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COLOUR AND DIMENSIONAL MODIFICATIONS OF SOLID WOOD PANELS MADE FROM HEAT-TREATED SPRUCE WOOD AFTER THREE MONTHS OF OUTDOOR EXPOSURE

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Abstract

The paper presents the results of an experimental research performed with spruce wood (Picea abies L.), originating from mature trees and thinnings cut from the same forest parcel from the Stroesti-Arges region in Romania. Solid wood panels were manufactured, both from heat-treated and untreated strips. The panels were open-air exposed for three winter months, in order to evaluate the colour and dimensional modifications which may occur if this material is used under outdoor conditions. The results showed that the panels made from heat-treated wood strips swelled by up to 74% less in case of mature wood and by up to 60% less in the case of juvenile wood. The colour of the heat-treated wood panels got lighter in time, the total colour change after three months ranging up to ΔE=12, while the panels made from untreated wood strips suffered severe darkening during the period of open-air exposure (ΔL*=-16) and their total colour change ranged up to ΔE*=19. The overall conclusion of this research is that both mature and juvenile spruce wood are suitable for outdoor uses from the viewpoint of dimensional stability, but the severe colour modification (from glossy dark brown to glossy silver) after only three months of open-air exposure must be taken into consideration.*

Key words: *solid wood panels; spruce; outdoor uses; colour stability; dimensional stability.*

INTRODUCTION

Wood is a vivid material. When exposed to outdoor conditions it tends to change its shape and dimensions due to moisture variations. Therefore, in the past it was considered a non-suitable material for outdoor uses, but this is no longer valid, since researchers found a way to improve its dimensional stability through heat treatment. Thermal modification of wood was scientifically studied already in the 1930s in Germany and in the 1940s in the United States. More recent research work was carried out in the Netherlands, France and Finland in the 1990s. One industrial scale thermal wood modification process, the ThermoWood®process, was developed in Finland and the main collected research information was published in the ThermoWood® Handbook (2003), which serves up to this day as main guidebook to this heat treatment process. During the last decade, numerous other researches were performed worldwide with various species, different treating agents and treating parameters, in order to explore into depth the potential of this technology.

The present research deals with the possibility to valorize small-sized wood grades (strips) through heat-treatment in order to use them for solid wood panels for outdoor uses (e.g. veranda floorings). To this purpose, two parameters seemed of outstanding importance to decide on this possible application: the dimensional stability and the colour stability of these panels when exposed under outdoor conditions.

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Colour is an important aesthetic characteristic of wood, considering that many objects that surround us in our daily life are made of wood and are meant to increase our comfort. When heat-treating wood, its colour becomes darker, the surfaces become smoother and glossy. Thus, without any addition of chemical substances (as in the case of various coatings), the aesthetical value of wood is increased, only due to the high temperature applied within such a treatment (160…260°C).

The colour change which wood undergoes through a heat treatment is mainly due to changes in its chemical composition. This mechanism and its effect upon various wood species was described by several authors (Akgül and Korkut 2012; Allegretti et al. 2012; Esteves et al. 2008; Gonzales-Peña and Hale 2009; Karlsson et. al. 2012; Sehlstedt-Persson 2003).

In time, and especially when it is exposed to outdoor conditions, wood also suffers colour changes. UV radiation, direct water contact, air moisture variations, air currents, biological agents (fungi, insects) are the main factors which generally cause these colour changes (Williams 2005).This is a topic of major interest when we refer to heat-treated wood since this is mainly destined to outdoor uses. Ayadi et al. (2003) found that retified maritime pine wood heat-treated at 240°C for 2h under nitogen is 3 times more colour-stable than untreated wood: its total colour change was $\Delta E^*_{heat\text{-}treated}=8$ after 835h of artificial weathering with UV light, while $\Delta E^*_{untreated}=26$ under the same conditions. Unlike this result, Karlsson and Morén (2010) obtained that spruce wood heat-treated by the ThermoWood technology suffered significant lightness increase (colour lightening) after open air exposure during summer ($\Delta L^*=7$ after 2 weeks, $\Delta L^*=16$ after 4 weeks and $\Delta L^*=20$ after 7 weeks).

OBJECTIVE

The main objective of the present research was to evaluate the colour and dimensional changes which may occur in solid wood panels made from heat-treated spruce wood strips, compared to those made from untreated wood, after 1, 2 and 3 months of open-air exposure (December 2013 – March 2014). Both the heat-treated and the untreated wood strips being cut from mature and juvenile wood, respectively, the comparative behaviour of these two wood grades was also investigated.

MATERIAL, METHOD, EQUIPMENT

The wooden material used in the present research consisted of 1100 x 110…170 x 30mm boards, cut from 3 mature logs (Φ = 30 ... 35cm) and 7 thin logs resulted from thinnings (Φ = 15 ... 16 cm), all originating from the same forestry areal: Stroesti – Arges (45° 8' 0" North, 24° 47' 0" East). The boards were kiln-dried down to a moisture content of 12%. These were then planed and sectioned down to 340x110…170x28mm. Hereinafter, half of the samples were heat-treated in a BINDER electric oven, according to the schedule presented in Table 1, and the other half of samples were kept untreated, as controls.

The parameters for the actual heat-treatment phase (Table 1) were established based on some preliminary experiments with various combinations of temperature and time so as to reach a 5% mass loss (ML) of the strips. This criterion was grounded on Viitaniemi et al. (1997), who found that ML=5% is a threshold value, which ensures maximum efficiency of the heat treatment in case of spruce wood, without affecting its mechanical strengths.

Table 1

Heat-treating conditions

Phases	Parameters
Oven-drying	103°C
Heating	180°C/8h
Actual heat treatment	200°C/10h
Cooling	20°C/12h

The heat-treated wood strips were conditioned for 2 weeks, in order to reach 12% m.c, same as the untreated controls and then 300x300x20mm panels were manufactured,according to the scheme presented in Fig. 1. A set of eight panels was manufactured for each test and from each wood grade (mature heat-treated, juvenile heat-treated, mature untreated and juvenile untreated wood strips).

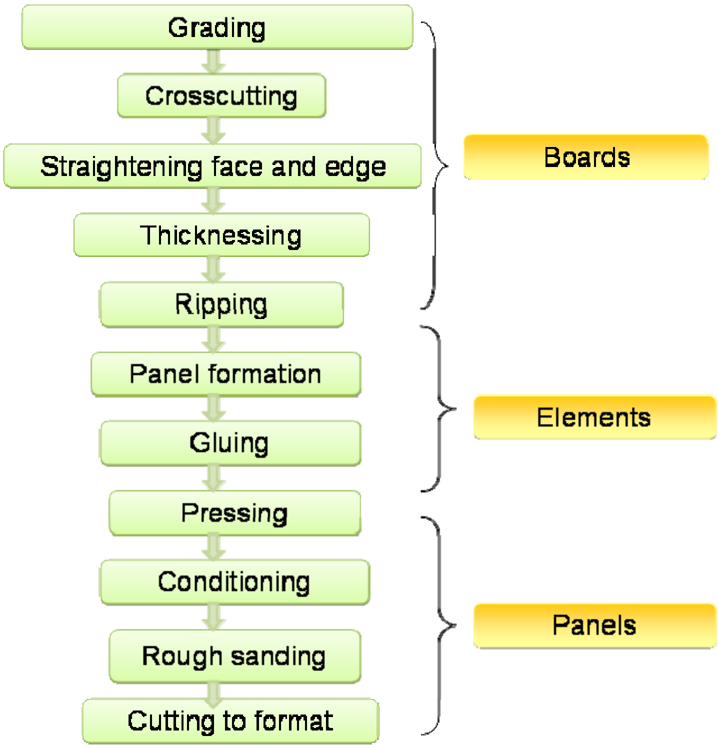

Fig. 1.
Manufacturing of the solid wood panels - Sequence of technological operations.

The next step within the experimental research consisted in determining the panel dimensions by means of the OPTOdesQ Measurement Table (Fig. 2), endowed with a magnetic 3D measuring system. The same equipment was used to determine the panels dimensions after 1, 2 and 3 months of open-air exposure. Based on these values, the swelling of the panels in each direction, and then their volumic swelling could be assessed. Furthermore, based on the calculated volumic swelling coefficients, it was also possible to evaluate the dimensional stabilization effect of the heat treatment.

The colour evaluation of the panels was performed by means of a AVANTES AVA SPEC 2048 spectrophotometer in nine points (Fig. 3), using the CIELab System.

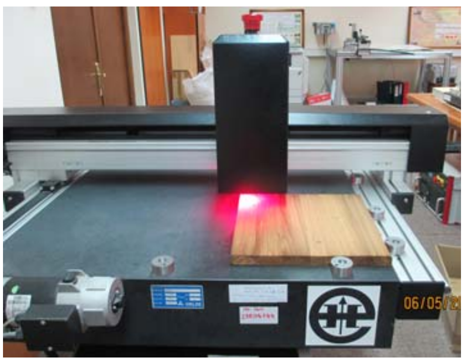

Fig. 2.
OPTOdesQ Measurement Table used to assess the panel dimensions.

Fig. 3.
AVANTES AVA SPEC 2048 spectrophotometer used for the colour stability evaluation of the panels.

After the initial assessment of colour and dimensions, the panels were open-air exposed for three months (December 2013 – March 2014). The exposure stand is presented in Fig. 4. The panels were placed 1m high from the ground, half in horizontal and half in vertical position. The environmental temperature and relative air humidity were measured daily at the same time, their variation being presented in the graph in Fig. 5. The monthly average values are given in Table 2.

Fig. 4.
Experimental open-air exposure stand of the untreated and heat-treated spruce wood panels.

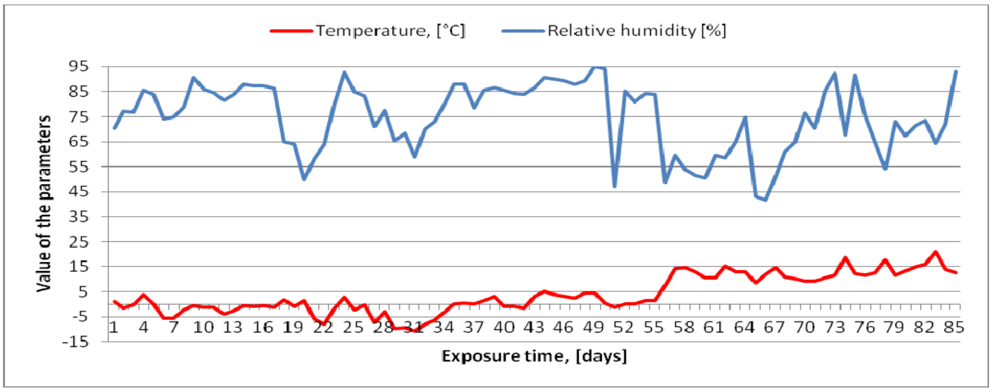

Fig. 5.
Variation of temperature and relative air humidity during the three months of open-air exposure of the panels

Table 2

Average values of climatic conditions during the open-air exposure period

Time of exposure	Temperature [°C]	Relative air humidity [%]
15 December - 15 January	-1,37	79,83
16 January - 15 February	-0,88	81,94
16 February – 15 March	11,65	46,54

After each month of exposure, the colour and dimensions of the panels were measured again.

Colour Change

The colour change was calculated for each colour coordinate (L^*, a^* and b^*) as related to its initial value on the same panel and in the same point. Finally, the total colour change (ΔE^*) was calculated in each point, according to equation (1):

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$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

where:
ΔL^* is the luminosity change in the respective point after open-air exposure compared to initial value:

$$\Delta L^* = L^*_{exposed} - L^*_{initial} \quad (2)$$

Δa^* is the change of the red-green coordinate in the respective point after open-air exposure compared to initial value:

$$\Delta a^* = a^*_{exposed} - a^*_{initial} \quad (3)$$

Δb^* is the change of the yellow-blue coordinate in the respective point after open-air exposure compared to initial value:

$$\Delta b^* = b^*_{exposed} - b^*_{initial} \quad (4)$$

The average of the nine ΔE^* values obtained on the same panel was considered as total colour change of the respective panel.

Dimensional Stability

Based on the panel dimensions (length *L*, width *B* and thickness *H*) measured initially (before open-air exposure) and after each month of exposure, the volumic swelling coefficient (α_v) was calculated according to equation (5) for each panel:

$$\alpha_v = \frac{L \cdot B \cdot H_{exposed} - L \cdot B \cdot H_{initial}}{L \cdot B \cdot H_{initial}} \cdot 100 \text{ [\%]} \quad (5)$$

Furthermore, the anti-swelling efficiency (ASE), as main indicator of the dimensional stabilization effect of the heat treatment was calculated according to equation (6), considering α to be the average value of the eight α_v – values obtained for the whole panel set of each type.

$$ASE = \frac{\alpha_{untreated} - \alpha_{treated}}{\alpha_{untreated}} \cdot 100 \text{ [\%]} \quad (6)$$

RESULTS AND DISCUSSION

Colour Changes

The colour changes suffered by the spruce wood panels as a consequence to open-air exposure for three months are illustrated in Table 3.

Table 4 presents the values of the luminosity change (ΔL^***)** and of the total colour change (ΔE^*) after each month and on each type of panel.

By comparing heat-treated to untreated panels, the first thing one can notice is that the heat-treated panels display the tendency of getting lighter (positive values of ΔL^*), while the untreated ones get darker (negative values of ΔL^*).

The lightening tendency of the heat-treated panels is stronger during the first two months (Fig.6), both for the mature wood panels and for the juvenile wood panels.

By comparing mature wood panels and juvenile wood panels, one may notice that the colour changes are always slightly higher with the juvenile panels.

Table 3
Colour modification of the spruce wood panels after 3 months of open-air exposure compared to the inital state

Wood type	**Panels made from heat-treated wood**		**Panels made from untreated wood**	
	Initial state	**After 3 months of open-air exposure**	**Initial state**	**After 3 months of open-air exposure**
Mature spruce				
	L^*=48.11 a^*=10.72 b^*=19.88	L^*=57.12 a^*=7.50 b^*=19.45	L^*=86.02 a^*=4.44 b^*=17.64	L^*=70.03 a^*=8.55 b^*=24.94
Juvenile spruce				
	L^*=49.35 a^*=10.76 b^*=22.35	L^*=58.23 a^*=7.22 b^*=17.85	L^*=86.77 a^*=3.44 b^*=16.55	L^*=70.19 a^*=8.23 b^*=24.16

Table 4
Luminosity change (ΔL*) and total colour change (ΔE*) of the spruce wood panels after 1, 2 and 3 months of open-air exposure

Panel type	**After 1 month**		**After 2 months**		**After 3 months**	
Mature heat-treated						
	ΔL^*=4,26	**ΔE^*=5,89**	**ΔL^*=8,44**	**ΔE^*=9,44**	**ΔL^*=9,00**	**ΔE^*=9,89**
Juvenile heat-treated						
	ΔL^*=5,72	**ΔE^*=6,24**	**ΔL^*=9,64**	**ΔE^*=10,87**	**ΔL^*=10,58**	**ΔE^*=11,55**

Mature untreated						
	Δ*L=-8,95**	**Δ*E**=13,41**	**Δ*L**=-12,90**	**Δ*E**=16,56**	**Δ*L**=-15,99**	**Δ*E**=18,30**
Juvenile untreated						
	Δ*L=-9,63**	**Δ*E**=14,71**	**Δ*L**=-14,34**	**Δ*E**=17,74**	**Δ*L**=-16,58**	**Δ*E**=18,93**

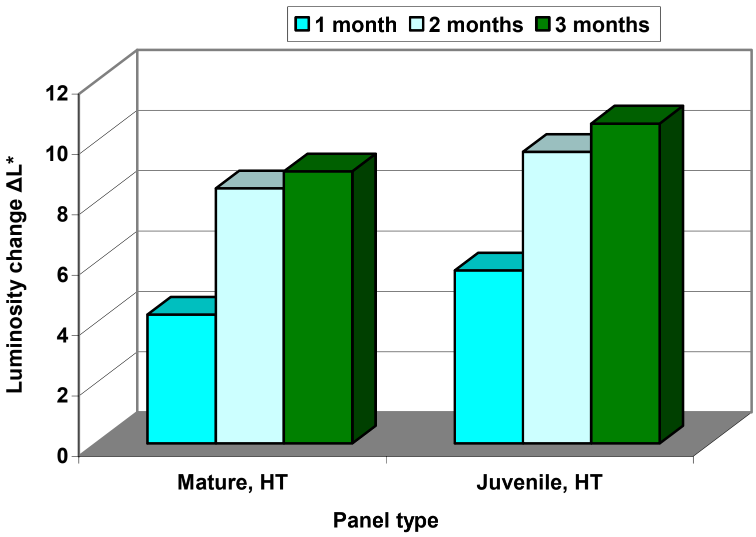

Fig. 6.
Luminosity change (ΔL*) of the heat-treated spruce wood panels after 1, 2 and 3 months of open-air exposure.

Dimensional Stability

The average volumic swelling coefficients determined for each spruce wood panel type after each month of open-air exposure are presented in Tables 5 - 8.

Table 5

Volumic swelling of panels made from heat-treated mature spruce wood, %

Time of exposure	M1	M2	M3	M4	M5	M6	M7	M8	Average
1 month	2,8	2,0	3,3	3,3	2,3	0,5	2,4	2,3	**2,4**
2 months	0,2	0,5	0,6	2,3	2,2	1,0	1,0	1,5	**1,2**
3 months	0,0	0,0	0,0	2,4	1,3	0,0	0,0	0,0	**0,5**

Table 6

Volumic swelling of panels made from heat-treated juvenile spruce wood , %

Time of exposure	S1	S2	S3	S4	S5	S6	S7	S8	Average
1 month	4,9	3,0	3,5	0,2	0,2	4,8	1,6	4,6	**2,9**
2 months	1,6	3,6	0,5	0,7	0,8	4,7	1,6	3.2	**2,1**
3 months	0,3	2,3	0,4	0,1	0,6	0,4	2,2	0,1	**0,8**

Table 7

Volumic swelling of panels made from untreated mature spruce wood , %

Time of exposure	NM1	NM2	NM3	NM4	NM5	NM6	NM7	NM8	Average
1 month	4,4	4,4	0,9	1,4	1,8	3,1	2,6	2,8	**2,7**
2 months	5,5	1,1	0,9	1,7	1,8	1,6	2,0	2,2	**2,1**
3 months	2,9	0,8	2,0	0,7	4,1	0,9	1,8	1,7	**1,8**

Table 8

Volumic swelling of panels made from untreated juvenile spruce wood, %

Time of exposure	NS1	NS2	NS3	NS4	NS5	NS6	NS7	NS8	Average
1 month	8,0	5,0	2,6	3,8	1,7	1,4	3,7	3,8	**3,8**
2 months	6,8	3,6	2,8	3,8	1,2	1,5	2,5	1,0	**2,9**
3 months	4,4	5,0	2,1	0,0	1,2	1,4	1,0	0,4	**2,0**

The obtained results show that the volumic swelling of the panels ranged between 2,4…3,8% after the first month and between 0,5…2,0% after the third month, the highest values being recorded for the panels made from untreated juvenile wood. With all panel types, it was obvious that the maximum swelling occurred after the first month, when the panels got accomodated with the humid environment, and then the swelling decreased with each further month.

By comparing the values obtained for the heat-treated vs. untreated panels, one can notice that the heat-treated wood panels swelled less: by 11% after the first month, by 45% after the second month and by 74% after the third month, in the case of mature wood, respectively by 24% less after the first month, by 28% after the second and by 60% after the third month in the case of the juvenile wood.

Fig. 7 presents the comparative values of the anti-swelling efficiency (ASE), calculated according to equation (6) after each month. It can be noticed that after the first month of exposure, the stabilization effect of the heat-treatment was stronger in the case of the juvenile wood, but after the second and third month, the ASE values were higher in the case of mature wood, ranging up to 74% after three months of open-air exposure.

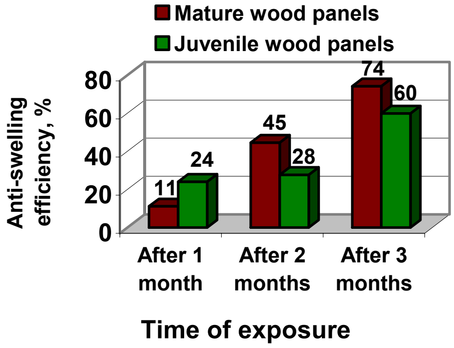

Fig. 7.

Anti-swelling efficiency of the heat treatment applied to mature and juvenile spruce wood strips used to manufacture solid wood panels for outdoor uses.

CONCLUSIONS

The results obtained within the present research demonstrated that heat-treating the spruce wood strips prior to their assembling within a solid wood panel may considerably increase the dimensional stability of this panel, making it suitable for outdoor uses. Both mature and juvenile spruce wood are suitable for this purpose. However, severe colour modification (from glossy dark brown to glossy silver) after only three months of open-air exposure must be taken into consideration.

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