Eur. J. Wood Prod. (2014) 72:685–687
DOI 10.1007/s00107-014-0815-7

BRIEF ORIGINAL

Increasing the water uptake of wood veneers through plasma treatment at atmospheric pressure

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Received: 22 November 2013 / Published online: 3 July 2014

Abstract In order to provide a database which documents the influence of plasma treatment on water uptake of wood veneers, veneers of 27 wood species underwent immersion tests in untreated and plasma-treated states. Plasma treatment was executed using an air driven dielectric barrier discharge at atmospheric pressure. The results showed that plasma treatment led to significantly improved water uptake for most of the wood species, but some wood species remained unaffected after plasma treatment.

1 Introduction

In recent years many studies have been published on plasma treatment of wooden materials. In most cases, the goals of these studies were either to improve surface wettability for the purpose of enhancing the adhesion coatings or adhesives, or to furnish the surfaces with protective layers or water repellent properties (Viöl et al. 2012). An additional use of plasma treatment in the wood-processing industry involves the improvement of liquid uptake in the modification of wooden materials.

The modification and/or impregnation of wood are often achieved by water soluble agents (e.g., DMDHEU, melamine, phenolic resins, and acetic anhydride) (Rowell 2012). Furthermore, the curing of water-based coatings and adhesives such as polyvinyl acetate (PVAc) is influenced by the extraction of water. Since the curing time and the velocity of solution uptake are crucial parameters in wood processing, methods that accelerate these parameters are desirable.

Wolkenhauer et al. (2007) have demonstrated in immersion tests that the water uptake of thin (3 mm) particle board and fibreboard can be significantly improved by plasma treatment. Haase and Evans (2010) have shown that the penetration depths of adhesives can be increased by plasma pre-treatment of black spruce. Avramidis et al. (2010) have shown that the uptake of waterborne DMDHEU-solution and melamine-solution in DBD-treated beech veneers or thermally treated beech veneers can be significantly accelerated. However, it has also turned out that the influence of plasma treatment on wettability and enhanced liquid uptake is dependent on the wood species (Avramidis et al. 2010). Therefore the objective of this study was to prepare a database which documents the influence of plasma treatment on various wood species with regard to the enhanced liquid uptake of their veneers. To determine this susceptibility, veneer samples of 27 wood species in both untreated and plasma treated states were subjected to air-driven dielectric barrier discharge (DBD) treatment at atmospheric pressure.

2 Materials and methods

Sliced veneers of 27 wood species - consisting of 15 (sub)tropical species and 12 species native to moderate latitudes - were used for the tests. Additionally, veneers of

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Table 1 Improvement of water uptake (U_I) after plasma treatment for various wood species

Species	Family	Wood tissue	U_W (%)		U_I (%)	Thickness (mm)
			Reference	Treated		
Quercus spec. subfossil	*Fagaceae*	n/a	24.7 ± 1.1	54.9 ± 4.4	122	1.0
Kahya ivorensis	*Meliaceae*	Heartwood	24.2 ± 2.5	40.7 ± 3.5	68	0.7
Tectona grandis	*Verbenaceae*	Heartwood	18.2 ± 1.8	29.7 ± 3.2	63	0.7
Prunus avium	*Rosaceae*	Heartwood	30.5 ± 7.1	49.6 ± 11.1	62	0.6
Entandrophragma cylindricum	*Meliaceae*	Heartwood	25.8 ± 3.2	39.6 ± 4.1	54	0.5
Mansonia altissima	*Sterculiaceae*	Heartwood	29.4 ± 2.6	45.0 ± 6.0	53	0.5
Taxus baccata	*Taxaceae*	Heartwood	19.6 ± 2.9	29.7 ± 4.8	51	0.7
Fagus sylvatica	*Fagaceae*	n/a	37.0 ± 2.5	55.9 ± 6.7	51	0.6
Pterocarpus soyauxii	*Fabaceae*	Heartwood	20.6 ± 1.5	30.8 ± 2.4	50	0.6
Guibourtia arnoldiana	*Caesalpiniaceae*	Heartwood	23.8 ± 3.7	35.5 ± 3.2	49	0.6
Robinia pseudoacacia	*Fabaceae*	Heartwood	21.7 ± 1.9	30.2 ± 3.2	39	0.8
Fraxinus excelsior	*Oleaceae*	n/a	57.1 ± 4.5	78.4 ± 3.7	37	0.6
Detarium senegalense	*Caesalpiniaceae*	Heartwood	14.7 ± 2.4	20.0 ± 3.3	36	0.7
Microberlinia brazzavillensis	*Caesalpiniaceae*	Heartwood	25.1 ± 1.9	32.2 ± 4.9	28	0.6
Alnus glutinosa	*Betulaceae*	n/a	54.2 ± 3.8	67.9 ± 7.5	25	0.6
Guibourtia tessmannii	*Caesalpiniaceae*	Heartwood	22.3 ± 1.7	27.6 ± 1.7	24	0.7
Millettia laurentii	*Fabaceae*	Heartwood	17.0 ± 3.1	21.0 ± 0.9	24	0.7
Pinus silvestris	*Pinaceae*	Heartwood	45.6 ± 2.0	55.7 ± 6.1	22	0.4
Machaerium scleroxylon	*Fabaceae*	Heartwood	16.1 ± 2.1	19.7 ± 1.4	22	0.6
Acer pseudoplatanus	*Aceraceae*	n/a	38.0 ± 2.2	45.1 ± 2.8	19	0.6
*Dracontomelum dao*a	*Anacardiaceae*	Mixed	31.7 ± 2.7	37.4 ± 5.7	18	0.7
Juglans regia	*Juglandaceae*	Heartwood	26.0 ± 2.7	30.1 ± 2.6	16	0.6
Tieghemella heckelii	*Sapotaceae*	Heartwood	30.5 ± 2.2	34.5 ± 3.7	13	0.6
Terminalia superba	*Combretaceae*	n/a	46.8 ± 4.5	52.4 ± 1.9	12	0.6
Juglans nigra[a]	*Juglandaceae*	Heartwood	44.4 ± 6.2	48.0 ± 5.4	8	0.6
Pterygota spec.[a]	*Sterculiaceae*	n/a	46.1 ± 4.7	49.5 ± 4.7	7	0.5
Quercus spec.[a]	*Fagaceae*	Heartwood	26.5 ± 3.2	25.2 ± 0.8	−5	0.7
Picea abies	*Pinaceae*	n/a	51.5 ± 3.3	46.6 ± 6.0	−10	0.8

[a] No significant differences according to *t*-test

Quercus spec. subfossil were tested, so that overall 28 types of veneers were investigated.

The veneer sheets were cut to samples of 50 × 50 mm^2 (thickness of 0.4–1.0 mm) and were stored (72 h) at 20 °C and 65 % RH (standardized climate, DIN 50 014) prior to treatment. The setup and operating conditions used are described in Avramidis et al. (2010). Using this setup the veneers were plasma treated on both sides simultaneously. The applied alternating voltage was ~23 kV (peak) and the injected power of the discharge in the gap was 180 W. The treatment duration was 60 s. Gas temperatures during plasma treatment were measured with a fibre-optical thermometer (FTI-10, FISO Technologies, Sainte-Foy, Canada) and did not exceed 70 °C, so that minimal thermal influence can be presumed.

The water uptake of the samples was determined by a simple immersion test at atmospheric pressure and a temperature of 20 °C. The immersion duration was 30 s. Since the cross sections of the veneers were not sealed, the water penetrated via the longitudinally cut surfaces as well as via the cross sections. The samples were weighed before and after immersion in water, and residual water on the surface was removed by a stripper. The percentage of increase in mass (water uptake U_W) was calculated according to the following equation (Niemz 1993):

$$\text{Water uptake } (U_W) = ((M_2 - M_1)/M_1) \times 100\,\% \qquad (1)$$

where M_1 is the mass before immersion and M_2 is the mass after immersion.

The improvement of uptake (U_I) of the plasma treated samples compared to the references was calculated by:

$$\text{Uptake improvement } (U_I) = ((U_{W\text{treat}}/U_{W\text{ref}}) - 1) \times 100\,\% \qquad (2)$$

where U_{Wtreat} is the water uptake of the plasma treated samples and U_{Wref} is the water uptake of the untreated samples.

3 Results and discussion

The results of the immersion tests for the 28 types of veneer are given in Table 1. The values were analyzed by two-sample *t*-test to determine the statistical significance of differences in water uptake between untreated and plasma treated specimens (significance level $= 0.05$).

Four out of 28 types of veneers showed no significant alteration in water uptake (*Dracontomelum dao, Juglans nigra, Pterygota spec., Quercus spec.*). Only in the veneers of *Picea abies* did plasma treatment lead to significantly decreased water uptake. All other types of veneer showed significantly increased water uptake when plasma treated.

No correlation could be detected between improvement of water uptake and diameter of vessels, lumen, pores, original uptake capability, occurrence of cracks, knots or membership in a certain family.

Further in-depth case studies of single wood species or types of wood veneers are necessary in order to reveal factors that make them susceptible to improved water uptake after plasma treatment. A promising approach is given for example by the SEM-studies of Jamali and Evans (2011), which revealed the etching of wood cell walls and notably of pits due to low-pressure H_2O-plasma treatment. The etching of pits can open penetration channels, which can lead to improved capillary uptake of liquids.

From these results it can be assumed that most types of veneers might show similar beneficial effects of plasma pre-treatment using water-based systems in applications such as bonding, painting and impregnation.

4 Conclusion

The results demonstrate that plasma treatment of wood veneers can considerably increase the water uptake capability for most of the tested wood species or veneer types. More research is needed to reveal mechanisms of the observed effects of plasma treatment and to evaluate its suitability for applications in wood processing.

Acknowledgments This work was funded by the German Federal Ministry of Education and Research (BMBF), under the supervision of Dr.-Ing. Karen Otten, in Jülich, Germany and the joint research project "PlaNaWood" (Grant No. 03X5519B).

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