carried out. To obtain targeted compression thickness (10 mm), metal stopping sticks were placed onto the pressing tray at particular intervals (Pelit et al. 2015). Compressed samples were held under pressure for 10 min, and after this period these samples were taken out from the press machine and cooled to room temperature under a pressure of 5 kg/cm$^2$ in order to minimize spring-back effects.

After densification, heat treatment was performed on the experimental samples in order to provide dimensional stability. Heat treatment application it was carried out during 2 h and at the proposed three different temperatures (190, 200, and 210 °C) according to the method described in the ThermoWood Handbook (2003). After heat treatment, experimental samples were properly stored under of 65±3% relative humidity and 20±2 ˚C for 2-3 weeks. Afterwards, the samples were cut as to have dimensions of 80 × 80 × 10 mm (length-longitudinal direction × width-tangential direction × thickness-radial direction) and as to be repetitive for 8 times for each test variant. According to TS 2471 (1976) after cutting, the samples were kept on hold at a temperature of 20±2 °C and relative humidity of 65±3% until they reached a stable weight. Then, sample surfaces were ground with 150 and 180 sandpapers and dust was removed using pressurized air, after which they were ready for varnishing.

### *Varnish*

In the varnishing of experimental samples; glossy, water-based, one-component and two-component wood varnishes produced with nanotechnology were used. Resin groups of the varnishes and abbreviation codes used in the study are given in Table 3 and some technical properties are given in Table 4.

Table 3. Resin groups of the varnishes and abbreviation codes

| Type of varnish | Resin group | Research code |
|---|---|---|
| Water-based filling varnish | Acryl copolymer resins | WF |
| One-component water-based varnish (topcoat) | Acryl copolymer resins | OCW |
| Two-component water-based varnish (topcoat) | Acryl modified polyurethane resins | TCW |

Table 4. Characteristics of the varnishes

| Type of varnish | pH | Density (g/cm³) | Application viscosity (s/DIN Cup 4mm/20 ˚C) | Amount of varnish applied (g/m²) | Solid content (%) |
|---|---|---|---|---|---|
| WF | 8.1 | 1.11 | 18 | 70 | 34.20 |
| OCW | 8.1 | 1.13 | 18 | 65 | 26.92 |
| TCW | 8.2 | 1.15 | 18 | 75 | 34.14 |

The standards stated in ASTM-D 3023-98 (2011) were used in the varnishing of experimental samples. Varnishing applications were carried out using a spray gun with a 0.8 mm spray opening with an air pressure of 1-1.5 bar approximately 20 cm from the sample surfaces. WF application onto the surfaces of experimental samples was performed three times at one hour time intervals between each application according to the advice of producing company. After waiting 24 hours, sample surfaces were ground with 280 sandpaper to eliminate fiber swells and to provide surface smoothness. Dust was removed with a soft haired brush. Afterwards, OCW finish layer varnish was applied to half of the samples to which WF had been applied and TCW finish layer varnish was applied to the other half of the samples. Considering the rate of solid material and the advice of the manufacturer, OCW finish layer varnish application was performed three times at one hour time intervals between each application and TCW finish layer varnish application was performed twice at one hour time intervals. To allow complete drying of the varnishes, experimental samples were stored parallel to the ground surface at room temperature for a period of three weeks.

### *Determination of surface hardness (pendulum damping)*

The surface hardness were determined using the pendulum hardness tester according to the principles of TS EN ISO 1522 (2007) as shown in Figure 1. The device is placed on the sample, and the hardness is determined according to the pendulum swings. The pendulum swings with two balls that have a hardness of HRC 63±3.3 and are 5±0.0005 mm in diameter. Surfaces that have more swings are harder surfaces, and those with fewer swings have lower hardness (Sönmez 1989).

Figure 1. Surface hardness (pendulum damping) test

### *Statistical evaluation*

The MSTAT-C package program was used for statistical evaluation. Multiple analysis of variance (ANOVA) tests were performed between process groups and control groups, andthe differences between the Duncan test results and mean values were compared when significant differences were detected. Therefore, success ranking among the factors included in the experiment was determined by separating them into homogeneity groups according to Least Significant Difference (LSD) critical values.

## 3. RESULTS AND DISCUSSION

Variance analysis results for the surface hardness of the densified and heat treated samples to which water-based varnishes were applied are given in Table 5.

Table 5. Analysis of variance results of surface hardness values

| Factors | Degrees of freedom | Sum of squares | Mean square | F-value | Level of significance (P≤0.05) |
|---|---|---|---|---|---|
| Wood type (A) | 1 | 4282.689 | 4282.689 | 638.1867 | 0.0000* |
| Densification (B) | 4 | 668.911 | 167.228 | 24.9195 | 0.0000* |
| Heat treatment (C) | 2 | 187.725 | 93.863 | 13.9870 | 0.0000* |
| Varnish type (D) | 2 | 5617.733 | 2808.867 | 418.5645 | 0.0000* |
| Interaction (AB) | 4 | 43.200 | 10.800 | 1.6094 | Ns |
| Interaction (AC) | 2 | 26.219 | 13.110 | 1.9536 | Ns |
| Interaction (BC) | 8 | 25.872 | 3.234 | 0.4819 | Ns |
| Interaction (ABC) | 8 | 61.183 | 7.648 | 1.1397 | Ns |
| Interaction (AD) | 2 | 2086.411 | 1043.206 | 155.4537 | 0.0000* |
| Interaction (BD) | 8 | 299.322 | 37.415 | 5.5755 | 0.0000* |
| Interaction (ABD) | 8 | 35.367 | 4.421 | 0.6588 | Ns |
| Interaction (CD) | 4 | 98.742 | 24.685 | 3.6785 | 0.0057* |
| Interaction (ACD) | 4 | 25.881 | 6.470 | 0.9642 | Ns |
| Interaction (BCD) | 16 | 33.494 | 2.093 | 0.3119 | Ns |
| Interaction (ABCD) | 16 | 84.300 | 5.269 | 0.7851 | Ns |
| Error | 630 | 4227.750 | 6.711 | | |
| Total | 719 | 17804.800 | | | |

*: Significant at 95% confidence level Ns: Not significant

According to variance analysis results: effect of wood type, densification, heat treatment, and varnish type with dual interactions of wood type-varnish type, densification-varnish type, and heat treatment-varnish type on the surface hardness values were significant; all other interactions were not significant (P≤0.05). Mono comparison results of the Duncan test conducted by using LSD critical values for wood type, densification, heat treatment, and varnish type level are shown in Table 6.

Table 6. Comparison results of Duncan test related to surface hardness values at wood type, densification, heat treatment, and varnish type level

| Wood type | $\bar{x}$ | HG | LSD |
|---|---|---|---|
| Scots pine | 47.63 | b | ± 0.3792 |
| Eastern beech | 52.51 | a* | |
| Densification | $\bar{x}$ | HG | LSD |
| Undensified | 48.92 | b | ± 0.5995 |
| A1 | 49.49 | b | |
| A2 | 51.38 | a* | |
| B1 | 49.50 | b | |
| B2 | 51.04 | a* | |
| Heat treatment | $\bar{x}$ | HG | LSD |
| 190 ºC | 50.09 | b | ± 0.4644 |
| 200 ºC | 50.68 | a* | |
| 210 ºC | 49.43 | c | |
| Varnish type | $\bar{x}$ | HG | LSD |

| | | | |
|---|---|---|---|
| Unvarnished | 46.12 | b | ± 0.4644 |
| OCW | 52.08 | a* | |
| TCW | 52.00 | a* | |

$\bar{x}$ : Average value, HG: Homogeneous group, *: The highest hardness value, A1: 110 ˚C / 20%, A2: 110 ˚C / 40%, B1: 150 ˚C / 20%, B2: 150 ˚C / 40%, OCW: One-component water-based, TCW: Two-component water-based

According to results in Table 6, higher surface hardness value was obtained in the Eastern beech (52.51) compared to the scotch pine (47.63). The highest hardness value at densification level was obtained in the samples densified under A2, and B2 conditions (51.38, and 51.04), and the lowest value was obtained in the samples densified under A1, and B1 conditions with the undensified samples (48.92, 49.49, and 49.50). The surface hardness increased after densification; higher hardness values were obtained at higher compression rates. This is because of the increase in the density of the wooden material after densification processes (Pelit et al. 2014; Pelit and Sönmez, 2015). It has been reported in previous studies that many properties of wooden materials are related to their density and that with an increase of the density, these properties can be enhanced (Sandberg et al. 2013; Kutnar and Sernek 2007).

The highest surface hardness value in the heat treatment level was obtained in the samples heat treated at 200 ºC (50.68), whereas the lowest hardness value was obtained in the samples to which the heat treatment was applied at 210 ºC (49.43). The surface hardness values initially increased, then decreased depending upon the heat treatment temperature. The increase in the surface hardness may be explained by the decrease in the equilibrium humidity. It is indicated in literature that excess humidity in a wooden material decreases the surface hardness; higher surface hardness values have been obtained in 8% humidity as compared to 10% and 12% humidity (Pelit 2007; Sönmez et al. 2011b). The decrease in the surface hardness with the increase in the heat-treatment temperature may also be explained by the density losses and the increase in surface roughness (Pelit 2014).

The highest surface hardness value in the varnish type level was obtained in the samples applied to OCW, and TCW (52.08, and 52.00); the lowest hardness value was obtained in the samples unvarnished (46.12). After varnish application, the surface hardness of the samples increased. This situation may be explained by the fact that the hardness of the varnish layer at the surface is higher than the hardness of the wooden material. Moreover, both varnish types resulted in similar hardness values; no statistically significant difference was observed.

The surface hardness values of Scots pine and Eastern beech are presented comparatively in Figures 2 and 3.

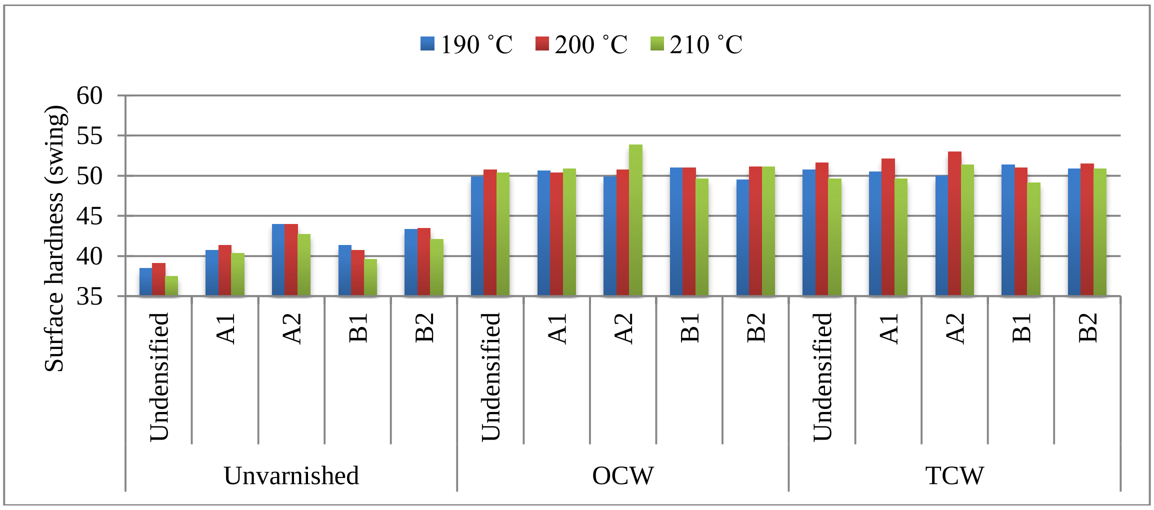

Figure 2. Comparative appearance of surface hardness values in Scots pine

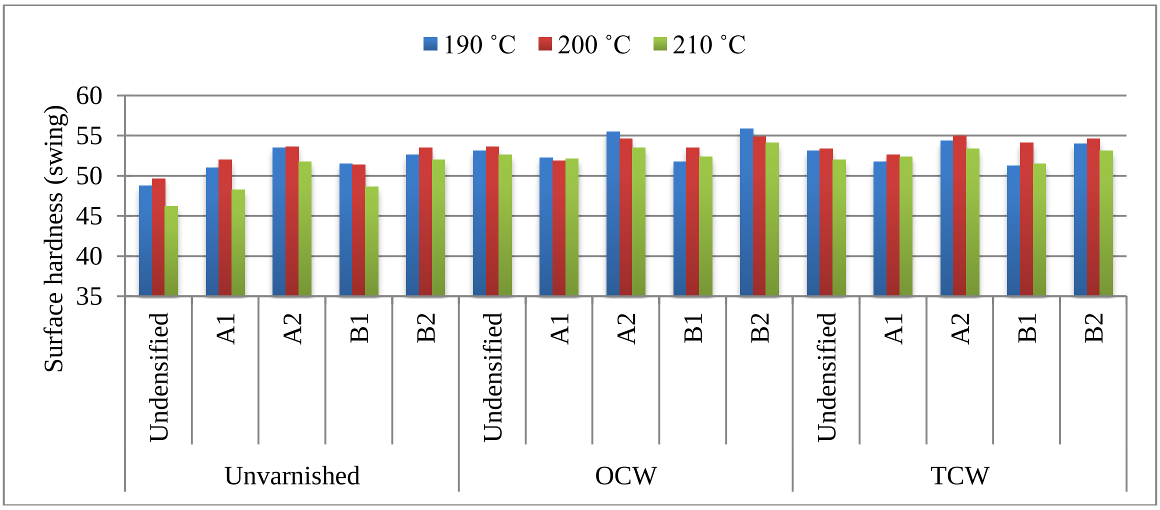

Figure 3. Comparative appearance of surface hardness values in Eastern beech

## 4. CONCLUSIONS

In this study have been investigated the surface hardness properties of scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) woods to which water-based varnishes were applied after densification and heat treatment. After densification, the surface hardness values were increased by 5.1% in Scotch pine and 4.9% in Eastern beech due to compression rates. Higher hardness values were obtained with 40% compression rates. The effect of the densification temperature on surface hardness was found to be insignificant. In heat treated samples, the surface hardness values initially increased then decreased. The hardness values of the samples that were heat treated at 200 °C were found to be higher than those that were heat treated at 190 or 210 °C. After being varnished, the surface hardness of the samples increased. This increase was 23% in Scotch pine samples and 5% in Eastern beech samples. However, no difference was observed between water-based varnishes consisting of one and two components in terms of surface hardness.

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Corresponding author:
H. Pelit
Duzce University, Faculty of Technology, Department of Wood Products Industrial Engineering, 81620-Konuralp, Duzce, Turkey
Tel.: + 90 380 5421133 / 2123; fax: + 90 380 5421134.
e-mail: huseyinpelit@duzce.edu.tr