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Research article (Araştırma makalesi)

Evaluation of the hardness properties of the thermally modified tree-of-heaven *(Ailanthus altissima)* for parquet production

Hızır Volkan Görgün[a,*]

Abstract: Developing wood-based industries such as structure, pallet, parquet etc., expanded the usage area of the wood. However, the development increased rivalry between these industries and naturally pressure to the forests for serving raw material. Therefore, many industries and scientist studied obtaining fast-growing tree species and increasing its properties to meet the related industry requirements. Many modification techniques with using heat, chemical treatments etc. were tried. In this study, tree-of-heaven (*Ailanthus altissima*) as a fast-growing species was investigated to evaluate in the solid-based (solid and upper layer of the laminate) parquet production. Thermal modification method was applied with 205ºC temperature and 2 hours duration to increase its stability and darkening the colors. In the same samples, Brinell hardness were measured before and after the treatment. They were both classified related to characteristic values for evaluating the species to meet the parquet production requirements according to a standard. Results showed that hardness values of the 90% of the all thermally-treated samples were found higher than untreated samples. It's thought that the decrement of the equilibrium moisture content (11-13% to 3-4%) after the treatment could increase the hardness values. Additionally, both values of the untreated and treated tree-of-heaven samples was at the highest level with the many species which were shown as a reference in the related standard. Consequently, if the invasive characteristic of this species can be controlled, unmodified and modified wood can be a good alternative for solid-based parquet production.
Keywords: Brinell hardness, Invasive tree species, Solid parquet, Thermal modification

Isıl işlem görmüş cennet ağacının (*Ailanthus altissima*) sertlik özelliklerinin parke üretimi için değerlendirilmesi

Öz: Yapı, palet, parke vb. gibi ahşap esaslı sanayilerin gelişmesiyle ahşabın kullanım alanı genişlemiştir. Ancak, gelişme bu endüstriler arasındaki rekabeti artırmış ve doğal olarak hammadde sağlamak için ormanlara olan baskıyı da arttırmıştır. Bu nedenle birçok firma ve bilim insanı, ilgili sanayi gereksinimlerini karşılamak amacıyla hızlı büyüyen ağaç türlerini değerlendirme ve özelliklerini iyileştirme konusunda çalışmalar yapmıştır. Isı, kimyasal gibi birçok farklı yöntemin kullanıldığı modifikasyon teknikleri denenmiştir. Bu çalışmada, hızlı büyüyen bir tür olan cennet ağacı (kokar ağaç, *Ailanthus altissima*), masif esaslı (masif ve lamine parkenin üst tabakasında) parke üretiminde değerlendirilmek üzere incelenmiştir. Stabilite artışı ve renk koyulaşmasını da sağlamak amacıyla 205ºC sıcaklık ve 2 saat süre ile termal modifikasyon yöntemi de uygulanmış ve aynı örneklerde işlem öncesi ve sonrası Brinell sertlik değerleri ölçülmüştür. Her iki örnek grubu da bu ağaç türünün sertlik açısından parke üretim gerekliliklerini karşılama durumunun değerlendirilmesi için, TS EN 1534 (2020) standardı kullanılarak karakteristik değerlere göre sınıflandırılmıştır. Sonuçlar, tüm ısıl işlem görmüş numunelerin %90'ında, sertlik değerlerinin işlenmemiş numunelerden daha yüksek bulunduğunu göstermiştir. Isıl işlemden sonra denge nem içeriğinin azalmasının (%11-13'ten %3-4'e) sertlik değerlerini artırmış olabileceği düşünülmektedir. Ayrıca hem işlem görmüş hem de işlem görmemiş cennet ağacı örneklerinin değerleri, ilgili standartta referans olarak ve en yüksek seviyede gösterilen birçok türle benzer şekilde yüksek çıkmıştır. Sonuç olarak, bu türün istilacı özelliği kontrol altına alınabilirse, işlenmemiş ve termal olarak işlenmiş ağacının masif parke üretimi için iyi bir alternatif olabileceği düşünülmektedir.
Anahtar kelimeler: Brinell sertlik, İstilacı ağaç türü, Masif parke, Termal modifikasyon

1. Introduction

Wood is an important material with its advantages such as strength against lower density, naturality, aesthetic properties etc. These advantages caused to be preferred in many usage areas and as a result of that many wood and wood-based industries developed. Industrial development increased the consumption and consequently threaten the forest and its sustainability. Therefore, many companies and researchers has tried to find the substitute species and generally focused the fast-growing species to secure the sustainability characteristics of the forest. However, most of the species (poplar, paulownia, eucalyptus etc.) have lower physical and mechanical properties and do not meet the requirements of the many usage areas (Tenorio et al., 2021; Millaniyage et al., 2022). Therefore, modification techniques such as hot pressing (Candan et al., 2013), thermal modification (Suri et al., 2021), chemical treatments (Mattos et al., 2015) were tried to improve the properties of the fast-growing species (Németh et al. 2020). Besides these species, eucalyptus and tree-of-heaven species come forward with better properties (Amer et al., 2021; Panayotov et al., 2011;

[a] Department of Wood Mechanics and Technology, Faculty of Forestry, Istanbul University-Cerrahpaşa, 34473, İstanbul, Türkiye
[*] **Corresponding author** (İletişim yazarı): volkan.gorgun@iuc.edu.tr
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Szabolcs and Varga, 2021). However, *Eucalyptus* has important drying risks before the production. Its characteristically high shrinkage and low mass diffusivity values are notoriously difficult to season without degrade, especially backsawn boards (Vermaas, 1995). Although the invasive characteristics of the tree-of-heaven, it is evaluated by the local people in northern China due to its availability (Miao et al., 2014). The relatively better physical and mechanical properties of this species although it has fast-growing characteristics shows that it has an important potential for industrialization (Brandner and Schickhofer, 2010).

Parquet from wood material is frequently preferred on the floors when especially aesthetic properties and naturality were desired. However, all tree species can not be used on the wooden parquets. While stability for variable ambient atmosphere and hardness against static or dynamic forces from such as furniture leg, shoe hells etc. are critical required specifications. Because of the upper layer of the multi-layer wood parquets are exposed these forces, too, similar requirements on solid wood parquets are desired (Kantay and Güngör, 2009). Therefore oak (Kadem and Fakir, 2017), ash, beech species which can be graded "higher" for hardness class (according to As et al., 2016) are generally used for both solid wood and multi-layer parquet production.

Aim of this study is investigating the potential usage of the tree-of-heaven (*Ailanthus altissima*) in the wooden parquet (solid and laminated) industry. Accordingly, hardness properties of untreated and thermally modified of the tree-of-heaven were investigated. Because, although the thermal modification method decreases especially mechanical properties of wood (such as bending strength, hardness etc.), it can be preferred for the parquet production due to increasing stability and obtaining desirable darker colors (Gyuricsek et al., 2014; Militz and Altgen, 2014). Additionally, the thermally modified wood can show different results after the standard methods (Ayata et al., 2017), due to changing the material composition and characteristics.

2. Materials and methods

2.1. Material

A 23-year old tree-of-heaven *(Ailanthus altissima)* with a diameter variance of 28 – 32 cm diameter tree grown in the Bahçeköy region (Sarıyer, Istanbul, Türkiye) was used for this study. The specimens were prepared from slabs while lumbers were evaluated in another study (Görgün and Ünsal, 2023). The slabs were kiln-dried to the air-dry moisture content (11-13 %) which were measured with a resistance type moisture meter (TS EN 13183-2, 2002). Defect-free tangential tree-of-heaven samples were cut to 25 × 50 × 100 mm dimensions from the slabs.

The effect of the thermal modification was investigated with before-after hardness tests. The hardness measurements were applied on untreated samples. After that, all samples were thermally modified in an industrial Thermowood© kiln at 205°C and 2 hours. The moisture contents of treated samples were measured according to oven-dry method (TS EN 13183-1, 2012) and found 3-4 % (Figure 1).

2.2. Hardness measurements

The Brinell hardness measurements were done according to TS EN 1534 (2020) standard. Based on the standard, before the measurements, samples were sanded to clean the surface. The sanding process was applied on the direction of parallel to grain with 60-grit sandpaper in sanding machine. Hardness measurements were applied before (Hu) and after (Ht) the treatment on the tangential surface (perpendicular to the grain) (Figure 2).

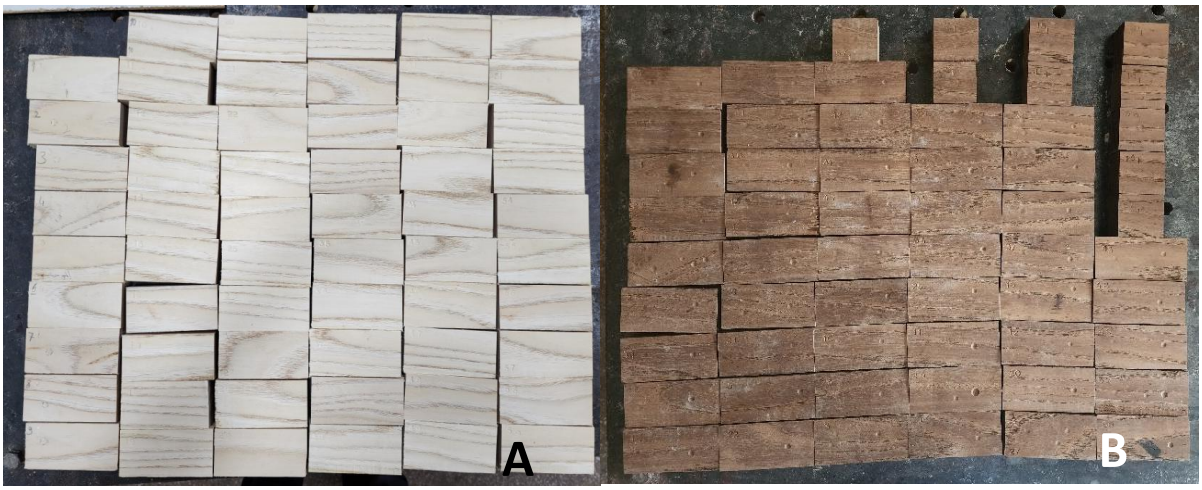
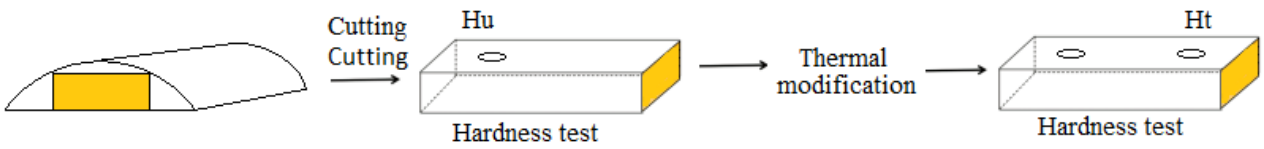


Figure 1. Untreated (A) and treated (B) samples



*Hu: Hardness on untreated and Ht: treated samples, Yellow area: Sample cross-section

Figure 2. Flow chart of sample preparation

Hardness tests were applied with by an indenter which diameter of 10 ± 0.01 mm. The indenter applied 1 kN which was reached after (15 ± 3) s. The force was maintained for (25 ± 5) s. After withdrawal of the indenter, the samples were waited for recovering at least 2 min. Diameters were measured with a caliper with an accuracy of 0.01 mm. After withdrawal of the indenter, the sample was waited to let recovering for at least 3 min. The Brinell hardness (HB) was calculated, according to the following formula:

$$HB = \frac{2F}{\pi .D.[D-\sqrt{D^2-d^2}]} \quad (1)$$

Where; HB was the Brinell hardness (N/mm^2), F was the maximum load applied force (N), D was the diameter of the ball (mm) and d was the diameter of the residual indentation (average of d_1 and d_2, mm).

Characteristic value, which was defined as the fifth percentile of the assumed normal distribution, was calculated by the following formula:

$$X_k = m - (t_{05} \times s) \quad (2)$$

Where, m was the mean value, s was the standard deviation, X_k was the characteristic value and t_{05} was the student coefficient for a one sided 5 % probability. Student coefficient was taken 1.67 for 60 of indentations according to table in standard.

3. Results and discussion

As seen in Figure 3, except four samples, the hardness values of all treated samples were found higher than untreated samples.

In fact, thermal modification process generally decreases mechanical strength of wood. The opposite results may be arisen from moisture content (MC) decrement. There are few studies on the thermal modification of the tree-of-heaven species. However, due to its anatomical structure is similar as ash (Kúdela and Mamoňová, 2006), the effect of the thermal modification was compared on this species. When control and modified ash samples compared, Milić et al. (2023) found similar the values, while Leitch (2009) found higher hardness values on the modified samples.

In an international hardness standard TS ISO 13061-12 (2021), although it describes Janka hardness method, there is an adjustment formula to adjust the values while the samples have different MCs from 12±5%. If the MCs are lower than 12%, the values get higher according to formulation and conversion coefficient. TS EN 1534 (2020) standard has Brinell hardness values of perpendicular to the grain for some species from literature. In this study, the characteristic values of untreated and treated tree-of-heaven samples were calculated (Table 1). The characteristic values of the studied samples were compared with other species, which were mentioned in the standard (Figure 4) and a study (Figure 5) (Swaczyna et al., 2011).

According to figures, untreated tree-of-heaven (ToH) wood had middle and/or low hardness characteristics, while treated ToH wood had the highest hardness values. In other words, according to XP B 53-669 (2012) standard (which was mentioned in TS EN 1534 (2020), untreated samples might be evaluated in B class, while treated samples in C class (FCBA, 2023). If the TS EN 14354 (2017) is used for the classification according to resistance to indentation, parquets from both treated and untreated woods (without coating) can be evaluated in domestic (including heavy traffic) end uses.

Table 1. Characteristic values of untreated and treated tree-of-heaven wood

(in MPa)	Untreated	Treated
Mean	28.08	36.99
Standard deviation	4.47	5.92
Characteristic value	20.61	27.11

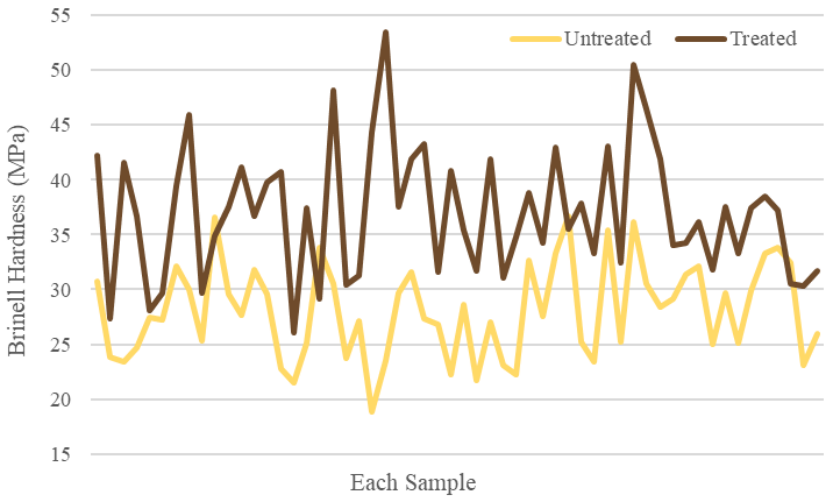
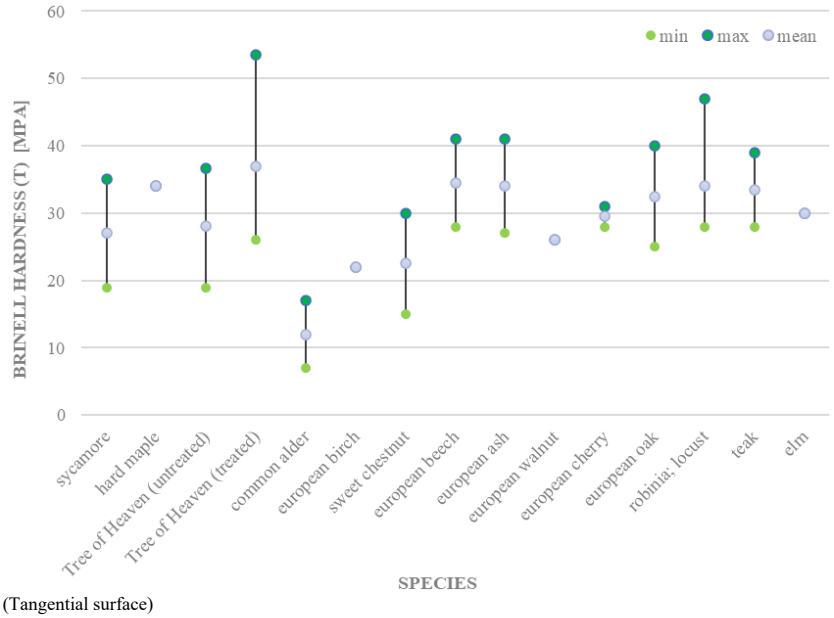


Figure 3. Brinell Hardness comparison of untreated and treated samples



* T: perpendicular to the grain (Tangential surface)

Figure 4. Brinell hardness values (MPa) on the perpendicular direction of some hardwood species (TS EN 1534, 2020) with tree-of-heaven values from this study

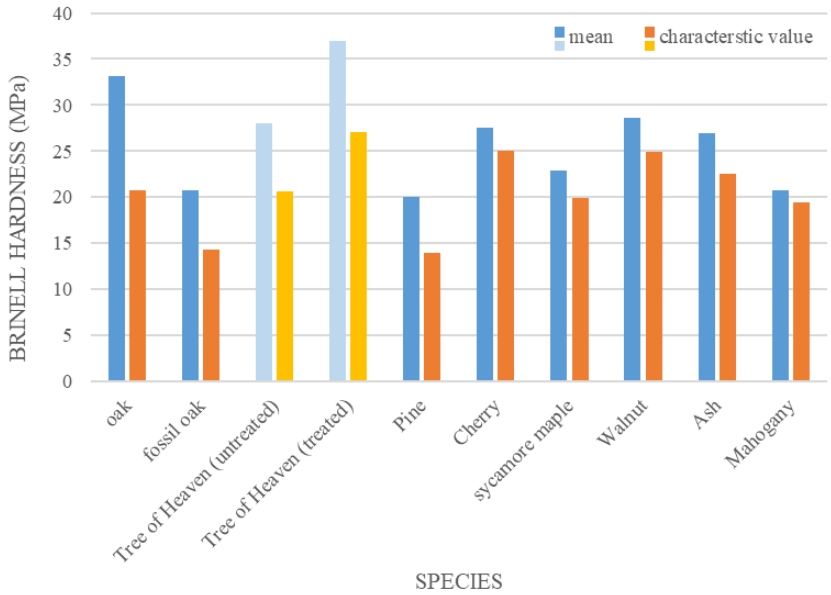


Figure 5. Brinell hardness values (MPa) on the radial direction (tangential surface) of some hardwood species (Swaczyna et al., 2011)

4. Conclusion

In this study, the suitability of the parquet production of the tree-of-heaven (*Ailanthus altissima*) which is known as a fast-growing and invasive tree species. Due to thermal treatment can increase the stability and darken the color that these properties can be required in the solid-based parquet production, Brinell hardness of the both untreated and treated samples were measured. Results showed that hardness values of the 90% of the all thermally-treated samples were found higher than untreated samples. It is thought that the decrement of the equilibrium moisture content (11-13% to 3-4%) after the treatment could increase the hardness values. Additionally, both values of the untreated and treated tree-of-heaven samples was at the highest level with the many species which were shown as a reference in the related standard. Consequently, if the invasive characteristic of this species can be controlled, its untreated and thermally-modified wood can be a good alternative for solid-based parquet production.

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