Journal of Tropical Forest Science 24(4): 490–497 (2012)

FUNGAL DECAY AND BENDING PROPERTIES OF BEECH PLYWOOD OVERLAID WITH TROPICAL VENEERS

L Reinprecht*, L Kmeťová & J Iždinský

Faculty of Wood Sciences and Technology, Technical University of Zvolen, TG Masaryka 24, SK-960 53 Zvolen, Slovak Republic

Received August 2011

REINPRECHT L, KMEŤOVÁ L & IŽDINSKÝ J. 2012. Fungal decay and bending properties of beech plywood overlaid with tropical veneers. Both surfaces of three-layer beech plywood were separately overlaid with thin veneers of seven tropical species: aningré (*Aningeria robusta*), bubinga (*Guibourtia demeusei*), iroko (*Milicia* sp.), khaya (*Khaya ivorensis*), padouk (*Pterocarpus* sp.), sapelli (*Entandrophragma* sp.) and wengé (*Millettia laurentii*), and one domestic species: beech (*Fagus sylvatica*), in order to assess their influence on the natural durability of the final panels against basidiomycetes. Laboratory preparation of beech plywood and its veneering were performed by hot pressing process using waterproof phenol-formaldehyde resin in order to produce panels suitable to be used in exterior exposure without ground contact, i.e. in use class 3. Durability of the veneered plywood was assessed by their exposure to two brown-rot fungi (*Serpula lacrymans* and *Coniophora puteana*) and two white-rot fungi (*Phanerochaete chrysosporium* and *Trametes versicolor*) for 16 weeks according to the modified EN 113 using edge protected specimens. Beech plywood overlaid with padouk veneers had the lowest mass loss after fungal attack. However, good antifungal effects were also accomplished using the iroko, bubinga and wengé veneers. Bending characteristics (MOR, MOE) of the veneered plywood boards were partly influenced by the type of surface veneers, with the lowest values for iroko veneers and the highest values for wengé.

Keywords: Wood-based panels, natural durability, wood-destroying fungi, exterior exposure

REINPRECHT L, KMEŤOVÁ L & IŽDINSKÝ J. 2012. Pereputan kulat dan ciri-ciri lentur papan lapis bic yang dilapisi venir kayu tropika. Kedua-dua permukaan papan lapis bic tiga lapis dilapis secara berasingan dengan venir tujuh spesies tropika iaitu aningré (*Aningeria robusta*), bubinga (*Guibourtia demeusei*), iroko (*Milicia* sp.), khaya (*Khaya ivorensis*), padouk (*Pterocarpus* sp.), sapelli (*Entandrophragma* sp.) dan wengé (*Millettia laurentii*) serta satu spesies domestik iaitu bic (*Fagus sylvatica*). Tujuannya adalah untuk menilai pengaruh venir terhadap ketahanan semula jadi panel yang dihasilkan menentang basidiomiset. Persediaan makmal papan lapis bic serta kerja-kerja memasang venir dijalankan secara penekanan panas menggunakan resin fenol formaldehid yang kalis air. Panel yang dihasilkan sesuai untuk kegunaan pendedahan luar tanpa menyentuh tanah, yakni kelas kegunaan 3. Ketahanan papan lapis bervenir dinilai setelah pendedahan kepada dua kulat reput perang (*Serpula lacrymans* dan *Coniophora puteana*) dan dua kulat reput putih (*Phanerochaete chrysosporium* dan *Trametes versicolor*) selama 16 minggu mengikut EN 113. Papan lapis bic yang dilapisi venir padouk mengalami kehilangan berat yang paling rendah selepas serangan kulat. Bagaimanapun, kesan antikulat yang baik turut ditunjukkan oleh venir iroko, bubinga dan wengé. Ciri lentur (MOR, MOE) papan lapis venir dipengaruhi sebahagiannya oleh jenis permukaan venir dengan nilai terendah ditunjukkan oleh venir iroko sementara yang tertinggi venir wengé.

INTRODUCTION

Plywood is an important engineered wood material with excellent physical and mechanical properties. It is often used in building construction systems, shipbuilding, transportation, furniture, etc. In European countries, plywood boards for exterior use must be manufactured in accordance with EN 636-3 (2003) and their durability should be addressed as outlined in EN 335-3 (1996). Biological degradation, delamination, decrease in strength and stiffness, or other detrimental phenomena in plywood are associated mainly with high moisture content, moisture dynamics and complex ageing processes (Brischke & Rapp 2008, Van den Bulcke et al. 2009).

Plywood with moisture content above 20–30% is prone to damage by moulds, staining fungi or wood-destroying fungi. Decay of

---

*reinpret@vsld.tuzvo.sk

plywood, laminated veneer lumbers (LVL), particleboards and other wood composites starts at the threshold moisture content which for plywood materials ranges usually from 19.5 to 25.5% (Van Acker et al. 2001). Plywood close to threshold moisture content will decay very slowly but its optimum decay is achieved at 6% above the threshold moisture content (Van Acker et al. 2001). Decay resistance of plywood is important if it must withstand the impact of wetting. Attack of plywood by basidiomycetes is not a critical factor if it is never exposed to high moisture levels. Susceptibility of plywood or LVL to wood-damaging fungi in a humid environment depends mainly on the anatomical, permeability and chemical characteristics of the wood species used for the veneer preparation (Faraji et al. 2004). The type of glue used and the pressing process also have considerable influence (Reinprecht et al. 2010b).

In conditions with high risk of wetting, the fungal resistance of plywood made from non-durable, less durable or medium durable timbers (belonging to durability class 5, 4 or 3 in accordance with EN 350-2 (1994), e.g. beech, birch, poplar, spruce, pine, sapelli) is usually insufficient (Lahiry 2005, Van den Bulcke et al. 2011). Improvement of fungal resistance and increasing the service life of plywood materials can be achieved by the following methods: (1) chemical treatment of plywood with fungicides, (2) chemical preservation of veneers with fungicides, (3) application of thermally- or chemically-modified veneers, (4) combination of non-durable veneers with durable veneers in plywood lay-ups, (5) use of glue with antifungal effects and (6) surface treatment of plywood with more durable synthetic or natural materials.

A higher biological resistance of plywood and other wood composites made from durable veneers, and also of plywood additionally veneered with more durable veneers, is attributed mainly to the presence of tannins, flavonoids, terpenoids and other extractives with antifungal effect which are present in various tropical wood species (Wong et al. 2005) and also in black locust or oak species (Reinprecht et al. 2010b, c). It has been reported that high natural durability of padouk is attributed to santal extractives, or of okan to the tetrahydroxy-3',4',7,8 flavonol (Déon & Schwartz 1988). LVL made from durable black locust wood had very high resistance against the white-rot fungus *Trametes versicolor* and a high resistance against the brown-rot fungus *Coniophora puteana* (Reinprecht et al. 2010c). The biological resistance of plywood and LVL made from veneers of non-durable species (maple, poplar, beech) can be increased by incorporation of veneers from more durable species (black locust, chestnut, cypress, cedar) applied on both faces of the composite (Faraji et al. 2004, Nzokou et al. 2005).

This study examined decay resistance and bending characteristics of beech plywood overlaid with surface veneers of seven tropical wood species, namely, aningré (*Aningeria robusta*), bubinga (*Guibourtia demeusei*), iroko (*Milicia* sp.), khaya (*Khaya ivorensis*), padouk (*Pterocarpus* sp.), sapelli (*Entandrophragma* sp.) and wengé (*Millettia laurentii*), which had different classes of durability according to EN 350-2 (1994), from 4–5 (aningré) to 1 (padouk). The basic hypothesis of the experiment was that covering the less durable beech plywood with veneers made from more durable tropical wood species could be a convenient method to increase durability of the veneered beech plywood (final wood-based panels) against fungal decay. Concurrently, the effects of tropical veneers on bending strength and modulus of elasticity of the final panels were analysed. These mechanical properties are important for building and other construction materials.

MATERIALS AND METHODS

Beech plywood

European beech (*Fagus sylvatica*) veneers with a constant thickness of 1.2 ± 0.1 mm, free of knots above 6 mm, reaction wood, false heartwood, cracks, decay and insect damages or other defects were sorted, manually cut to plates of size 400 mm × 400 mm and air-conditioned (EMC 6 ± 1%). Next, using these veneers, three-layer beech plywood boards with nominal thickness of 3.6 mm were prepared. Phenol-formaldehyde Fenokol 43 glue was spread on one side of the veneers in an amount of 160 g m^{-2} and the pressing process for plywood preparation was performed at 150 °C with a pressure of 1.8 MPa for 342 s. The time of the pressing process (τ_p = 342 s) was established by equation 1:

$$\tau_p = \tau_1 + (TH_p \times \tau_2) \qquad (1)$$

where τ_1 = curing time for Fenokol 43 glue (270 s), τ_2 = time for heat transfer through a 1-mm thick veneer (60 s), TH_p = non-dimensional thick factor for heat transfer from surface to the glue layer nearest to the axis of plywood symmetry (1.2).

Surface veneers

Seven commercial tropical veneers (aningré, bubinga, iroko, khaya, padouk, sapelli, wengé) and also one European standard veneer, namely, beech, were used for veneering the beech plywood. Thickness of all veneers was 0.6 ± 0.1 mm each. Tropical veneers were prepared by slicing from heartwood zones of logs. Natural durability of surface veneers, classified by the standard EN 350-2 (1994), was from class 1 (very durable species) to 5 (non-durable species) (Table 1). Densities of the wood of surface veneers were not determined in this work; the oven-dry density values were listed according to Wagenführ (2007) (Table 1).

Veneered beech plywood

Final veneered beech plywood panels with a nominal thickness of 4.8 mm were prepared from the air-conditioned beech plywood (EMC of 6 ± 1%) and surface veneers (EMC of 6 ± 1%) (Table 1). At the overlaying processes, phenol-formaldehyde Fenokol 43 glue was spread on both surfaces of beech plywood in an amount of 100 g m^{-2} and then the surface veneers were placed on both faces of plywood in press at 150 °C and 0.6 MPa for 306 s. Finally, the veneered plywood panels were air conditioned in a chamber with relative humidity of 45% and temperature of 20 °C for 4 weeks (EMC of 6 ± 1%).

Fungal susceptibility of veneered plywood

Resistance of the eight veneered beech plywood panels against wood-destroying fungi was tested according to the EN 113 (1996), with modifications in the dimension of specimens and their sterilisation and using another optional fungus, *Phanerochaete chrysosporium*. Specimens with sizes 50 mm × 50 mm × 4.8 mm were exposed to the following two brown-rot fungi: *Serpula lacrymans* and *C. puteana* and two white-rot fungi: *P. chrysosporium* and *T. versicolor*. Before fungal exposure, the edges of specimens were sealed with a thin layer of Fenokol 43 glue (100 ± 10 g m^{-2}). Specimens were then oven dried and sterilised at 103 ± 2 °C for approximately 4 hours and later cooled in desiccators and weighed (m_0), soaked for 10 min in sterilised distilled water with the aim of achieving moisture content above 20%, and finally placed into 1 L Kolle-flasks (two pieces into one flask) on top of stainless steel grids around which the fungal mycelium had already grown. Specimens were incubated for 16 weeks at 22 °C (*S. lacrymans, C. puteana, T. versicolor*) or 32 °C (*P. chrysosporium*) and relative humidity of 75–80%. The experiments were done in replicates of four, giving the total number of specimens 128. Virulence of the fungi was determined with

Table 1 Wood species used for veneer production with their durability classification against decay fungi, the oven-dry density of wood of used veneers and mass losses (Δm) of veneers after attack by decay fungi *Serpula lacrymans*, *Coniophora puteana*, *Phanerochaete chrysosporium* and *Trametes versicolor* for 16 weeks

Veneer	Durability EN 350-2	Density (kg m^{-3})	Δm (%)			
			S. lacrymans	*C. puteana*	*P. chrysosporium*	*T. versicolor*
Padouk	1	650	2.54	0.88	2.65	7.03
Iroko	1–2	480–630–670	1.35	3.51	5.02	4.85
Bubinga	2	750–850	15.25	8.25	13.27	17.42
Wengé	2	750–790	8.99	7.51	3.98	26.91
Khaya	3	420–470–570	24.08	23.31	5.79	40.68
Sapelli	3	490–620–720	31.50	18.85	17.54	29.70
Aningré	4–5	480–520–580	11.34	24.75	63.22	42.60
Beech	5	490–680–880	41.58	36.14	59.39	46.07

decay test of solid beech specimens (50 mm × 25 mm × 15 mm) in accordance with EN 113 (1996) on the basis of mass losses, Δm (*S. lacrymans* = 28.26%, *C. puteana* = 34.40%, *P. chrysosporium* = 25.17% and *T. versicolor* = 27.45%).

After fungal attacks, decayed specimens were cleaned by removing the mycelia. The specimens underwent a two-stage drying process to achieve their oven-dry state ($m_{0\text{-decayed}}$) according to the method described by Reinprecht et al. (2007), i.e. first at 60–70% RH and 20–25 °C/100 hours; subsequently in a drying chamber at 60 °C/1 hour, 80 °C/1 hour and 103 °C/4 hours, with the aim of avoiding cracks or deformations. The durability of the veneered plywood specimens was evaluated on the basis of their mass losses in per cent by equation 2:

$$\Delta m = [(m_0 - m_{0\text{-decayed}})/m_0] \times 100 \qquad (2)$$

Density and bending characteristics of veneered plywood

Density (sample size 100 mm × 100 mm × 4.8 mm) and bending characteristics (sample size 180 mm (in the grain direction of the surface tropical veneers) × 75 mm × 4.8 mm) of veneered plywood specimens were tested at conditioned state (20 °C, 65% RH) in accordance with European standards, i.e. EN 323 (1993) and EN 310 (1993) respectively. Equations used for the modulus of rupture (MOR) and the modulus of elasticity (MOE) evaluation were

$$MOR = \frac{3.F_{max}.l_0}{2.b.h^2} \qquad (3)$$

$$MOE = \frac{\delta F.l_0^{\,3}}{4.b.h^3.\delta\gamma} \qquad (4)$$

where l_0 = distance between supports at the three-point bending test (120 mm), b = width (75 mm), h = height (4.8 mm), F_{max} = maximum force (N), δF = force increment within the linear area of deformation (N) and δy = increment of deformation in the middle of the specimen (mm).

Statistical analyses

Influence of the tropical veneers on the decay resistance, density and bending characteristics of the veneered beech plywood boards was statistically analysed using one-way ANOVA and the Duncan's test.

RESULTS AND DISCUSSION

Fungal susceptibility

The decay resistance of the veneered beech plywood boards (final panels) against brown- and white-rot fungi was significantly influenced by wood species of the surface veneers (Tables 2 and 3, Figure 1). Plywood overlaid with surface veneers of the most durable species, i.e. padouk, iroko, bubinga and wengé had higher resistance against the wood-destroying fungi in comparison with the rest of the tropical species. Their average mass losses varied between 3.35 and 5.49% after attack by *S. lacrymans*, between 5.98 and 14.99% after attack by *C. puteana*, between 5.72 and 10.39% after attack by *P. chrysosporium* and between 4.34 and 12.79% after attack by *T. versicolor*. On the other hand, decay resistance of beech plywood overlaid with khaya or sapelli veneers (Δm from 8.50 to 19.04%), and with aningré or beech veneers (11.50 to 20.58%) was evidently lower. Nevertheless, on the basis of Duncan's test, khaya, sapelli and partly also aningré veneers had slightly better antifungal effects against white- than brown-rot fungi (Table 2).

The decay resistance of individual veneers with dimensions of 50 mm × 25 mm × 0.6 mm was lower (Reinprecht 2010a, Table 1) in comparison with final veneered plywood panels when testing less durable veneers such as beech, aningré, sapelli or khaya (Table 2). On the other hand, the padouk and iroko veneers resisted better to decay compared with the final veneered beech plywood (Tables 1 and 2). However, it must be noted that results from fungal testing of individual veneers and final panels cannot be compared with each other mainly due to the different sizes of veneers and panels, and the presence of phenol-formaldehyde glue in veneered plywood.

In a study using 4-mm thick three-layer commercial plywood manufactured with phenol-formaldedyde resin (type 4FF), a high mass loss of 20% was observed after 16 weeks attack by the fungus *T. versicolor* (Fojutowski & Kropacz 2008). Their result is comparable with our findings for the beech plywood overlaid with beech veneers. However, in our work beech plywood overlaid with tropical veneers of different natural durability generally performed better (Table 2).

The antifungal effects of protective overlaying were not homogeneous between the different

Table 2 Mass losses (Δm) of the veneered beech plywood exposed to decay fungi *Serpula lacrymans*, *Coniophora puteana*, *Phanerochaete chrysosporium* and *Trametes versicolor* for 16 weeks

Surface veneer	Δm (%)				
	S. lacrymans	*C. puteana*	*P. chrysosporium*	*T. versicolor*	Average for four fungi
Padouk	3.35 (1.36) ***	5.98 (1.21) ***	5.72 (2.24) ***	4.34 (0.56) ***	4.85
Iroko	5.49 (1.50) ***	7.92 (1.25) ***	6.59 (2.30) ***	12.79 (0.92) ***	8.20
Bubinga	4.28 (0.78) ***	11.17 (2.57) ***	8.96 (3.76) ***	9.76 (1.23) ***	8.54
Wengé	4.71 (1.44) ***	14.99 (5.60)	10.39 (2.78) ***	8.37 (0.54) ***	9.62
Khaya	8.96 (0.43)	15.21 (3.29)	8.50 (3.74) ***	12.06 (1.78) ***	11.18
Sapelli	8.59 (0.27) *	19.04 (4.63)	15.07 (3.28) **	13.00 (2.48) ***	13.93
Aningré	11.73 (0.50)	17.51 (0.98)	20.58 (1.40)	12.18 (1.24) ***	15.50
Beech	11.50 (4.10)	20.02 (4.63)	19.76 (3.30)	16.67 (1.36)	16.99
Average for eight panel types	7.33	13.98	11.95	11.15	

Numbers in the parentheses are standard deviations, Duncan's test of significance evaluated based on beech standard—99% significance level (***), 95% significance level (**) or 90% significance level (*)

Table 3 One-way analysis of significance for mass losses of the veneered beech plywood after attack by decay fungi

Statistical data	One-way test of significance for mass loss (Δm)								
	DF	*S. lacrymans*		*C. puteana*		*P. chrysosporium*		*T. versicolor*	
		F-test	p	F-test	P	F-test	p	F-test	p
Intercept	1	569	0.000	523	0.000	525	0.000	2031	0.000
Surface veneer type	8	14.5	0.000	8.9	0.000	15.5	0.000	27.6	0.000

DF = degree of freedom

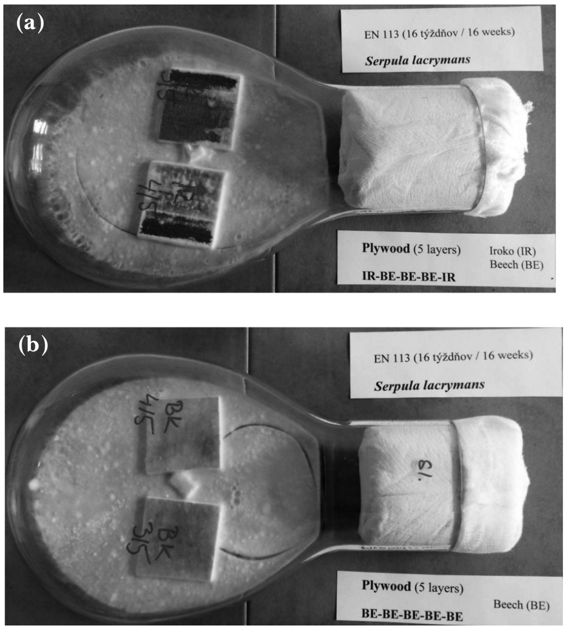

Figure 1 Specimens of the veneered beech plywood attacked by *Serpula lacrymans* after 16 weeks: (a) iroko surface veneers and (b) beech surface veneers

fungi (Table 2). These could be explained by the unequal biocide effects of extractive(s) in padouk, iroko or the rest of the tested veneers against different fungi, i.e. one type of extractive could be more effective against *T. versicolor* and less effective against *C. puteana*. For the eight types of veneered plywood panels, average mass losses caused by *C. puteana* (13.98%), *P. chrysosporium* (11.95%) and *T. versicolor* (11.15%) were mutually comparable and more extensive than those caused by *S. lacrymans* (7.33%), as shown in Table 2.

Overall, padouk veneer was the most effective for surface protection of non-durable plywood. Extractives of padouk ensured very good antifungal effect on wood products as was also reported by Wong et al. (2005). From our results, it could be suggested that the combination 'padouk surface veneer + beech (or other non-durable) plywood + padouk surface veneer' would be able to withstand moderate wet interior or exterior conditions without ground contact, i.e. in use class 2 or 3 by EN 335-3 (1996). Beech plywood overlapped with padouk veneer had mass loss close to the 3% critical threshold stipulated by EN 113 (1996) for wood preserved with effective fungicides.

Generally, durable outer veneers such as okoumé (Van den Bulcke et al. 2011), padouk and iroko can be considered to behave as a preservative biocide coating on wood-based panels. Their protective effect should be influenced mainly by their thickness and their anatomical and chemical structures. Slower elution of extractives occur from thicker and less permeable veneers and for less water-soluble extractives. Similarly, entry of fungal spores and hyphae into the inside parts of panels should be more difficult through thicker and less porous surface veneers. Chemical structure of extractives and their localisation in surface veneers seem to be important not only for the biological resistance of veneered plywood panels but also for their water resistance (hydrophobicity), durability (stability of extractives against leaching and evaporation) and bonding quality. Life time of veneered plywood can be additionally improved with silane, alkyd, polyurethane or other types of water- and UV-light resistant coatings (Donath et al. 2006). A very important factor to consider will be the sealing quality of paints used on their edges as well (Van den Bulcke et al. 2011).

Density and bending characteristics

The density of veneered beech plywood types after conditioning at 12% moisture content was in the range of 729 (iroko) to 820 kg m^{-3} (bubinga). Densities of veneered beech plywood (Table 4) were not in contradiction with densities of surface veneers (Table 1).

Generally, MOR of beech plywood determined by bending test range from 60 to 95 MPa and it depends on more factors, e.g. thickness of veneers and plywood, type of glue and conditions of the pressing process (Réh 2001, Hrázský & Král 2005, Dieste et al. 2008). Bekhta et al. (2009) investigated the possibility of improving mechanical properties of plywood using pre-compressed (densified) veneers of birch

Table 4 Density (ρ), modulus of rupture (MOR) and modulus of elasticity (MOE) of the veneered beech plywood

Surface veneer	ρ (kg m^{-3})	MOR (MPa)	MOE (MPa)
Padouk	763 (14)	50.7 (4.2) ***	7 112 (957) ***
Iroko	729 (11) **	49.0 (2.9) ***	6 109 (183) ***
Bubinga	820 (24) ***	72.5 (9.4) **	10 401 (479)
Wengé	774 (19)	81.7 (11.7)	11 041 (1133) *
Khaya	742 (8)	59.7 (4.3) ***	7 344 (417) ***
Sapelli	750 (9)	69.3 (8.9) ***	8 816 (1078) ***
Aningré	733 (19) **	59.1 (5.6) ***	8 426 (737) ***
Beech	760 (12)	86.6 (12.2)	10 212 (1187)

Numbers in the parentheses are standard deviations, Duncan's test of significance evaluated based on beech standard—99% significance level (***), 95% significance level (**) or 90% significance level (*)

(*Betula pubescens*) and alder (*Alnus glutinosa*). Their investigations showed that the MOR in bending and the shear strength improved when compression of veneers increased from 5 to 15%.

In this work the highest value of MOR was observed for beech plywood overlaid with beech veneers (86.6 MPa) and the lowest, iroko (49.0 MPa) which had the lowest density (729 kg m^{-3}). Similar result trends were observed for MOE, i.e. the highest value was achieved when using wengé (11.0 GPa), bubinga (10.4 GPa) and beech veneers (10.2 GPa). The lowest MOE was for beech plywood overlaid with iroko veneers (6.1 GPa). Comparing with the standard beech panel 'beech surface veneer + beech plywood + beech surface veneer', significantly lower values of MOR and MOE were recorded for the wood panels with iroko, padouk, khaya, sapelli or aningré surface veneers (Table 4). Except for iroko and aningré, the densities of these veneered plywood panels were comparable with the standard beech panel (Table 4). Final panels covered with bubinga veneers had the highest density; however, their MOR was also lower then the beech standard (Table 4). Lower bending properties of beech plywood overlaid with the tropical veneers iroko, padouk, khaya, sapelli or aningré in comparison with the standard beech panel can probably be attributed to the negative influence of extractives on wettability of wood or adhesive properties of the phenol-formaldehyde resin. In future, this hypothesis should be tested and confirmed on the basis of bonding quality tests and compared with the chemical structure, amount and stability of extractives in the surface veneers.

Generally, the effect of density of veneered plywood types on their bending characteristics was not unequivocal (Table 4). The linear relationships established between mean densities (ρ) and the mean bending properties (MOR, MOE) of the veneered plywood types were not statistically significant at 95% level (Figure 2, $r^2 = 0.23$ and 0.45 respectively (less than 0.476 for eight pairs)). So, in the final wood-based panels, densities of surface veneers were not critical for MOR and MOE values. However, extractives in tropical veneers could play a crucial role in bending properties of panels due to their effect on the surface tension of wood (Gardner et al. 1991, Tohmura 1998, Meijer et al. 2000) and subsequently on the adhesion process when using phenol-formaldehyde glue, and finally on the adhesion or bonding strength between beech plywood and tropical veneers.

CONCLUSIONS

Decay resistance of beech plywood was significantly improved by overlapping with surface veneers of more durable tropical wood species, especially padouk, iroko, bubinga and wengé. On the other hand, surface veneers made from less durable tropical wood species, especially aningré, khaya and sapelli had no or only a slight positive effect on the biological durability of the veneered beech plywood panels. Nevertheless, antifungal effect of these veneers was partly better against the white-rot than brown-rot fungi. The final veneered plywood panels had slightly better resistance to the dry-rot fungus *S. lacrymans* than to the rest of the fungi tested. MOR and MOE of veneered plywood panels were mostly affected by the type

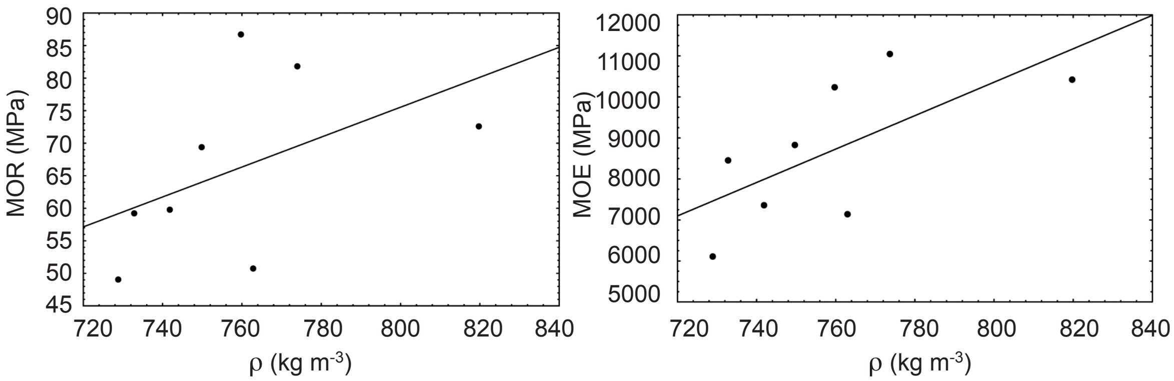

Figure 2 Linear correlations between the mean density (ρ) and mean bending characteristics (MOR, MOE) of eight types of veneered beech plywood (see Table 4)

of tropical veneers and only partially affected by smaller differences in their density.

ACKNOWLEDGEMENTS

The research was funded by the Grant Agency of the Slovak Republic (No. 1/0574/12). The authors would like to thank J Baroňák and M Kubačák for technical assistance.

REFERENCES

Bekhta P, Hiziroglu S & Shepelyuk O. 2009. Properties of plywood manufactured from compressed veneer as building material. *Materials and Design* 30: 947–953.

Brischke C & Rapp AO. 2008. Dose–response relationships between wood moisture content, wood temperature and fungal decay determined for 23 European field test sites. *Wood Science and Technology* 42: 507–518.

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 als Roh- und Werkstoff* 66: 281–287.

Déon G & Schwartz R. 1988. Résistance naturelle des bois tropicaux aux attaques biologiques. *Bulletin de la Sociéte Botanique de France. Actualités Botanique* 135: 37–48.

Donath S, Militz H & Mai C. 2006. Creating water-repellent effect on wood by treatment with silanes. *Holzforschung* 60: 40–46.

EN 113. 1996. *Wood Preservatives. Test Methods for Determining the Protective Effectiveness Against Wood Destroying Basidiomycetes. Determination of the Toxic Values.* European Committee for Standardization (CEN), Brussels.

EN 310. 1993. *Wood-Based Panels. Determination of Modulus of Elasticity in Bending and of Bending Strength.* CEN, Brussels.

EN 323. 1993. *Wood-Based Panels. Determination of Density.* CEN, Brussels.

EN 335-3. 1996. *Durability of Wood and Wood-Based Products. Definition of Hazard Classes of Biological Attack. Part 3: Application to Wood-Based Panels.* CEN, Brussels.

EN 350-2. 1994. *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.* CEN, Brussels.

EN 636-3. 2003. *Plywood—Specifications.* CEN, Brussels.

Faraji F, Thévenon MF & Thibaut B. 2004. *Evaluation of the Natural Durability and Ultrasonic Method for Decay Detection of Some European Hardwood and Softwood Species.* Document No. IRG/WP/04–10537. The International Research Group on Wood Preservation, Stockholm.

Fojutowski A & Kropacz A. 2008. *The Susceptibility of Hardwood Plywood to White Rot.* Document No. IRG/WP/08–40397. The International Research Group on Wood Protection, Stockholm.

Gardner DJ, Generalla NC, Gunnells DW & Wolcott MP. 1991. Dynamic wettability of wood. *Langmuir* 7: 2498–2502.

Hrázský J & Král P. 2005. Assessing the bending strength and modulus of elasticity in bending of exterior foiled plywood in relation to their construction. *Journal of Forest Science* 51: 77–94.

Lahiry AK. 2005. *Non-Pressure Treatability of Plywood by CCA, CCB and Boron.* Document No. IRG/WP/05–40295. The International Research Group on Wood Protection, Stockholm.

Meijer M, Haemers S, Cobben W & Militz H. 2000. Surface energy determinations of wood: comparison of methods and wood species. *Langmuir* 16: 9352–9359.

Nzokou P, Zyskowski J, Boury S & Kamdem DT. 2005. Natural decay resistance of LVL made of veneers from durable and non-durable wood species. *Holz als Roh- und Werkstoff* 63: 173–178.

Réh R. 2001. Fyzikálne vlastnosti preglejovaných materiálov. *Stolársky magazín* 2: 8–9.

Reinprecht L, Novotná H & Štefka V. 2007. Density profiles of spruce wood changed by brown-rot and white-rot fungi. *Wood Research* 52: 17–28.

Reinprecht L, Kmeťová L & Iždinský J. 2010a. Decay resistance of beech plywood treated with decorative veneers having a different natural durability. Pp 31 in *Advances in Investigation Of Lignocellulosic Raw Materials and Products of Their Conversion—Proceedings of Second International Conference.* Poznan. (Abstract)

Reinprecht L, Svoradová M, Réh R, Marchal R & Charrier B. 2010b. Decay resistance of laminated veneer lumbers from European oaks. *Wood Research* 55: 79–90.

Reinprecht L, Zubková G & Marchal R. 2010c. Decay resistance of laminated veneer lumber from black locust wood. *Wood Research* 55: 39–52.

Tohmura S. 1998. Acceleration of the cure of phenolic resin adhesives. VII: Influence of extractives of merbau wood on bonding. *Journal of Wood Science* 44: 211–216.

Van Acker J, Stevens M & De Clercq E. 2001. *Evaluation of the European Standard ENV 12038 for Durability Testing of Plywood.* Document No. IRG/WP/01–20237. The International Research Group on Wood Preservation, Stockholm.

Van den Bulcke J, Van Acker J & De Smet J. 2009. An experimental set-up for real-time continuous moisture measurements of plywood exposed to outdoor climate. *Building and Environment* 44: 2368–2377.

Van den Bulcke J, De Windt I, Defoirdt N, De Smet J & Van Acker J. 2011. Moisture dynamics and fungal susceptibility of plywood. *International Biodeterioration and Biodegradation* 65: 708–716.

Wagenführ R. 2007. *Holzatlas.* Carl Hanser Verlag, Munchen.

Wong AHH, Kim YS, Singh AP & Ling WC. 2005. *Natural Durability of Tropical Wood Species With Emphasis on Malaysian Hardwoods—Variations and Prospects.* Document No. IRG/WP/05–10568. The International Research Group on Wood Protection, Stockholm.