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INFLUENCE OF HEAT TREATMENTS ON THE MOR AND MOE OF PANELS MADE FROM THIN (D_{MAX}=160 MM) SESSILE OAK (QUERCUS PETRAEA SPP. MATT. LIEBL.) TREES

Alin M. OLĂRESCU
Lecturer dr.eng. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: a.olarescu@unitbv.ro

Marina CIONCA
Prof.dr.eng. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: marinacionca@unitbv.ro

Loredana Anne-Marie BĂDESCU
Prof.dr.eng. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: loredana@unitbv.ro

Abstract:

Sustainable forest management is meant to ensure forest goods and services purchased in response to immediate requirements and at the same time ensuring their continued availability and contribution to long-term development. On the 8^{th} of July 1999, the European Council Regulation regarding measures to promote the conservation and management of forests came into force and refers to the potential recovery of wood secondary resources approximated to 9-10%, which opens subjects of research for a better insight to this matter.

The ecological benefit of using secondary wood resources can be further enhanced by heat treatment, which is an ecological modality to improve some properties, such as hygroscopicity, dimensional stability and durability, as a consequence of the changes which occur in the chemical composition of wood under the effect of high temperature. In this research a comparison was made between untreated solid longitudinally textured wood panels and heat treated ones, regarding density, mass, modulus of elasticity and bending strength. The objective of the study was to determine if heat treatment, besides its benefits, has any negative effect on the MOR and MOE of solid wood panels.

The solid wood panels are made of timber cut from thin (d_{max}=160mm) sessile oak (Quercus petraea spp. Matt. Liebl.) trees, which resulted from thinning operations of forestry. Two types of joining were investigated: edge to edge joint and finger joint panels, both heat treated and untreated. Raw material was heat treated at 130°C for 2h and the tests on panels were performed according to EN 310:1993.

Heat treatment caused a drop of density (by 19kg/m^3) and mass (by 0.3-0,4kg/m^2) in both panel types compared to the untreated panels. The differences between the values of MOR and MOE for treated and untreated panels is insignificant (around 1,5%).

This research confirmed the hypothesis that making panels out of thin sessile oak trees is feasible and rewarding. The results regarding MOE and MOR show that these panels can be used successfully in furniture production and the values, comparable with laminated densified wood, indicate an expansion of the utilisation field, if their dimensional stability offers good results.

Key words: *sustainable forest management; secondary wooden resources; solid wood panels; mechanical properties.*

INTRODUCTION

Sustainable forest management is meant to ensure forest goods and services purchased in response to immediate requirements and at the same time ensuring their continued availability and contribution to long-term development. On the 8th of July 1999, the European Council Regulation about measures to promote the conservation and management of forests came into force and refers to the potential recovery of wood secondary resources approximated to 9-10%, which opens subjects of research for a better insight to this matter.

In the capitalization of secondary wood resources technological, environmental and economic constraints that are imposed by these sorts must be kept in mind (Efthymiou 2008). Until now, capitalization of the secondary wood resources was materialized in inferior products like fire wood, poles for scaffolding and formwork, beams for traditional constructions, pulp and crafts. Research conducted on particleboard and fibreboard which included secondary wood resources demonstrated that they have inferior mechanical qualities caused by the proportion of juvenile wood (Baillères *et al.* 1996, Cloutier *et al.* 2007, Dimitri *et al.* 1981, Geimer and Crist 1980, Gurău *et al.* 2009, Larson *et al.* 2001, Lehman and Geimer 1974, Pugel *et al.* 2004, Stefaniak 1981, Zobel and Sprague 1998).

The sessile oak (*Quercus petraea spp. Matt. Liebl.*) is the most important native oak species in Romania representing about 10,5% of the total forests, the thin trees from thinning operations represent an important secondary resource that must be given a superior use. The results on its physical and mechanical properties have indicated similar strengths for wood from the thin trees compared to mature trees, but a slightly greater dimensional instability, especially in the radial direction, which compensates with a lower anisotropy coefficient (Olărescu *et al.* 2011a, Olărescu *et al.* 2011b). Similar strengths of wood from thin sessile oak trees compared to mature wood recommend it for value added capitalization providing its dimensional variation is controlled.

The objective of this paper is to study the possibility of incorporating wood provided by thin sessile oak trees (*Quercus petraea spp. (Matt.) Liebl*) into panels and their mechanical properties: MOR and MOE.

MATERIALS AND METHOD

Twenty *Quercus petraea Liebl*. trees with maximum diameters of 160mm, resulted from thinning operations were taken from a forest warehouse in Stroeşti – Argeş, southern Romania. Located 45° 8' 0" North, 24° 47' 0" East with an annual rate of precipitation of 600 – 700mm, and annual medium temperature between 8 – 9.5^{o}C, the area is characterized by De Martonne aridity index of 35 – 40; the Thorntwaite moisture index between 0 – 20 and Koncek humidity index 0 – 60 (Beldie 2012, Turcu 1961).

The test area stretched on 15.1ha, had a South-West exposure on a 15^{o} slope and 500 – 560m altitude. The type of forestry zone was 5152 (*Hill with Quercus petraea Bm, soil brown podzolic)* and the forestry type was 5221 (*Quercus – Fagus with Carex pilosa)*. The litter was thin, with *Carex pilosa* as the characteristic flora type. The present composition of the stand is: 7 sessile oak *(Quercus petraea spp. Matt. Liebl*), 2 beech (*Fagus sylvatica L.*) and 1 hornbeam (*Carpinus betulus L.*). The stand of sessile oak trees was characterised by: medium age 45 years; medium diameter 18cm; medium height 16m; stand density 0.63; annual growth 5.1m^3/ha; standing volume 133m^3/ ha.

The twenty test trees were harvested and for every tree a harvest record has been made. This record contained information about position on the plot area, tree diameter, bole height, level of the crown and number of logs. The first cut was made at 30 centimetres from the ground and the last at the insertion point of the crown. Logs were cut with 2m increments.

Then, logs were sawn into 50 mm thick timber pieces, which were kiln-dried from the initial moisture content (app. 75%) to 12% final MC. Drying was followed by conditioning for one week at 20°C and 55% RH to equilibrate the internal stresses and the moisture content distribution.

Two types of joints were investigated: edge to edge joint and finger joint, both heat treated and untreated. For heat treated panels, raw material was heat treated at 130^{o}C for 2h. This heat treatment can offer the best results concerning dimensional stability improvement and simultaneous preservation of bending strength and MOE were obtained after the treatment at 130°C for 2h, where: the anisotropy coefficient was reduced by 24% compared to untreated wood; the radial ASE 22.88%, and the tangential ASE was 38.61%; the static bending strength was reduced by only 3%; MOE was increased by 13% compared to untreated wood [13].

The technological process of panels manufacture supposes: ***1.*** Cutting strips of dry timber. Slicing and splitting runs on Festool CS 70 Precisio universal circular saw, then straightening and planing to thickness of the combined machine Holzmann PT 260. Resulted strips have a section of 40x20mm. ***2.*** Sort and preparation of strips to form the panel. This preparation includes trimming and marking strips in descending order of their length. ***3.*** Milling finger on Festool CMS + OF 1010 and finger joint cutter Festool HW S8 D34/NL 32 (just for finger joint panels). ***4.*** Apply adhesive to the strips edge. The adhesive used for gluing prisms is a polyurethane adhesive Jowapur 687:40. Apply adhesive can be done manually with trowel or brush, or mechanical gluing machine drum. Specific consumption of polyurethane adhesive type Jowapur

687:40 is 181g/m^2. ***5***. Panel assembly by frontal and parallel clamping. Specific pressure is 0.02N/mm^2, pressing time is 2h at temperature of 20±2°C and relative humidity of air φ=60±5%. ***6***. Panel conditioning for 8 hours at a temperature of 20±2°C and relative humidity of air φ=60±5%. ***7***. Panel calibration. ***8.*** Panel sizing.

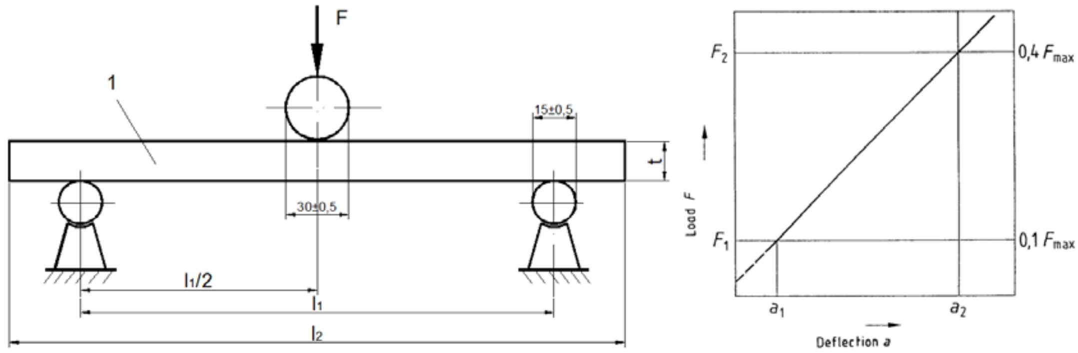
MOE and MOR was determinate according EN 310:1993 *Wood-based panels — Determination of modulus of elasticity in bending and of bending strength.*

The modulus of elasticity in bending and bending strength are determined by applying a load to the centre of a test piece supported at two points. The modulus of elasticity is calculated by using the slope of the linear region of the load-deflection curve; the value calculated is the apparent modulus, not the true modulus, because the test method includes shear as well as bending. The bending strength of each test piece is calculated by determining the ratio of the bending moment *M*, at the maximum load F_{max}, to the moment of its full cross section.

The modulus of elasticity *E*m (in N/mm2), of each test piece, is calculated from the formula 1, where: *l*1 is the distance between the centres of the supports, in millimetres; *b* is the width of the test piece, in millimetres; *t* is the thickness of the test piece, in millimetres; *F*2 – *F*1 is the increment of load on the straight line portion of the load-deflection curve, (Figure 2 b) in N. *F*1 shall be approximately 10% and *F*2 shall be approximately 40% of the maximum load; *a*2 – *a*1 is the increment of deflection at the mid-length of the test piece (corresponding to *F*2 – *F*1). The bending strength *f*m (in N/mm2), of each test piece, is calculated from the formula 2, where *F*max is the maximum load, in newtons.

$$E_m = \frac{l_1^3(F_2 - F_1)}{4bt^3(a_2 - a_1)}[N/mm^2] \qquad (1)$$

$$\sigma_i = \frac{3F_{max} l_1}{2bt^2}[N/mm^2] \qquad (2)$$



a. b.

Fig. 2

a - Arrangement of bending apparatus: 1 - test piece, 2 – load, t – thickness of test piece, l_1 = 20 t, l_2 = 20t + 50 mm; b - load – deflection curve within the range of elastic deformation (according EN 310: 1993).

Sampling and cutting of the test pieces was according to EN 326-1 *Solid wood panels requirements.* From each panel six test pieces were cut. The test pieces were rectangular with shape and dimensions shown in Fig. 3. The test pieces have a symmetrical cross-sectional area with the assembly plan in the middle of the test piece (Fig. 3). The test pieces were conditioned to a constant mass in an atmosphere with a relative humidity of (65±5)% and a temperature of (20±2)^{0}C.

The test was developed in the Laboratory of Research and Testing of Wooden Products, according to European Regulations, accredited by RENAR (Romanian Accreditation Association) since 09.06.2008, in accordance with the certificate No. LI 664. An IMAL Model IBX600 universal tests machine were used. The load was applied at a constant rate of cross-head movement throughout the test. The rate of loading was adjusted so that the maximum load is reached within (60±30)s. Measure the deflection in the middle of the test piece (below the loading head) to an accuracy of 0,1mm and plot these values against the corresponding loads measured to an accuracy of 1% of the measured value. Record the maximum load was to an accuracy of 1% of the measured value.

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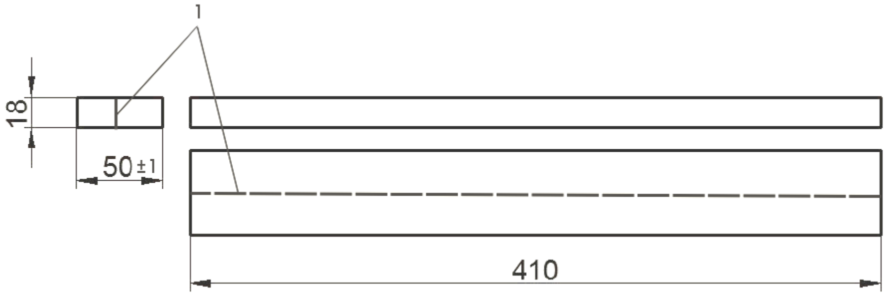

Fig. 3
Shape and dimensions of test pieces: 1 – assembly line.

The experimental data was statistically processed according to ISO 2602–2:1981, by calculating the statistical mean $\overline{x}$, the standard deviation *s* and the lower limit of the confidence interval $(\overline{x} - t_n s, \overline{x} + t_n s)$, which eliminates eventual errors. For a 95% confidence level, t_n is calculated according to (3). The lower limit of the confidence interval is calculated with (4) and is an important indicator for the comparison with the admissible value of a certain parameter.

$$t_n = \frac{t_{0,95}}{\sqrt{n}} \quad (3)$$

$$L_{5\%}^{q} = \overline{x} - t_n s \quad (4)$$

where:
n - is the number of samples;
$t_{0.95}$ – value of Student distribution with n+1 degrees of freedom at 95% confidence level. Its values are specified in a table in ISO 2602 – 2:1981;
$L_{5\%}^{q}$ - is the lower limit of the confidence interval.

RESULTS AND DISCUSSION

The tests results are shown in Tables 2 and 3.

For untreated panels the MOR was 140.565N/mm^2 for edge to edge joint panels and 129.06 for finger joint panels. Also the MOE was 15709.025 for edge to edge joint panels and 14485.1232 for finger joint panels.

For heat treated panels the MOR was 138,336N/mm^2 for edge to edge joint panels and 129.303 for finger joint panels. Also the MOE was 16281.782 for edge to edge joint panels and 15081.771 for finger joint panels.

These values are higher than MOE (10635.85 N/mm^2) and MOR (97.91N/mm^2) for sessile oak species solid wood with density 790Kg /m^3 (Olărescu *et al.* 2011a). This behaviour of wood composite materials was reported also in literature (Curtu and Ghelmeziu 1984).

MOR are comparable with laminated densified wood reported by Curtu and Ghelmeziu 1984: for a density 1300±100Kg/m^3, MOR values are 180N/mm^2 (type A), 130N/mm^2 (type B) and 100N/mm^2 (type C); for density 800±100Kg/m^3, MOR values are 100N/mm^2 (type A), 100N/mm^2 (type B) and 80N/mm^2 (type C). Therefore the resistance/density ratio is 0.183 for edge to edge joint panels and 0.164 for finger joint panels compared with 0.076 – 0.138 for laminated densified wood. This fact indicates a greater resistance at lower density for these panels compared to laminated densified wood.

The finger joint test pieces have a long area of failure and edge to edge joint test pieces have a short area of failure. Also the specific noise which appeared at failure was almost similar with solid wood for the edge to edge joint.

For the finger joint panels, the failure type indicate a uniform panels behaviour even if MOR is less with 8.1% than edge to edge panels. This kind of joint brings to increase of dimensional stability of panels without significantly affecting mechanical resistance. The lower resistance of finger joint panels compared with edge to edge panels was reported in literature (Boieriu 2007).

Heat treatment increase the homogeneity of wood panels, caused a drop of density (by 19kg/m^3) and mass (by 0.3 - 0.4kg/m^2) in both panel types compared to the untreated panels. The differences between the values of MOR and MOE for treated and untreated panels is insignificant (around 1.5%). As a conclusion heat treatment improve the homogeneity of wood material and decrease weight of panels without to notably affect of mechanical properties.

Table 1

MOE and MOR for the edge to edge joint panels

Sample	**Surface weight** [Kg/m²]		**Density** [Kg/m³]		**Maximum load** [N]		**MOR** [N/mm²]		**MOE** [N/mm²]	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
I.1	15.15	13.74	813.00	756.24	15.15	3675.00	151.19	119.26	16632.72	16434.70
I.2	14.72	13.90	788.10	761.90	14.72	4596.00	140.32	149.02	15486.21	16433.34
I.3	14.32	13.98	764.94	765.10	14.32	4860.00	151.34	157.06	16115.49	16811.00
I.4	14.37	14.18	765.19	776.25	14.37	4610.00	156.04	148.18	16928.73	16188.79
I.5	15.07	14.00	796.55	761.39	15.07	4641.00	133.65	148.33	15483.14	16291.82
I.6	14.39	14.45	773.37	788.72	14.39	4889.00	161.25	156.48	16860.40	16339.93
I.7	-	14.47	-	785.80	-	5083.00	-	161.50	-	17027.22
Average	14.67	14.10	783.53	770.77	14.67	4622.00	148.96	148.55	16251.12	16503.83
Standard deviation [%]	0.37	0.28	19.21	12.83	0.37	454.32	10.21	13.91	658.68	302.52
$L^{5}_{\%}$	**14.3663**	**13.899**	**767.72**	**761.349**	**14.366**	**4288.528**	**140.5658**	**138.336**	**15709.025**	**16281.782**

Table 2

MOE and MOR for the finger joint panels

Sample	**Surface weight** [Kg/m²]		**Density** [Kg/m³]		**Maximum load** [N]		**MOR** [N/mm²]		**MOE** [N/mm²]	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
I. 1	14.07	14.03	781.26	765.11	4208.00	4171.00	138.15	133.53	16064.71	15043.59
I.2	15.31	13.83	850.26	757.95	4153.00	5050.00	138.47	163.02	15595.86	16093.85
I.3	15.03	14.24	834.13	782.37	4814.00	5283.00	159.82	171.80	17072.20	16904.79
I.4	14.45	14.13	800.04	763.95	3362.00	4117.00	113.43	129.58	12791.97	14956.47
I.5	14.06	14.37	775.99	790.85	4698.00	4414.00	154.56	144.10	16079.54	15330.00
I.6	15.03	14.30	824.26	780.08	4802.00	2962.00	154.51	95.27	17308.20	14212.88
I.7	-	13.96	-	763.70	-	5355.00	-	172.11	-	16899.88
I.8	-	15.63	-	851.05	-	5431.00	-	173.33	-	17975.09
Average	14.66	14.31	810.99	781.88	4339.50	4597.88	143.16	147.84	15818.75	15927.07
Standard deviation [%]	0.54	0.56	29.94	30.18	561.28	850.59	17.13	27.67	1620.44	1261.64
$L^{5}_{\%}$	**14.2152**	**13.933**	**786.3464**	**761.661**	**3877.569**	**4027.980**	**129.0601**	**129.303**	**14485.1232**	**15081.771**

CONCLUSION

Massive wood exploitation represents a major concern of the near future. Therefore, among other ways of reducing wood waste, new alternatives were thought to increase the added value of secondary wood resources, among which sessile oak (*Quercus petraea spp. Matt. Liebl.) thin trees,* which resulted by thinning operation of forestry.

This research confirmed the hypothesis that making panels out of thin sessile oak trees is feasible and rewarding. The results regarding MOE and MOR show that these panels can be used successfully in furniture production and the values, comparable with laminated densified wood, indicate expansion of utilisation field if their dimensional stability can to offer good results.

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