F O L I A   F O R E S T A L I A   P O L O N I C A

© *PAN*   *Series B, Issue 42, 3-16, 2011*

WOODEN COMPOSITES FROM BEECH PLYWOOD AND DECORATIVE VENEERS OF DIFFERENT NATURAL DURABILITY – THEIR DECAY RESISTANCE AND SELECTED PHYSICO-MECHANICAL PROPERTIES

Ladislav Reinprecht, Ján Iždinský, Laura Kmet'ová

Faculty of Wood Sciences and Technology
Technical University of Zvolen

SYNOPSIS. This work deals with decay resistance and selected physical and mechanical properties of wooden composites (WCs) prepared from 3.6 mm thick three-layer beech plywood and 0.6 mm thick decorative surface veneers of selected exotic (aningré, bubinga, iroko, khaya, padouk, sapelli, wengé) and domestic (beech, European oak, sweet chestnut, walnut) wood species. Joining of veneers in the plywood and then also in the WCs was carried out by pressing processes using the PF glue Fenokol 43. The aim of the experiment was to determine the influence of surface veneers of different natural durability on rotting of the WCs, and on resistance of the WCs to water and mechanical loadings, as well. Decay resistance of individual veneers and WCs was tested by modified EN 113 against the brown-rot fungi *Serpula lacrymans* or *Coniophora puteana*, and the white-rot fungi *Phanerochaete chrysosporium* or *Trametes versicolor*. Weight losses of individual types of veneers and WCs caused by wood-destroying fungi were compared with weight losses of beech-veneer and beech-WC, respectively. The lowest weight losses at rotting processes showed the padouk-WC, i.e. WC prepared from the beech plywood and two the most durable padouk surface veneers. Density, water soaking, water swelling, tensile strength perpendicularly to the plane ($\sigma_{\perp}$), and bending characteristics (MOR, MOE) of all WCs were determined in accordance with European standards. These physical and mechanical properties of the WCs were only partly influenced by the type of surface veneers. Selected types of the WCs, e.g. padouk-WC, could also be convenient for exterior expositions out of ground contact.

KEY WORDS: wooden composites, durability, rotting fungi, water resistance, strength

INTRODUCTION

Plywood, Laminated Veneer Lumber (LVL), Oriented Strand Boards (OSB), or other wooden composites (WC) are widely used as construction materials indoors and outdoors (Yang et al. 2001). They are often prepared from less important and non-durable timbers, and due to this fact, their resistance against moulds, wood--destroying fungi and insects is limited in conditions with higher risk of wetting (Lahiry 2005, Fojutowski et al. 2009).

Decay of wooden products made from wood and WCs starts at the threshold moisture content (TMC). For several plywood materials the value of TMC ranges from 19.5% to 25.5%. However, their equilibrium moisture content (EMC) at 20°C and 90% relative humidity of air is only 15-18%. Therefore, for decay of plywood, the liquid water from rain, condensation or other sources is needed. Boards close to TCM will decay very slowly, at 4% above TCM decay is increased, and optimum decay is achieved at 6% above TCM (Van Acker et al. 2001). Suitable moisture conditions for decay of plywood materials are often in their outdoor exposition out of ground contact defined in the European Hazard Class 3 by the standard EN 335-3. Antifungal resistance of plywood and other WCs is important only if they withstand the impact of wetting, i.e. if these boards are never exposed to higher moisture levels (e.g. as given by the European Hazard Class 1) their fungal durability will not be an important factor (Bravery and Lea 1987). On the other hand, their resistance against fungi in the Hazard Class 3 is only important when these materials are not subjected to irreversible damage connected with degradation of the adhesive upon wetting (Fojutowski and Kropacz 2008). It means that plywood materials with a good fungal durability but with an insufficient water resistance, whose veneers are glued with water-unstable adhesives (e.g. urea-formaldehyde resins), are not convenient for exterior use where they can be damaged by moisture.

For antifungal protection of plywood are suitable various chemical and physical techniques. Service life of plywood made from beech or other non-durable timbers can be improved by the following methods:

- chemical treatment of plywood with fungicides using conventional non-pressure processes – dipping, painting, etc. (Lahiry 2005), vacuum or pressure processes, or untraditional vapour boron (Murphy and Turner 1989) or supercritical fluid "SCF" processes (Morrell et al. 2005);
- chemical preservation of veneers with fungicides (Norton 2002);
- applying of thermally or chemically modified veneers;
- combination of non-durable veneers with durable veneers at preparation of plywood (Faraji et al. 2004);
- using of glues with antifungal effects (Mahút et al. 1985);
- treatment of plywood surfaces with durable natural or synthetic materials, with the aim to create composites "plywood + surface layers" with a higher resistance to fungi.

Original decay resistance of untreated wooden products to fungi is attributed mainly to the presence of natural chemical compounds, named extractives. It is commonly valid that decay resistance of plywood, LVL, and other wooden materials can be increased by using more durable wood species which contain efficient antifungal extractives. Deon and Schwartz (1988) studied extractives of padouk and of five other tropical species (okan, difou, mukulungu, doussie, and tali) from the point of view of their influence on the resistance of these woods against two brown-rot fungi (*Poria* sp. and *Poria placenta*) and two white-rot fungi (*Lentinus squarrosulus* and *Coriolus versicolor*). A high natural durability of padouk was given by santal extractives, or that of okan by the tetrahydroxy-3',4',7,8 flavonol. Reinprecht et al. (2010) determined a high resistance of LVL from black locust wood against the white rot fungus *Trametes versicolor*, and a partly lower resistance against the brown-rot fungus *Coniophora puteana*. By Nzokou et al. (2005), the biological resistance of LVL made from veneers of non-durable species can be increased by incorporation of veneers from more durable species applied on both faces of the LVL. Faraji et al. (2004) investigated durability of five wood species (*Castanea sativa*, *Cupressus sempervirens*, *Cedrus atlantica*, *Populus* sp. I-214, and *Fagus sylvatica*) which could be as a potential of mixed plywood made from durable and non durable plies. Weight losses and ultrasound velocity decreases confirmed that poplar and beech were non-durable against the fungi *T. versicolor* and *C. puteana*, unlike very durable chestnut, cypress and cedar having extractives in the heartwood.

The aim of this research was to improve the decay resistance of beech plywood with its additional treatment with surface veneers of more durable exotic and domestic wood species, without a negative influence of these veneers on selected physical and mechanical properties of the wooden composite "beech plywood + surface veneers".

MATERIAL AND METHODS

Beech plywood

Graded European beech (*Fagus sylvatica* L.) veneers having a constant thickness of 1.2 ±0.1 mm, all free of defects such as knots, reaction wood, decay, insect damages or cracks, were manually cut to plates of size 400 × 400 mm. Next, three-layer beech plywood boards with a thickness of 3.6 mm were prepared from air-dried beech veneers with EMC of 6 ±1% and the phenol-formaldehyde (PF) glue Fenokol 43 spread on veneers in an amount of 160 $g \cdot m^{-2}$. Pressing process at plywood preparation was performed under the following conditions: 150°C/1.8 MPa/342 s.

Wooden composites (WCs) – beech plywood treated with surface veneers

WCs were prepared from air-conditioned beech plywood (EMC 6 ±1%) and two 0.6 mm thick decorative surface veneers of selected exotic (aningré, bubinga, iroko, khaya, padouk, sapelli, wengé) and domestic (beech, European oak, sweet chestnut, walnut) wood species with EMC of 6 ±1%. The PF glue Fenokol 43 was spread in an amount of 100 $g \cdot m^{-2}$ on both surfaces of plywood, and a subsequent pressing process was performed under the following conditions: 150°C/0.6 MPa/306 s.

Surface veneers were prepared from heartwood zones of 11 wood species of different classes of natural durability, from class 1 = very durable species, to class 5 = non-durable species (by EN 350-2):

Common name	Scientific name	Class of durability against fungal-rot
Padouk	*Pterocarpus soyauxii* Taub.	1
Iroko	*Milicia excelsa* (Welw.) C. C.	1-2
Bubinga	*Guibourtia demeusii* (Harms) J.	2
European oak	*Quercus robur* L.	2
Sweet chestnut	*Castanea sativa* Mill.	2
Wengé	*Millettia laurentii* De Wild.	2
Khaya	*Khaya ivorensis* A. Chev.	3
Sapelli	*Entandrophragma cylindricum* Sprague	3
Walnut	*Juglans regia* L.	3
Aningré	*Aningeria robusta* A. Chev.	4-5
Beech	*Fagus sylvatica* L.	5

From the WCs produced under laboratory conditions and air-conditioned for 1-month were then cut samples for determination of selected properties according to European standards (Fig. 1).

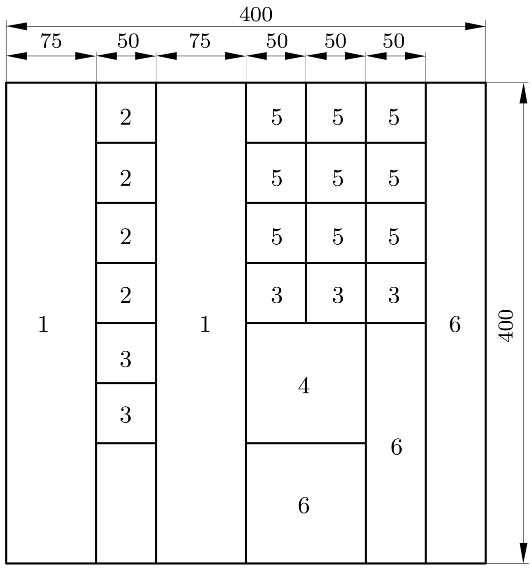

Fig. 1. Cutting scheme of a laboratory produced wooden composite (WC): 1 – samples for MOR and MOE by 3-point bending test (EN 310), 2 – samples for tensile strength perpendicularly to the plane (EN 319), 3 – samples for swelling and water soaking after 2 and 24 hours (EN 317), 4 – samples for density and moisture content determination (EN 323, EN 322), 5 – samples for decay test with modified dimensions of 50 × 50 × 4.8 mm (EN 113), 6 – residual and reserve samples

Decay test

Resistance of 11 types of WCs to fungi was tested by a Kolle's flask method whose principles are in accordance with the standard EN 113. Samples were exposed to the brown-rot fungi *Serpula lacrymans* (Wulfen) J. Schröt. or *Coniophora puteana* (Schumach.) P. Karst., and to the white-rot fungi *Phanerochaete chrysosporium* Burds. or *Trametes versicolor* (L.) Pilát. Samples from WCs (50 × 50 × 4.8 mm), and also from decorative veneers (5 pieces 50 × 25 × 0.6 mm cord with a steel wire into one stack), were firstly dried at 103 ±2°C to the oven-dry state (m_0 – determined with accuracy of 0,001 g for sterilized and in desiccators cooled samples). After that, the samples were soaked for 10 minutes in sterilized water and placed into 1 litre Kolle-flasks on the top of stainless steel legs around which, on a sterilized malt-agar soil, the fungal mycelium was already grown. Each Kolle-flask with two testing samples and closed with a sterilized cotton cap was incubated at a temperature of 22°C (*S. lacrymans*, *C. puteana*, *T. versicolor*) or 32°C (*P. chrysosporium*), and at a relative humidity of air 75-80% during 16 weeks. In each group of WCs, four replicates were tested, 11 × 4 × 4 = 176 samples in total.

At the end of the decay test, all samples were taken out from Kolle's flasks, their surfaces were purified from fungal mycelia, and then weighed in wet state (m_{wd}) for evaluation of their moistures $w = [(m_{wd} - m_{0d})/m_{0d}] \cdot 100$ (%). Subsequently, the samples were submitted to a two-stage drying process (I. $\varphi =$ 60-70%, 20-25°C/100 h; II. in laboratory drying-chamber 60°C/1 h, 80°C/1 h, 103 ±2°C/4 h) to achieve their oven-dry state (m_{0d}). The aim of such drying was to avoid formation of checks or deformations in samples and to stop decay processes in samples.

Decay resistance of all samples (veneers; WCs) was evaluated on the basis of their weight losses $\Delta m = [(m_0 - m_{0d})/m_0] \cdot 100$ (%).

Tests of physical and mechanical properties

At all types of the WCs, the following physical and mechanical properties in accordance with European standards were tested:

- Moisture content after conditioning and density (EN 322, EN 323),
- Thickness swelling and water soaking after 24 hours (EN 317),
- MOR and MOE determined by the 3-point bending test (EN 310),
- Tensile strength perpendicularly to the plane (EN 319).

Evaluation and statistical procedure

Influences of surface veneers on the decay resistance of the WCs, and also on their physical and mechanical properties were statistically analysed by the one-way ANOVA analyses of variance and by the Duncan's test.

RESULTS AND DISCUSSION

Fungal attack of surface veneers

Surface veneers of individual wood species had a different resistance to fungal attacks. Their decay resistance was in a good accordance with the classes of their natural durability by the EN 350-2 (Table 1). Bio-deterioration of the most durable padouk and iroko veneers by the brown-rot (*Serpula lacrymans*, *Coniophora puteana*) and white-rot (*Phanerochaete chrysosporium*, *Trametes versicolor*) fungi was only minimal, when their average weight losses Δm after 16 weeks of decay varied from 0.88% to 7.03% (Table 1). Veneers of the wengé had a quite good resistance against the fungi *S. lacrymans*, *C. puteana* and *P. chrysosporium* (Δm from 3.98% to 8.99%); however their resistance against the fungus *T. versicolor* was evidently poorer ($\Delta m = 26.91\%$). Fungal damaging of veneers of the sweet chestnut, European oak and bubinga was on the average slightly higher (Δm from 3.97% to 17.42%), and rot of the khaya, sapelli and walnut veneers was on the average evidently higher (Δm from 5.79% to 40.68%). Non-durable veneers of the aningré and beech were very easily damaged by all rotting fungi (Δm usually around 40%, or even 60%).

Table 1. Weight losses of surface veneers caused by rotting fungi

Surface veneers	Durability EN 350-2	Weight loss of surface veneers Δm (%)			
		S. lacrymans	*C. puteana*	*P. chrysosporium*	*T. versicolor*
Padouk	1	2.54	0.88	2.65	7.03
Iroko	1-2	1.35	3.51	5.02	4.85
Bubinga	2	15.25	8.25	13.27	17.42
European oak	2	12.16	5.60	13.70	14.89
Sweet chestnut	2	13.77	8.64	3.97	17.05
Wengé	2	8.99	7.51	3.98	26.91
Khaya	3	24.08	23.31	5.79	40.68
Sapelli	3	31.50	18.85	17.54	29.70
Walnut	3	28.89	15.61	14.90	14.68
Aningré	4-5	11.34	24.75	63.22	42.60
Beech	5	41.58	36.14	59.39	46.07

Decay by modified EN 113 (16 weeks, each replicate consisted of 5 pieces of veneers $50 \times 50 \times 0.6$ mm cord with a steel wire into one stack)

Fungal attack of the WCs "beech plywood + surface-veneers"

Antifungal resistance of the wooden composites (WCs) "beech plywood + surface-veneers" was usually significantly influenced by the wood species of surface veneers (Tables 2 and 3). WCs with surface veneers of more durable wood species, i.e. the padouk, iroko, bubinga, European oak, sweet chestnut and wengé, usually resisted better against the wood-destroying fungi in comparison with the others. Their average weight losses Δm varied between 3.35-7.14% after attack by *S. lacry-*

mans, between 5.98-14.99% after attack by *C. puteana*, between 5.72-11.73% (except for oak) after attack by *P. chrysosporium*, and between 4.34-12.79% after attack by *T. versicolor*. On the other hand, decay resistance of the WCs covered with the khaya or sapelli veneers (Δm from 8.50% to 19.04%), and above all of WCs covered with the walnut, aningré or beech veneers (Δm from 10.76% to 20.58%) was insufficient.

Table 2. Weight losses of the WCs "beech plywood + surface-veneers" caused by rotting fungi

Surface veneers	Weight loss of beech plywood treated with surface veneers Δm (%)			
	S. lacrymans	*C. puteana*	*P. chrysosporium*	*T. versicolor*
Padouk	3.35 (1.36)***	5.98 (1.21)***	5.72 (2.24)***	4.34 (0.56)***
Iroko	5.49 (1.50)***	7.92 (1.25)***	6.59 (2.30)***	12.79 (0.92)***
Bubinga	4.28 (0.78)***	11.17 (2.57)***	8.96 (3.76)***	9.76 (1.23)***
European oak	7.01 (4.34)**	7.05 (0.57)***	19.79 (2.28)	12.74 (1.80)***
Sweet chestnut	7.14 (2.61)**	11.70 (8.29)**	11.73 (4.58)***	12.24 (2.48)***
Wengé	4.71 (1.44)***	14.99 (5.60)	10.39 (2.78)***	8.37 (0.54)***
Khaya	8.96 (0.43)	15.21 (3.29)	8.50 (3.74)***	12.06 (1.78)***
Sapelli	8.59 (0.27)*	19.04 (4.63)	15.07 (3.28)**	13.00 (2.48)***
Walnut	10.76 (1.68)	18.49 (0.57)	17.31 (2.10)	14.38 (1.82)*
Aningré	11.73 (0.50)	17.51 (0.98)	20.58 (1.40)	12.18 (1.24)***
Beech	11.50 (4.10)	20.02 (4.63)	19.76 (3.30)	16.67 (1.36)
Average for all 11 types of composites	7.59	13.55	13.13	11.68

*Decay caused by rotting fungi in accordance with EN 113 (16 weeks, replicates with a modified dimension of 50 × 50 × 4.8 mm).

**Weight losses are presented as the arithmetic mean values of 4 replicates.

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

****Duncan's tests of significance for weight losses of the WCs covered with "Beech" and "Other types" of surface veneers, valued to the beech-WC on the 99% significance level (***), 95% significance level (**), or 90% significance level (*).

Table 3. One-way analysis of significance for weight losses of the WCs "beech plywood + surface-veneers" caused by rotting fungi

Statistical data		One-way test of significance for weight loss							
		S. lacrymans		*C. puteana*		*P. chrysosporium*		*T. versicolor*	
	DF	F-test	p	F-test	p	F-test	p	F-test	p
Intercept	1	530	0.000	539	0.000	832	0.000	2 326	0.000
Surface veneer	11	7.3	0.000	6.9	0.000	13.7	0.000	16.3	0.000

DF – degrees of freedom.

Decay resistance of the tested wooden composites was first of all influenced by the wood species of surface veneers (Tables 2 and 3), at which effect of the different moistures of the WCs at decay tests was probably only minimal, i.e. average moistures of the WCs attacked by brown-rot fungi ranged from 66.3%

to 90.9% without any important statistical significance between more and less decayed types of WCs (Tables 4 and 5).

Table 4. Moistures of the WCs "beech plywood + surface-veneers" at the end of decay tests

Surface veneers	Moistures of beech plywood treated with surface veneers w (%)	
	S. lacrymans	*C.puteana*
Padouk	77.0 (3.1)**	73.4 (6.8)
Iroko	87.7 (3.9)	87.0 (4.6)
Bubinga	76.0 (13.5)**	66.3 (3.7)
European oak	81.4 (15.4)	84.5 (4.7)
Sweet chestnut	84.3 (1.6)	71.6 (11.6)
Wengé	77.5 (2.7)**	76.3 (5.9)
Khaya	90.4 (1.2)	82.2 (13.2)
Sapelli	83.0 (5.7)	79.8 (18.7)
Walnut	88.4 (1.9)	79.5 (17.8)
Aningré	89.9 (2.4)	85.1 (6.1)
Beech	90.9 (2.4)	79.7 (4.5)
Average for all 11 types of composites	84.2	78.7

Moistures were determined only at decay tests with the brown-rot fungi.
*Moistures are presented as the arithmetic mean values of 4 replicates.
**Numbers in the parentheses are the standard deviations.
***Duncan's tests of significance for moistures of WCs covered with "Beech" and "Other types" of surface veneers, valued to the beech-WC on the 99% significance level (***), 95% significance level (**), or 90% significance level (*).

Table 5. One-way analysis of significance for moistures of the WCs "beech plywood + surface-veneers" at the end of decay tests

Statistical data		One-way test of significance for moisture			
		S. lacrymans		*C. puteana*	
	DF	F-test	p	F-test	p
Intercept	1	6 840	0.000	2 565	0.000
Surface veneer	11	2.8	0.013	1.5	0.184

DF – degrees of freedom.

When testing various commercial hardwood plywood materials against the fungus *T. versicolor*, Fojutowski and Kropacz (2008) determined for 4 mm three-layer plywood manufactured with the use of PF glue (plywood type 4FF) average weight loss of 20% and average moisture of 84% at the end of decay test by EN 113. This result is comparable with those results presented in this work for the beech-WC (beech plywood + beech surface veneers).

When summarizing the damaging action of rotting fungi on all 11 types of wooden composites it is evident that the average decay effect of the fungi *C. puteana* (Δm = 13.55%), *P. chrysosporium* (Δm = 13.13%) and *T. versicolor* (Δm = 11.68%) was mutually comparable, while the average decay effect of the fungus *S. lacrymans* was lower (Δm = 7.59), see Table 2.

In all cases, the best antifungal resistance of the WCs against tested brown-rot and white-rot fungi was ensured by the padouk surface veneers in the padouk-WC (Table 2, Fig. 2).

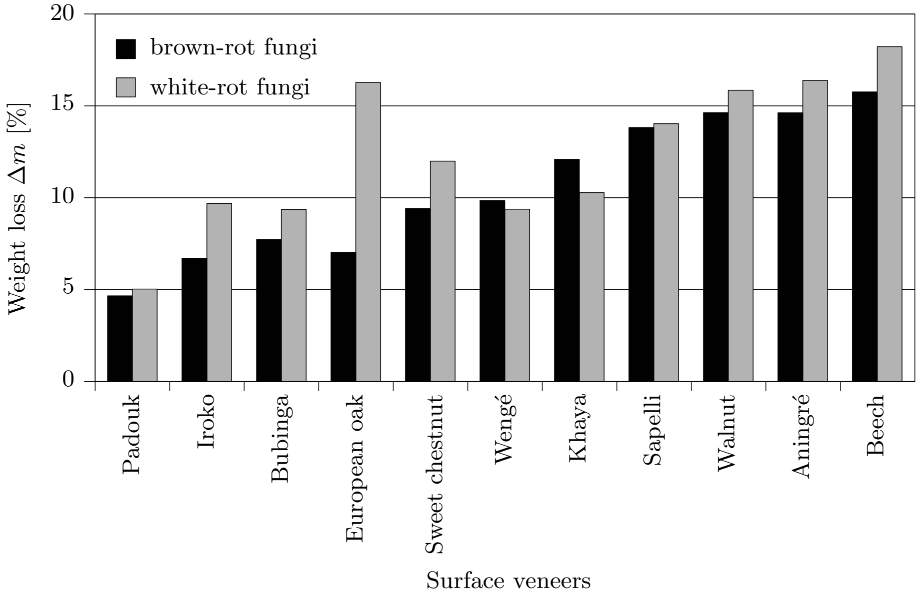

Fig. 2. Average weight losses of WCs by two white-rot fungi (*T. versicolor* and *P. chrysosporium*) and two brown-rot fungi (*S. lacrymans* and *C. puteana*)

The achieved results are comparable with those from other research works made e.g. for LVL composites containing durable black locust and non-durable maple veneers (Nzokou et al. 2005), or for plywood containing non-durable poplar or beech veneers and durable chestnut, cypress or cedar heartwood veneers on surfaces (Faraji et al. 2004). These results could help determine the influence of extractives on natural durability of plywood and other WCs recommended for exterior exposures.

Physical and mechanical properties of the WCs

Selected physical properties of wooden composites "beech plywood + surface veneers" are summarized in Table 6. Moisture content of the WCs after their conditioning varied between 5.3-6.0%. Density of the conditioned WCs varied between 0.726-0.820 $g \cdot cm^{-3}$, at which the highest density was at the bubinga-WC and the lowest one at the walnut-WC. Thickness swelling of the WCs in water after 24 hours varied from 3.5% to 8.5%, and it was lower or comparable with swelling of the beech-WC. Expressively 2.37-times lower (about 57.8% lower) swelling had the padouk-WC, while swelling of the iroko-WC, khaya-WC, sweet chestnut-WC and walnut-WC was moderately lower (about 20.5-9.6% lower) in comparison to the beech-WC. Soaking of the WCs in water after 24 hours varied from 38.9% for the padouk-WC to 52.9% for the khaya-WC. The padouk-WC had the best resistance against water and also against fungal attacks. These results give opportunity for using this composite product also in exteriors.

Table 6. Moisture after conditioning, density, thickness swelling and water soaking of WCs "beech plywood + surface-veneers"

Surface veneers	Moisture [%]	Density [$g \cdot cm^{-3}$]	Swelling – 24 h [%]	Soaking – 24 h [%]
Padouk	5.3 (0.07)***	0.763 (0.01)	3.5 (1.2)***	38.9 (6.7)***
Iroko	5.9 (0.03)*	0.729 (0.01)**	6.6 (0.8)***	48.0 (2.7)
Bubinga	5.6 (0.05)	0.820 (0.02)***	7.9 (0.8)	42.7 (2.3)***
European oak	5.7 (0.08)	0.741 (0.02)	7.6 (1.1)**	48.1 (2.3)
Sweet chestnut	5.7 (0.09)	0.766 (0.02)	7.2 (0.7)***	43.8 (2.2)***
Wengé	5.6 (0.05)	0.774 (0.02)	8.5 (0.7)	44.6 (2.2)**
Khaya	5.8 (0.09)	0.742 (0.01)	7.0 (0.9)***	52.9 (5.1)***
Sapelli	6.0 (0.11)***	0.750 (0.01)	8.4 (0.8)	52.8 (1.8)***
Walnut	6.0 (0.40)**	0.726 (0.01)**	7.5 (0.8)**	50.8 (3.8)***
Aningré	6.0 (0.09)***	0.733 (0.02)**	8.2 (1.2)	49.9 (2.2)***
Beech	5.7 (0.11)	0.760 (0.01)	8.3 (1.0)	47.1 (2.0)
Average for all 11 types of composites	5.8	0.755	7.3	47.2

*Physical properties determined by European standards are presented as the arithmetic mean values of 4 replicates (moisture, density) or of 16 replicates (thickness swelling, soaking).

**Numbers in the parentheses are the standard deviations.

***Duncan's tests of significance for physical properties of the WCs covered with "Beech" and "Other types" of surface veneers, valued to the beech-WC on the 99% significance level (***), 95% significance level (**), or 90% significance level (*).

The most important mechanical and physical properties of plywood and factors affecting them were described by Réh (2001). He states that the strength properties of beech plywood are significantly better than those of plywood from other types of wood. Hrázský and Král (2005) stated that MOR in bending of the 5-layer beech plywood is 78.65 MPa. Dieste et al. (2008) achieved similar value of MOR 87.46 MPa for the 5-layer beech plywood prepared with 150 $g \cdot m^{-2}$ of PF glue. Bekhta et al. (2009) investigated possibility to improve mechanical properties of plywood by pre-compressed (densified) veneers of birch (*Betula pubescens*) and alder (*Alnus glutinosa*). Their investigations showed that the MOR in bending and shear strength improved as compression degree of veneers increased from 5 to 15%.

In our work, different strength properties of three-layer beech plywood treated with various types of surface veneers in the WCs could also be expected. Selected mechanical properties of the WCs are presented in Table 7.

The highest modulus of rupture (MOR) was determined for the beech-WC (86.6 MPa) and the lowest one for the iroko-WC (49.0 MPa). Similar results were achieved at the modulus of elasticity (MOE), when the beech-WC together with the wengé-WC and the bubinga-WC had the highest values of MOE (from 10.2 GPa to 11 GPa), while the iroko-WC had the lowest MOE (6.1 GPa). Evi-

Table 7. Modulus of rupture (MOR), modulus of elasticity (MOE) and tensile strength perpendicularly to the plane ($\sigma_\perp$) of WCs "beech plywood + surface-veneers"

Surface veneers	MOR [MPa]	MOE [MPa]	$\sigma_\perp$ [MPa]
Padouk	50.7 (4.2)***	7 112 (957)***	2.11 (0.33)
Iroko	49.0 (2.9)***	6 109 (183)***	2.21 (0.46)
Bubinga	72.5 (9.4)**	10 401 (479)	2.77 (0.44)***
European oak	55.4 (14.8)***	7 507 (644)***	2.39 (0.36)*
Sweet chestnut	80.0 (19.0)	9 100 (835)***	2.88 (0.37)***
Wengé	81.7 (11.7)	11 041 (1 133)*	2.41 (0.57)*
Khaya	59.7 (4.3)***	7 344 (417)***	2.29 (0.34)
Sapelli	69.3 (8.9)***	8 816 (1 078)***	2.97 (1.04)***
Walnut	77.9 (6.7)	7 605 (366)***	3.36 (0.8)***
Aningré	59.1 (5.6)***	8 426 (737)***	1.90 (0.27)
Beech	86.6 (12.2)	10 212 (1 187)	2.00 (0.65)
Average for all 11 types of composites	67.4	8 516	2.48

*Mechanical properties determined by European standards are presented as the arithmetic mean values of 8 replicates (MOR, MOE) or of 12 replicates ($\sigma_\perp$).

**Numbers in the parentheses are the standard deviations.

***Duncan's tests of significance for mechanical properties of the WCs covered with "Beech" and "Other types" of surface veneers, valued to the beech-WC on the 99% significance level (***), 95% significance level (**), or 90% significance level (*).

dently lower values of MOR and MOE had also the WCs which were covered with the padouk, khaya, European oak and walnut veneers. Lower bending properties of these WCs can probably be reasoned by a negative influence of extractives in these wood species on the adhesive properties of PF glue. Tohmura (1998) found that extractives of merbau wood decreased the wettability of veneer surfaces for PF glue, and also slightly increased the gelation rate of PF resin at plywood preparation. Dziurka et al. (2009) improved bending properties of beech plywood at addition of alkylresorcinols and hydrogen peroxide to PF resin. Similarly, it means as extractives or additives, can act wood preservatives. Ayrilmis and Winandy (2007) determined a negative effect of four fire-retardants (borax, boric acid, monoammonium and diammonium phosphates) on the shear properties of plywood. However, Colakoglu and Demirkir (2006) did not find a difference between control plywood panels and plywood panels containing borax at testing the shear strength, MOR and MOE.

On the other hand, tensile strength perpendicularly to the plane ($\sigma_\perp$) of the WCs covered with more durable exotic or domestic surface veneers was not negatively influenced by the type of veneers (or by the type of extractives) and it was comparable or even significantly higher (for the walnut-WC, sapelli-WC, sweet chestnut-WC, and bubinga-WC) as of the beech-WC (see Table 7).

CONCLUSIONS

1. Decay resistance of beech plywood was significantly improved by its treatment with surface veneers of more durable wood species, above all from heartwoods of the padouk, but also from the iroko, bubinga, European oak, sweet chestnut and wengé.
2. However, decay resistance of wooden composites (WCs) "beech plywood + surface veneers" was insufficient at using of the khaya or sapelli surface veneers, and evidently insufficient at using of the walnut, aningré or beech surface veneers.
3. 11 types of the WCs had a slightly better resistance to the dry-rot fungus *S. lacrymans* than to other fungi *C. puteana*, *P. chrysosporium* or *T. versicolor*.
4. The padouk-WC "beech plywood + padouk surface veneers" had the best resistance not only to decay, but also to soaking and swelling in water.
5. Tensile strength perpendicularly to the plane of the WCs containing more durable exotic or domestic surface veneers was comparable or higher than of the beech-WC.
6. On the other hand, modulus of rupture and modulus of elasticity of the majority of the WCs covered with more durable exotic and domestic surface veneers were lower than of the beech-WC.

Acknowledgement

The authors would like to express their thanks the Ministry of Education of the Slovak Republic and the project agency VEGA 1/0421/10 for financial support of this scientific work.

REFERENCES

Ayrilmis N., Winandy J.E. (2007): Effects of various fire-retardants on plate shear and five-point flexural shear properties of plywood. For. Prod. J. 57(4): 44-49.

Bekhta P., Hiziroglu S., Shepelyuk O. (2009): Properties of plywood manufactured from compressed veneer as building material. Mater. Design 30: 947-953.

Bravery A., Lea R. (1987): Assessing the fungus resistance of wood based composites. In: Protection of Wood Based Composite Products 1987. IUFRO Proceedings: 67-86.

Colakoglu G., Demirkir C. (2006): Characteristics of plywood panels produced with urea formaldehyde resin (UF) containing borax. Holz Roh-u. Werkst. 64: 250-251.

Deon G., Schwartz R. (1988): Natural resistance of tropical timbers to biological attacks. Bull. Soc. Bot. Fr. Actual. Bot. 135(3): 37-48.

DIESTE A., KRAUSE A., BOLLMUS S., MILITZ H. (2008): Physical and mechanical properties of plywood produced with 1.3-dimethylol-4.5-dihydroxyethyleneurea (DMDHEU)-modified veneers of *Betula* sp. and *Fagus sylvatica*. Holz Roh-u. Werkst. 66: 281-287.

DZIURKA D., ŁĘCKA J., MIRSKI R. (2009): The effect of modification of phenolic resin with alkylresorcinols and H_2O_2 on properties of plywood. Acta Sci. Pol. Silv. Colendar. Rat. Ind. Lignar. 8(4): 67-74.

EN 113: Wood preservatives. Test methods for determining the protective effectiveness against wood destroying basidiomycetes. Determination of the toxic values. (STN EN 113: 1998, Ochranné prostriedky na drevo. Skúšobná metóda zisťovania ochrannej účinnosti proti drevokazným hubám Basidiomycetes. Zisťovanie hraníc účinnosti – STN 49 0702).

EN 310: Wood-based panels. Determination of modulus of elasticity in bending and of bending strength. (STN EN 310: 1998, Dosky na báze dreva. Zisťovanie modulu pružnosti v ohybe a pevnosti v ohybe – STN 49 0147).

EN 317: Particleboards and fibreboards. Determination of swelling in thickness after immersion in water. (STN EN 317: 1999, Drevotrieskové a drevovláknité dosky. Zisťovanie hrúbkového napúčania po ponorení do vody – STN 49 2610).

EN 319: Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board. (STN EN 319: 1995, Trieskové a vláknité dosky. Zisťovanie pevnosti v ťahu kolmo na rovinu dosky – STN 49 0151).

EN 322: Wood-based panels. Determination of moisture content. (STN EN 322: 1995, Dosky z dreva. Zisťovanie vlhkosti – STN 49 0143).

EN 323: Wood-based panels. Determination of density. (STN EN 323: 1996, Dosky z dreva. Zisťovanie hustoty – STN 49 0142).

EN 335-3: Durability of wood and wood-based products. Definition of hazard classes of biological attack. Part 3: Application to wood-based panels. (STN EN 335-3: 1997, Trvanlivosť dreva a výrobkov na báze. Definícia tried ohrozenia podľa napadnutia biotickými činiteľmi. 3. časť: Použitie na dosky na báze dreva – STN 49 0660).

EN 350-2: Durability of wood and wood-based products. Natural durability of solid wood. Part 2: Guide to natural durability and treatability of selected wood species of importance in Europe. (STN EN 350-2: 1997, Trvanlivosť dreva a výrobkov na báze. Prirodzená trvanlivosť rastlého dreva. 2. časť: Návod na zisťovanie prirodzenej trvanlivosti a impregnovateľnosti vybraných druhov dreva dôležitých v Európe – STN 49 0661).

FARAJI F., THÉVENON M.F., THIBAUT B. (2004): Evaluation of the natural durability and ultrasonic method for decay detection of some European hardwood and softwood species. International Research Group on Wood Preservation. Document No. IRG/WP/04-10537.

FOJUTOWSKI A., KROPACZ A. (2008): The susceptibility of hardwood plywood to white rot. International Research Group on Wood Protection. Document No. IRG/WP/08-40397.

FOJUTOWSKI A., KROPACZ A., NOSKOWIAK A. (2009): Determination of wood-based panels resistance to wood attacking fungi. Fol. For. Pol. Ser. B 40: 79-88.

HRÁZSKÝ J., KRÁL P. (2005): Assessing the bending strength and modulus of elasticity in bending of exterior foiled plywood in relation to their construction. J. For. Sci. 51(2): 77-94.

LAHIRY A.K. (2005): Non-pressure treatability of plywood by CCA, CCB and boron. International Research Group on Wood Protection. Document No. IRG/WP/05--40295.

Mahút J., Osvald A., Reinprecht L., Krakovský A. (1985): Fire retardant treatment of plywood with modificated PF resin. 5th Symp. Modyfikacja drewna. Poznań: 216-227.

Morrell J.J., Acda M.N., Zahora A.R. (2005): Performance of oriented strandboard, medium density fiberboard, plywood, and particleboard treated with tebuconazole in supercritical carbon dioxide. International Research Group on Wood Protection. Document No. IRG/WP/05-30364.

Murphy R.J., Turner P. (1989): A vapour phase preservative treatment of manufactured wood-based board materials. Wood Sci. Technol. 23: 273-279.

Norton J. (2002): The protection of plywood with benzalkonium chloride (BAC) wood preservative. International Research Group on Wood Preservation. Document No. IRG/WP/02-40219.

Nzokou P., Zyskowski J., Boury S., Kamdem D.T. (2005): Natural decay resistance of LVL made of veneers from durable and non-durable wood species. Holz Roh-u. Werkst. 63: 173-178.

Réh R. (2001): Fyzikálne vlastnosti preglejovaných materiálov. Stolár. Mag. 2(2): 8-9.

Reinprecht L., Zubková G., Marchal R. (2010): Decay resistance of laminated veneer lumber from black locust wood. Wood Res. 55(2): 39-52.

Tohmura S. (1998): Acceletration of the cure of phenolic resin adhesives VII: Influence of extractives of merbau wood on bonding. J. Wood Sci. 44: 211-216.

Van Acker J., Stevens M., De Clercq E. (2001): Evaluation of the European standard ENV 12038 for durability testing of plywood. International Research Group on Wood Preservation. Document No. IRG/WP/01-20237.

Yang V.W., Illman B.L., Ferge L.A., Ross R.J. (2001): Wood-based composites exposed to fungal degradation – laboratory results. International Research Group on Wood Preservation. Document No. IRG/WP/01-40215.

Received in November 2010

Authors' address:
Prof. Ing. Ladislav Reinprecht, PhD.
Ing. Ján Iždinský, PhD.
Ing. Laura Kmeťová
Faculty of Wood Sciences and Technology
Technical University of Zvolen
T.G. Masaryka 24
SK-960 53 Zvolen
Slovakia
e-mail: reinpret@vsld.tuzvo.sk