Quality of Silicone Coating on the Veneer Surfaces

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The surface quality of silicone resin coating on the veneer surface was evaluated. Silicone resins of various types (weakly, moderately, strongly hydrophobic, and hydrophilic resins) were applied on veneer and cured. The quality of the coatings was assessed according to the impact resistance of the surface and the resistance to cold liquids (acetic acid, citric acid, ethanol, sodium carbonate, sodium chloride, cleaner SAVO). The gloss value of silicone coatings on the veneer surface was determined from the aesthetic qualities. Radially sliced beech, oak, walnut, and ash veneers were tested. Veneer surface roughness was measured before and after modification with the silicone resins. The results obtained show that after modification by silicone resins, the surface roughness of the veneers was not significantly different from that of resin-free veneers. Impact resistance testing showed that intrusions on veneer surfaces with silicone coatings were free of cracks visible to the naked eye. Surface resistance to cold liquids on the surfaces with silicone coatings was lower if compared to that of commonly used coatings. In some cases, the surfaces showed strong damage, mostly without changing the structure of the coating, after only 10 min exposure to cold liquid. The gloss value of silicone coatings on wood veneers was graded as matte to semi-gloss.

Keywords: Veneer; Silicone resin; Gloss; Roughness; Resistance; Cold liquids

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INTRODUCTION

Veneers are thin wood materials. They are used for veneering of chipboard and medium density fiberboard and production of plywood and laminated wood. Veneered materials, plywood, and laminated wood need to be protected from physical, mechanical, and chemical influences. They can be protected by different coatings. To increase wood protection and adjust the properties of the coatings (*e.g.* gloss, roughness, hardness, resistance to liquids), the coatings can be modified in various ways (Lee *et al.* 2003; Kaygin and Akgun 2009; Tesařová *et al.* 2010; Kumar *et al.* 2015; Weththimuni *et al.* 2016; Cataldi *et al.* 2017; Miklečić *et al.* 2017; Yong *et al.* 2017). Pavlič *et al.* (2004) pointed out a basic approach for evaluation of the quality of surface finishing.

Prior to coating, it is important to machine the wood surface properly to achieve the required roughness. The surface roughness after different ways of machining was investigated by Coatings *et al.* (1999), Liptáková and Kúdela (2000), Gáborík and Žitný (2010), Gurau *et al.* (2013), Kúdela *et al.* (2014), Csanády *et al.* (2015), Ugulino and Hernández (2016), Cool and Hernández (2016), and Kúdela *et al.* (2016).

Wood veneer is a formable material that can be shaped. The issue of forming and modification of veneers has been studied previously (Wagenführ and Buchelt 2005; Wagenführ *et al.* 2006; Huber and Reinhard 2007; Buchelt and Wagenführ 2008; Yamashita *et al.* 2009; Schulz *et al.* 2012; Zemiar and Fekiač 2014; Fekiač *et al.* 2015).

The most commonly used modification method to improve the 2D-formability of wood is plasticizing. Modification of veneer to improve the 3D-formability can be based on the use of a liquid substance applied to the veneer surface. One of the substances is a silicon resin. When applying these resins, large silicone macromolecules remain more or less only in the lumen of wood cells. When being applied to wood, the resins are most often used in the form of aqueous micro-emulsions. With an organic substituent, for example methyl or ethyl, they partially increase the hydrophobicity of wood (Reinprecht 2008). According to Slabejová and Šmidriaková (2013) and Slabejová *et al.* (2017), silicone resins increase the 3D-formability of veneers and at the same time create a coating on the veneer surface and form the surface finish. The above-mentioned paper and others did not address the surface quality of wood veneers modified with silicone resins. The silicone top coating on wood is not a common surface finish. Surface properties and the quality of this type of coating on a wood surface have not yet been described.

Silicone coatings are used for building facades and for high-temperature coatings on metal. Silicone resins are widely used as adhesives for the production of wooden windows. The adhesion and bonding strength of silicone resins were addressed by Pantaleo *et al*. (2012).

This work investigated the quality of silicone coatings on veneers made from a variety of tree species. The coatings were created by different silicone resins. The first function of the coating was to increase the formability of the veneers and the second to finish the surface.

EXPERIMENTAL

Materials

The test samples were veneers of beech (*Fagus sylvatica* L.), ash (*Fraxinus excelsior* L.), oak (*Quercus robur* L.), and walnut (*Juglans regia* L.), radial cut, with moisture contents of 6 ± 2%. The moisture content of the wood was measured gravimetrically. The dimensions of veneer sheets were 150 mm × 100 mm × 0.6 mm. Before experimental testing, the test pieces (80 specimens for each wood species) were conditioned at the temperature of 20 ± 2 °C and a relative humidity of 60 ± 5% for 30 days.

The silicone resins (Slochem, Slovakia) used (as supplied) to modify the veneers are listed in Table 1. The resin was brush-applied on one side of the veneer to form the coating with thickness below 60 µm. The coating film thickness was measured with Thickness Gauge (type PosiTector 200) working on the ultrasonic principle. Coating film thicknesses are given in Table 1.

Table 1. Silicone Resins

Type of Silicone Resin	Mark	Dynamic Viscosity*(mPa.s)	Solid Content (%)	Film Thickness (µm)
Hydrophilic	S-7739	600	81.16	41.7
Strongly Hydrophobic	S-8741	19	55.35	49.3
Moderately Hydrophobic	S-77/B	1450	80.35	39.2
Weakly Hydrophobic	S-77/A	1600	74.15	41.7

*Dynamic viscosity at 25 °C

Methods

The surface roughness was measured before and after the silicone resin was applied and cured. Pocket Surf Mahr Portable Surface Roughness (Providence, RI, USA) was used (tip radius r = 0.005 mm). The arithmetic mean deviation of the profile R_a [μm] was calculated from the values measured on the basic traverse length of 0.8 mm. The roughness was measured 10 times on each veneer in both directions: parallel and perpendicular to the grain.

The measured values of roughness (R_a) were evaluated by 3-factor analysis of variance using the program STATISTICA 10 (StatSoft, Tulsa, OK, USA).

The impact resistance of the silicone coating on veneer surface was evaluated on veneers freely placed on medium density fiberboard according to the standard STN EN ISO 6272-2 (2011). The intrusion (a pinhole diameter) was measured and the coating was evaluated subjectively according to Table 2.

Table 2. Impact Resistance, Degree, and Evaluation

Degree	Visual Evaluation
1	No visible changes
2	No cracks on the surface and the intrusion was only slightly visible
3	Visible light cracks on the surface, typically one to two circular cracks around the intrusion
4	Visible large cracks at the intrusion
5	Visible cracks were also off-site of intrusion, peeling of the coating

Surface resistance to cold liquids was determined according to the standard STN EN 12720 (2014). Table 3 shows the selected cold liquids and exposure time. After exposure to a cold liquid, the surface was evaluated and graded according to Table 4.

Table 3. Cold Liquids

Cold Liquid	Test Duration (min)
Acetic acid 10% aqueous solution	10
Citric acid 10% aqueous solution	10
Ethanol (p.a.) 48% aqueous solution	10
Sodium carbonate 10% aqueous solution	10
Sodium chloride 15% aqueous solution	10
Cleaner SAVO	10

Table 4. Surface Resistance to Cold Liquids

Grade	Description of Quality
5	No visible changes (No damage)
4	Slight change in gloss – visible only in reflection of light source
3	Slight traces of damage (gloss) – visible from different directions
2	Strong traces of damage usually without changing the structure of varnish
1	Strong damage with change in varnish structure

The surface gloss was measured using the glossmeter BYK GARDNER micro TRI gloss/micro gloss 60° (Geretsried, Germany) and measured according to the standard EN ISO 2813: 2001-10 (2014).

RESULTS AND DISCUSSION

Roughness

The measured values of roughness (R_a) were evaluated statistically. The effect of wood species (four levels of factor 1), the type of silicone resin (five levels of factor 2), and wood grain direction (two levels of factor 3) on the surface roughness (of resin-free veneers and veneers with silicone coating) were evaluated. The results are presented in Table 5 and Fig. 1.

Table 5. Basic Analysis of Variance for Surface Roughness (R_a)

Factors	Sum of Squares	Degrees of Freedom	Variance	F-test	Level of significance *p**
Wood species (WS)	20.378	3	6.793	3.570	0.014
Type of silicone resin (TSR)	23.022	4	5.756	3.030	0.018
Wood grain direction (WGD)	27.519	1	**27.519**	14.480	0.000
Interaction WS * TSR	29.506	12	2.459	1.290	0.220
Interaction WS * WGD	21.815	3	7.272	3.830	0.010
Interaction TSR * WGD	1.203	4	0.301	0.160	0.959
Interaction WS * TSR * WGD	42.398	12	3.533	1.860	0.038
Absolute member	1365.765	1	**1365.765**	718.476	0.000
Error	686.232	361	1.901		
*p** < 0.001 statistically high significant; *p** > 0.05 statistically insignificant					

Statistical evaluation confirmed previous reports on the roughness of beech wood after simulated weathering (Kúdela and Ihracký 2014). Coatings *et al.* (1999), Liptáková and Kúdela (2000), Gáborík and Žitný (2010), Csanady *et al.* (2015), Cool and Hernández (2016), and Ugulino and Hernández (2016) evaluated the roughness of wood surface for various mechanical treatments. They concluded that grain direction has a highly statistically significant influence on the surface roughness of veneer. According to our results, this statement was true only if all the tested wood species were evaluated together.

The importance of evaluation of the surface quality of materials after various modifications or machining was described by Gáborik and Žitný (2010), Ťavodová (2013), and Matyašovský *et al*. (2014).

The effect of the interaction of wood species (WS) with the type of silicone resin (TSR) was statistically insignificant. The differences in surface roughness among the individual coatings as well as the differences in surface roughness between individual wood species were statistically insignificant (Table 5 and Fig. 1).

The surface roughness of resin-free beech veneer was 1.3 µm in the longitudinal direction and 3.1 µm in the perpendicular direction. The surface roughness of the veneers with silicone coatings was slightly increased in the longitudinal direction. The increase was caused by lifting the impregnated cut wood fibers. In the perpendicular direction, the surface roughness of the veneer with the hydrophilic resin coating was, on average, the same as the surface roughness of the uncoated surface, but the variance was higher. Filling the cut vessels with silicone resin and raising the wood fibers increased the surface roughness variability. The similar values of surface roughness were also measured for the veneer coated with moderately hydrophobic resin. Strongly and weakly hydrophobic resins decreased the surface roughness in the perpendicular direction to 2.2 µm and 2.1 µm, respectively.

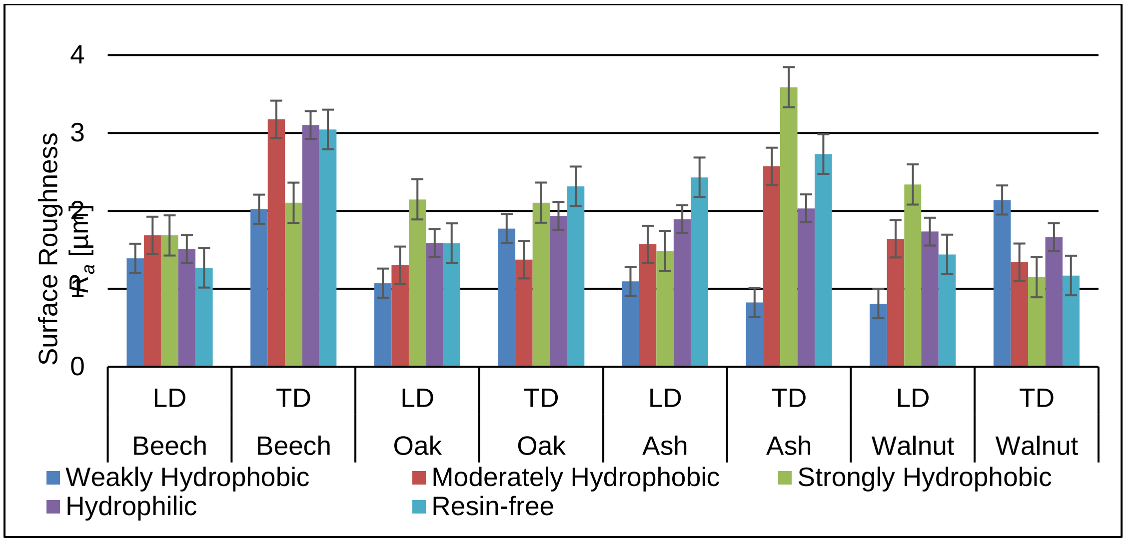


Fig. 1. Influence of the interaction between wood species and the type of silicone resin on the roughness (Note: arithmetic mean deviation of the profile R_a, measured in two directions: longitudinal (LD) with wood fibers and transversal (TD) direction, before and after modification with silicone resins, in traverse length of 0.8 mm)

The surface roughness of resin-free oak veneer was 1.6 µm in the longitudinal direction and 2.3 µm in the perpendicular direction. In the longitudinal direction, the surface roughness of the veneer with hydrophilic resin was not changed. Strongly hydrophobic resin increased the surface roughness to 2.2 µm, but the moderately and weakly hydrophobic resins reduced the surface roughness. Changes in roughness were not statistically significant; inhomogeneity (anisotropy) of wood surface was the factor responsible for small increase or decrease in roughness. In the perpendicular direction, all four silicone coatings decreased the surface roughness of the veneer.

The resin-free ash veneer had a surface roughness of 2.5 µm in the longitudinal direction and 2.7 µm in the perpendicular direction. In the longitudinal direction, all silicone resins reduced the surface roughness. In the perpendicular direction, only the strongly hydrophobic resin increased the surface roughness slightly; the other resins reduced the roughness.

The resin-free walnut veneer had a surface roughness of 1.5 µm in the longitudinal direction and 1.2 µm in perpendicular direction. After the silicone resins had been applied, the surface roughness was not statistically significantly different from the initial roughness.

The interactions between wood and silicone resin did not show statistically significant differences between the surface roughness of resin-free veneers and veneers with the coatings. For beech veneer, cut wood fibers impregnated by the resin raised and slightly increased the surface roughness. In the transverse direction, the silicone resins filled cut vessels and reduced the surface roughness. Oak and ash belong to the ring-porous wood species, so their pores are bigger if compared with diffuse-porous wood species. The silicone resins filled the cut vessels and so reduced the surface roughness. Walnut belongs to the partly ring-porous wood species. The slight increase in surface roughness on the walnut veneer after application of silicone resins can also be attributed to the raised impregnated wood fibers.

Impact Resistance

Figure 2 shows the extent of the formed intrusions on veneer surfaces.

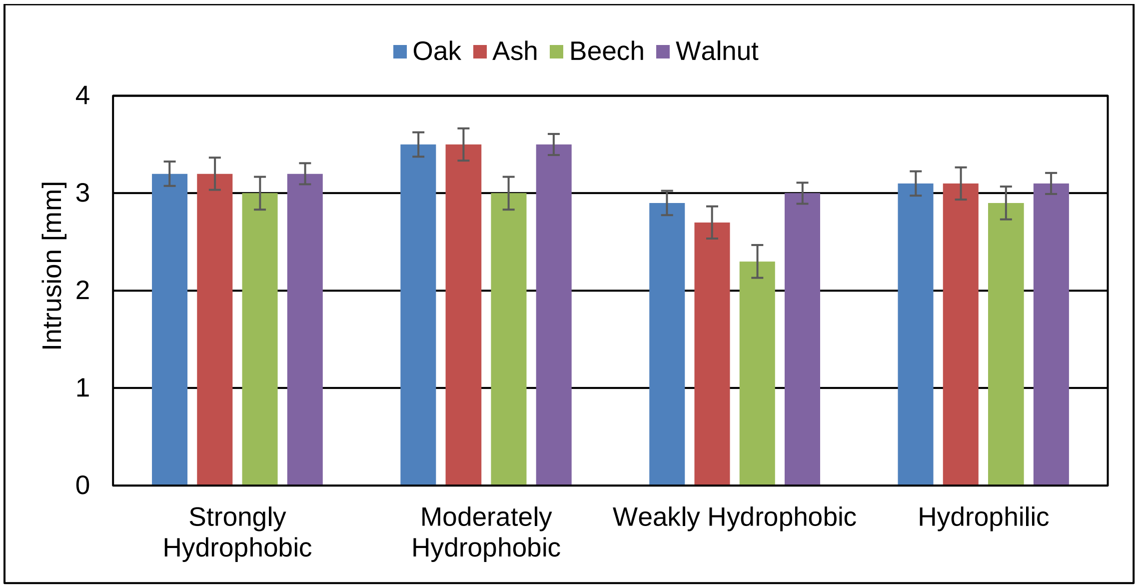


Fig. 2. Diameters of intrusions in silicone coatings on various wood species at a drop height of 400 mm

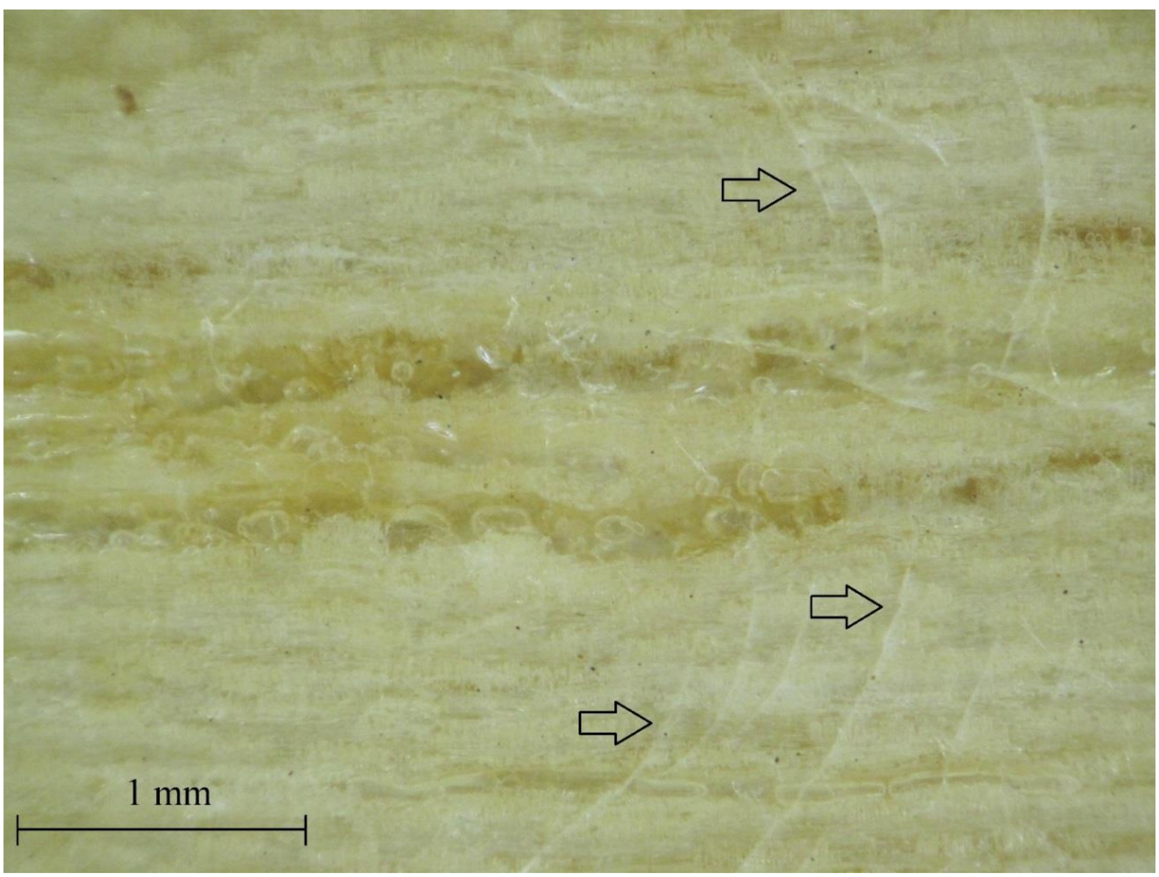


Fig. 3. Cracking visible on the surfaces of ash veneer with hydrophilic silicone resin coating after impact resistance testing at the drop height of 400 mm (visible at magnification 35×)

The best impact resistance of silicone coating was reached by weakly hydrophobic resin on beech veneer. This type of coating material reached the best resistance of the film on all the veneers. The hardness of the coating and the impact resistance are predestined mainly by the chemical composition of the resin. The difference in the resistance of silicone coatings is caused by additives, which ensure hydrophilicity or hydrophobicity of the coating film.

The coatings had a thickness of 40 ± 10 μm. This value of coating thickness is included in a range of thin coating films (up to 60 μm).

Impact resistance of the coating increases with increasing thickness of the coating to some extent (Slabejová 2012). The other factor is a degree of surface damage. A thicker coating resulted in a greater risk of cracking under test conditions. The tested silicone coatings were sufficiently flexible, so no cracks in the coatings were visible to the naked eye. At 35× magnification, however, the cracking was visible on the surfaces of the veneers modified by hydrophilic silicone resin (for a drop height of 400 mm; Fig. 3). The degree of damage was of grade 2 at the maximum.

Surface Resistance to Cold Liquids

The surface of veneers was exposed to selected cold liquids for 10 min. After 24 h, the surface was evaluated visually and graded according to Table 4. The results are summarized in Tables 6 through 9, which show numeric values expressing the degree of damage of the surface. To more easily evaluate the experiment, the average values of degrees of damage for the individual cold liquids and also for individual wood species were used. The veneer that achieved the highest average value was the most resistant to the cold liquids tested.

The resistance to cold liquids on the veneer surface with silicone resin coating was low if compared to that of commonly used coatings. Pavlič *et al.* (2004) and Kaygin and Akgun (2009) have stated that the resistance to selected cold liquids on the surfaces with UV acrylate or UV polyester coatings reach the highest grade (5). Polyester, polyurethane, nitrocellulose, and water-soluble coatings reach the grade 3 or more. Good resistance to cold liquids of UV water-soluble coatings was reported by Tesařová *et al.* (2010).

After 10 min exposure to a liquid, the damage of the surfaces reached, in some cases, grade 2 (strong traces of damage usually without changing the structure of varnish) (Fig. 4). Ash veneer with the surface coated with weakly hydrophobic resin was the most resistant (Table 8). It reached grade 5; only once the grade of 4 was recorded (slight change in gloss visible only in reflection of light source).

Table 6. Surface Resistance to Cold Liquids for Strongly Hydrophobic Silicone Resin Coating

Cold Liquid	Strongly Hydrophobic Resin				
	Ash*	Beech*	Walnut*	Oak*	Mean
Acetic Acid 10% aq. solution	3	3	2	3	2.75
Citric Acid 10% aq. solution	4	4	4	4	4.00
Ethanol pure 48% aq. solution	5	5	5	5	5.00
Sodium Carbonate 10% aq. solution	2	2	3	2	2.25
Sodium Chloride 15% aq. solution	2	2	3	5	3.00
Cleaner SAVO	2	2	3	2	2.25
Mean	3.00	3.00	3.33	3.50	3.21

*Surface assessed according to Table 4

Table 7. Surface Resistance to Cold Liquids for Moderately Hydrophobic Silicone Resin Coating

Cold Liquid	Moderately Hydrophobic Resin				
	Ash*	Beech*	Walnut*	Oak*	Mean
Acetic Acid 10% aq. solution	3	2	2	2	2.25
Citric Acid 10% aq. solution	4	4	4	4	4.00
Ethanol pure 48% aq. solution	5	5	5	5	5.00
Sodium Carbonate 10% aq. solution	3	3	4	2	3.00
Sodium Chloride 15% aq. solution	3	2	4	2	2.75
Cleaner SAVO	2	2	4	2	2.50
Mean	3.33	3.00	3.83	2.83	3.25
*Surface assessed according to Table 4					

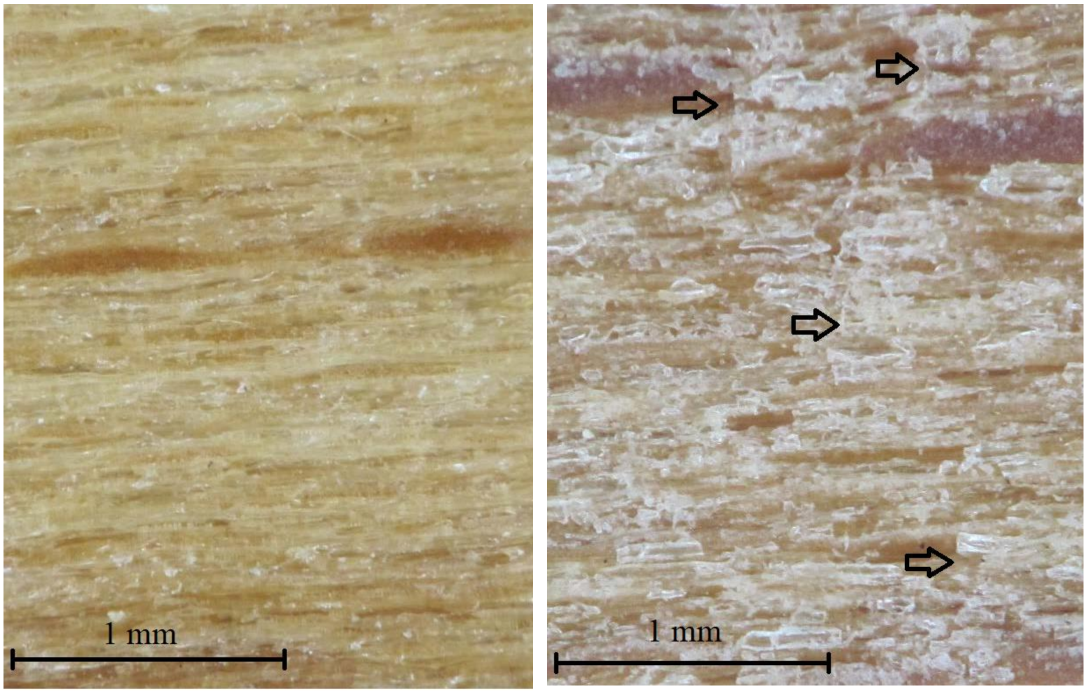
Table 8. Surface Resistance to Cold Liquids for Weakly Hydrophobic Silicone Resin Coating

Cold Liquid	Weakly Hydrophobic Resin				
	Ash*	Beech*	Walnut*	Oak*	Mean
Acetic Acid 10% aq. solution	4	4	3	3	3.50
Citric Acid 10% aq. solution	5	5	5	5	5.00
Ethanol pure 48% aq. solution	5	5	5	5	5.00
Sodium Carbonate 10% aq. solution	5	2	5	5	4.25
Sodium Chloride 15% aq. solution	5	2	5	5	4.25
Cleaner SAVO	5	4	5	5	4.75
Mean	4.83	3.67	4.67	4.67	4.46
*Surface assessed according to Table 4					

Table 9. Surface Resistance to Cold Liquids for Hydrophilic Silicone Resin Coating

Cold Liquid	Hydrophilic Resin				
	Ash*	Beech*	Walnut*	Oak*	Mean
Acetic Acid 10% aq. solution	2	2	2	2	2.00
Citric Acid 10% aq. solution	4	4	4	4	4.00
Ethanol pure 48% aq. solution	5	5	5	5	5.00
Sodium Carbonate 10% aq. solution	2	2	2	2	2.00
Sodium Chloride 15% aq. solution	2	2	2	2	2.00
Cleaner SAVO	2	2	3	2	2.25
Mean	2.83	2.83	3.00	2.83	2.88
*Surface assessed according to Table 4					

Based on the average values listed in Tables 6 through 9, the weakly hydrophobic silicone resin created the most durable coating on the surfaces of all the tested veneers. The biggest changes on the veneer surface were recorded on beech veneer; in each of the coatings, the degree of damage of 2 was recorded at least twice.



Reference surface

The surface exposed to Acetic Acid 10% aq. sol. – damaged, grade 2

Fig. 4. Moderately hydrophobic silicone resin coating on beech veneer (magnification 35×)

Gloss

The gloss values measured using the geometry of 60° are shown graphically in Fig. 5. A larger luminous flux reflected at the given geometry was always measured in the longitudinal direction when compared with the transverse direction. The gloss is influenced by the structure of wood surface (wood species, direction of wood fibers), surface machining (cutting in the longitudinal direction), and the thickness of coating film (Kaygin and Akgun 2009). The highest value of reflected light was measured from the surfaces coated with weakly hydrophobic resin. Veneers coated with this type of resin reached the degree of semi-gloss in the longitudinal direction and the degree of semi-matte in the transverse direction. The difference in the gloss of transparent surface finishes on wood in the longitudinal and transverse directions has also been noted by Lee *et al.* (2003), Tesařová *et al.* (2010), and Slabejová *et al.* (2016). Interaction of the semi-gloss coating with the transverse direction on the wood surface reduces the gloss. The light is refracted on the surface roughness (cut vessels and wood fibers) and therefore the surface achieves less gloss. The moderately hydrophobic silicone resin created a semi-matte coating in both directions. The other silicone resins created matte coatings on the wood surface. Figure 5 shows that the degree of gloss was lower in the transverse direction than in the longitudinal direction for each of the surfaces. On matte surfaces, the effect of the transverse direction on the refraction is smaller than on semi-gloss or gloss surfaces.

Silicone resin can be used to modify a veneer for 3D-forming (Slabejová and Šmidriaková 2013; Slabejová *et al.* 2017). Based on the results of the gloss values, the silicone coating affected the gloss of the veneer surface. The resulting gloss was caused by the interaction of gloss of wood and the gloss of silicone coating. The gloss can also be affected by a different type of modification of veneer. Bekhta *et al.* (2014) have described changes in the gloss of veneers densified by heat.

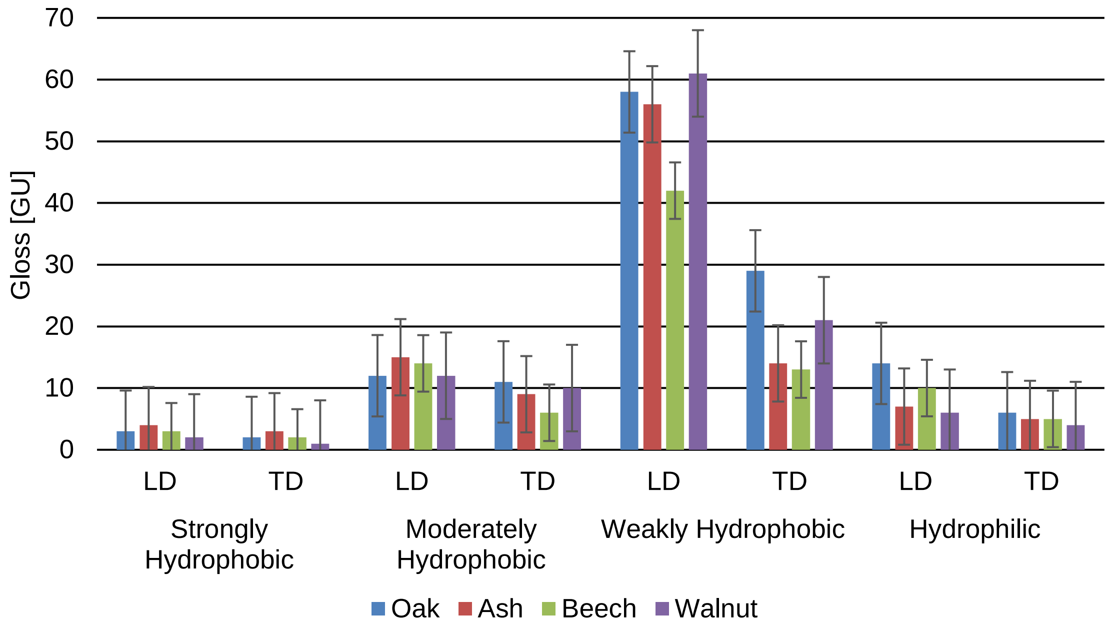


Fig. 5. The gloss of veneer surface coated with silicone resins; longitudinal (LD) and transversal (TD) directions

CONCLUSIONS

Based on the analysis of the results, one can draw the following conclusions:

1. Veneers modified with silicone resins had lower surface roughness in the longitudinal direction when compared with the roughness in the transversal direction.
2. The surface roughness of veneers with silicone resins was statistically the same as the surface roughness of resin-free veneers.
3. The impact resistance of silicone coatings on the veneer surface was of grade 2. The intrusions in the surfaces were visible to the naked eye. At the point of intrusion, the coatings showed no cracks visible to the naked eye. The cracks were visible at magnification 35×.
4. The resistance to cold liquids on veneer surfaces with silicon coatings was lower when compared to that of commonly used coatings.
5. The surfaces showed moderate (grade 3) to substantial (grade 2) damage after just 10 min of exposure to the selected liquids (Acetic acid, Citric acid, Ethanol, Sodium carbonate, Sodium chloride, Cleaner SAVO).
6. The gloss of the surface of the veneer with a silicone coating was greater in the longitudinal direction than in the transversal direction; for more glossy coatings, the difference was greater.

   The quality of the coating created with the tested silicone resins was low. The tested silicone resins are not proper to form the wood surface finish.

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