Polyurethane Coatings on Hardwood and Softwood Surfaces: Their Resistance to Household Liquids as an Educational Case Study

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Effects of cold liquids on the cured film of selected coatings, the thickness of the final film coating on the resulting surface resistance, and different wood species on the resistance of the coating were investigated. It was demonstrated that different liquids affected the degradation of the cured film coating. The most aggressive liquid used was nail polish remover, followed by ethanol 40%, bleach, vinegar, and mouthwash. The least aggressive was dishwashing liquid. There was no evidence of a difference in the quality of the cured film coating applied on softwood and hardwood. The thickness of the coating had no statistically significant effect on the quality of the film. The liquids used for the tests are commonly used in households.

Keywords: Coating; Coating thickness; Cold liquid; Polyurethane; Resistance

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INTRODUCTION

Polyurethane coating products achieve a high-quality cured film that can offer good resistance to solvents, chemicals, and the influence of weather conditions. These characteristics stem from the primary and secondary structure of polyurethane chains (Melchiors *et al.* 2000). A polyurethane-based coating system can be designed with the desired characteristics to fully satisfy its specific application. It is believed that polyurethane coating systems will gain an increasing market share thanks to the properties and possibilities that they offer, particularly two-component waterborne polyurethane coatings (Melchiors *et al*. 2000; Scrinzi *et al.* 2011). Based on daily household activities, coatings applied in interiors must withstand a wide range of degradation factors. These factors particularly include UV radiation, a change in microclimate conditions, exposure to chemicals, and mechanical damage such as scratching, abrasion, and shock (Scrinzi *et al.* 2011; Gaff *et al.* 2015; Kminiak and Gaff 2015; Kvietková *et al.* 2015a,b; Kubs *et al.* 2016). Surface treatments increase the product's value, prolong its life, and complete its aesthetic appearance. To evaluate the quality of the surface treatment, many standardized and non-standardized tests of surface treatment properties have been developed. Primarily the optical and technological properties of the coatings and their resistance to environmental influences have been assessed (Stoye and Freitag 1998; Polášek 2003).

Zafer *et al.* (2013) have previously dealt with the effects of thermal aging of polyurethane varnishes; the results of their work provides knowledge indicating the effect of heat and reduced adhesion values, as well as a reduction in the gloss of the varnish.

In the work of Sonmez *et al.* (2015), the effect of the moisture content in wood on the adhesion of polyurethane-based coatings was investigated. The results of their work indicate that the moisture content of wood has a significant effect on the adhesion of coatings to the surface of the wood. The highest adhesion values were measured in the application of two-part polyurethane varnish applied on oak specimens with a moisture content of 8%.

There is some evidence of the effect of weathering (Yalcim and Ceylan 2017) on the adhesion strength and surface roughness of beech wood (*Fagus orientalis*), from which it is clear that samples impregnated with mimosa and quebracho tannins decreased by a maximum of 20%, while an increase in the average surface roughness (R_a) was detected. The highest adhesion and the lowest average surface roughness were achieved with polyurethane varnish.

The amount of research on this topic points to the fact that it is an interesting topic with great research potential for science and practice. However, there has been a lack of knowledge about the effect of cold liquids on the cured film of a selected coating material, the effect of the thickness of the coating film on the resulting surface resistance, and the effect of the wood species on the resistance of the coating film.

This research aims to assess the resistance of selected coatings' cured films to the effects of certain cold liquids (bleach, dishwashing liquid, mouthwash, alcohol, nail polish remover, and vinegar).

EXPERIMENTAL

Materials

The selected base materials were beech and spruce (*Picea abies* L.) plywood with a thickness of 3 mm. The tested coatings were two kinds of polyurethane varnish. The first was a single-component PU kombilak 1879 (Ciranova, Beveren, Belgium). The second was a colorless two-component polyurethane furniture varnish with an acrylic resin base with UV protection (without nitrocellulose) Ewidur novacryl (Ing. Egon Wildschek & Co., OG, Vienna, Austria). Both types of varnish were applied in two 80-g/m^2 coating weights and in three 150-g/m^2 coating weights. For cleaning the exposed surface, a hard floor cleaner detergent was used (Debal Coatings nv, Beveren, Belgium), which is a cleaning detergent for varnished floors and parquets and designed for thorough removal of old polishes. Seven test liquids were selected, which are listed along with their composition in Table 1.

Methods

Preparation of samples

The plywood samples were cut to 260 mm × 150 mm plates and sanded with a 150-grain sandpaper to be further ridden of impurities such as dust and grease. The varnish was thinned to a viscosity of 22 s at 20 °C ± 2 °C (Zahn cup method). Ten test specimens were made for each wood species-varnish-coating combination. The first group was sprayed with a 80 g/m^2 varnish coating, which represented two layers. The second group was sprayed with a 150 g/m^2 varnish coating, which represented three layers. After the coatings were applied, the samples were allowed to cure for 30 days.

Table 1. Liquids with a Description of the Composition and the Duration of their Action on the Surface of the Coating

Liquids Used	Composition (Brand information; Producer, City, Country)	Test Duration
Alcohol 40%	Ethanol, pear distillate, and aroma (Slivovice; RUDOLF JELÍNEK a.s, Vizovice, Czech Republic)	1 h
Nail polish remover	Acetone, water, alcohol, caprylic/capric triglyceride, perfume, octocrylene, butyl methoxydibenzoylmathane, linalool, sodium sulfate, sodium chloride, and CL 42090 (Odlakovač Cien; Lidl Česká republika v.o.s., Praha, Czech Republic)	1 h
Vinegar 8%	Water, distilled vinegar, coloring, and ammonia caramel (Ocet Klasik; Globus ČR, k.s., Praha, Czech Republic)	6 h
Bleach	< 5% of nonionic surfactant, phosphoric acid, benzyl salicylate, methylchloroisothiazolinone, methyliazolinone, and perfume (Savo; UNILEVER ČR, s.r.o., Praha, Czech Republic)	6 h
Dishwashing liquid	5% to 15% anionic surfactants, < 5% nonionic surfactants, methylisothialinone, phenoxyethanol, perfumes, geraniol, and limonebe (Jar; Procter & Gamble - Rakona, s.r.o., Rakovník, Czech Republic)	24 h
Mouthwash	Water, glycerine, PEG-60 hydrogenated castor oil, sodium citrate, aroma, zinc chloride, sodium fluoride, cetylpyridium chloride, and sodium saccharin (Odol; GlaxoSmithKline, s.r.o., Praha, Czech Republic)	24 h

Liquid stress

The tests were conducted 30 days after the varnish application. The test area was in a horizontal position. The tests were performed with selected liquids in places spaced at least 60 mm apart. The filter papers were immersed in the test liquid for 30 s, removed with tweezers, and wiped against the edge of the container. They were then quickly placed on the test area and covered with an upside-down Petri dish. The filter papers were not allowed to touch the edge of the Petri dish. After the test, the Petri dishes were removed, and the filter paper was removed with tweezers. The paper fibers adhering to the test surface were not removed. The remaining test liquid was sucked up with paper without wiping, and the test surface was left to rest uncovered for 16 h to 24 h in the test environment. The test area needed to be protected against dust, without limiting free air flow. After 16 h to 24 h, the test surface was cleaned by gently wiping with an absorbent cloth, soaked first in a cleaning solution and then in water. Finally, the surface was carefully dried with a dry cloth. At the same time, one reference surface that was not exposed to a liquid was washed and dried off in the same way. The tested surface was left uncovered to rest in the testing environment for 30 min according to BS EN 12720 (1998).

Evaluation of surface damage

Damage to the test surface, *i.e.* discoloration, changes in shine and color, blistering, and other defects, were checked using an observation chamber (Fig. 1). The surface was observed from various angles, including angles where the light was reflected from the test surface towards the observer. The evaluation was performed by three independent persons. The test surface was compared with the reference surface for each test liquid, and evaluated according to the following numerical values according to BS EN 12720 (1998): Level 1: Strong signs of damage, the surface structure is changed, the surface material is completely or partially removed, or the filter paper stuck to the surface; Level 2: Strong signs of damage, the surface structure is mostly unchanged; Level 3: Slight traces of damage, visible from different viewing angles such as an almost complete or just visible circle; Level 4: Slight changes in shine and color, only visible when the light source reflects in the test surface or the trace of damage, or close to them (or several separate traces of damage that are barely visible), and is reflected against the observer's eye; and Level 5: No visible damage (no damage). This scale was based on visual observation and is dimensionless.

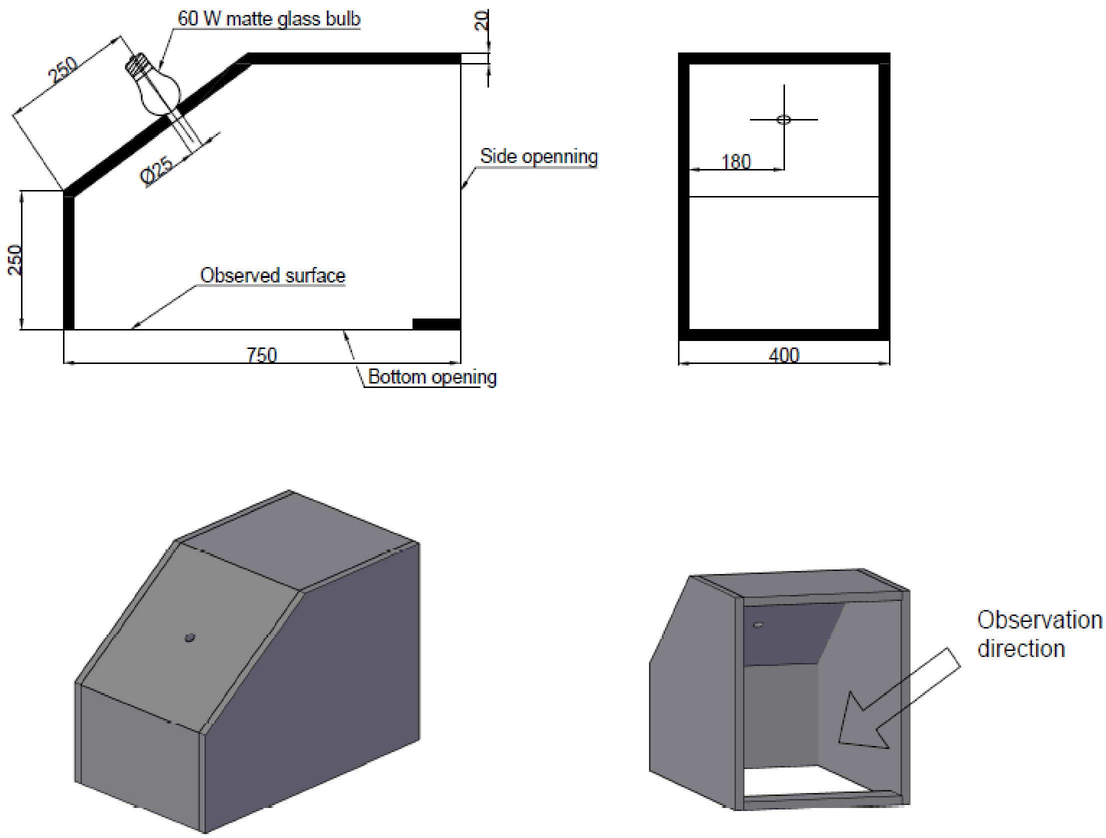

Fig. 1. Observation chamber

RESULTS AND DISCUSSION

Table 2 shows the effects of different factors and their interaction on the average damage values. It is clear from the level of significance of the "P" results listed in the tables that the factors with a statistically significant effect are the "Liquid" and "Number of Components". The "Coating" and "Wood species" factors proved to be statistically insignificant.

Two-factor interactions only showed a significant effect of the interactions Wood species*Liquid and Liquid*Number of components; other two-factor interactions were shown to have an insignificant effect.

Based on three-factor interactions, only the interaction Wood species*Liquid*Number of components could be considered significant.

The effect of all four monitored factors could also be considered insignificant based on the level of significance "P".

Table 2. Four-Factor Variance Analysis Evaluating the Effect of Individual Factors and Two-factor to Four-factor Interactions

Evaluated Factor	Sum of Squares	Degree of Freedom	Variance	Fisher's F-test	Significance Level P
Intercept	4942.972	1	4942.972	10631.342	***
1) Coating (***N***)	1.445	1	1.445	3.107	NS
2) Wood Species (***D***)	165.948	5	33.190	71.384	NS
3) Liquid (***K***)	1.102	1	1.102	2.370	***
4) Number of Components (***PZ***)	1055.145	1	1055.145	2269.404	***
N * D	5.304	5	1.061	2.282	NS
N * K	0.169	1	0.169	0.363	NS
D * K	4.391	5	0.878	1.889	***
N * PZ	1.302	1	1.302	2.801	NS
D * PZ	58.859	5	11.772	25.319	NS
K * P	0.861	1	0.861	1.853	***
N * D * K	1.630	5	0.326	0.701	NS
N * D * PZ	5.830	5	1.166	2.508	NS
N * K * PZ	0.028	1	0.028	0.060	NS
D * K * PZ	4.248	5	0.850	1.827	***
1 * 2 * 3 * 4	1.354	5	0.271	0.582	NS
Error	200.856	432	0.465		

NS- not significant, ***- significant, Significance was accepted at $P < 0.001$

One-factor Interaction

In most cases, the coating weight had no significant effect on the quality of the coating (Fig. 2a). This result corresponded with theoretical assumptions. The selected weight that was used is in the range of 80 g/m^2 to 150 g/m^2. In this range, the quality of the coating was guaranteed by the manufacturer and the coating met the specified parameters.

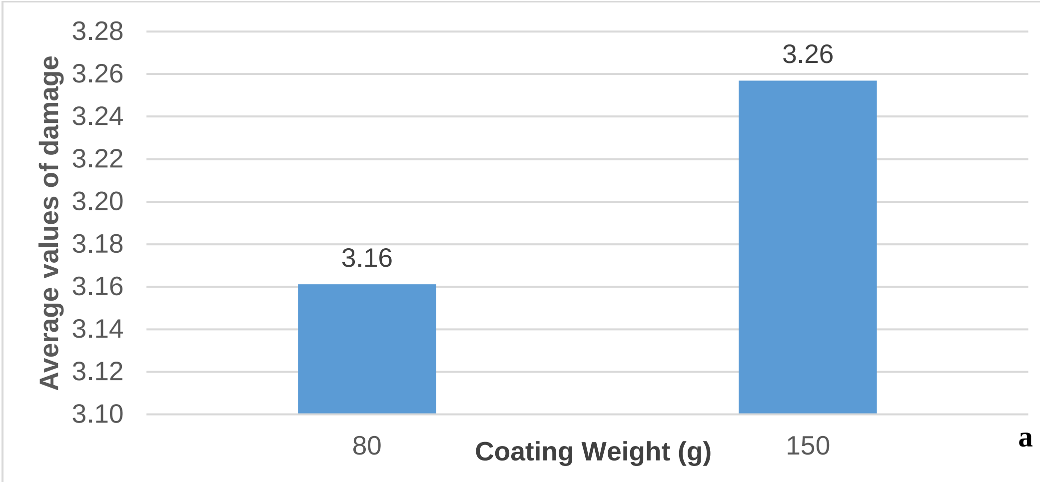

Fig. 2. (a) The effect of the coating weight on average values of damage

In most cases, the wood species showed no significant effect on the quality of the coating (Fig. 2b). The wood species most likely had no effect because plywood was chosen for the test specimens, and it was possible that part of the top veneer was soaked with the cured adhesive, which prevented the seepage of large quantities of the coating material.

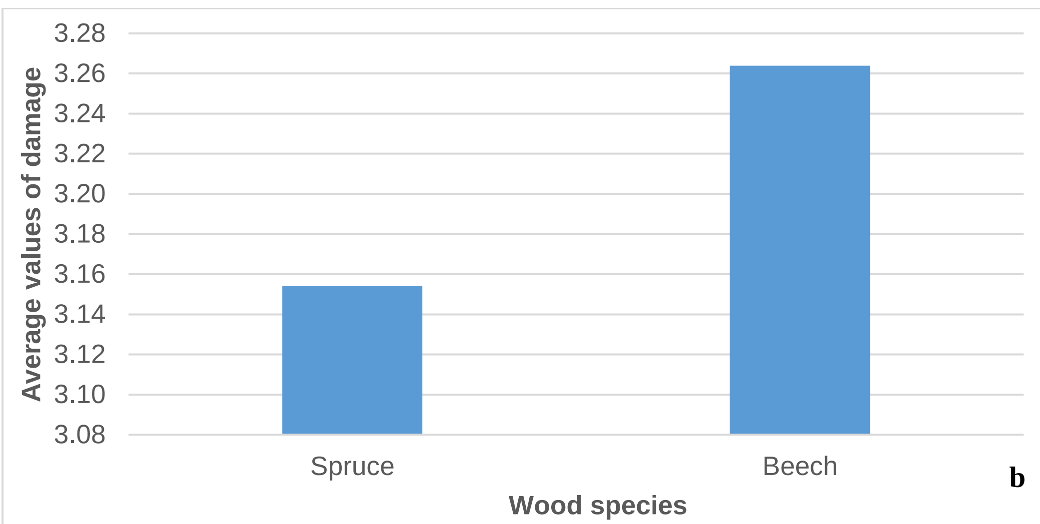

Fig. 2. (b) The effect of the wood species on average coating values

The liquids (Fig. 3a) were shown to have a greater significant effect on the values of the monitored characteristic, which was confirmed by the level of significance “P” shown in Table 2. Figure 3 shows that the most aggressive liquid was nail polish remover (ON), and the least aggressive liquid was the dishwashing liquid “JR”. The other liquids (alcohol, vinegar, bleach, and mouthwash) were similar to the dishwashing liquid.

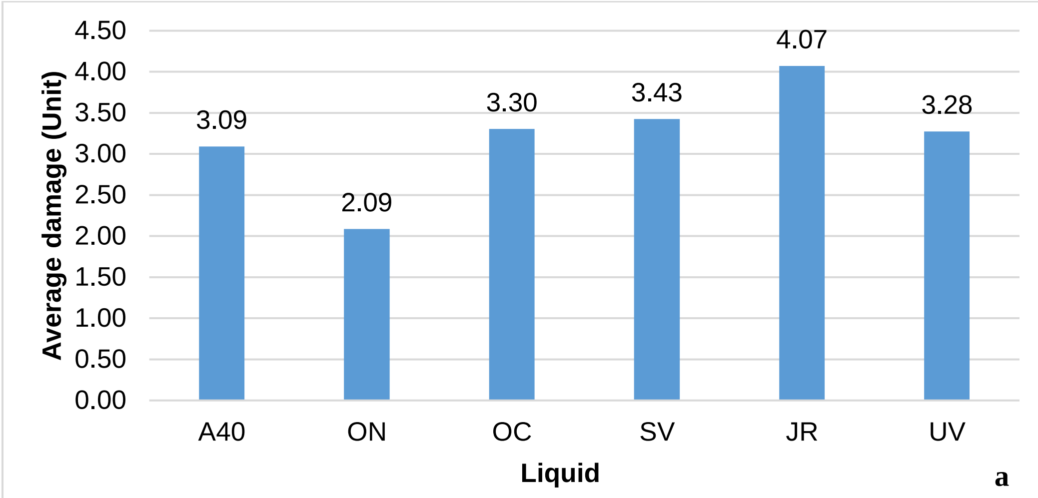

Fig. 3. (a) Effect of liquids on reasonable damage values; Legend: Alcohol 40% (A40), Nail Polish Remover (ON), Vinegar (OC), Bleach (SV), Dishwashing Liquid (JR), and Mouthwash (UV)

The effects of the number of components on the values of average damage is shown in Fig. 3b. The figure shows the confirmation of a significant effect of the monitored factor on the reasonable damage characteristic. The values given in the figure showed that the resistance of the single-component polyurethane of damage by liquids was inferior to that of the two-component polyurethane.

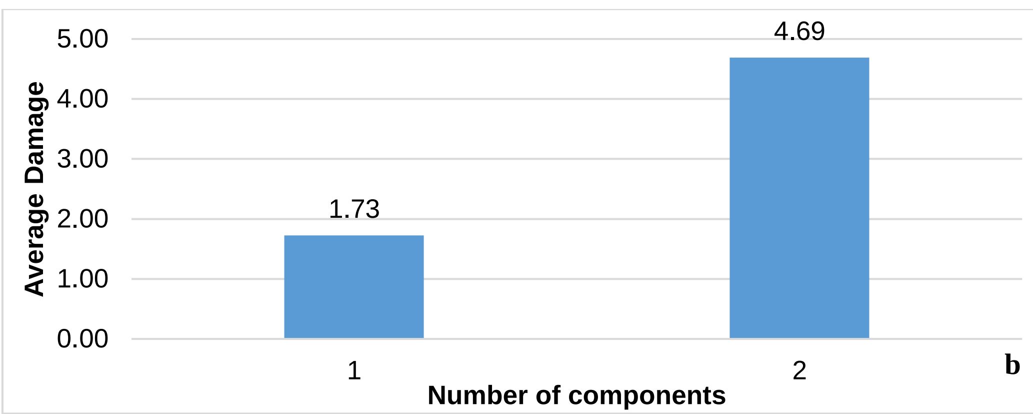

Fig. 3. (b) The effect of the number of components on average values of damage; Legend: Single-component Polyurethane (1), and Two-component Polyurethane (2)

Four-factor Interactions

Although exposure to all four factors failed to confirm a significant effect, it was considered appropriate to present these results in Figs. 6a through b. These figures show that the two-component polyurethane had the same results in both cases, while the single-component polyurethane showed clear changes in the effects of the liquids, the coatings, and the wood species.

It was also clear from Figs. 2a through b that the two-component polyurethane coating was more resistant than the single-component polyurethane coating. It was interesting that on a beech substrate, the two-component polyurethane was more damaged by the nail polish remover than the single-component polyurethane damaged by the dishwashing liquid. In all other cases, the single-component coating was always damaged to a higher extent.

In the case of two-component polyurethane, the curing agent used to prepare it is important.

The results of the work of Cheumani-Yona *et al.* (2015) show that the resistance of the coating film is affected by the type of curing agent used, which can reduce or increase the resistance of the coating film. In our case, the curing agent used was supplied with our coating material. Our work was not aimed at determining the effect of the curing agent, but it is clear that this is an issue of practical application, and it should be given more attention.

The two-component polyurethane exhibited the same degree of damage by individual liquids on both beech and spruce (*Picea abies* L.), with a 80 g/m^2 coating, as well as a 150 g/m^2 coating. In contrast, the substrate material and coating thickness had a slight effect on the single-component polyurethane. For example, the alcohol damaged the single-component polyurethane on the beech with a 150 g/m^2 coating less than on the spruce with the same or thinner coating.

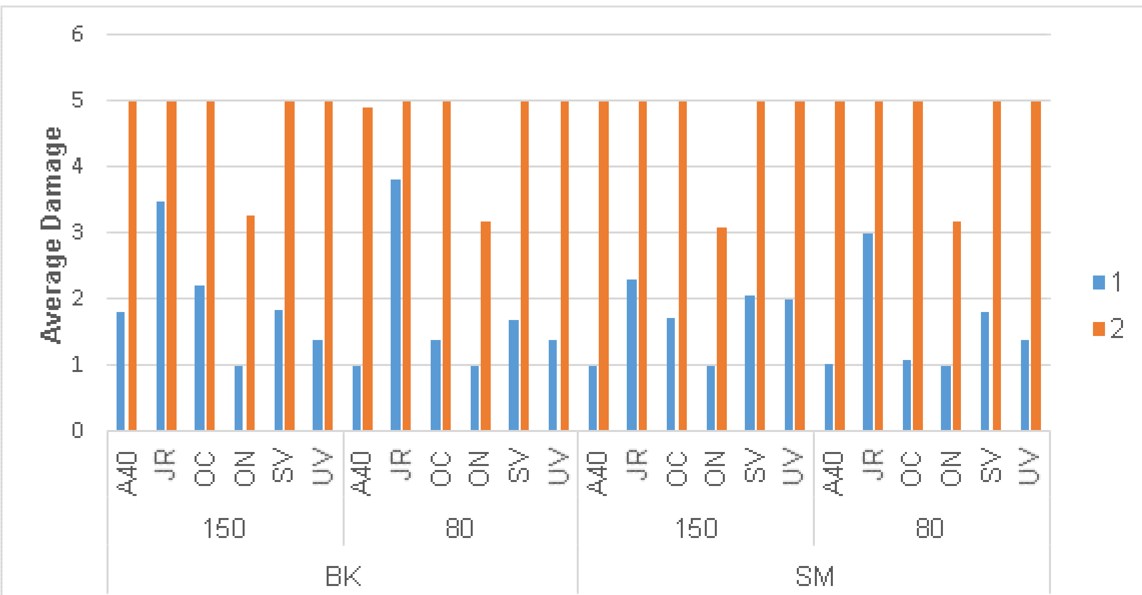

Fig. 4. The effects of the wood species, coating weight (80 g/m^2 or 150 g/m^2), and number of components (1-component or 2-component) on average damage by liquids; Legend: Alcohol 40% (A40), Nail Polish Remover (ON), Vinegar (OC), Bleach (SV), Dishwashing Liquid (JR), Mouthwash (UV), *Picea abies* L. (SM), and *Fagus sylvatica* L. (BK)

The level of significance "P" (Table 3), that described the effect of the wood species on the average damage values, showed that the effect of the wood species on the monitored characteristic was insignificant. In monitoring the effect of the wood species, the level of significance was P = 0.078.

When evaluating the type of liquid factor, the differences in the achieved values were significantly different. The only difference that was not confirmed was between liquids A40 and OC, where the level of significance was P = 0.062, and the comparison of values measured in a set subjected to liquids A40 and UV (P = 0.089), as well as SV and UV, where the level of significance was P = 0.191.

The coating weight was an insignificant factor. The level of significance in the comparison of sets of test specimens with a coating of 80 g/m^2 and 150 g/m^2 was P = 0.124. Conversely, the application of the single-component (1) and the two-component polyurethane (2) had a significant effect. By comparing the values measured in the test specimens, the authors found differences with a significance level of P = 0.000.

We cannot claim, however, that the number of components affects the average damage values. It is necessary to realize that the two specific coating systems were tested purposefully. In order to confirm the presented hypothesis, it would be necessary to test a larger quantity of single and two-component coating systems.

Table 3. Comparison of the Effects of Individual Factors using Duncan's Test on the Values of the Average Damage

Average Damage			
Wood Species		(1) 3.1542	(2) 3.2639
1	SM		0.078
2	BK	0.078	

SM - (*Picea abies L.*),
BK - (*Fagus Sylvatica L.*)

Average Damage							
Type of Liquid		(1) 3.0917	(2) 2.0875	(3) 3.3042	(4) 3.4250	(5) 4.0708	(6) 3.2750
1	A40		0.000	0.062	0.004	0.000	0.089
2	ON	0.000		0.000	0.000	0.000	0.000
3	OC	0.062	0.000		0.262	0.000	0.787
4	SV	0.004	0.000	0.262		0.000	0.191
5	JR	0.000	0.000	0.000	0.000		0.000
6	UV	0.089	0.000	0.787	0.191	0.000	

Alcohol 40% (A40), Nail Polish Remover (ON), Vinegar (OC), Bleach (SV), Dishwashing Liquid (JR), and Mouthwash (UV)

Average Damage			
Coating		(1) 3.1611	(2) 3.2569
1	80		0.124
2	150	0.124	

Coating 80 g/m^2 and 150 g/m^2

Average Damage			
Number of Components		(1) 1.7264	(2) 4.6917
1	1		0.000
2	2	0.000	

Single-component polyurethane (1), two-component polyurethane (2)

Wood is a natural material and its production might be sustainable. However, it has some disadvantages in comparison with plastic, glass, or steel, *e.g.* surface resistance is lower than materials mentioned early. In contrast, some plastics have a highly negative impact for human health, *e.g.* problems concerning human reproduction (Žalmanová *et al.* 2017) and to replace plastics with wood must be a priority of the industry. Potential users of wood need to be educated with this priority goal to enhance wood consumption, and researchers are looking for the proper ways to enhance wood consumption. The present results are very important for creating tutorials and worksheets within forest pedagogy programs focused on the woodworking industry and the use of wood and wood products in residences. The results obtained can be applied within forest pedagogy as a good example, as tested liquids are commonly found in households. With proper application of the results and the quality presentation of these results, the public can see that wood products are justified with a gentle treatment, and that they have their advantages and qualities compared to other materials used in households, such as plastics. This can therefore increase public interest in wood products, improve the image of the woodworking industry, and support sustainable forest management. We propose that items from our study suggests that the public can participate in this kind of research, for which panels of judges are needed. Finally, we are proposing to publish results of such studies on department websites.

CONCLUSIONS

1. The aim of the study was to determine the influence of selected cold liquids on selected coatings, or cured film. It was clearly demonstrated that the nail polish remover was the most aggressive liquid, followed by the alcohol, bleach, vinegar, and mouthwash. The least aggressive was dishwashing liquid.
2. The results of this study showed that there were no proven differences in the quality of the film coatings applied to softwood and hardwood test specimens, specifically *Picea abies* L. and *Fagus sylvatica* L.
3. The effects of the coating weight on the quality of the film were not statistically significant. The 80-g/m^2 and 150-g/m^2 coating weights were used, which were the boundary values of the interval recommended by the manufacturer. Therefore, the producers of the coating materials recommend that to be a correct coating weight.

ACKNOWLEDGMENTS

The authors are grateful for the support of the University-wide Internal Grant Agency (CIGA) of the Faculty of Forestry and Wood Sciences, Project No. 20164313.

REFERENCES CITED

Cheumani-Yona, A. M., Budija, F., Hrástnik, D., Kutnar, A., Pavlič, M., Pori, P., Tavzes, Č., and Petrič, M. (2015). "Preparation of two-component polyurethane coatings from

bleached liquefied wood," *BioResources* 10(2), 3347-3363. DOI: 10.15376/biores.10.2.3347-3363
ČSN EN 12 720. (1998). "Furniture - Evaluation of surface resistance to cold liquids action," International Organization for Standardization, Geneva, Switzerland.
Gaff, M., Kvietková, M., Gašparík, M., Kaplan, L., and Barcík, Š. (2015). "Surface quality of milled birch wood after thermal treatment at various temperatures," *BioResources* 10(4), 7618-7626. DOI: 10.15376/biores.10.4.7618-7626
Kminiak, R., and Gaff, M. (2015). "Roughness of surface created by transversal sawing of spruce, beech, and oak wood," *BioResources* 10(2), 2873-2887. DOI: 10.15376/biores.10.2.2873-2887
Kubs, J., Gaff, M., and Barcík, Š. (2016). "Factors affecting the consumption of energy during the of thermally modified and unmodified beech wood," *BioResources* 11(1), 736-747. DOI: 10.15376/biores.11.1.736-747
Kvietková, M., Gaff, M., Gašparík, M., Kaplan, L., and Barcík, Š. (2015). "Surface quality of milled birch wood after thermal treatment at various temperatures," *BioResources* 10(4), 6512-6521. DOI: 10.15376/biores.10.4.6512-6521
Kvietková, M., Gašparík, M., and Gaff, M. (2015b). "Effect of thermal treatment on surface quality of beech wood after plane milling," *BioResources* 10(3), 4226-4238. DOI: 10.15376/biores.10.3.4226-4238
Melchiors, M., Sonntag, M., Kobusch, C., and Jürgens, E. (2000). "Recent developments in aqueous two-component polyurethane (2K-PUR) coatings," *Progress in Organic Coatings* 40(1), 99-109. DOI:10.1016/S0300-9440(00)00123-5
Polášek, J. (2003). "Zkoušení nátěrových hmot a povrchových úprav - část II," Nábytek, Mendelova zemědělská a lesnická univerzita v Brně, Brno, Czech Republic.
Scrinzi, E., Rossi, S., Deflorian, F., and Zanella, C. (2011). "Evaluation of aesthetic durability of waterborne polyurethane coatings applied on wood for interior applications," *Progress in Organic Coatings* 72(1), 81-87. DOI:10.1016/j.porgcoat.2011.03.013
Sonmez, A., Budakci, M., and Bayram M. (2015). "Effect of wood moisture content on adhesion of varnish coatings," *Academic Journals* 4(12), 1432-1437.
Stoye, D., and Freitag, W. (1998). "Paints, coatings and solvents (2^{nd} completely rev. Ed.), Wiley, Weinheim, Germany.
Yalcim, M., and Ceylan H. (2017). "The effects of tannins on adhesion strength and surface roughness of varnished wood after accelerated weathering," *Journal of Coatings Technology and Research* 14(1), 185-193. DOI 10.1007/s11998-016-9841-1
Zafer, D., Abdullah S., and Budakci, M. (2013). "Effect of thermal ageing on the gloss," *BioResources* 8(2), 1859-1867. DOI: 10.15376/biores.8.2.1859-1867
Žalmanová, T., Hošková, Nevoral, J., Adámková, K., Kott, T., Šulc, M., Kotíková, Z., Prokešová, Š., Jílek, F., Králíčková, M., and Petr, J. (2017). "Bisphenol S negatively affects the meotic maturation of pig oocytes," *Scientific Reports*, Volume 7, Issue 1, 1 December 2017, Article number 485.

Article submitted: March 14, 2017; Peer review completed: June 10, 2017; Revised version received: June 15, 2017; Second revision received and accepted: June 19, 2017; Published: July 3, 2017.
DOI: 10.15376/biores.12.3.5867-5877