Effect of Heat Treatment on Shore-D Hardness of Some Wood Species

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Hardness is an important wood property for several applications. Typically, it is necessary to use traditional methods, such as a universal test machine, to determine a wood's hardness value. This work reports the hardness of some wood species before and after heat treatment (ThermoWood method) using the Shore-D hardness method. The Shore-D hardness value of untreated wood ranged between 35.3 for Limba wood and 77.2 for Santos wood. With heat treatment, hardness decreased, and the decrease was greater for samples that underwent harsher treatment (2 h at 212 °C). The decrease of hardness was highest for Sipo wood (14%) and the lowest for Afrormosia wood (2.5%). Analysis of variance tests showed that there was a significant difference between wood species, heat treatment, and the interaction between both variables at the chosen level of significance ($P \leq 0.05$). Results showed that Shore-D hardness could be used to measure hardness directly in a production line or in small wood companies without using a universal test machine.

Keywords: Shore-D hardness; Exotic wood species; Heat treatment; ThermoWood

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INTRODUCTION

Currently, several years after the use of wood heat treatment processes began, there are many well-established commercial processes, such as ThermoWood® (Finland), Plato Wood® (Netherlands), OHT-Oil Heat Treatment wood (Germany), Retification (France), and Perdure (started in France but moved to Canada since a Canadian company (PCI industries) bought the patent). In the last decade, several new processes have emerged, some using vacuum to protect wood from oxygen, such as Termovuoto® (Allegretti *et al*. 2012), Moldrup-SSP®, and TanWood®; others using overheated steam by a closed autoclave system, such as ThermoTreat 2.0® or Firmolin®; and others that apply minor changes to the original processes, such as Westwood®. The changes in wood properties depend on the heat treatment method, but mostly they depend on temperature and time of treatment. The high temperatures used in thermal modification alter the chemical composition of the wood, producing a new material with improved properties (Esteves and Pereira 2009). The decrease in equilibrium moisture content is one of the main advantages of treated wood, which in turn increases dimensional stability. This increase has been attributed to the decreased accessibility by water molecules to hydroxyl groups in the wood, resulting from increased crystallinity of cellulose and increased cross-linking in

lignin (Boonstra and Tjeerdsma 2006; Esteves *et al*. 2006, 2007). The treatment also improves wood durability by increasing resistance to fungi, except when in contact with soil, and slightly increases resistance to insects, though it has little effect on termite resistance (Nunes *et al*. 2004; Hakkou *et al*. 2006; Surini *et al*. 2012; Ayata *et al*. 2017). Wood also becomes darker in color, with less gloss (Aksoy *et al*. 2011; Esteves *et al*. 2019), less wettability (Hakkou *et al*. 2005), and lower thermal conductivity (Şahin Kol and Sefil 2011). The weakest part of heat treatment is the degradation of most of the mechanical properties, such as impact, static bending strength, and stiffness (Poncsák *et al*. 2006); compression strength (Korkut *et al*. 2008); and tensile strength (Boonstra *et al*. 2007). Most of the mechanical properties seem to increase in the beginning of the treatment or during low temperature treatments, and subsequently decrease (Kubojima *et al*. 2000; Boonstra *et al*. 2007).

Heat treatment is generally applied to low-value species to enable their utilization in harsher environments. In the last few years, however, heat treatment has been used to non-chemically change wood color of more valuable species, mainly in flooring applications. This affects wood properties including hardness, which is one of wood's most important properties, and critical for applications like flooring, decking, and stairs. Like to other mechanical properties, an initial increase in hardness has been reported by several authors (Tjeerdsma *et al*. 1998; Sivonen *et al*. 2002; Poncsák *et al*. 2006; Sundqvist *et al*. 2006; Korkut *et al*. 2008; Gurleyen *et al*. 2017). This initial increase has been attributed to condensation reactions in lignin and hemicellulose (Sundqvist *et al*. 2006).

In contrast, hardness decreases when wood is subjected to more severe treatments using higher temperatures or longer treatment times (Gunduz *et al*. 2009). The cited authors reported that surface hardness of heat-treated hornbeam treated at 210 °C for 12 h decreased 55%, 54%, and 38% for tangential, radial, and longitudinal directions, respectively. The decrease was generally greater in tangential and radial directions than in the longitudinal direction. For instance, the Yildiz (2002) study of heat-treated wood at 180 °C for 10 h showed a decrease in beech of 41.8%, 45.1% and 25.9%, and, in spruce, a decrease of 42.5%, 43.0%, and 19.7%, in tangential, radial, and longitudinal directions, respectively. Contrary results were reported by Korkut *et al*. (2008) for heat-treated Scots pine at 180 °C for 10 h, which showed a 41% decrease in the longitudinal direction, 39% in the tangential direction, and 27% in the radial direction. In accordance to Salca and Hiziroglu (2014), who studied the effect of heat treatment at 120 °C and 190 °C for 3 h and 6 h on the surface hardness of black alder (*Alnus glutinosa* L.), red oak (*Quercus falcata* Michx.), Southern pine (*Pinus taeda* L.), and yellow poplar (*Liriodendron tulipifera*), the changes in hardness depended on the species. They achieved a high decrease for red oak (41.7%) and a lower decrease for black alder (7.9%), but found no notable differences in Southern pine or yellow poplar for similar treatments. These differences were attributed to anatomical features such as porosity. Likewise, Shi *et al*. (2007) mentioned that hardness increased or decreased in accordance with species, directions (radial, tangential, and longitudinal), and type of treatment.

The decrease in hardness can be associated to the mass loss in the cell wall as well as to density, which has a similar behavior to hardness (Gunduz *et al*. 2009). For instance, in the Yildiz (2002) study that examined the heat treatment of beech and spruce woods, there was a minor density increase for beech (2.25%) and spruce (1.73%) woods that underwent treatments at 130 °C for 2 h. For treatments at higher temperatures (200 °C, 10 h), however, density decreased 18.37% and 10.53% for beech and spruce woods, respectively; hardness, too, decreased.

Shore hardness, like most hardness methods, measures the resistance toward indentation of a material with the difference that can be done *in situ*. Similar tests were already made, for instance, for in-process properties estimation and monitoring of silicone rubbers (Zhao *et al*. 2015). Shore hardness in accordance with ASTM D2240 (2010) has 12 different scales and can determine the hardness of elastomers, rubbers, plastic, cellular materials, and gels. The most common scales are the Shore A for the softer materials and Shore D for harder ones. In wood and wood composites, Shore-D hardness is preferred (Karamanoglu and Akyildiz 2013; Mattos *et al*. 2015; Chu *et al*. 2016; Li *et al*. 2018). Shore hardness is already commonly used with several wood composites such as wood plastic composites (Vedrtnam *et al*. 2019; Bhaskar *et al*. 2020), pine sawdust mixed with polyvinyl alcohol adhesive (Li *et al*. 2011), wood polymerized with montmorillonite (Wang *et al*. 2014), composites prepared by free radical in situ polymerization of methacrylate monomers into pinewood (Mattos *et al*. 2015), poplar wood impregnated with phenolic resins (Li *et al*. 2018), or rubber composites using wood flour has filling (Nitz *et al*. 2000; Kılınç *et al*. 2019). Uses with solid wood have been more scarce, but nevertheless there are some examples such as the tests made by Sahin and Onay (2020) for alternative wood species for playgrounds wood from fruit trees or a study on suitability of some wood species for landscape applications (Şahin *et al*. 2020). There have also been some studies with heat-treated wood such as the determination of hardness properties of heat-treated Anatolian black pine, Calabrian pine, sessile oak, and chestnut (Karamanoglu and Akyildiz 2013) or the determination of surface characteristics of poplar wood with high-temperature heat treatment (Chu *et al*. 2016).

This paper studied the Shore-D hardness (ASTM D2240 2010) of some wood species before and after heat treatment (ThermoWood method), and the effect that wood species and heat treatment had on the observed changes.

EXPERIMENTAL

Fourteen different species were used in this study in order to include the highest range possible from low density to high density species in accordance to the species that are commonly used and naturally more available for heat treatment in the Duzce region (Turkey). Density ranged from 0.367 g/cm^3 to 1.122 g/cm^3. Sipo (*Entandrophragma utile*), merbau (*Intsia bijuga*), afrormosia (*Pericopsis elata*), wenge (*Millettia laurentii*), sapelli (*Entandrophragma cylindricum*), teak (*Tectona grandis* L.), zebrano (*Microberlinia brazzavillensis*), doussié (*Afzelia africana*), Santos (*Myroxylon balsamum*), rose (*Dalbergia nigra*), Acajou d'Afrique (*Khaya anthotheca*), limba/fraké (*Terminalia superba*), duka (*Tapirira guianensis*), and tali (*Erythrophleum suaveolens*) species were obtained from the Duzce industrial zone in Duzce, Turkey. The samples were 100 mm × 100 mm × 10 mm (longitudinal × tangential × radial) and conditioned according to ISO 554 (1976). The samples were kept at 23±2 °C and 50±5% relative humidity until equilibrium was reached.

Methods

Heat treatment

All wood samples were heat-treated at 212 °C for 1 h and 2 h, according to the ThermoWood method, in the Novawood Factory located in Gerede, Bolu, Turkey. After

the treatment, the samples were reconditioned according to ISO 554 (1976) at 23±2 °C and 50±5% relative humidity.

Density determination

Density was determined for wood conditioned at 23±2 °C and 50±5% relative humidity by measuring the sample dimensions with a caliper and weighing them in a scale.

Determination of Shore-D hardness

The Shore-D hardness measurements of all samples, untreated and heat-treated, were done according to the ASTM D2240 (2010) standard. Figure 1 shows the Shore-D hardness device (Shenzhen Omena Technology Co., Ltd., Guangdong, China). A 5-kg load was used as the weight to determine hardness.

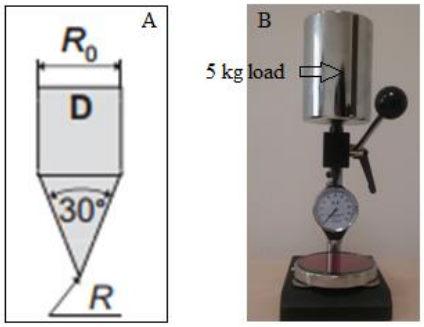

Fig. 1. Definition (0 N ≤ F ≤ 44.5 N, 0 mm ≤ h ≤ 2.5 mm) (Grellmann and Seidler 2014) (A), and Shore-D hardness device (B)

The values of R_0 and R depend on the scale used. For Shore-D hardness, R_0 = 1.25 mm and R = 0.1 mm. The Shore-D scale goes from 0 to 100, where 100 corresponds to having a 44.45 N spring force calibration.

Statistical analysis

The SPSS 17 (Sun Microsystems, Inc., Santa Clara, CA, USA) program was used to calculate the statistical analysis. Minimum, maximum, variation coefficients, homogeneity groups, standard deviations, and averages of the Shore-D hardness test results applied to heat-treated and untreated wood materials were determined. The analysis of variance (ANOVA) and Duncan tests were also performed.

RESULTS AND DISCUSSION

Table 1 presents the Shore-D hardness of all untreated and heat-treated wood for 1 h and 2 h at 212 °C in accordance with the ThermoWood method. The Shore-D hardness of untreated wood ranged between 35.3 for Limba wood and 77.2 for Santos wood, giving Limba the lowest hardness and Santos the highest hardness of all studied materials. In Fig. 1 it can be seen that Limba wood exhibited much smaller hardness than the remaining woood species. The untreated wood hardness of this study was in the range of that presented by other authors with different species, such as Ayata (2020) with Ayous wood (*Triplochiton scleroxylon*) who obtained 37.6; Devi and Maji (2012) found a 40.0 Shore-D hardness for simul wood (*Salmalia malabarica*); Mattos *et al*. (2015) determined 42.6

for loblolly pine (*Pinus taeda*), Hazarika and Maji (2013) determined 45.0 for fig (*Ficus hispida*); Yan *et al*. (2015) determined 46.4 for poplar (*Populus tomentosa*); Devi *et al*. (2003) determined 46.6 for rubber wood (*Hevea brasiliensis*); and Karamanoğlu and Kaymakçi (2018) determined 64.1 for chestnut (*Castanea sativa*).

With heat treatment, hardness decreased for all the species studied. The decrease was higher in samples with harsher treatment (2 h at 212 °C). The decrease in hardness was higher for Sipo wood, falling from 68.4 to 58.6, which corresponded to a 14% decrease compared with the untreated wood. The lowest decrease was observed in Afrormosia, whose hardness decreased from 56.8 to 55.4, corresponding to a 2.5% reduction (Table 1 and Fig. 1). There seems to have been no relation between the degree of hardness decrease with heat treatment and the initial hardness of the wood samples, as can be seen in Fig. 1. Similar results in several species have been presented by different authors. For instance, Salca and Hiziroglu (2014) studied the heat treatment of four wood species, black alder (*Alnus glutinosa* L.), red oak (*Quercus falcata* Michx.), Southern pine (*Pinus taeda* L.), and yellow poplar (*Liriodendron tulipifera*), each treated at two temperatures, 120 °C and 190 °C, for 3 h and 6 h. These authors reported a hardness decrease that reached 41.7% for red oak when treated at 190 °C for 6 h. Smaller decreases were found for black alder (7.9%), and no notable differences were found between the treated and untreated samples of Southern pine and yellow poplar.

Results, however, have shown that hardness can increase when using less severe treatments, leading to a marked decrease for higher temperatures and treatment times. These results were reported by Karamanoglu and Akyildiz (2013) in Anatolian black pine (*Pinus nigra*), Calabrian pine (*Pinus brutia*), sessile oak (*Quercus petraea*), and chestnut (*Castanea sativa*), each treated at 130 °C, 180 °C, and 230 °C temperatures (2 and 8 h). The authors stated that although the hardness increased at 130 °C and 180 °C, it decreased at 230 °C. Analogous results were obtained in different studies, such as Akyildiz *et al*. (2009), who reported the heat treatment of Anatolian black pine wood at 130 °C, 180 °C, and 230 °C, and Ates *et al*. (2009) with Calabrian pine. Although their studies used the Janka method to determine hardness, both obtained a similar increase followed by a decrease. These results show that the use of higher temperatures might also have some impact in the decrease in hardness. Therefore, even with the same mass loss, higher temperature might lead to a higher decrease in hardness. Since in this study a temperature of 212 °C was used, which is normally considered as a high temperature, that would explain why there was a decrease in hardness even with only 1 h hour treatment at 212 °C. The type of hardness measurement might also have some impact in these results, since Shore-D hardness is a measurement taken more superficially than other hardness measurements, and for heat-treated wood there might be some difference between hardness of the first layer of wood that is more exposed than the layers beneath. In accordance with Dumail *et al.* (1998), the shape of the indentation tool, the speed of loading, the depth of penetration and most likely how wood failure is induced during testing significantly affected hardness results.

The initial increase in hardness might be due to the increased crosslinking in lignin turning the material harder. The decrease in hardness for more severe treatments is probably due to the high mass loss that weakens the wood, and this effect is higher than the effect in lignin crosslinking. The mass loss starts with hemicelluloses that are known to have a significant influence on wood properties, and for more intense treatments the loss of hemicelluloses is significant. Similar conclusions were reported by Ates *et al.* (2009).

Table 1. Shore-D Hardness and Density for Untreated and Heat-treated Wood

Wood Type	Heat Treatment	Mean	*HG*	*SD*	Mini-mum	Maxi-mum	COV	Density (g/cm^3)
Sipo (*Entandrophragma utile*)	Control	68.40	E	0.52	68.00	69.00	0.76	0.812
	212 °C for 1 h	63.00	H	2.94	59.00	66.00	4.67	0.791
	212 °C for 2 h	58.60	NO	1.71	57.00	61.00	2.92	0.673
Tali (*Erythrophleum suaveolens*)	Control	68.50	E	1.18	66.00	70.00	1.72	0.912
	212 °C for 1 h	65.60	F	0.52	65.00	66.00	0.79	0.875
	212 °C for 2 h	65.40	F	0.52	65.00	66.00	0.80	0.838
Santos (*Myroxylon balsamum*)	Control	77.20	A*	1.23	75.00	78.00	1.59	1.122
	212 °C for 1 h	73.60	B	0.52	73.00	74.00	0.71	0.925
	212 °C for 2 h	70.90	D	1.10	68.00	72.00	1.55	0.837
Rose (*Dalbergia nigra*)	Control	76.80	A	1.93	75.00	79.00	2.51	1.023
	212 °C for 1 h	73.20	BC	0.79	72.00	74.00	1.08	0.913
	212 °C for 2 h	72.40	C	0.70	71.00	73.00	0.97	0.908
Zebrano (*Microberlinia brazzavillensis*)	Control	64.20	G	0.79	63.00	65.00	1.23	0.792
	212 °C for 1 h	60.20	KL	0.92	59.00	61.00	1.53	0.785
	212 °C for 2 h	60.10	KLM	0.57	59.00	61.00	0.95	0.752
Teak (*Tectona grandis* L.)	Control	59.10	LMN	0.74	58.00	60.00	1.25	0.641
	212 °C for 1 h	52.90	S	0.99	52.00	55.00	1.87	0.459
	212 °C for 2 h	51.00	T	0.67	50.00	52.00	1.31	0.408
Afrormosia (*Pericopsis elata*)	Control	56.80	PQ	0.79	56.00	58.00	1.39	0.663
	212 °C for 1 h	56.20	QR	0.63	56.00	58.00	1.12	0.603
	212 °C for 2 h	55.40	R	0.52	55.00	56.00	0.94	0.584
Sapelli (*Entandrophragma cylindricum*)	Control	61.80	I	1.32	60.00	63.00	2.14	0.745
	212 °C for 1 h	60.30	JKL	0.48	60.00	61.00	0.80	0.596
	212 °C for 2 h	57.70	OP	0.82	57.00	59.00	1.42	0.568
Doussié (*Afzelia africana*)	Control	64.70	FG	2.45	61.00	67.00	3.79	0.672
	212 °C for 1 h	59.10	LMN	1.20	58.00	61.00	2.03	0.645
	212 °C for 2 h	57.00	PQ	1.76	54.00	59.00	3.09	0.633
Acajou d'Afrique (*Khaya anthotheca*)	Control	56.20	QR	0.79	55.00	57.00	1.41	0.570
	212 °C for 1 h	52.20	S	0.79	51.00	53.00	1.51	0.555
	212 °C for 2 h	50.10	T	1.29	49.00	52.00	2.57	0.424
Duka (*Tapirira guianensis*)	Control	60.40	JK	1.84	58.00	63.00	3.05	0.665
	212 °C for 1 h	58.90	MN	1.20	58.00	61.00	2.04	0.627
	212 °C for 2 h	58.90	MN	0.74	58.00	60.00	1.26	0.604
Wenge (*Millettia laurentii*)	Control	63.90	GH	1.79	62.00	68.00	2.80	0.692
	212 °C for 1 h	59.60	KLMN	1.51	58.00	61.00	2.53	0.675
	212 °C for 2 h	57.20	PQ	0.92	55.00	58.00	1.61	0.663
Limba/Fraké (*Terminalia superba*)	Control	35.30	U	0.48	35.00	36.00	1.36	0.367
	212 °C for 1 h	33.30	V	0.48	33.00	34.00	1.44	0.353
	212 °C for 2 h	32.20	W**	1.03	31.00	33.00	3.20	0.317
Merbau (*Intsia bijuga*)	Control	65.80	F	2.04	63.00	68.00	3.10	0.830
	212 °C for 1 h	61.40	IJ	0.84	61.00	63.00	1.37	0.801
	212 °C for 2 h	59.20	KLMN	1.03	58.00	61.00	1.74	0.783
HG: Homogeneity group, SS: Standard deviation, COV: Coefficient of variation, *: Highest value, **: Lowest value								

Fig. 1. Hardness variation for the tested untreated and heat-treated woods

In accordance with Mania *et al*. (2020), the most commonly accepted function describing the relation between density and hardness is the power function ($H = \rho^n$), with n ranging from 1.1 to 2.25. Nevertheless, different functions were reported to describe the relation between density and hardness.

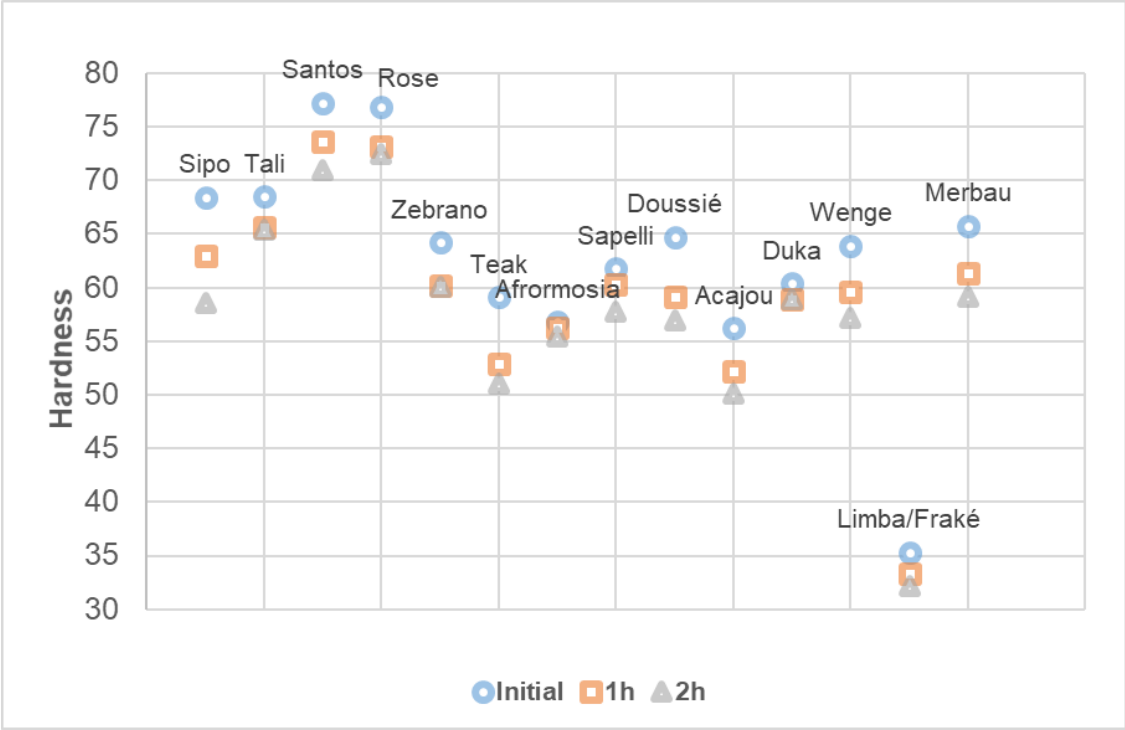

Fig. 1. Hardness variation for the tested untreated and heat-treated woods

Figure 2 presents the relation between Shore-D hardness and wood density. Additionally, Table 2 presents the best regressions obtained between hardness and density. The linear model using all of the samples obtained an R^2 of 0.854, which improved slightly to 0.876 when using only untreated wood. Gunduz *et al*. (2009) found linear relations between density and hardness of heat-treated hornbeam wood. Similar results were reported by Peng *et al*. (2016), who studied the influence of density and equilibrium moisture content on the hardness anisotropy of wood for three softwoods, Chinese fir, red pine, Mongolian scotch pine, and three hardwoods, Manchurian walnut, Asian white birch, and Mongolian oak. These authors reported different linear correlations for radial (R^2 = 0.72; R^2 = 0.88), tangential (R^2 = 0.44; R^2 = 0.77), and cross sections (R^2 = 0.33; R^2 = 0.88) for softwoods and hardwoods, respectively. Since in this study the measurement was made in tangential section, the obtained R^2 were higher than the obtained by Peng *et al*. (2016). Dumail *et al*. (1998) reported R^2 ranging from 0.53 to 0.88 for the relation between density and hardness of juvenile maritime pine wood. These authors also cited an earlier work made by Ylinen (1943) where a linear correlation was also obtained.

The potential model obtained better R^2 ranging from 0.860 for all samples to 0.909 for untreated samples. Similar results but with lower determination coefficients were reported before. Damayanti *et al*. (2020) reported several potential models relating density and hardness of young fast grown plantation teak with R^2 ranging from 0.51 for radial section to 0.53 for tangential section.

Nevertheless, the model that gave the best results was the exponential model with R^2 of 0.906 for all samples and 0.944. This model is presented in Fig. 2, and it seems to fit well the results.

Heat treatment seems to reduce the quality of the fittings since all the determination coefficients for heat treated wood alone were lower than the ones for untreated wood (Table

2), which is probably due to the chemical changes in wood due to heat treatment that transform wood into an altered material with different properties.

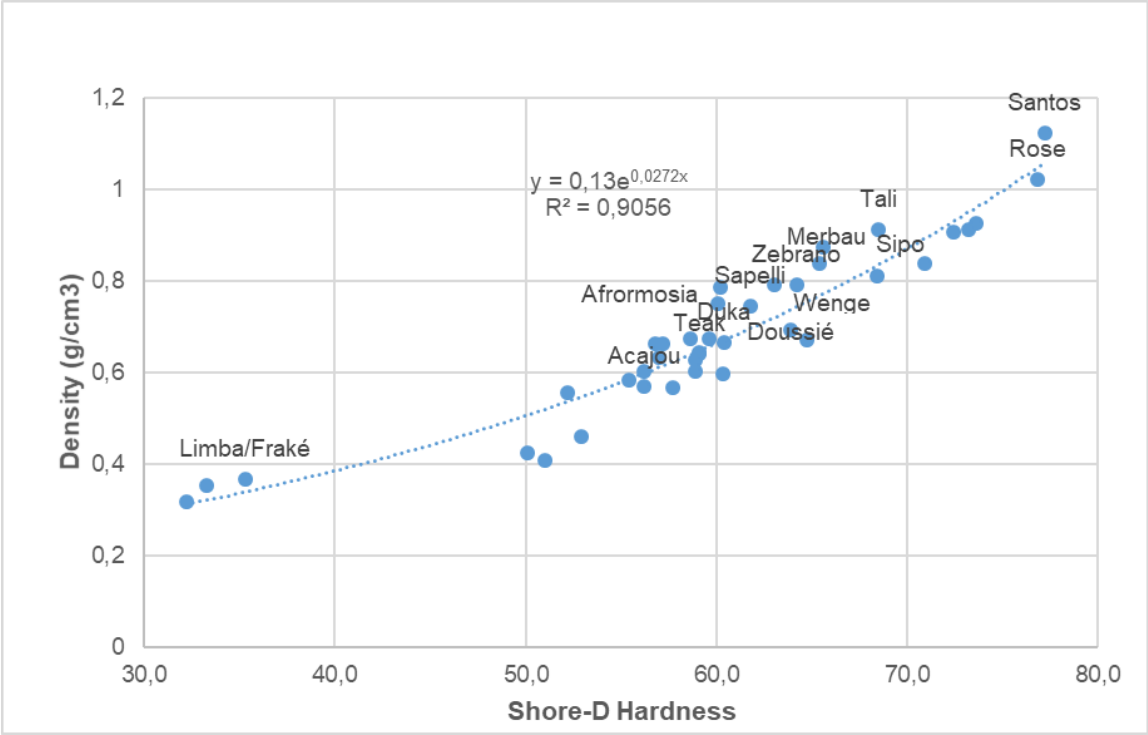

Fig. 2. Relation between Shore-D hardness and wood density

Table 2. Linear, Potential, and Exponential Regression Analysis for Untreated and Heat-treated Wood Alone or Together

Regression analysis	Untreated	Heat-treated	All
Linear	y = 0.0174x - 0.3443	y = 0.0163x - 0.2881	y = 0.0168x - 0.3159
	R^2 = 0.8758	R^2 = 0.8307	R^2 = 0.8542
Potential	$y = 0.0024x^{1.3807}$	$y = 0.0023x^{1.3869}$	$y = 0.0022x^{1.3977}$
	R^2 = 0.909	R^2 = 0.8321	R^2 = 0.8602
Exponential	$y = 0.1417e^{0.026x}$	$y = 0.1261e^{0.0276x}$	$y = 0.13e^{0.0272x}$
	R^2 = 0.9442	R^2 = 0.8832	R^2 = 0.9056

A two-way ANOVA test was performed to understand whether the Shore-D hardness was significantly different between wood species and varied heat treatments. The results are shown in Table 2. According to ANOVA tests, there was a significant difference between wood species at the chosen level of significance ($P \leq 0.05$). This difference can also be seen in Table 1 in the homogeneity groups where only Sipo, Tali, Santos, and Rose untreated wood belonged to the same groups, meaning that their Shore-D hardness was statistically similar. Parallel behavior was seen in treated wood. ANOVA tests also showed that there was a significant difference between various heat treatments, as discussed before. The interaction (Table 3) was also considered significant at the level $P \leq 0.05$, showing that the effect of heat treatment on hardness varied with wood species. In accordance with Salca and Hiziroglu (2014), the statistical analysis showed that hardness of the samples was mostly influenced by the heat temperature and the cumulative effect of treatment temperature and wood species.

Table 3. Variance Analysis Results for Shore-D Hardness Test Determined in Wood Species Before and After Heat Treatment

Sources	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Level of Significance
Wood Species (A)	37463.212	13	2881.786	1953.928	0.000*
Heat Treatment (B)	1984.933	2	992.467	672.919	0.000*
Interaction (AB)	460.667	26	17.718	12.013	0.000*
Error	557.500	378	1.475		
Total	1546113.000	420			
*: Significant (P ≤ 0.05)					

The results of the Shore-D hardness test singly carried out comparisons for each wood type and heat treatment and are given in Table 4. Again, these results clearly showed that there was a decrease in hardness of the tested wood species with the heat treatment.

Shore-D hardness is an efficient method to compare wood hardness. A main advantage of this method is that Shore hardness can be measured directly in a production line or in small wood companies without using a universal test machine. The knowledge of this hardness might help decision makers choose the right wood for each application.

Table 4. Results of Singly Carried Out Comparisons for Each Wood Type and Heat Treatment

Wood Type	Number of Measurements	Mean	*HG*
Limba/Fraké (*Terminalia superba*)	30	33.60	K**
Acajou d`Afrique (*Khaya anthotheca*)	30	52.83	J
Teak (*Tectona grandis* L.)	30	54.33	I
Afrormosia (*Pericopsis elata*)	30	56.13	H
Duka (*Tapirira guianensis*)	30	59.40	G
Sapelli (*Entandrophragma cylindricum*)	30	59.93	FG
Wenge (*Millettia laurentii*)	30	60.23	F
Doussié (*Afzelia africana*)	30	60.27	F
Zebrano (*Microberlinia brazzavillensis*)	30	61.50	E
Merbau (*Intsia bijuga*)	30	62.13	D
Sipo (*Entandrophragma utile*)	30	63.33	C
Tali (*Erythrophleum suaveolens*)	30	66.50	B
Santos (*Myroxylon balsamum*)	30	73.90	A
Rose (*Dalbergia nigra*)	30	74.13	A*
Heat Treatment	Number of Measurements	Mean	*HG*
Control (Untreated)	140	62.79	A*
212 °C for 1 h	140	59.25	B
212 °C for 2 h	140	57.58	C**
HG: Homogeneity Group, *: Highest Value, **: Lowest Value			

CONCLUSIONS

1. The Shore-D hardness of untreated wood ranged between 35.3 for Limba wood and 77.2 for Santos wood representing a wide range of hardness.
2. With heat treatment, hardness decreased for all the species studied, and the decrease was greater in samples with harsher treatment (2 h at 212 °C). The decrease in hardness was greater for Sipo wood (14%) and lowest for Afrormosia wood (2.5%). There seems

to be no relation between the degree of hardness decrease with heat treatment and the initial hardness of wood.

3. A close relation was found between density and Shore-D hardness. Hardness was higher for higher densities. The exponential model gave the best results followed by the potential model and the linear one.
4. ANOVA tests showed that there was a significant difference between wood species, heat treatment, and interaction between both variables at the chosen level of significance ($P \leq 0.05$).

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