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INFLUENCE OF SILICONE RESIN MODIFICATION ON VENEER TENSILE STRENGTH AND DEFORMATION

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ABSTRACT

The submitted paper deals with the modification effect evaluation of silicone resins as far as oak, ash and walnut veneers are concerned; particularly focusing on the strength and tensile deformation. The emphasis was put on the impact of the wood type, the modification itself and the angle of wood fibres on the maximal deformation and tensile strength. The tests were performed on oak, ash and walnut veneers. The veneers were modified by means of silicone resins (semi-hydrophobic and low- hydrophobic silicone resins). The tensile force direction and the wood fibres made angles of 0°, 10°, 45° and 90°. The most considerable deformation was achieved on the modified ash veneers within the longitudinal direction (wood fibres being inclined at an angle of 0°); the deformation itself increased from 2% to 3.8%. A significant increase of deformation in tension, which is a contribution towards the 3D-moulding, was achieved by the modification through silicone resins within all the three tree species mentioned above, whereas the wood fibres were inclined at angles of 45 ° and 90 °. The tensile strength, in all the tested woody plants, was also increased by means of the silicone-resin modification.

Key words: veneer, 3D-shaping (moulding), tensile deformation, tensile strength, silicone resin.

INTRODUCTION

Wood is a material which is used to produce furniture, toys, musical instruments, sporting goods, and other products. Wood is mostly shaped by traditional technologies with stock removal or by moulding technology without chip removal. Technologies, where there is no chip removal are the 2D- and 3D-moulding.

The 3D-shaping of thin materials can be characterised as a simultaneous or sequential multidirectional bending (WAGENFÜHR, BUCHELT 2004). The 3D-shaping capacity, or more precisely formability, of thin materials can be evaluated through several tests, such as the Erichsen test, the Engelhardt test and others alike (VELES 1985). The above mentioned tests are mainly used to evaluate the formability of thin metal materials. Currently, for assessing the formability of the 3D-veneers, there is no valid standardised evaluation method. “A certain picture about the formability of thin wood materials can be provided by means of mechanical properties of wood, especially the strength and tensile deformation, as far as wood is concerned, if the tensile load is applied at different angles towards the wood grain, as well as the creation and development of crack fissures within a given method and the direction of the load (ZEMIAR *et al*. 2012)”.

The issue of formability and modification of veneers has been depicted in several scientific studies, e.g. FEKIAČ *et al.* (2016), FEKIAČ *et al.* (2015); ZEMIAR, FEKIAČ (2014); SCHULZ, *et al.* (2012); ZEMIAR *et al.* (2012); YAMASHITA, *et al.* (2009); BUCHELT, WAGENFÜHR (2008); HUBER, REINHARD (2007); WAGENFÜHR, *et al.* (2006); WAGENFÜHR, BUCHELT (2005).

ZEMIAR *et al.* (1999) deal with the following methods of wood modification: hydrothermal, electromagnetic and chemical plasticising. The most frequently practice-used methods are the first two methods mentioned above, in particular. The modification of veneers, that can improve their 3D-formability, can also be based on the application of another polymer liquid substance on the veneer surface.

The 3D-moulding is a demanding technology that, in the wood-processing, is predominantly used on thin materials (veneers), only. In the process of 3D-veneer moulding, the three planes are subjected to both compressive and tensile loads, i.e. forces are applied to wood fibres at an angle of 0 ° up to 90 °.

Wood is a material which can be compressed to a certain extent, but far less, can it be stretched. Because of the low formability of veneers and their inability to maintain the obtained shape, it is necessary to modify the veneers. ZEMIAR, FEKIAČ (2014) focused on fixing the shape of veneers by means of glue. The following paper focuses on modification of veneers by silicone resins in the experimental work.

The aim of this study was to research the effect of silicone coatings on oak, ash and walnut veneers as far as the strength and the maximal tensile deformation are concerned. The impact of the angle between the wood fibres and the direction of the applied load on strength and tensile deformation were also monitored.

EXPERIMENTAL PART

To implement the experimental tests, test specimens from the radially flat-cut common oak (*Quercus robur* L.), common ash (*Fraxinus excelsior* L.) and Persian walnut (*Juglans regia* L.) veneers were used, having the moisture content of 6 ± 2%. The test specimens for mechanical tensile tests were produced by cutting. The sample dimensions were 150 mm × 30 mm × 0.6 mm (the length under tensile load was up to 60 mm).

In each group, four sub-groups of samples were created. In each subgroup, the inclination of wood fibres from the longitudinal axis of sample had a different angle: 0°, 10°, 45° a 90°. The angles of wood fibre inclination were determined by following the preliminary research results, whereas the research focused on the material properties subjected to the tensile load at angles of 0 ° to 90 ° (scaled by 10 °). The boundary angles of 0 °, 10 °, 45 ° and 90 ° were set, where the strength and deformation in tension significantly changed. Each sample subgroup consisted of 10 bodies.

The test specimens were divided into the following groups:

1. oak - unmodified samples,
2. ash - unmodified samples,
3. walnut - unmodified samples,
4. oak – samples modified by silicone resin (semi-hydrophobic),
5. oak – samples modified by silicone resin (low-hydrophobic),
6. ash – samples modified by silicone resin (semi-hydrophobic),
7. ash – samples modified by silicone resin (low-hydrophobic),
8. walnut – samples modified by silicone resin (semi-hydrophobic),
9. walnut – samples modified by silicone resin (low-hydrophobic).

The silicone resins (Tab. 1) were applied and coated on both sides of veneer by brush. The absolute strength and tensile deformation were determined using the tensile testing equipment LaborTech 4.050, which allows the load up to 3 kN. The test specimens were bound in the machine clamps at a distance of 45 mm from the edge of the sample. The sliding speed was 2 mm/min and the data were aquired at the frequency of 5 Hz.

Tab. 1 Description and identification of silicone resins.

Type of silicone resin	Sign	Amine Number [mg KOH/g]	Dynamic viscosity η at 25 ° C [mPa.s]	Application rate [g/m^2]	Volatile / non-volatile components [%]
semi-hydrophobic silicone resin	S-77/B	190	1450	70,29	19,65 / 80,35
low-hydrophobic silicone resin	S-77/A	200	1600	93,35	25,85 / 74,15

RESULTS AND DISCUSSION

Both the values of tensile deformation (Tab. 2) and the tensile strength (Tab. 3) were processed statistically by means of the 3-factor analysis of variance. The impact of the following factors was studied: type of wood, wood fibres´ inclination, modification of veneers and their interactions. Differences between modified and unmodified veneers were traced. As the difference between the semi-hydrophobic silicone resin and the low-hydrophobic silicone resin did not statistically proved to be of great importance, these two types of silicone resin were evaluated as one file.

Table 2 shows that the effect of the three depicted factors as well as their interactions on the tensile deformation, except for the interaction of wood species - veneer modification, is statistically of great significance. On contrary to unmodified veneers, a statistically more significant values of tensile deformation were achieved by walnut and oak veneers modified by silicone resin, having the inclination angles of 45° and 90°of wood fibres. On the modified oak veneers, the tensile deformation increased on the average from 0,33% to 0,66% at the inclination angle of 45° of wood fibres. As for the walnut veneers treated with the same modification and at the identical inclination angle of 45°of wood fibres, the deformation increased from 0.5% to 1%.

At an inclination angle of 90°of wood fibres, the tensile deformation increased from 0.50% to 0.84% on oak modified veneers and it increased from 0.66% to 0.84% on walnut veneers. The maximum deformation was observed on ash modified veneers, i.e. from 2% to 3.8%, in the longitudinal direction (the inclination angle of 0° of wood fibres).

WAGENFÜHR, BUCHELT, PFRIEM (2006) show that the woody plants with a small number of tracheas, with a highly homogeneous fibre fraction, uniform width of rays and without differences between the spring and summer timber are the best to be deformed. In our research, we focused on the particular woody plants with circularly porous structure (oak, ash and walnut), where the assumption that they can be used for 3D-moulded products makes sense.

When the material is exposed to the 3D-shaping process, it is also subjected to the tensile and compressive load. The measured results of both the unmodified and silicone resin modified veneers confirm the significant anisotropy of strength with regard to the direction of wood fibres, as demonstrated in the following paper ZEMIAR *et al.* (2012). However, the same can be said about the type of wood as depicted in FEKIAČ *et al.* (2016). “Tree species differ from each other in their structure and properties, upon which the differences in their behaviour during the 3D-shaping process are based" (FEKIAČ *et al.*, 2016).

The modified veneers have a significantly higher tensile strength than the unmodified veneers, as can be seen in the graph, Fig. 2. A modified oak veneer at the inclination angle of 10 ° of wood fibres proved the increased tensile strength by 27.4%. A modified walnut veneer at the inclination angle of 10 ° of wood fibres increased its tensile strength by 72%. Concerning the modified ash veneer, there again was a significantly greater tensile strength in the longitudinal direction present (at the inclination angle of 0 °of wood fibres). The tensile strength was increased by 71%.

Tab. 2 Analysis of variance results of veneer tensile deformation.

	Sum of squares	**Degrees of freedom**	**Mean square**	**F-values**	**Probability α = 0.05**
Absolute value	256.5693	1	256,5693	3807.120	**0.000000**
Type of wood (TW)	4.5518	2	2.2759	33.771	**0.000000**
Inclination angle of the wood fibres (AIW)	74.9654	3	24.9885	370.793	**0.000000**
Type modification of veneers (TMV)	3.5844	2	1.7922	26.593	**0.000000**
TW * AIW	3.4275	6	0.5712	8.476	**0.000000**
TW * TMV	0.2166	4	0.0542	0.804	0.523577
AIW * TMV	3.8805	6	0.6468	9.597	**0.000000**
TW * AIW * TMV	3.4389	12	0.2866	4.252	**0.000003**
Error	21.8350	324	0.0674		

Tab. 3 Analysis of variance results of tensile strength.

	Sum of squares	**Degrees of freedom**	**Mean square**	**F-values**	**Probability α = 0.05**
Absolute value	409402.6	1	409402.6	3910.138	**0.000000**
Type of wood (TW)	12384.4	2	6192.2	59.141	**0.000000**
Inclination angle of the wood fibres (AIW)	378053.0	3	126017.7	1203.575	**0.000000**
Type modification of veneers (TMV)	10395.8	2	5197.9	49.644	**0.000000**
TW * AIW	12116.3	6	2019.4	19.287	**0.000000**
TW * TMV	432.0	4	108.0	1.031	0.390991
AIW * TMV	9031.3	6	1505.2	14.376	**0.000000**
TW * AIW * TMV	8243.9	12	687.0	6.561	**0.000000**
Error	33923.7	324	104.7		

Based on Figures 1 and 2, it can be concluded that due to the modifications all the wood species proved an increased deformation and tensile strength. The measurements confirmed the assumption that the modification of veneers by silicone resins (polymers) increases both the deformation and the tensile strength. The choice of the modification substance was based on the knowledge that the composite wood materials (i.e. wood-plastic composites) achieve better properties than their individual components themselves (wood, polymer). In our study, the combination of wood and polymer is specific, as wood is maintained in the form of solid wood and is only impregnated with resin. "When applying resin, great macromolecules of silicones are not able to penetrate the cell walls of wood and remain more or less in the lumens of wood cells, only" (REINPRECHT *et al.* 2015, REINPRECHT 1998). "The wood modification by means of copolymer creates a thin film layer on the surface of the cell elements" (TIRALOVÁ, MAMOŇOVÁ 2005). Taking these statements into consideration, it can be said that the silicone resin filled the cell lumens and it also bound to the surface of the cellular elements in the form of a film.

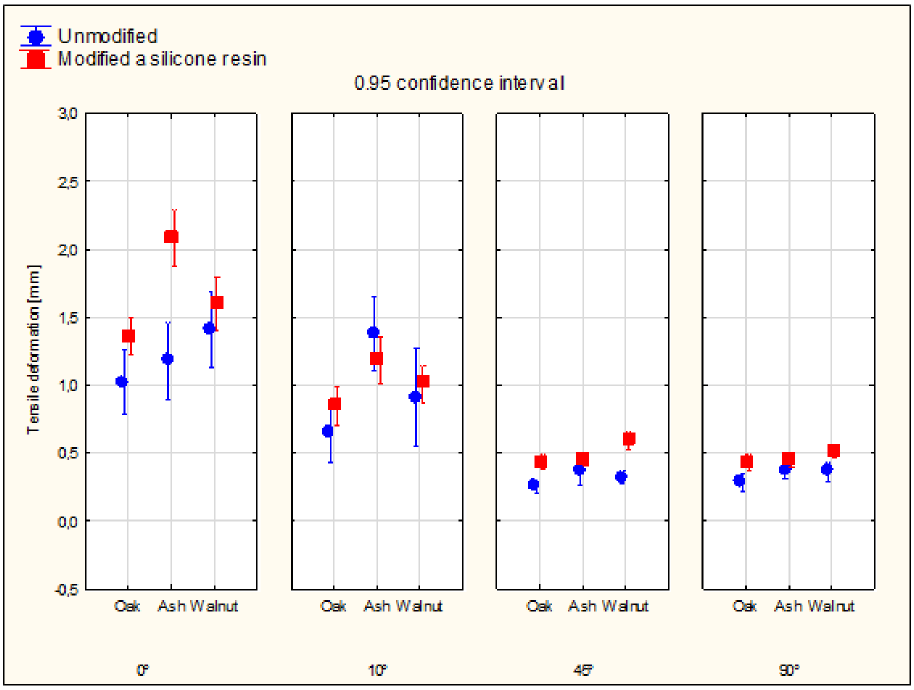

Fig. 1 The dependence of tensile deformation on the inclination angle of wood fibres of modified and unmodified veneers, concerning the particular wood types.

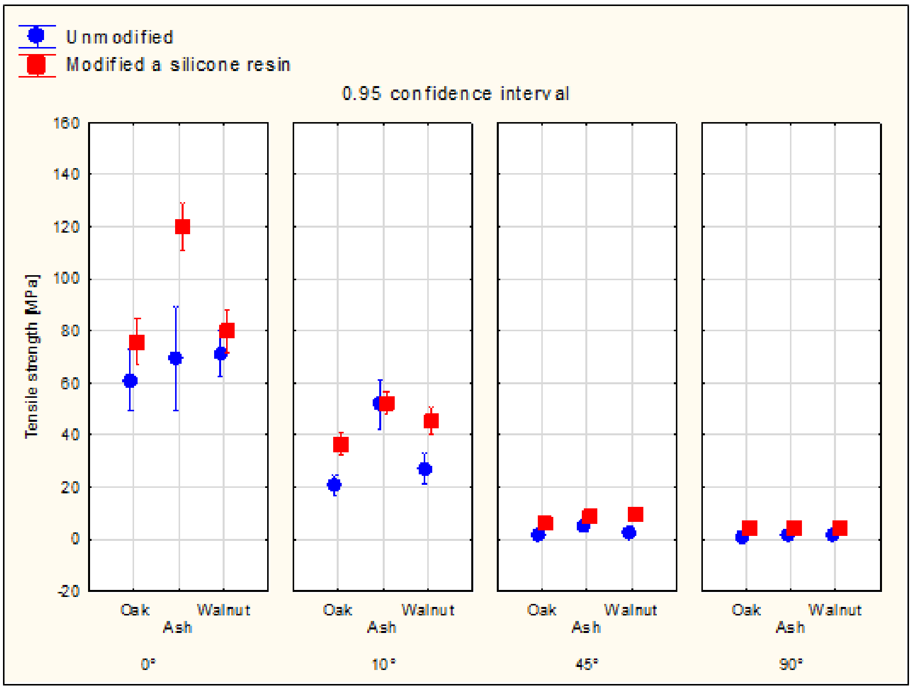

Fig. 2 The dependence of tensile strength on the inclination angle of wood fibres of modified and unmodified veneers, concerning the particular wood types.

“The most common connecting means of composites are represented by derivatives based on silicon-merging, the so called organosilicon coupling means (organic silanes, e.g. silicone rubber), and titanium (organic titanates)” (LIPTÁKOVÁ *et al.* 2012). LIPTÁKOVÁ *et al.* (2012) also report that the silicones belong to the connecting means in the production of composites, i.e. in the production of wood-plastic composites, as well. It follows that the silicone resin is characterised by good binding capacity to the wood surface. This binding caused a higher tensile strength of the modified veneers. The silicone resin has a good flexibility and that is also why it contributed to the increased tensile deformation of modified veneers. Under the tensile load, the cell elements were deformed, but the silicone resin bound to the cell walls increased both their strength and deformation.

CONCLUSION

Based on the results depicted above, it can be claimed, that modification of veneers, using the silicone-resin coating on both sides (semi- or low-hydrophobic) increased both the absolute tensile strength and deformation, as opposed to the compared unmodified veneers.

A statistically significant increase of the tensile deformation, which is desirable within the 3D-moulding, was observed on the walnut and oak veneers modified by semi-hydrophobic silicone resin, at the inclination angle of 45° and 90° of wood fibres.

A statistically significant increase of the tensile deformation on the ash veneer was observed on modified veneers, at the inclination angle of 0°of wood fibres.

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