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BRIEF ORIGINAL

Shape- and dimensional stability of solid wood panels made from heat-treated lime wood strips

M. C. Olarescu[1] · M. Campean[1] · C. Cosereanu[1]

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Abstract The paper presents the results of an experimental research performed with solid wood panels made from heat-treated and untreated lime wood (*Tilia cordata* Mill.) strips and then subjected to open-air exposure for 3 months. The dimensions of the panels were measured by means of an OPTODesQ Measurement Table, first after conditioning and sanding, then after each month of open-air exposure in order to assess their shape- and dimensional stability. After 3 months, the panels made from heat-treated wood strips showed up to 70% lower volumetric swelling and up to 143% lower flatness deviation than the panels made from untreated strips.

1 Introduction

Solid wood panels made from heat-treated wood strips are more and more involved in exterior arrangements such as claddings, veranda floorings, garden tables and benches. The chemical change that wood undergoes during heat treatment makes it less hygroscopic and thus, suitable for uses in direct contact with water or with a humid environment.

Wood and wood-based products for exterior applications are classified according to EN 335-2:2006 in the use class 3 (which includes unprotected outdoor uses, long-term exposure to rainfall and water in liquid or vapour state in a humid but well ventilated environment).

According to EN 1995-1-1 (2004) Eurocode 5, which assigns strength and deformation values of building structures under defined climatic conditions, solid wood panels made from heat-treated wood strips can be included in the service class 3, characterised by climatic conditions leading to moisture contents higher than 20%. For this class of service, the maximum allowed value of the deformation factor is $k_{def}=2.0$.

Many researchers worldwide investigated the effects of various heat treatment methods upon the dimensional stability of different wood species, but very few research reports refer to the dimensional stability or shape stability of solid wood panels made from heat-treated wood strips (Gurau et al. 2012; Gereke et al. 2008).

2 Objective of the present research

The present research aimed to evaluate the effect of the heat treatment in case of lime wood (*Tilia cordata* Mill.) by using a field test instead of the simulation in a climatic chamber. For this purpose, solid wood panels made from heat-treated lime wood strips and from untreated strips, respectively, were open-air exposed for 3 months on a covered and on an uncovered terrace (on the latter, the panels came into direct contact with rainfall and sunshine radiation, but they were situated above the ground, without direct soil contact). Shape- and dimensional stability were assessed after each month of exposure.

3 Material, method—equipment

The wooden material used in the present research consisted of $1100\times110\ldots170\times30$ mm boards, cut from

✉ M. Campean
campean@unitbv.ro

[1] Faculty of Wood Engineering, "Transilvania" University of Brasov, Str. Universitatii nr. 1, 500068 Brasov, Romania

three mature logs ($\Phi = 30 \ldots 35$ cm) of lime wood (*Tilia cordata* Mill.), originating from the Stroesti—Arges (45°8′0″N, 24°47′0″E) forestry areal. The boards were kiln-dried to a moisture content of 12%, then planed and sized down to 340 × 110…170 × 28 mm. Hereinafter, half of the samples were heat-treated in a BINDER electric oven in air, at atmospheric pressure and the other half of the samples was kept untreated, as controls.

The *heat treatment* consisted of four phases: oven-drying at 103 °C, then heating at 150 °C/6 h, followed by the actual heat-treatment at 200 °C/3 h and finally, cooling down to 20 °C in 12 h.

The parameters used for the actual heat-treatment phase 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 based on Viitaniemi et al. (1997), who found that $ML = 5\%$ is a threshold value, which ensures maximum efficiency of the heat treatment without affecting significantly the mechanical strengths of wood.

Both the heat-treated and the untreated wood strips were conditioned for 2 weeks at 20 °C/55% before being used for the manufacturing of the solid wood panels.

Thirty-two 300 × 300 × 20 mm^3 panels were manufactured, by using a PU adhesive Jowapur 687.22. Half of the panels were made from heat-treated strips and half from untreated strips. Whilst pressed, the panels were conditioned at 20 ± 2 °C and 55 ± 5% RH for 7 days and then sanded by means of a Rojek 1921 type sanding machine.

All panels were open-air exposed for 3 months (between April and June). Half of the panels (both treated and untreated) were exposed on an open terrace, with direct contact to rainfall and sunshine radiation (average temperature/relative air humidity: 14 °C/43%) (Fig. 1a, c), while the other half were exposed on a covered terrace, nearby (average climatic conditions: 17 °C/48%) (Fig. 1b, d).

The panel dimensions were measured on an OPTODesQ Measurement Table right after sanding (initial state, before open-air exposure) and then again, after each month of open-air exposure, as follows:

- The panel length was measured in longitudinal direction of the wood strips, along two lines (1–2 and 3–4 in Fig. 1e) and then their average was considered as length of the respective panel (*L*);
- The panel width was measured across the wood strips, along two lines (1–3 and 2–4 in Fig. 1e) and then their average was considered as width of the respective panel (*b*);
- The panel thickness was measured in five points (1–5 in Fig. 1e) and then their average was considered as thickness of the respective panel (*g*).

The dimensional stability of the panels was evaluated by calculating the swelling coefficients in panel length (*L*), width (*b*), thickness (*g*) and within the whole panel volume (α_v):

$$\alpha_v = \frac{L_{\max} \cdot b_{\max} \cdot g_{\max} - L_{\min} \cdot b_{\min} \cdot g_{\min}}{L_{\min} \cdot b_{\min} \cdot g_{\min}} \cdot 100 \quad (1)$$

where L_{min}, b_{min}, g_{min} are the panel dimensions in the initial state (after conditioning and sanding), in mm; L_{max}, b_{max}, g_{max} are the panel dimensions after 1, 2 and respectively 3 months of open-air exposure, measured along the same guidelines and points as in the initial state, in mm.

Based on the α_v values obtained after each month, the anti-swelling efficiency (*ASE*) of the heat treatment was assessed, according to Eq. (2):

$$\text{ASE} = \frac{\alpha_{v,untreated} - \alpha_{v,heat-treated}}{\alpha_{v,untreated}} \times 100\% \quad (2)$$

The shape stability of the panels was evaluated by calculating their flatness deviation (cupping). The maximum height of the panel curvature was assessed for each panel by means of the OPTODeskQ software.

4 Results and discussion

4.1 Dimensional stability

The average values of the swelling coeffcients in longitudinal direction (panel length), transversal direction (panel width) and the volumetric swelling, calculated on sets of eight panels for each testing condition, are given in Table 1.

As expected, the swelling in longitudinal direction of the panels was much smaller than over the width. The panels made from heat-treated strips did not swell at all longitudinally ($\alpha_v = 0$ in most cases—see Table 1), while the panels made from untreated strips recorded swelling coefficients of 0.086% (after 1 month of open-air exposure) up to 0.994% (after 3 months of open-air exposure).

The panels made from heat-treated strips did neither swell in transversal direction during the first month of open-exposure. After the second month, the panels from the uncovered terrace displayed a very small swelling value (0.786%) and after the third month it increased up to 0.844%. The panels from the covered terrace began to swell only during the third month of exposure. Their swelling value was two times lower compared to the panels made from untreated strips.

The *ASE* values calculated according to Eq. (2) showed that heat-treatment of the wood strips for solid wood panels has a major influence upon the dimensional stability of these panels when exposed to outdoor conditions. After 3 months of open-air exposure on the covered terrace,

Fig. 1 Materials and method: **a, b** open-air exposure of panels made from heat-treated strips and untreated controls on an uncovered terrace (**a**) and a covered terrace nearby (**b**). **c, d** Climatic conditions (temperature and relative air humidity) measured along the 3 months on the uncovered terrace (**c**) and on the covered terrace (**d**). **e** measuring directions and measuring points

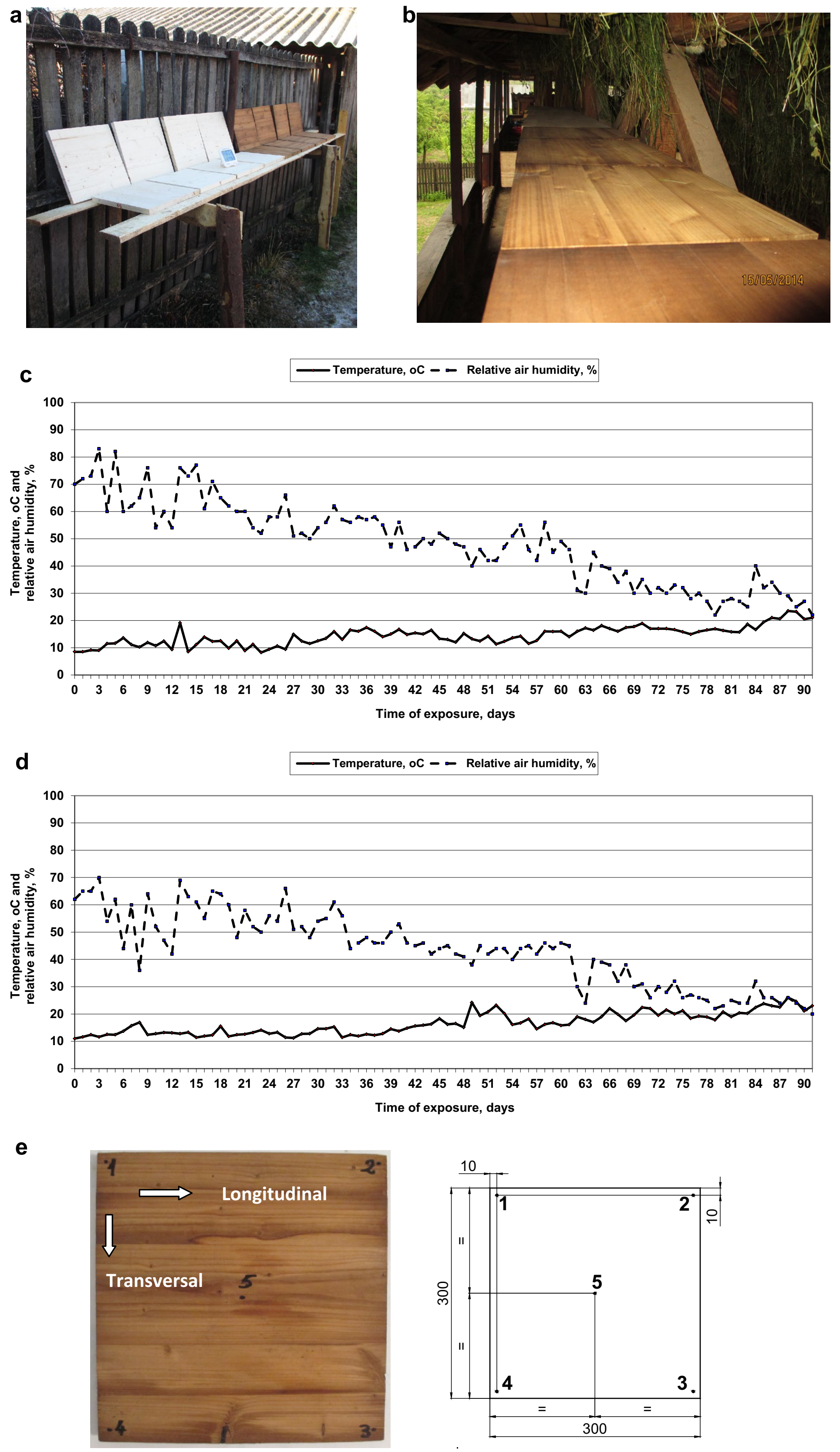

Table 1 Shape- and dimensional stability of lime wood panels after 1, 2 and 3 months of open-air exposure

Dimensional stability				
Type of exposure	Panel strips	Swelling in panel length (%)		
		After 1 month	After 2 months	After 3 months
Uncovered terrace	Heat-treated	0 ± 0.270	0 ± 0.221	0.013 ± 0.004
	Untreated	0.092 ± 0.045	0.184 ± 0.095	0.994 ± 0.561
Covered terrace	Heat-treated	0 ± 0.035	0 ± 0.021	0 ± 0.740
	Untreated	0.086 ± 0.154	0.119 ± 0.054	0.344 ± 0.120
		Swelling in panel width (%)		
Uncovered terrace	Heat-treated	0 ± 0.095	0.786 ± 0.245	0.844 ± 0.032
	Untreated	0.286 ± 0.245	1.567 ± 0.564	1.615 ± 1.212
Covered terrace	Heat-treated	0 ± 0.164	0 ± 0.936	0.500 ± 1.694
	Untreated	0.221 ± 1.431	0.562 ± 0.468	1.084 ± 0.176
		Volumic swelling of the panel (%)		
Uncovered terrace	Heat-treated	0.366 ± 1.569	0.672 ± 0.234	1.055 ± 0.985
	Untreated	1.496 ± 4.632	2.197 ± 0.984	2.912 ± 1.056
Covered terrace	Heat-treated	0.254 ± 0.866	0.336 ± 0.024	0.740 ± 0.985
	Untreated	1.382 ± 0.035	1.888 ± 0.699	2.468 ± 1.056
		Anti-swelling efficiency of the heat treatment (%)		
Uncovered terrace	Heat-treated	76	69	64
Covered terrace	Heat-treated	82	82	70

Shape stability				
Type of exposure	Panel strips	Flatness deviation of the panel (mm)		
		After 1 month	After 2 months	After 3 months
Uncovered terrace	Heat-treated	1.37 ± 0.00	1.51 ± 0.06	1.91 ± 1.30
	Untreated	2.48 ± 0.08	2.51 ± 0.62	4.65 ± 1.19
Covered terrace	Heat-treated	0.51 ± 0.04	0.63 ± 0.57	0.73 ± 0.28
	Untreated	0.76 ± 0.10	1.06 ± 0.31	1.31 ± 0.84

the panels made from heat-treated wood strips showed a 70% lower volumetric swelling than the ones made from untreated wood strips and on the uncovered terrace, the reduction was 64% (Table 1). The highest *ASE* values (82% on the covered terrace and 76% on the uncovered one) were recorded after the first month of exposure, when the environmental relative air humidity was highest, and the panels made from untreated wood suffered significant swelling, while the panels made from heat-treated wood did almost not swell at all.

4.2 Shape stability

The heat treatment of the lime wood strips for solid wood panels has a beneficial influence upon the shape stability of the panels, too. Even if in the case of flatness, no panel displayed zero deviation, the values obtained for all panels made from heat-treated wood displayed lower values than those made from untreated wood, as shown in Table 1.

After 3 months of open-air exposure, the flatness deviation of the panels made from heat-treated lime wood strips was 0.73 mm on the covered terrace and 1.91 mm on the uncovered one, much lower than the flatness deviation of the panels made from untreated lime wood strips, which reached more than two times higher values: 1.31 mm on the covered terrace and 4.65 mm in the complete open.

5 Conclusion

The experimental results regarding the shape- and dimensional stability of solid wood panels made from heat-treated lime wood strips clearly showed that:

- heat-treatment of the strips leads to a significant increase in the dimensional stability of the solid wood panels. When exposed to open air on an uncovered terrace for 3 months, the solid wood panels made from heat-treated lime wood strips swelled by 64% less than the panels made from untreated lime wood strips. The maximum swelling coefficient recorded for the panels made from heat-treated strips was $\alpha_v = 1.055\%$, while for the untreated controls, the maximum value recorded was $\alpha_v = 2.912\%$. When exposed to open air but on a covered terrace (without direct contact to rainfall and sunshine radiation) for the same 3 months, the solid wood panels made from heat-treated lime wood strips swelled by 70% less than the panels made from untreated lime wood strips. The maximum swelling coefficient recorded in this case for the panels made from heat-treated strips was $\alpha_v = 0.740\%$, while for the untreated controls, the maximum value recorded was $\alpha_v = 2.468\%$.

- heat-treatment of the strips also increased significantly the shape stability of the solid wood panels made from these strips: the flatness deviation of the panels made from heat-treated strips was up to 143% higher in the case of the panels exposed on the uncovered terrace and by 80% higher for the ones exposed on the covered terrace compared to the panels made from untreated strips.

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