The Effects of Heat Treatment with the ThermoWood® Method on the Equilibrium Moisture Content and Dimensional Stability of Wild Cherry Wood

Ayhan Aytin,[a,]* Süleyman Korkut,[b] Öner Ünsal,[c] and Nevzat Çakıcıer [b]

Low hygroscopicity is an important factor favoring the use of heat-treated wood materials. Hence, wild cherry (*Cerasus avium* (L.) Moench) wood was subjected to heat treatment with the ThermoWood® method for about 1 and 2 hours at temperatures of 190 and 212 °C in an industrial business. Then, trial samples were prepared and divided into two groups. By being conditioned in the environments of 20 °C and 65% relative humidity (WC1), 20 °C and 85% relative humidity (WC2), 20 °C and 30% relative humidity (WC3), and 23 °C and 50% relative humidity (WC4), equilibrium moisture content (EMC) and dimensional stability (DS) values of the samples in the first group were determined. The water thickness swelling (WTS) and water retention (WR) features of the samples of the second group were examined by keeping them in water both 24 and 72 h. The results show that EMC and WTS decreased with increasing treatment temperature and durations. Also, DS was improved. On the other hand, the WR values of all the samples stayed approximately the same.

Keywords: Dimensional stability; Equilibrium moisture content; ThermoWood®; Wild cherry; Water thickness swelling

*Contact information: a: Program of Furniture and Decoration, Duzce Vocational School, Duzce University, 81100, Duzce, Turkey; b: Department of Forest Industry Engineering, Duzce University, 81620, Duzce, Turkey; c: Department of Forest Industry Engineering, Istanbul University, 34473, Istanbul, Turkey; * Corresponding author: ayhanaytin@duzce.edu.tr*

INTRODUCTION

Although many alternative materials have been developed throughout history and also today, the dimensional changes emerging in connection with the hygroscopic features still impose various restrictions on the evaluation of the wooden materials in a wide application area. To reduce or to eliminate the problems which stem from dimensional changes, a variety of solutions are employed. For example, drying the wooden material to below 20% moisture is an important solution. The treatment of the wooden material with some toxic chemicals against biological degradation could also be performed for dimensional stability. However, increasing environmental awareness has caused researchers to search for alternatives to toxic chemicals, and the issue of preparing the wooden material with environmentally friendly technologies has become important (Johansson 2005).

In this regard, as a modification method, the heat treatment of the wood at elevated temperatures is seen as an alternative that is environmentally friendly (Li *et al.* 2011). That is because the improvements of the dimensional stability that are provided with thermal modification allow the wooden material to be used in areas such as garden and kitchen furniture, wall coating and flooring, and also saunas (Viitaniemi 2000).

Heat treatment, which is based on the basic idea of the heat treatment of the wooden material at the temperatures above 150 °C at which chemical reactions accelerate, leads to permanent changes in the chemical composition of the polymer compounds of the cell wall. Meanwhile, resistance against biological degradation is provided without any spoiling in the structure of the wood (Johansson 2005). According to Enjily and Jones (2006), heat treatment modifies the molecular structure of the wooden material so that a product with low equilibrium moisture content and reduced dimensional changes is obtained (Enjily and Jones 2006).

Heat treatment contributes to the dimensional stability of wood because the wood swells and shrinks due to water adsorption and desorption. Further reduction in the adsorption of water and expansion of the wood reduces all the constriction and increases its dimensional stability. Generally, heat-treated wood is fairly hydrophobic with low shrinkage and swelling values (Boonstra 2008; Korkut and Kocaefe 2009).

Wood hygroscopicity is influenced by the temperature and time during which heat is applied. In particular, heat treatment temperature is a very effective parameter. Because of the reduction in the hydroxyl groups of the wood, heat treatment causes the wood to hold water and the cell wall to absorb less water. With heat treatment, the equilibrium moisture content (EMC) of wood decreases by about 50% (Rapp 2001). Studies conducted with various tree species with a view to determining the effects of heat treatment on EMC, dimensional stability (DS), water thickness swelling (WTS), and water retention (WR) features have revealed that heat treatment contributes in a positive way in terms of the mentioned features. For example, in a study by Li *et al*. (2011) conducted with Douglas fir (*Pseudotsuga menziesii*), it was found that DS is increased by heat treatment, with lower values obtained with higher temperatures and longer duration, and the reduction in the volumetric expansion increased. The study found that EMC was decreased 42.63%, WR was decreased 34.93%, and volumetric expansion was decreased 67.47% in heat-treated samples compared to UT samples. Poncsak *et al*. (2011) emphasized that increasing the temperature of the heat treatment will contribute to the increase in DS. Dubey (2010) indicates that DS increased 60% in radiata pine heat-treated with linseed oil at temperatures of 160 to 210 °C. Similar results have been reported by Srinivas and Pandey (2012), Cademartori *et al.* (2012), and Bak and Nemeth (2012). In another study, Korkut and Budakçı (2010) reported that expansion of mountain ash (*Sorbus aucuparia* L.) decreased 25.68%, 25.10%, and 26.08%, respectively, on the radial, tangential, and longitudinal surfaces after heat treatment. Altınok *et al*. (2010) concluded that there was volumetric shrinkage and expansion decrease in heat-treated black pine (*Pinus nigra* var. pallasiana) and ash (*Fraxinus excelsior* L.) woods.

Although there have been many studies, the vast majority of them have been laboratory studies. For industrial purposes, by researching a large number of species with heat treatment methods like ThermoWood®, the results must be demonstrated, since this is a main issue for heat-treatment users. ThermoWood® is a heat treatment method developed by VTT (Finland). The wood material is heated to a temperature of at least 180 °C while it is protected with steam. With ThermoWood®, some properties of the wood material are enhanced: the colour darkens and becomes more stable than normal wood in conditions of changing humidity. Heat treatment clearly reduces the EMC of wood, and at high temperatures (220 °C), the EMC is about half that of untreated wood. Additionally, its thermal insulation properties are improved. If carried out at a sufficiently high temperature, treatment also makes the wood resistant decay. On the other hand, the treatment causes a decrease in the bending strength (Anonymous 2003).

The aim of this study is to reveal the contributions for the places of use by determining the differences in physical properties such as EMC, DS, WR, and WTS of wild cherry (*Cerasus avium* (L.) Moench) wood heat-treated with the ThermoWood® method, which is the most industrialized and commonly used method.

EXPERIMENTAL

Materials

Five trees with a diameter at breast height of 30 to 50 cm were harvested from mixed stands in Duzce, Turkey. The trees used in the study were chosen in accordance with TS 4176 (1984), and turned into planks used for sample preparation according to TS 2470 (1976). Planks were exposed to heat treatment with the ThermoWood® method at 190 and 212 °C for 1 and 2 h in the Novawood Factory, Gerede, in Bolu Turkey.

Methods

The numbers of samples were determined according to TS CEN/TS 15679 (2010). Then, a total of 100 (50 × 2) test samples, including 10 pieces for each variation, with dimensions of 20 mm × 20 mm × 30 mm for EMC and DS tests and 10 mm × 50 mm × 50 mm for WR and WTS tests, were prepared. To determine the change rates as percent, Eq. 1 was used,

$$D = [I - E] / I \times 100 \,(\%) \tag{1}$$

where D is the change between the initial measure and final measure as a percent; I is the initial measure; and E is the final measure. At the same time, this formula was used to calculate the percent change for EMC and DS.

Determination of equilibrium moisture content (EMC) and dimensional stability (DS)

To determine the EMC, the prepared test samples were first prepared in oven dry form (DF). Afterwards, according to TS CEN/TS 15679, the EMC of the samples was determined at a temperature of 20 °C and a relative humidity (RH) of 65% (WC1). In addition, for humid and exterior applications, the EMC was determined also at 20 °C and RH 85% (WC2), and for applications in dry conditions, the EMC was determined at 20 °C and RH 30% (WC3).

Finally, for flooring applications, in dry conditions, the EMC was determined at 23 °C and RH 50% (WC4). At the end of each stage, the weights of the test samples for EMC and sizes for DS were determined with a IB600 laboratory testing machine (Divapan Integrated Inc., Duzce, Turkey) (Fig. 1).

The IB600 has been designed to conduct a series of laboratory tests on wood-based samples, particleboard samples, MDF, OSB, or similar products. The machine consists of a motorised column capable of highly accurate speed control, fitted with a two-way (push and pull) load cell, and on which it is possible to mount special utensils to perform the individual tests. Furthermore, the system includes of a precision weighing scale, a dimensions gauge, PC, monitor and printer, and utensils for conducting the tests (Anonymous 2014).

Fig. 1. The measurement of dimensions and weight at the IB600 laboratory testing machine

Expansion quantities from DF to WC1 and to WC2 were calculated for dimensional stability. Then, based on WC2 values, the narrowing quantities to WC3 and to WC4 were determined.

Determination of water retention (WR) and water thickness swelling (WTS)

The prepared test samples were used to determine WTS and WR. The samples were conditioned at 20 ± 2 °C and 65 ± 5% RH until the weight was unchanged.

The test pieces were immersed in 20 ± 1 °C water with a pH value of 7.0 ± 1.0 vertically and to the bottom of the water tank so as not to touch the sides (Fig. 2). According to TS EN 317 (1999), the upper parts of the test pieces must be inside the water approximately 25 ± 5 mm. After 24 and 72 h, the test sample immersion process measurements were taken by pouring off the excess water. The WTS and WR were then calculated as a percentage according to Eq. 1.

Fig. 2. Preparation of the test samples for WTS and WR

The values obtained from the experiments were evaluated with SPSS 15.0 for Windows Evaluation Version (IBM, USA). Statistical evaluation of the results, made basic variance analysis (BVA) and multivariate variance analysis (MVA) using SPSS and significant differences between average values of control and treated samples were determined using Duncan's multiple range test at a P-values of 0.05 (Korkut *et al*. 2013).

RESULTS AND DISCUSSION

Equilibrium Moisture Content (EMC)

The results of MVA conducted to determine the effects of the heat treatment (HT) and weather conditions (WC) on EMC are given in Table 1.

Table 1. MVA of Effects of the HT and WC on the EMC

Source	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared
Intercept	11674.8	1	11674.8	29421	0.001	0.994
WC	913.3	3	304.4	767	0.001	0.927
HT	790.5	4	197.6	498	0.001	0.917
WC**HT	98.6	12	5.7	14	0.001	0.490
Error	71.4	180	0.0			
Total	13518.7	200				

According to Table 1, the WC and HT factors seem to have a very strong influence on EMC. Additionally, the effect of WC (0.927) seems to be slightly higher than the effect of the HT (0.917). The Duncan test determined if there were significant differences among the arithmetic mean (Mean), standard deviation (SD), and the homogeneity groups (HG) of the EMC values of the test samples formed in different climatic conditions (Table 2).

Table 2. Change in EMC Values According to WC

Specimen Quality		WC1		WC2		WC3		WC4	
UT	Mean	9.61	E*	15.18	E*	6.58	D*	8.66	D*
	SD	0.66		0.94		0.17		0.36	
190 °C 1 h (HT_1)	Mean	9.11	D	13.53	D	5.79	C	7.82	C
	SD	0.18		0.31		0.16		0.13	
190 °C 2 h (HT_2)	Mean	7.32	C	11.26	C	5.10	B	6.63	B
	SD	0.77		1.17		0.40		0.64	
212 °C 1 h (HT_3)	Mean	5.49	B	8.32	B	3.93	A	5.10	A
	SD	0.46		0.77		0.29		0.41	
212 °C 2 h (HT_4)	Mean	4.95	A	7.45	A	3.75	A	4.73	A
	SD	0.54		0.96		0.42		0.55	
*Groups with the same letters in each column indicate that there is no statistical difference ($p<0.05$) between the samples according to the Duncan's multiple range test									

According to Table 2, EMC appears to decrease depending on the increase of the heat treatment temperature and duration. Wetzig *et al.* (2011) state similar results in their study.

Considering all WC, it was found that the highest EMC values belonged to the UT, while the lowest values belonged to the samples of HT_4. In the samples of HT_4, the values were 48.29, 50.92, 43.00, and 45.38% lower than the EMC values, respectively, compared to UT that were obtained in the conditions of WC1, WC2, WC3, and WC4. The change of the EMC values are given Fig. 3 in the HT samples according to UT.

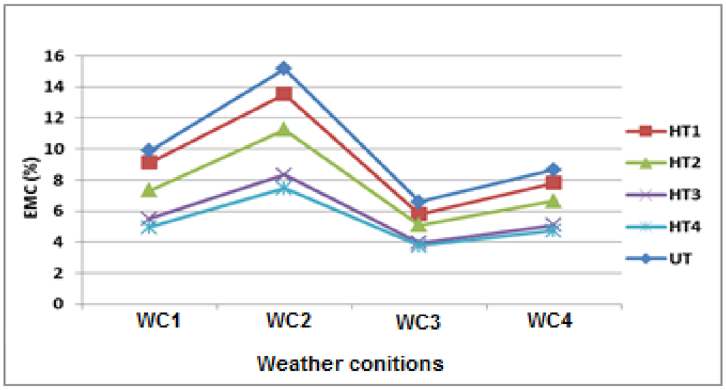

Fig. 3. The change of the EMC in the HT samples according to UT samples

Dimensional Stability (DS)

The results related to DS were divided into two groups. Initially, the results obtained under the conditions of WC1 and WC2 according to DF were analyzed. The multiple variance analysis results related to the changes in DS at volumetric (V), tangential (T), and radial (R) directions are given in Table 3.

Table 3. MVA Results (WC1 and WC2)

Specimen Quality	Source	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared
V	Intercept	2741.465	1	2741.465	7965.955	0.001	0.989
	WC	84.144	1	84.144	244.499	0.001	0.731
	HT	187.874	4	46.969	136.478	0.001	0.858
	WC*HT	10.270	4	2.567	7.460	0.001	0.249
	Error	30.973	90	0.344			
	Total	3054.726	100				
T	Intercept	885.420	1	885.420	5103.917	0.001	0.983
	WC	34.810	1	34.810	200.659	0.001	0.690
	HT	51.457	4	12.864	74.155	0.001	0.767
	WC*HT	5.122	4	1.281	7.382	0.001	0.247
	Error	15.613	90	0.173			
	Total	992.422	100				
R	Intercept	382.515	1	382.515	3308.715	0.001	0.974
	WC	7.874	1	7.874	68.106	0.001	0.431
	HT	31.461	4	7.865	68.034	0.001	0.751
	WC*HT	0.592	4	0.148	1.281	0.001	0.054
	Error	10.405	90	0.116			
	Total	432.847	100				

It can be seen in Table 3 that the effects of HT and of the WC on DS were significant, with some significant differences except WC*HT interaction occur among groups, at the level of $P \leq 0.05$, in the radial direction. As is evident from the values in column partial eta squared (PEA), heat treatment had a higher effect on DS than the WC. It is understood from the significance ($P > 0.05$) column that the effect of the interaction of the HT and WC on DS was lower than the effects of the factors individually; there was no difference even among groups in the radial direction (PEA 0.054).

The results of mean of standard error (SE) and of the Duncan test are related to the amount of expansion and were conducted to determine the significance of differences among groups in DS at WC1 and WC2 conditions. These values are given in Table 4.

Table 4. Mean, SE, and Duncan Test Results Related to the Expansion at Conditions WC1 and WC2

SQ	T			R			V		
	Mean	HG*	SE	Mean	HG*	SE	Mean	HG*	SE
UT	4.07	E	0.093	2.76	E	0.076	7.31	E	0.131
HT_1	3.42	D		2.42	D		6.17	D	
HT_2	2.87	C		1.80	C		4.99	C	
HT_3	2.40	B		1.34	B		3.97	B	
HT_4	2.01	A		1.26	A		3.46	A	

*Groups with the same letters in each column indicate that there is no statistical difference ($p<0.05$) between the samples according to the Duncan's multiple range test

According to Table 4, the greatest change was found in the UT samples, while the lowest change was found in HT_4 test samples. The expansion values of HT_4 samples occurred in the T, R, and V directions, 50.61, 54.34, and 52.66%, respectively, being lower than UT samples.

The dimensional changes of the test samples in WC1 and WC2 according to DF are given in Fig. 4. Taking WC2 values as a basis, BVA results related to the dimensional changes which occur according to WC2 at the conditions of WC3 and WC4 are given in Table 5.

Table 5. BVA Results Related to WC3 and WC4 According to WC2

SQ		WC3*				WC4*			
		Sum of Squares	df	MS	F	Sum of Squares	df	MS	F
T	Between Groups	17.744	4	4.43	42.33	14.511	4	3.628	32.573
	Within Groups	4.715	45	0.10		5.012	45	0.111	
	Total	22.458	49			19.523	49		
R	Between Groups	8.162	4	2.04	26.054	5.957	4	1.489	5.312
	Within Groups	3.524	45	0.07		12.617	45	0.280	
	Total	11.687	49			18.574	49		
V	Between Groups	45.091	4	11.27	25.46	38.666	4	9.666	25.312
	Within Groups	19.917	45	0.44		17.185	45	0.382	
	Total	65.008	49			55.851	49		

* $p<0.05$

According to Table 5, it is understood that there are significant differences at the level of $P \leq 0.05$ among the dimensional stability values of all the variations at the conditions of both WC3 and WC4.

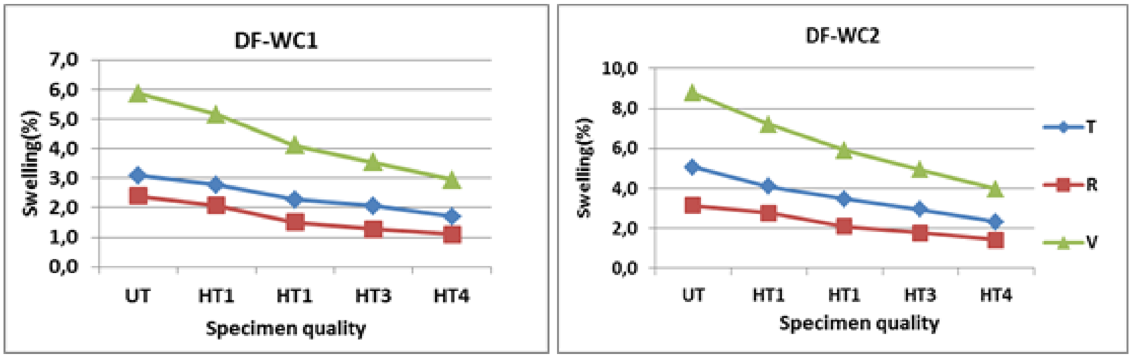

Fig. 4. The quantities of dimensional change at the conditions of WC1 and WC2 (%)

Duncan tests were conducted to determine the way of the differences between control and heat-treated variations, which are given with mean and SD values in Table 6.

Table 6. Mean, SD, and Duncan Test Results at Conditions WC3 and WC4

SQ		T			R			V		
		Mean	HG*	SD	Mean	HG*	SD	Mean	HG*	SD
WC3	UT	2.86	D	0.31	1.83	D	0.43	4.76	D	0.53
	HT_1	2.23	C	0.27	1.51	C	0.26	3.81	C	0.39
	HT_2	1.78	B	0.35	1.08	B	0.27	2.93	B	0.6
	HT_3	1.45	A	0.20	0.82	B	0.11	2.66	B	1.04
	HT_4	1.18	A	0.43	0.79	A	0.22	2.04	A	0.44
WC4	UT	2.30	D	0.32	1.52	D	0.31	3.94	D	0.63
	HT_1	1.72	C	0.30	1.08	C	0.28	2.90	C	0.44
	HT_2	1.39	B	0.36	0.82	B	0.15	2.26	B	0.47
	HT_3	1.01	A	0.37	0.6	AB	0.12	2.01	B	0.99
	HT_4	0.77	A	0.28	0.46	A	0.47	1.35	A	0.31

*Groups with the same letters in each column indicate that there is no statistical difference ($p<0.05$) between the samples according to the Duncan's multiple range test

According to the results of the Duncan test, DS values of all heat-treated groups were different from the UT control samples. Based on the changes in sizes from WC2 to WC3, the highest values were found in the control samples, while the lowest values were found in the HT_4 samples. According to UT, change of DS values in WC3 and WC4 are given as percent in Fig. 5.

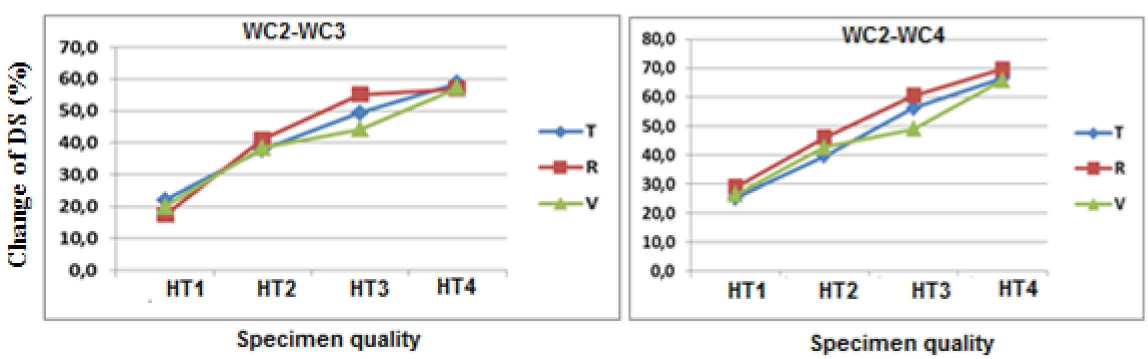

Fig. 5. Change of DS values in WC3 and WC4 (%) according to UT

Likewise, based on the changes in sizes from WC2 to WC4, the highest values were found to be in UT while the lowest values were found to be in HT_4 samples. According to WC2 the change of the DS values are given Fig. 5.

Water Retention (WR) and Water Thickness Swelling (WTS)

The results of BVA for WTS and WR values after being held in water for 24 and 72 h are given in Table 7.

Table 7. BVA Results Related to WTS and WR Values

SQ		WTS*				WR*			
		Sum of Squares	df	MS	F	Sum of Squares	df	MS	F
24 h	Between Groups	36.446	4	9.111	15.5	113.120	4	28.280	1.01
	Within Groups	26.434	45	0.587		1250.74	45	27.794	
	Total	62.879	49			1363.86	49		
72 h	Between Groups	80.559	4	20.140	14.7	235.809	4	58.952	0.70
	Within Groups	61.363	45	1.364		3739.52	45	83.100	
	Total	141.92	49			3975.32	49		

* p<0.05

According to the BVA results, there are significant differences at the level of $P < 0.05$ among WTS results of all groups which were found after being held in water for 24 and 72 h ($P < 0.05$); however, there was no significant difference among WR values ($P > 0.05$). Statistical values of the features of WTS and WR are given in Table 8 with Duncan test results.

Table 8. Mean, SD, and Duncan Test Results Related to WTS and WR

SQ		WTS (%)				WR (%)			
		24 h		72 h		24 h		72 h	
UT	Mean	3.35	C*	4.92	C*	19.43	A*	31.24	A*
	SD	0.78		1.64		1.16		1.50	
HT_1	Mean	2.45	BC	6.42	B	20.87	A	37.09	A
	SD	0.45		0.83		6.99		10.15	
HT_2	Mean	1.60	AB	2.03	AB	17.88	A	31.69	A
	SD	1.24		1.62		4.33		11.09	
HT_3	Mean	1.26	A	2.00	AB	16.69	A	33.35	A
	SD	0.47		0.58		4.34		7.23	
HT_4	Mean	1.01	A	1.41	A	20.02	A	35.09	A
	SD	0.58		0.65		7.13		11.60	

*Groups with the same letters in each column indicate that there is no statistical difference (p<0.05) between the samples according to the Duncan's multiple range test

In the HT wild cherry (*Cerasus avium* (L.) Moench) test samples, the WTS rate decreased compared to UT test samples except for the HT_1 samples. After both 24 h and

72 h of being immersed in water, the lower WTS values were determined in the HT_4 test samples. However, between heat treatment variations, values were quite close together. On the other hand, between WR values of all the samples, there was no significant difference in each of the submerged variations.

CONCLUSIONS

1. Positive results were obtained in the features of wild cherry (*Cerasus avium* (L.) Moench) wood heat-treated with ThermoWood® Method with respect to the temperature and duration of the heat treatment.
2. The EMC was reduced remarkably with heat treatment. This is a significant change, as seen in Table 2.
3. Low EMC points to the fact that wooden material becomes more hydrophobic with heat treatment. The increase in hydrophobicity will contribute to the increase in DS. According to the study results, it was observed that important improvements were obtained and dimensional change decreases as a result of heat treatment in DS.
4. The WTS decreases significantly with heat treatment.
5. As a result, wild cherry (*Cerasus avium* (L.) Moench) wood to which ThermoWood® was applied at high temperatures such as 212 °C is preferred in places of use where there is contact with relative humidity or water and no dimensional problem is encountered.

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