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DECAY RESISTANCE OF LAMINATED VENEER LUMBERS FROM EUROPEAN OAKS

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ABSTRACT

Natural durability of oaks depends mainly on the concentration of ellagotannins and some other polyphenols. Durability of oak-composite products (plywood, particleboard, laminated veneer lumber, etc.) is influenced also by the characteristics of wooden particles, e.g. their dimensions, hydrothermal pre-treatments, portion and localization of sapwood and heartwood particles in the composite structure, further by the applied glues, waxes and other additives, and by the pressing processes (temperature, time, pressure, etc.). In this work, decay resistance of the hydrothermal treated oaks and the Laminated Veneer Lumbers (LVL-s) prepared under various experimental conditions from European oaks *Quercus pedunculata* and *Quercus sessiliflora* was analysed. Mycological tests, by modified standard EN 113 using wood-destroying fungi *Coniophora puteana* and *Trametes versicolor*, shoved that the decay resistance of massive oaks and LVL-s was not influenced by the type of hydrothermal treatments or by the oak species. On the other hand, resistance of LVL-s against rot was significantly influenced by the zone of oak wood (poor from sapwood, better from medium heartwood, and good from young or old heartwood), respectively individually also by the veneer's thickness (1, 2 or 3 mm) and the type of glue (melamine-urea-formaldehyde, phenol-resorcinol-formaldehyde, polyurethane or PRF-tannin).

KEY WORDS: oaks, LVL-s, glues, natural durability, wood-destroying fungi

INTRODUCTION

Laminated Veneer Lumbers (LVL-s) are used for building constructions, stairs, windows, doors, furniture, etc. They are produced mainly from conifers, e.g. from Norway spruce, Douglas or Scots pine. LVL-s prepared from more durable wood species, e.g. from black locust or oaks have a higher resistance against biological attacks, and they are convenient also to exterior expositions. Durability of LVL-s is in a certain measure influenced by the selected technological parameters of their production and by the type of glue, in which is focused on experiments of this work.

Oak woods species belong to more durable ones (EN 350-2). Some of them (*Quercus rubra* L. *Quercus petraea* L., *Quercus robur* L., etc.) are advantageously used for production of LVL boards (Ozarska 1999, Kovács 2005). High natural durability of the heart-zone of oaks is predestinated mainly by presence of polyphenols - flavonoids and tannins. Their amounts (ranging from 6 till 12 %), types (flavonoids – robinetin, kvercetin, etc.; tannins – kastalagin, vescalagin, grandinin, roburin, etc.), and distributions in oak logs is depending on more factors: age of tree, type of field, growth conditions, season of cutting, localization near to sap or to pith, type of cell elements, density of wood (Boury 1998, Charrier et al. 2000, 2001, Masson et al. 1995, Mosedale et al. 1996, Solár 2001). Decrease of the natural durability of oak heartwood zones can occur during hydrothermal treatments of bolts before their peeling on veneers and also at drying of veneers. Assouada (2004) determined in dried oaks from 55 to 85 % lower amount of elagotannins. Hueso (2002) described degradation of the kastalagin and vescalagin on gallic acid, elallagic acid and glucose at drying oxidation processes in oaks.

This work had two aims:

- firstly, to determine influence of the temperature ranging from 50 to 90 °C at hydrothermal treatments of young heartwood of pedonculate oak (*Quercus pedunculata*) for its resistance against rot,
- subsequently, to analyse influences of the oak species (*Quercus pedunculata* and *Quercus sessiliflora*), of the presence of sapwood and selected heartwood zones in oak bolts, and of the changes in technological parameters of LVL-s preparation (thickness of veneer, type of glue) for their resistance against rot.

MATERIAL AND METHODS

Hydrothermal treatment of oak bolts

Logs of European oaks (*Quercus pedunculata* Ehrh., *Quercus sessiliflora* S.m.) with the length of 9-10 m and the diameter of 350-570 mm were firstly crosscut on 600 mm long bolts, and these bolts were not hydrothermal (HT) treated or were HT treated at 50, 60, 70 or 90 °C during 12, 24 or 48 hours (Tab. 1).

Preparation of oak LVL-s

Laminated Veneer Lumbers (LVL-s) were prepared from bolts of oaks *Quercus pedunculata* and *Quercus sessiliflora*. These bolts were HT treated constantly at 60 °C during 24 hours (Tab. 1). Peeling of 1, 2 or 3 mm thick veneers from oak bolts was performed on CNC peeling lathe in laboratory of ENSAM Cluny in France. Afterwards, the veneers were manually cut in wet state on plates of size 400 x 400 mm without knots, and finally they were dried to humidity of 10 %.

Totally 20 types of oak LVL-s 400 x 400 mm (Tab. 1) with a constant thickness of 20 ± 1 mm were prepared by pressing of 20 veneers of 1 mm, 10 veneers of 2 mm, or 7 veneers of 3 mm, using four different types of glue. Pressing process at 20 °C/800 kPa lasted from 4 to 20 hours (Svoradová 2007):

- MUF = melamine-urea-formaldehyde glue Cascomin 1238 with hardener 2540, 4:1 (250 $g.m^{-2}$) → 10 h
- PRF = phenol-resorcinol-formaldehyde glue Enocol XRL 490 with hardener XDL 490, 4:1 (300 $g.m^{-2}$) → 16 h
- PU = polyurethane glue Semparoc I 12 NV (200 $g.m^{-2}$) → 4 h
- T = PRF-tannin glue developed by Pizzi and Cameron (1984), when one veneer surface was spread with a commercial PRF glue containing hardener and the other veneer surface was spread with a solution of tannin from mimosa (300 $g.m^{-2}$) → 20 h

Testing of the decay resistance of massive oaks and oak LVL-s

In the 1st step of mycological tests, samples - replicates of 100 x 8.5 x 8.5 mm (100 mm in the direction of fibres) prepared from HT treated oak bolts of *Quercus pedunculata* were tested against the brown-rot fungus *Coniophora puteana* by the European standard EN 113 – during 16 weeks (Tab. 1). HT treatments of bolts were carried out at temperatures of 50, 70 or 90 °C during 12, 24 or 48 hours with aim to determine various hydrothermal extraction effects on changes in the decay resistance of the massive oak wood.

In the 2nd and 3rd steps of mycological tests, samples – replicates of 30 x 20 x 20 ± 1 mm (20 ± 1 mm is the thickness) prepared from oak LVL-s of various types (Tab. 1) were tested against fungal decay by modified EN 113 - during 8 weeks (Tab. 1).

All mycological tests were accomplished in the biological laboratory of TU Zvolen in Slovakia.

Tab. 1: Massive oaks and oak LVL-s - preparation and mycological tests by EN 113 using two wood-destroying fungi Coniophora puteana and Trametes versicolor

Oak material	**1st experiment (Massive – 10 types)**	**2nd experiment (LVL – 12 types)**	**3rd experiment (LVL – 8 types)**
Oak species	*Quercus pedunculata*	*Quercus pedunculata*	*Quercus pedunculata* *Quercus sessiliflora*
HT- treatment			
None	+	-	-
50 °C/12-24-48 h	+ (3-types)	-	-
60 °C/24 h	-	+	+
70 °C/12-24-48 h	+ (3-types)	-	-
90 °C/12-24-48 h	+ (3-types)	-	-
Zone of wood	-	sap	-
	young heart	young heart	-
	-	medium heart	-
	-	old heart	old heart

Oak material	1st experiment (Massive – 10 types)	2nd experiment (LVL – 12 types)	3rd experiment (LVL – 8 types)
Veneers	- - -	1 mm 2 mm 3 mm	- - 3 mm
Glue	-	MUF	MUF PRF PU T
Mycological tests	16 weeks	8 weeks	8 weeks
C. puteana *T. versicolor*	Δm, ΔIBS -	- Δm, ΔHB	Δm, ΔHB Δm, ΔHB

Note 1 – to the Tab. 1

Samples from massive oaks and from oak LVL-s with determined weights (m_w) have been attacked by the brown-rot fungus *Coniophora puteana* (Schumach.) P. Karst., or by the white-rot fungus *Trametes versicolor* (L.) Pilát. In each series have been used 5 testing replicates and 2 moisture samples. Using the moisture samples with determined moisture (w in %) we could compute weight of the sound testing replicates in the oven dry state (m_o = [100.m_w]:[w + 100]). Testing replicates were then dipped in sterile distilled water for 15 minutes and placed into 1 l Kolle's flasks with the mycelium of chosen wood-destroying fungus expanded on the malt agar soil. Decay process at a temperature of 20 ± 2 °C lasted 16 or 8 weeks. Testing replicates were then taken out of the Kolle's flasks, cleaned from the fungi mycelia, and subjected to a two-phase drying to reach their oven dry state after the decay process (m_{od}). The first phase of drying "air seasoning" – was carried out under milder conditions (t = 20 – 25 °C, φ = 60 – 70 %, τ = 100 h). The second phase "kiln seasoning" – was performed in three steps (t_1 = 60 °C, τ_1 = 1 h; t_2 = 80 °C, τ_2 = 1 h; t_3 = 103 ± 2 °C, τ_3 = 4 h) with aim to avoid or minimize formation of cracks and deformations in replicates and to prevent the wood-destroying fungi from their further activity.

Criteria for evaluation of the decay resistance of massive oaks and of oak LVL-s

The decay resistance of massive oaks and oak LVL-s was evaluated on the basis of their weight losses (Δm) after attacking by wood-destroying fungi:

$$\Delta m = [(m_o - m_{od}) / m_o] .100\ (\%) \qquad (1)$$

where: m_o – mass of the non-attacked replicate in the oven dry state
m_{od} – mass of the same replicate after mycological test (decay) in the oven dry state

Supplementary criteria of their decay resistance resulted from changes in their mechanical properties determined at a constant moisture content of 12 ± 1 % (Tab 1):

Decrease of the impact bending strength [Note2] (ΔIBS):

$$\Delta IBS = [(IBS_o - IBS_{od}) / IBS_o] .100\ (\%) \qquad (2)$$

Decrease of the Brinell hardness [Note3] (ΔHB):

$$\Delta HB = [(HB_o - HB_{od}) / HB_o] .100\ (\%) \tag{3}$$

Note 2 – Impact bending strength (IBS)

Massive oak samples (replicates) 100 x 8.5 x 8.5 mm were conditioned at t = 20 ± 2 °C and φ = 65 ± 2 % on the moisture equilibrium state of 12 ± 1 %. Impact bending strength (IBS) was tested by small Charpy hammer, measuring the energy E (J) needed for fracture of the replicate with defined cross area A = 0.85 x 0.85 = 0.7225 cm^2:

$$IBS = E/A\ (J.cm^{-2}) \tag{4}$$

At a given type of HT treatment of massive oak, the IBS values were determined either for the original replicates of which were not exposed to fungi (IBS_o - average value from 5 replicates), and also for other 5 replicates exposed to decay process (IBS_{od}).

Note 3 - Brinell hardness (HB)

Oak LVL samples (replicates) 30 x 20 x 20 ± 1 mm were conditioned at t = 20 ± 2 °C and φ = 65 ± 2 % on the moisture equilibrium state of 12 ± 1 %. Brinell hardness (HB) was tested on their surfaces 30 x 20 mm perpendicularly to fibres using steel ball (D = 10 mm) and constant force (F = 500 N), measuring the diameter of ball imprints (d in mm) into LVL surfaces:

$$HB = 2\ .\ F / \{(\pi\ .\ D)\ .\ [\ D - (\sqrt{D^2 - d^2})]\}\ (MPa) \tag{5}$$

At a given series of oak LVL-s, the HB values were determined for the same replicates, firstly before decay (HB_o), and then after decay process (HB_{od}).

RESULTS AND DISCUSSION

1st experiment

Influence of HT-treatments on the decay resistance of massive oak *Quercus pedunculata*

Different hydrothermal (HT) treatments of young heartwood of the pedonculate oak (*Quercus pedunculata*) had only a minimal influence on its resistance against decay caused by the brown-rot fungus *Coniophora puteana* (Tab. 2). Content of polyphenols in HT treated oaks thought decreased from 4.52 % maximally to 1.99 % (at 90 °C/24 hours), and in this fact various boiling processes of oak bolts induced after 12, 24 and 48 hours the phenolics extraction - around 11 % at 50 °C, 46 % at 70 °C, and 54 % at 90 °C (Svoradová 2007). On the other hand, drops in decay resistance of HT treated oaks comparing to decay resistance of "natural" HT untreated oaks were only minimal (see Tab. 2 - evaluation on the basis of the Δm and the ΔIBS values).

*Tab. 2: Weight loss (Δm) and impact bending strength decrease (ΔIBS) of the massive pedonculate oaks (Quercus pedunculata) without or with HT treatments after attacking by the fungus Coniophora puteana***

Massive oak	Content of polyphenols* (%)	Δm (%) 12h/HTT	Δm (%) 24h/HTT	Δm (%) 48h/HTT	Δm (%)	ΔIBS (%)	$\Delta m_{Tot.}$ (%)	$\Delta IBS_{Tot.}$ (%)
Natural	4.52	-	-	-	4.76 (0.27)	22.7 (5.07)		
50 °C/HTT	4.02	5.12 (0.62)	5.09 (0.33)	5.15 (0.24)			5.12	10.9
70 °C/HTT	2.44	4.80 (0.33)	5.03 (0.32)	5.51 (0.45)			5.11	24.5
90 °C/HTT	2.07	5.02 (0.34)	5.62 (0.38)	5.44 (0.20)			5.36	9.0

* Polyphenols have been determined by Svoradová (2007).

** Mycological test by EN 113 (16 weeks, replicates with modified dimension of 100 x 8.5 x 8.5 mm).

*** Weight losses and impact bending strength decreases are the average values of 5 replicates (see the average values presented together with the standard deviations), or totally of 15 replicates (see the total average values Δm_{tot} and ΔIBS_{tot} without standard deviation).

**** Numbers in the parentheses are the standard deviations.

Weight losses (Δm) of oak replicates attacked by the brown-rot fungus *Coniophora puteana* increased in a consequence of their previous hydrothermal treatments maximally about 18.1 %, it means from Δm = 4.76 % for natural oak to Δm = 5.62 % for oak HT treated at 90 °C/24h. According to the criteria of EN 113 the untreated and also the HT treated oaks can be classified to the 2nd class of durability by EN 350-2 resulted from these tests:

$$x = \Delta m_{Oak} / \Delta m_{Beech} = (4.76\ \%\ \text{till}\ 5.62\ \%) / 26.7\ \% = (0.178\ \text{till}\ 0.21) \leq 0.30 \text{ and } > 0.15$$

Decreases of the impact bending strength (ΔIBS) of oaks attacked by *C. puteana* were higher than their competent weight losses, in average 9.0 till 24.5 %. This result well corresponds with known notions that IBS is a very good indicator of bio-deteriorations in wood (Reinprecht 1992, Wilcox 1978). However, this mechanical property has a typically high variability, and by our opinion this fact could cause that none reliable and statistically significant influences of the HT treatments of oaks on the ΔIBS values were observed.

On the base of these results, there only one HT treatment regime of oak bolts at 60 °C/24 h was proposed for preparation of various oak LVL-s (2nd and 3rd experiments).

2nd experiment

Influence of oak zone and veneer's thickness on the decay resistance of oak LVL-s

Using of sapwood and selected heartwood zones of the pedonculate oak (*Quercus pedunculata*) at preparation of LVL-s (Tab. 1) had a more or less expressive influence on the decay resistance of replicates from these boards against the white-rot fungus *Trametes versicolor* (Tabs. 3 and 4). Oak LVL-s from sapwood were not resistant to the fungal attack, at which their average weigh loss (Δm) was above 20 % and Brinell hardness decreased (ΔHB) more than about 30 % (Tab. 3). Oak LVL-s from heartwood zones evidently better resisted to decay processes, since their average weigh loss (Δm) was about 3.9 % and drop of Brinell hardness (ΔHB) about 3.3 % (Tab. 3). For some LVL replicates from oak heartwood zones the HB after fungal attack even increased or its drop was lower than weight loss. This unexpected result can be explained either by testing conditions (HB of each LVL replicate was measured on its two different places before and after fungal attack), but maybe also by shrinkage and local increasing of density of the surface veneers of decayed LVL-s after their subsequent drying at 103 °C before testing of this mechanical property.

Interesting is a moderately lower decay resistance of oak LVL-s from the medium heartwood in comparison to resistance of LVL-s from young or old heartwood, documented also by statistical Duncan´s tests (Tab. 4). This result can probably be explained by presence of certain portion of inner sapwood in the zone of medium heartwood in consequence with observations documented by Požgaj et al. (1993).

*Tab. 3: Weight loss (Δm) and Brinell hardness decrease (ΔHB) of LVL-s from the pedonculate oak (Quercus pedunculata) after attacking by the fungus Trametes versicolor***

Oak LVL-s*	**Δm (%)**	**Δm (%)**	**Δm (%)**	**$\Delta m_{Totally}$ (%)**	**$\Delta HB_{Totally}$ (%)**
Zone / Veneers	1 mm	2 mm	3 mm		
Sapwood	20.3 (4.17)	-	25.9 (3.40)	23.1	33.7
Young heartwood	5.0 (0.21)	3.8 (0.23)	1.8 (0.33)	3.5	5.4
Medium heartwood	5.8 (0.24)	5.2 (0.76)	3.9 (0.97)	5.0	4.2
Old heartwood	3.3 (0.36)	3.0 (0.21)	3.2 (0.14)	3.2	0.4
Heartwoods-Totally	4.7	4.0	3.0	**3.9**	**3.3**

* 2nd experiment: oak species → *Quercus pedunculata*; HT treatment → 60 °C/24h; 4 zones of oak → sapwood, young heartwood, medium heartwood, old heartwood; 3 thicknesses of veneers → 1, 2, or 3 mm; glue → MUF.

** Mycological test by modified EN 113 (8 weeks, replicates with modified dimension of 30 x 20 x 20 ± 1 mm).

*** Weight losses are the average value of 5 replicates (see the average values together with the standard deviations), or totally of 15 (or 45) replicates (see the total average values without standard deviation).

**** Brinell hardness decreases are the average values totally of 15 (or 45) replicates (see the total average values without standard deviation).

***** Numbers in the parentheses are the standard deviations.

Tab. 4: Significance levels (≤ 0.05) of the Duncan´s test – influence of the oak zones on the weight losses (Δm) of LVL-s attacked by the fungus Trametes versicolor

No.	**Oak LVL-s**	**1**	**2**	**3**	**4**
1	Sapwood	-	0.00	0.00	0.00
2	Young heartwood	0.00	-	0.00	0.54
3	Medium heartwood	0.00	0.00	-	0.00
4	Old heartwood	0.00	0.54	0.00	-

Using of thicker veneers in oak LVL-s from 1 to 3 mm caused different changes in their decay resistance (Tabs. 3 and 5). LVL-s from 3 mm sapwood veneers were less durable (Δm = 25.9 %) as boards from thinner 1 mm veneers (Δm = 20.3 %). This result is in a good accordance with the experiments of Boury (1998) when oak sapwood with a minimal content of toxic polyphenols can better resist to rotting processes in wooden composites having higher amount of glue or more glue-layers. On the other hand, for LVL-s prepared from oak heartwood zones the effect of veneer's thicknesses was usually opposite:- evidently for oak LVL-s prepared from young heartwood (Δm → for 1 mm = 5.0 %; for 2 mm = 3.8 %; for 3 mm = 1.8 %), partly but not always statistical significantly for oak LVL-s from medium heartwood (Δm → for 1 mm = 5.8 %, for 2 mm = 5.2 %, for 3 mm = 3.9 %), while at using of old heartwood the effect of veneer's thicknesses was not observed (Δm → for 1 mm = 3.3 %; for 2 mm = 3.0 %; for 3 mm = 3.2 %). On the basis of these results it was established hypothesis, that oak LVL-s from heartwood zones with more glue layers (or having thinner veneers: 1 mm → 19 glue layers; 3 mm → 6 glue layers) can be gently more accessible to diffusion of fungal enzymes through boards if the glue (in this experiment MUF glue) is partly damaged by moisture during the mycological test. Questions connected with the influence of type of glue in LVL-s on their decay resistance are solved in the following 3rd experiment.

Tab. 5: Significance levels (≤ 0.05) of the Duncan´s test – influence of the thicknesses of oak veneers on the weight losses (Δm) of LVL-s attacked by the fungus Trametes versicolor

No.	Oak LVL-s	Sapwood			Young heartwood			Medium heartwood			Old heartwood		
		1	2	3	1	2	3	1	2	3	1	2	3
1	1 mm – veneers	-	-	0.04	-	0.00	0.00	-	0.32	0.00	-	0.13	0.36
2	2 mm – veneers	-	-	-	0.00	-	0.00	0.32	-	0.03	0.13	-	0.19
3	3 mm – veneers	0.04	-	-	0.00	0.00	-	0.00	0.03	-	0.36	0.19	-

3rd experiment

Influence of oak species and type of glue on the decay resistance of oak LVL-s

The decay resistances of LVL-s from old heartwood zones of the pedonculate oak (*Quercus pedunculata*) and the sessile oak (*Quercus sessiliflora*) were comparable (Tab. 6). Differences in the durability of LVL-s from these two oak species were not statistically confirmed (for Δm the significance levels of the Duncan´s test were evidently over 0.05, i.e. at *C. puteana* 0.25 and at *T. versicolor* 0.18). In chemical composition of these two oak species are some differences, e.g. in the portion of tannins (Charrier et al. 2000). However, this factor was not a more important in this experiment. LVL-s from both oak species better resisted to the brown-rot fungus *Coniophora puteana* (Δm → for LVL-s from pedonculate oak = 1.4 %; for LVL-s from sessile oak = 1.6 %), and partly less to the white-rot fungus *Trametes versicolor* (Δm → for LVL-s from pedonculate oak = 4.4 %; for LVL-s from sessile oak = 5.3 %). This result confirmed the general option, that hardwoods and composite products from broadleaves are usually less resistant to white-rot fungi in comparison to brown-rot fungi (Schmidt 2006). However, in laboratory experiments or in practice can be achieved also opposite results, e.g. high amount of robinetin and dihydrorobinetin in the structure of *Robinia pseudoacacia* was connected with better resistance of massive black locust and black locust Laminated Veneer Lumbers (LVL-s) to *T. versicolor* in comparison to *C. puteana* (Reinprecht et al. 2010).

The decay resistance of oak LVL-s was significantly influenced by the type of glue (Tab. 6). LVL-s bonded with the T glue (PRF-tannin glue prepared by Pizzi and Cameron 1984) had the worst decay resistance (Δm → by *C. puteana* = 2.4 %; by *T. versicolor* = 7.3 %). LVL-s bonded with the PRF "phenol-resorcinol-formaldehyde" glue were evidently attacked by the white rot fungus *T. versicolor* (Δm → by *C. puteana* = 1.2 %; by *T. versicolor* = 6.0 %). Durability of LVL-s bonded with MUF "melamine-urea-formaldehyde" and PU "polyurethane" glues was evidently higher and mutually comparable (Δm → by *C. puteana* = 1.7 and 0.7 %; by *T. versicolor* = 2.9 and 3.2 %). A lower decay resistance of LVL-s bonded with phenol-based (T and PRF) glues against the white rot fungus *T. versicolor* can be explained by the enzymatic character of this fungus which produces peroxidases with ability to break covalent bonds not only in lignin (Eriksson et al. 1990) but also in other natural or synthetic polyphenols (Lebedeva and Ugarova 1996, Yamasaki et al. 1997). From the view points of the durability and ecology, the polyurethane glue should be the most advisable for further experiments and practical applications.

*Tab. 6: Weight loss (Δm) and Brinell hardness decrease (ΔHB) of oak LVL-s attacked by the fungi Coniophora puteana and Trametes versicolor***

Oak LVL-s*	**Δm (%)**	**Δm (%)**	**Δm (%)**	**Δm (%)**	**Δm (%)**	**$\Delta HB_{Totally}$ (%)****
Species / Type of glue	**MUF**	**PRF**	**PU**	**T**		
Coniophora puteana						
Quercus pedunculata	1.5 (0.52)	0.8 (0.12)	0.6 (0.14)	2.7 (0.22)	1.4	4.5
Quercus sessiliflora	1.8 (0.31)	1.6 (0.20)	0.8 (0.13)	2.2 (0.30)	1.6	7.7
Oaks–Totally	1.7 (0.55)	1.2 (0.33)	0.7 (0.15)	2.4 (0.32)	**1.5**	**6.1**
Trametes versicolor						
Quercus pedunculata	1.9 (0.91)	6.7 (1.46)	2.3 (0.65)	6.5 (0.85)	4.4	6.6
Quercus sessiliflora	3.8 (0.84)	5.3 (1.32)	4.0 (0.27)	8.1 (1.07)	5.3	10.9
Oaks–Totally	2.9 (1.72)	6.0 (1.90)	3.2 (1.13)	7.3 (1.09)	**4.9**	**8.7**

* 3rd experiment: 2 oak species → *Quercus pedunculata* and *Quercus sessiliflora*; HT treatment → 60 °C/24h; zone of oak → old heartwood; thickness of veneers → 3 mm; 4 types of glue → MUF, PRF, PU, T.

** Mycological test by modified EN 113 (8 weeks, replicates with modified dimension of 30 x 20 x 20 ± 1 mm).

*** Weight losses are the average values of 5 replicates (see the average value together with the standard deviation), or of 10 replicates for the given glue type "Oaks–totally" (see the average value together with the standard deviation), or totally of 20 (40) replicates (see the total average value without standard deviation).

**** Brinell hardness decreases (ΔHB) had a high variability – so in the table are only the total average values from 20 (40) replicates. In spite of this fact, evidently the highest decreases of HB after action of fungi *C. puteana* and *T. versicolor* were at LVL-s bonded with tannin glue (T → ΔHB = 15.5 %) comparing to others (MUF → ΔHB = 3.7 %; PRF → ΔHB = 5.8 %; PU → ΔHB = 4.6 %).

***** Numbers in the parentheses are the standard deviations.

CONLUSIONS

Decay resistance of the young oak heartwood *Quercus pedunculata* was not influenced by its previous hydrothermal treatments at 50, 70 or 90 °C lasted 12, 24 or 48 hours. Similarly, decay resistance of various Laminated Veneer Lumbers (LVL-s) was not influenced by the used oak species *Quercus pedunculata* or *Quercus sessiliflora*. On the other hand, the oak LVL-s prepared from sapwood, and partly also from medium heartwood having a small part of inner sapwood, were more disposed for the fungal attack in comparison with oak LVL-s from young or old heartwood. Increasing of the veneers thickness from 1 to 3 mm was profitable for the durability of oak LVL-s from heartwood zones, which can be explained by higher accessibility of MUF glue layers for fungal enzymes after their partial damaging by moisture during the mycological test. From tested glues, the phenol-based ones (PRF-tannin and PRF) secured to the oak LVL-s a partly lower decay resistance in comparison with other ones (MUF and PU) – it was evident mainly at tests with the white-rot fungus *Trametes versicolor*, or at PRF-tannin glue also at tests with the brown-rot fungus *Coniophora puteana*.

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