The Efficiency of Different Wood Coatings against Water Surface Absorption

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Abstract. In the market of the Latvia different wood surface coating materials suitable for use in outdoor conditions are offered, but available information on the efficiency of these against direct water exposure is insufficient. For structural timber building elements, such as glued laminated timber (GLT), the surface coating should be applied taking into account technological, visual or colour changes (ISO 7724:1984) and – last, but not least – economic aspects are considered. Wood surfaces coated with coating materials, such as varnishes, paints, etc. can stabilize some properties such as movement of moisture content, dimensional changes and attack by microorganisms and fungi. The changes in the moisture content of timber may influence such important parameters as mechanical properties and the total life time of the structural timber elements. A study has been conducted with the aim of assessing the efficiency of coating materials used for wood protection against water absorption. In this study, six different commercial coating products used for the treatment of spruce (*Picea Abies* L. Karst.) and pine (*Pinus Sylvestris* L.) samples were tested. The efficiency of different coating substances was assessed using two modified test methods according to the standards EN 382-2 (1994) and EN 927-5 (2006), determining the surface water absorption after immersion in water for 24 h and the dynamics of water absorption of the glued laminated timber for 696 h kept in water. As a result of the study, it has been ascertained that organic solvent-based commercial coating products are more efficient against short-term and long-term wood water absorption compared to oil-based coating materials.

Keywords: construction wood, pine and spruce, heartwood and sapwood, oils, paints.

Introduction

Wood is a biodegradable material, its durability against fungi and insects is presented in the European standard EN 350 (2016) and in many researches (Alfredsen, Flate, & Evans, 2007; Van Acker, Stevens, & Nys, 1992). This is the reason for protecting wooden materials, especially those which are used in outdoor conditions.

High water absorption capacity of wood materials influences moisture content changes in wood. Dimensional changes are not linear when the moisture content exceeds 20% and the microbiological attack is encouraged (Carll & Wiedenhoef, 2009). Therefore, there is a need to protect wood products for exterior uses with different coating systems that inhibit water uptake by wood. This issue is particularly pressing in

construction elements, because the increasing moisture in wood can also reduce the mechanical strength of wooden structures and increase elasticity.

The production and application of glued laminated timber (GLT) for construction purposes have rapidly developed in Europe and also in Latvia over the last decade (Dubois, Verkasalo, & Claessens, 2020; Stalidzane, 2019). These materials are mainly used as load-bearing construction elements for indoors, but are increasingly designed to be used for outdoor conditions or in service class 3 accordance EN 1995-1-1 (2004) and protect from the impact of the direct moisture (water, snow, ice), ultraviolet radiation and extensive fluctuations in air temperature. Thus, the issue of protecting glued structural timber against the effects of the environmental conditions has become a

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theme for deeper investigation. The most durable wood species in the Central Europe is the black locust (*Robinia pseudoacacia* L.) (Pollet, Jourez, & Hebert, 2008) and in the near future it could be used with high potential for exterior use. Nowadays for building construction elements the spruce and pine structural timber (EN 338:2016) covered with different coating systems are used, and the main reason is to protect the building load-bearing constructions from direct environmental impact. Wood species with high content of tannins, wood resins and extractives have a higher natural durability and this is the basis of the eco-friendly protection of wood products as well (Huang, Maher, & Amartei, 2004; Amusant *et al.*, 2005; Asamoah & Antwi-Boasiako, 2007).

The coatings with various types and chemical composition are widely used to protect timber against environmental impacts in the world. This experience of practical and knowledge-based use nowadays are vital for Latvian GLT production companies. Wood coating materials of different chemical composition may form a principally different coating system with different operating mechanism (Perera & Selier, 1973). For example, an excessive use of surface active substances prior to the use of alkyd emulsion coating materials reduces the ability of coating material to repel water, but such an indicator as the particle size of water-based acrylic dispersion paints can significantly affect the ability of the coating material to absorb water. Water absorption capacity for alkyd emulsion paints is higher when compared, for example, with solvent-based paints and acrylic paints (Ekstedt, 2003).

Duration of the use of coating material under certain operating conditions is emphasized as one of the most significant factors which reduces the efficiency of coating materials against water exposure. Several studies analyse the efficiency of coating materials against water exposure after aging the samples in artificial conditions which provide a more complete picture of the long-term efficiency of a coating material against direct water exposure. For example, for aged wood protected with coating material, water absorption capacity increases by 30% compared to the protected wood, which has not been aged (Ekstedt, 2002).

Pine (*Pinus sylvestris* L.) and spruce (*Picea abies* L. Karst.) wood is the most widely used in the construction elements all around Europe. Comparing the biological resistance of these species to the exposure of microorganisms, it can be concluded that pine heartwood is moderately durable, while pine sapwood and spruce wood are not durable accordance EN 350 (2016). As a result, both tree species used outdoors, need to be protected against the effects of biological microorganisms.

The difference between the chemical composition of pine heartwood, sapwood and spruce wood (e.g., presence of extractives) micro and macro structure determine the different water absorption capacity of each wood species. This difference is observed not only among different tree species, but also in the coating of the same tree species, such as pine and oak between heartwood and sapwood (Olsson *et al.*, 2001). Differences of wood structure in the radial and tangential direction of fibres also significantly affect wood water absorption capacities (Côté, 1963; Nussbaum, Sutcliffe, & Hellgren, 1998).

This study analyses the exposure of water with coating materials, because the exposure to water makes more serious damages in wood structures compared with water vapour exposure (Ekstedt, 2002). The most common efficiency of coating materials against water exposure is considered when treating wood in radial or tangential direction (EN 927-5:2006), but this study also considers the effects of water absorption dynamics for wood end grain, since water is absorbed most rapidly in the direction of wood fibres.

Materials and Methods

Temporary water absorption of treated wood surface

The efficiency of wood coating commercial products against water absorption has been assessed using two test methods – water absorption of coated wood surfaces based on the standard EN 382-2 (1994) test method and immersion in water for 24 hours based on the standard EN 927-5 (2006) requirements.

In total 84 samples were made from conditioned pine (*Pinus sylvestris* L.) wood lamellas (42 heartwood and 42 sapwood pieces) and 42 samples from spruce (*Picea abies* L. Karst.) wood. In all cases, wood fibres were in the tangential direction against the treated plane. The nominal dimensions of the samples in all cases were the following: thickness 20 mm, length and width 150 mm. All samples were stored under the conditions of $65 \pm 5\%$ and $20 \pm 2^\circ\text{C}$ up to a constant mass. The surface of the samples was planed and sanded with sandpaper #220. Within 24 h after sanding, the coating, using six different commercial products, was provided. The specification of the coating products according to the manufacturers' information is given in Table 1.

For spruce, pine heartwood and sapwood additionally six uncoated samples were made to determine the reference indicators of the surface water absorption of uncoated wood. Prior to the application of the coating product, the sample area and the required total amount and consumption of the coating material were determined according to the requirements of the manufacturer. The coatings were applied in two layers using a brush or roller Table 1. The surface sanding

Table 1

Description of commercial coating products according to the manufacturers' data

Product	Type	Density (kg·l ⁻¹)	Consumption		Applying type	Number of coatings
			(m ² ·l ⁻¹)	(g·m ⁻²)		
STAFOR Linseed oil	linseed oil	0.95	8	118	Brush	1-4
ADLER Pullex bodenöl	solvent based pigmented oil	0.87	15	57	Brush	2
PROTIM	organic based pigmented oil	0.90	6	150	Brush, spraying	2
RILAK Tekstur dekor	semi-translucent alkyd colour	0.84	24	35	Brush	2
REMMERS HK lasur	solvent based alkyd resin	0.87	4	200	Brush	-3
STAFOR Swedish paint	solvent free natural oil	1.00	5	200	Brush or roller	2

between the applications of the first and second coating layer was not provided. The actual consumption of the coating product at the time of application was controlled with 0.01 g accuracy and the consumption of the coating product for each coating type is given in Table 2. The application of the last layer after 24 h was performed and the samples were placed in the conditioning room in standard atmosphere for 7 days for complete hardening of the coating material.

The water absorption capacity was determined using the test principle of the standard EN 382-2 (1994) Figure 1.

The next testing steps involved calculation of

water absorption in absolute values and percentages, according to the requirements of the standard EN 382-2 (1994) procedures.

Data processing resulted in the following statistical characteristics: the mean surface water absorption (AV) (g·m⁻²) and water absorption (%) of the control sample water absorption A% (%); standard deviations of sample groups, coefficients of variation and confidence level of the mean value. For comparing the mean values of the tested groups, the Student t-test and p-value at a 95% confidence level were used. In the following figures, the confidence levels of the mean values are given as data dispersal rates.

Table 2

Consumption of the coating products on the surface of the samples

	Type of lamellas								
	pine sapwood			pine heartwood			spruce wood		
	1 st coating	2 nd coating	total coating	1 st coating	2 nd coating	total coating	1 st coating	2 nd coating	total coating
	(g·m ⁻²)								
STAFOR Linseed oil	68	51	119	58	61	119	59	30	89
ADLER Pullex bodenöl	118	29	147	71	23	94	68	21	89
PROTIM	125	28	153	97	24	121	124	23	147
RILAK Tekstur dekor	58	23	81	77	28	105	57	26	83
REMMERS HK lasur	110	29	139	49	30	79	86	26	112
STAFOR Swedish paint	120	83	203	126	85	211	118	89	207

Figure 1. Test device accordance to standard EN 382-2: 1994 (on the left hand side) and laboratory device (on the right hand side):

1 – filter; 2 – clumping plate; 3 – pins with thread; 4 – clamping nuts; 5 – cylinder; 6 – rubber densely/dense rubber seal; 7 – sample; 8 – rubber; 9 – metal plate.

Water absorption of coated GLT after full immersion of samples in water

The three types of test samples used were: pine (*Pinus sylvestris* L.), spruce (*Picea abies* L. Karst.) and glued laminated timber (GLT). The GLT was made of four layer lamellas (nominal dimensions: $38 \times 128 \times 4000$ mm and strength class C30) glued together using two-component melamine-urea-formaldehyde (MUF) glue Akzo Nobel Cascomin 1257 with a hardener of 7557 in proportion 100:50. When the surface was planed, the GLT nominal sizes were: width 125 mm, height 130 mm and length 4000 mm. For each wood species – spruce and pine, two GLT samples were made. For each wood species 21 specimens were made whose cross-sectional dimensions were equal to the cross-sectional dimensions (width 125 mm, height 130 mm) of GLT and the length of the test piece in the direction of fibres was 75 mm (Figure 2.), without visual wood defects (knots, splits etc.).

The total side-face area of the same sample was 0.0395 m^2 , while the end grain surface area was 0.0346 m^2 (side-facing and end grain surface area ratio was 1.14:1). The sides of the samples were planed, the

end grain surface smooth-sawn. Afterwards, the samples were conditioned at $65 \pm 5\%$, $20 \pm 2^\circ\text{C}$ to a constant mass.

For the pine and spruce GLT coating 6 types of commercial coating products were used (for description of coating materials see Table 1). For each wood species 6 sample groups were obtained – 3 samples in each. A group of uncoated GLT samples was made for each wood species with 3 samples for determining water absorption rates and comparing coated GLT samples. Totally 14 sample groups were tested with a total number of samples being 42.

Before the application of the coating material the samples were weighed and the dimensions of the samples, the surface area in m^2 as well as the consumption and the amount of the required coating material for the samples were determined. Coating materials were applied using a brush or a roller. The mass of the applied coating layer was determined by a weighing method using a balance. Two coating layers were applied for both spruce and pine GLT samples. The second layer application was carried out after 24 h. The actual amount of the applied coating material is summarised in Table 3.

Figure 2. Specimens cutting scheme and dimensions:
dimensions – width 125 mm, height 130 mm, length 75 mm; blue lines – specimens cutting lines (sawing width 4 mm).

Table 3

Consumption of coating material depending on the type of the coating material and GLT

Name of coating products	Pine wood			Spruce wood		
	end edges	side edges	total consumption (g·m ⁻²)	end edges	side edges	total consumption (g·m ⁻²)
STAFOR Linseed oil	605	139	744	730	172	902
ADLER Pullex bodenöl	482	77	559	467	74	541
PROTIM	461	101	562	471	87	558
RILAK Tekstur dekor	421	60	481	445	67	512
REMMERS HK lasur	431	89	520	583	104	687
STAFOR Swedish paint	495	190	685	601	218	819

24 h after the second coating layer, the samples were placed in the conditioning room in the standard atmosphere for 7 days for complete hardening of the coated materials. After 7 days in the standard atmosphere the samples were weighed on a balance for determining the mass. Unlike the standard EN 927-5 (2006) testing method, in this study samples with different sizes were investigated. The samples were coated on all six surfaces. The samples were placed in water (temperature 20 ± 3 °C). When soaking the samples, stainless steel sieves were used to separate them, thus obtaining free circulation of water around them. The investigation of the mass of samples after 24, 72 or 96 hours with nine such periods was performed. The total duration of immersion of the samples in water was 696 h. At the end of each period, the samples were removed from the water bath, easily dried with a paper towel and weighed. After that they were reinserted into the water bath, and the cycle was continued until the end of the 9th period.

The dynamics of water absorption for each GLT species and type of coating material was expressed as an increased mass of the samples over a certain period of time as a percentage of the starting mass of the samples. After the end of the 9th cycle the samples were placed in a drying oven and dried in accordance with the requirements of the standard EN 13183-1 (2002) to a constant mass. The moisture content of each sample was calculated before the samples were immersed in water and after the end of the whole period of water immersion.

The study results reveal the relationships characterising the water absorption of coated and uncoated wood samples for the determination of the efficiency of coated materials. Additionally, there were curves derived for describing the moisture content changes in the samples.

Results and Discussion

The quality of the durability of the paints and varnishes as coating materials and coating systems for exterior wood elements is usually tested by a natural weathering test in conformity with the requirements of the standard EN 927-3 (2019). The influence of surface properties in different wood species on the quality of coating systems was observed also by De Windt (De Windt *et al.*, 2014). Water absorption is one of the methods for the investigation of efficiency of wood paints and varnishes.

Water absorption rates of coated spruce and pine wood samples after immersion in water for 24 h are shown in Figure 3. The water absorption of the pine heartwood surface 446 g·m⁻² is approximately four times lower than that of the pine sapwood value 1892 g·m⁻². Meanwhile, the water absorption capacity of the spruce wood surface (415 g·m⁻²) is comparable to the water absorption capacity of the pine heartwood surface. The obtained indicators confirm the different pine heartwood, sapwood and spruce wood water absorption capacity mentioned in the literature (Côté, 1963).

Figure 3 shows that all the coating materials used in the study significantly reduce the water absorption of pine and spruce wood surfaces ($p < 0.05$). Comparing the efficiency of oil-based coating products (STAFOR Linseed oil, STAFOR Swedish paint, ADLER Pullex bodenöl and PROTIM) against wood water uptake with the solvent-based coating products (RILAK Tekstur dekor, REMMERS HK lasur), lower water absorption rates for pine and spruce wood are observed for solvent-based coating materials ($p < 0.05$).

Comparing the efficiency of oil-based coating material against water absorption, significantly lower water absorption capacity has been obtained by using PROTIM coating product ($p < 0.05$). Regarding the

Figure 3. Water absorption of spruce and pine wood surfaces treated with coating materials after 24 h of water exposure.

solvent-based coating products (RILAK Tekstur dekor, REMMERS HK lasur) no significant difference in water absorption capacity was observed in any of treated wood surface types ($p > 0.05$).

Water absorption capacity of spruce and pine wood surfaces treated with coating materials expressed as a percentage of the water absorption of the reference samples is shown in Figure 4. The comparison of the types of wood tangential direction surfaces (pine heartwood, pine sapwood wood and spruce wood) shows that the greatest reduction in water absorption capacity is for pine sapwood. Using oil-based coating materials, surface water absorption decreases by 79 up to 86%, while for solvent-based coating materials pine sapwood surface water absorption is reduced even by up to 93%. Also, pine heartwood shows a similar trend that the decrease in water absorption capacity of oil-based coating materials is smaller than in organic solvents based coating materials. Accordingly, a reduction in water absorption rates from 16 to 55% for oil-based and from 77 to 80% for organic solvent-based coating materials was observed. In spruce wood coated with oil-based coating

materials water absorption capacity, after 24 h of water exposure, decreases by 17 to 69%, while coating with organic solvent-based coating materials water absorption rates decrease by 82 to 83%. The sustainability depends on the properties of timber species and the properties of coated materials – paints or varnishes.

Higher efficiency of solvent-based coating materials against the absorption of water compared to the oil-based coating materials is due to the different production principles and the ability of the material itself to absorb water (Schniewind & Arganbright, 1984). Secondly, organic solvent-based coating materials for wood form a “film” type of coating, while coating materials on oil base do not form it.

Figure 5 shows that for both coated and uncoated pine GLT samples the water absorption capacity can be divided into two phases: the initial phase (submerging in water from 0 to 288 h), in which the amount of water absorbed by the samples increases rapidly and the end phase (289 to 696 h), in which the increase in the amount of absorbed water decreases significantly and the moisture equalization throughout the entire cross-section of the sample occurs. Knowing

Figure 4. Water absorption of spruce and pine wood surfaces treated with coating materials expressed as a percentage of the reference samples (24 h of water exposure).

Figure 5. Changes in the mass of treated pine glued laminated timber depending on the time of sample immersion in water.

that the greatest size changes in wood occur due to wood swelling until the wood fibre saturation moisture is reached, which depending on tree species ranges from 27 to 30% (Koponen, 1985), the efficiency of wood coating material against water absorption should be assessed directly at the initial phase of moisture absorption. The quality and durability analyses of new paints under exterior conditions could give relatively exact results of their suitability for a given exposure

(Panek & Reinprecht, 2014). After 24 h of immersion in water, most rapidly water is absorbed by uncoated pine wood samples, with a mass increase averaging 12% and an increase in wood moisture of 15% (from 14 to 30%), Figure 6.

The highest values are for STAFOR Swedish paint: mass increase by 10% and moisture increase by 13% (from 14 to 27%), followed by STAFOR Linseed oil with 9% increase in mass and 10% moisture gain (from

Figure 6. Changes in the moisture of treated pine glued laminated timber depending on the time of sample immersion in water.

14 to 24%). Ranking third regarding the efficiency of coating materials against water absorption after 24 h of water exposure to glued laminated timber samples, is ADLER Pullex bodenöl and REMMERS HK lasur with an average mass increase of 6% and moisture increase of 7%. At the initial stage of the immersion the most effective protection against water absorption has been observed with PROTIM and the organic solvent-based coating product RILAK Tekstur dekor showing a mass increase of 5 and 4%, respectively and an increase in moisture content by 6 and 4%. Compared to the water absorption of the uncoated wood samples by absolute values, the mass increase of the samples is reduced by 17% to 67%, but the moisture increase by 13% to 73%.

Also, after 288 h in water, the average mass increment of the three samples was by 30% and the moisture increase – by 47%. During this period, the lower efficiency against long-term water absorption has been observed by using STAFOR Swedish paint, with an average mass increase by 28% and moisture increase by 44%, followed by ADLER Pullex bodenöl samples with 26% mass and 40% (from 14 per 54%) of moisture gain. Similar water absorption capacity after 288 h of water exposure was observed for four coating product samples (STAFOR Linseed oil, PROTIM; REMMERS HK lasur and RILAK Tekstur dekor) with all four coating materials showing an average mass increase by 23% and an average increase in sample humidity by 33 to 34% reaching an average moisture content between 47 and 48%.

The analysis of the overall trend shows that depending on the type of samples, the mass of the samples in relation to the initial mass of the samples after the immersion in water for 696 h had increased

by 27 to 32%, reaching an average sample moisture between 55 and 66%.

Wood is a natural environmentally friendly material used for a wide range of non-structural and structural applications (Priadi & Hiziroglu, 2013). The efficiency of the coating materials considered against the absorption of water by coating materials for spruce wood GLT also was analysed. Wood surfaces coated with paints or varnishes can be protected from environmental conditions such as relative humidity, attack by microorganisms or fungi and others (Kesik & Akyildiz, 2015). The level of absorption and also moisture content of the wood are important for the long-term quality of a protective wooden surface (De Meijer & Militz, 2001; Sonmez, Budakci, & Bayram, 2009).

To compare the efficiency of coating materials against water absorption of coated spruce and pine wood surfaces as well as GLT all coating materials for both tests and all five sample types were ranged from 1 to 6 points, where: 1 point was given for the most efficient coating material, while 6 points for the lowest efficiency against water absorption. The most effective coating product is the one which has the lowest sum of points. The results of the ranging are summarised in Table 4.

Table 4 shows that the most efficient materials against water absorption by coating spruce and pine wood are the coating materials formed on the organic solvent base. The highest efficiency against water absorption has been reported by RILAK Tekstur dekor obtaining 12 points, REMMERS HK lasur with 16 points in the second place. PROTIM ranks the third with 21 points, STAFOR Linseed oil with 29 points ranks the fourth and ADLER Pullex bodenöl with 30 points

Table 4

The efficiency of coating materials – ranging results

Type of coating product	Surface water absorption after immersion in water for 24 h			Long-term water absorption				Total score
	pine heartwood	pine sapwood	spruce wood	pine GLT		spruce GLT		
				24h	288h	24h	288h	
STAFOR Linseed oil	6	5	6	5	1	5	1	29
ADLER Pullex bodenöl	4	4	4	4	5	4	5	30
PROTIM	3	3	3	2	4	2	4	21
RILAK Tekstur dekor	2	2	1	1	2	1	3	12
REMMERS HK lasur	1	1	2	3	4	3	2	16
STAFOR Swedish paint	5	5	5	6	6	6	6	39

ranks the fifth. The lowest efficiency against pine and spruce wood water absorption has been observed for STAFOR Swedish paint which acquired 39 points.

Conclusions

1. In the tangential surface treatment process of pine and spruce wood, it has been observed that the consumption of coating material for the second coating layer compared to the first one depending on the type of coating material does not change or decrease up to 81% and the consumption of coating material decreases when treating the wood surfaces of pine trees. All coating materials used in the study significantly (by 16 to 93%) reduced the water absorption capacity of pine and spruce wood tangential surface ($p < 0.05$). The highest reduction in water absorption rates was observed in coated pine sapwood. Using oil-based coating materials surface water absorption decreases by 79 to even 86%, whereas by using solvent-based coating materials, water absorption reduced by 93%.
2. From oil-based coating materials significantly lower surface water absorption rates were observed by using PROTIM coating material ($p < 0.05$). No significant differences in surface water absorption rates ($p > 0.05$) have been found for organic solvent-based materials (RILAK Tekstur dekor; REMMERS HK lasur). Oil-based coating materials are of lower efficiency against short-term wood surface water absorption compared to organic solvent-based coating materials.
3. The consumption of coating material for treating the end grain surfaces of glued laminated timber increased from 3 (STAFOR Swedish paint from 190 to 495 g.m-2) to 7 (RILAK Tekstur dekor from 60 to 421 g m-2) times compared to the consumption of the material for treating the side surfaces of that wood.
4. By long-term immersion of coated spruce and pine-glued laminated timber in water, the water absorption of the glued laminated timber samples was most rapidly occurring during the first 288 h, when the sample mass on average increased from 23% to even 34% and moisture increased from 47 to 75%. In the period of 288 to 696 h the mass of immersed samples in water increased more slowly reaching a maximum sample moisture between 55 and 80%.
5. For the glued laminated timber samples treated with oil-based coating materials, the highest water absorption capacity has been reported with STAFOR Swedish paint, while the most effective – with a lower water absorption was RILAK Tekstur dekor. Also, as a result of long-term immersion in water

the materials on the oil base are of lower efficiency against the absorption through surface, compared to coating materials on the basis of organic solvents. It can be concluded that in the case of both tests of solid wood and glued laminated timber the most efficient of the coating materials considered in the study was RILAK Tekstur dekor, followed by REMMERS HK lasur, PROTIM in the third place, STAFOR Linseed oil – the fourth, ADLER Pullex bodenöl – the fifth, but STAFOR Swedish paint had the lowest efficiency against water absorption.

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