Turkish Journal of Agriculture and Forestry

Volume 37 | Number 1 Article 15

1-1-2013

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Recommended Citation

BUDAKÇI, MEHMET and TAŞÇIOĞLU, CİHAT (2013) "Adhesion properties of some protective layers exposed to outside weather conditions for five years," *Turkish Journal of Agriculture and Forestry*: Vol. 37: No. 1, Article 15. https://doi.org/10.3906/tar-1202-24
Available at: https://journals.tubitak.gov.tr/agriculture/vol37/iss1/15

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2013) 37: 126-132
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doi:10.3906/tar-1202-24

Adhesion properties of some protective layers exposed to outside weather conditions for five years

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Received: 09.02.2012 • **Accepted:** 23.06.2012 • **Published Online:** 15.01.2013 • **Printed:** 15.02.2013

Abstract: In this study, the long-term (5-year) performances of 2 varnish systems, semitransparent alkyd-based brown stain (SABBS) and alkyd-based clear varnish (ABCV), were evaluated on preservative-treated Scots pine (*Pinus sylvestris* L.) sapwood. Prior to varnish application, specimens were impregnated with 2 different types of wood preservative. The experimental variables were varnish type, layer thickness, and wood preservative. ASTM D 1641 was followed for exposing wood specimens to outdoor conditions. The effects of long-term exposure on adhesion properties of applied varnish systems were tested according to ASTM D 4541. Long-term outdoor exposure resulted in 4.2% and 33.9% reductions in the adhesion properties of SABBS and ABCV varnish systems, respectively. The layer thickness and preservative type did not show any statistical reductions in adhesion properties.

Key words: Adhesion strength, ageing, outside weather conditions, wood preservative, varnish, stain

1. Introduction

Wood material exposed to outdoor conditions without proper preservation is prone to biological and chemical degradation. While various finishing chemicals and techniques are available to prevent wood surfaces from such degradation, most applications fail due to long-term exposure to outdoor conditions. These failed finishes cannot protect the wood surfaces they are applied to. It has been reported that the chemical degradation of varnish layers is followed by discoloration and fading on wood surfaces. According to the literature, reapplication of finish to these faded surfaces also failed (Baysal 2004). UV light and surface temperatures were considered the major factors in discoloration and chemical degradation (Futo 1974; Ayadi et al. 2003). Discoloration on wood surfaces is described as a darkening effect in gray, yellow, red, or brown tones depending on the wood species (Sandermann and Schlambom 1962; Tolvaj and Faix 1995). According to Grantham et al. (1976) and Williams (2010), varnish layers applied on wood-preservative–treated wood lasted 2–8 years under outdoor exposure. Another study reported different performances when varnishes were combined with wood preservative chemicals (Feist and Mraz 1980). Sönmez and Özen (1996) found that polyurethane varnish showed the best performance against outdoor exposure when compared to synthetic varnish and white opaque stain. Varnish layers showed reductions in adhesion strength, hardness, and weight when applied combined (varnish followed by wood preservative application) and exposed outdoors in the East Black Sea region in Turkey. Changes in color and microscopic features have also been reported (Peker 1998). Another study highlighted reductions in the adhesion strength of synthetic stain and varnish layers applied on preservative-treated wood surfaces (Sönmez and Budakçı 2001).

Rain, humidity, UV radiation, and temperature fluctuations throughout the day or over seasons are considered major factors that accelerate wood degradation. The protection of wood against these factors requires proper preservative treatment, varnish application, or a combination of both (Hayoz et al. 2003; Budakçı et al. 2009). The objectives of this study were to determine the effects of various wood preservative chemicals, layer thicknesses, and outdoor exposures on the adhesion properties of varnish layers on Scots pine (*Pinus sylvestris* L.) sapwood.

2. Materials and methods

2.1. Wood material

Scots pine (*Pinus sylvestris* L.) sapwood was used in this study due to its common utilization in solid door and window manufacturing in Turkey. The mean oven-dried

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density of Scots pine specimens was 0.49 g cm^{-3}. Specimens were cut to 520 × 90 × 15 mm from randomly selected first-grade Scots pine sap wood lumber that showed no spiral grain, knots, splits, or discoloration. The specimens were kept in a conditioning chamber at 20 ± 2 °C and 65 ± 3% relative humidity until they reached stable weight. Specimens were then cut to a final size of 500 × 80 × 12 mm before their surfaces were sanded with grit 80 and 100 sandpapers, respectively. The sanded surfaces were cleaned with a soft brush and vacuum technique. A total of 160 specimens were prepared according to a 2 × 2 × 2 × 2 × 10 experimental design: 10 specimens for each method and preservative chemical, protective coating, and layer thickness, respectively.

2.2. Preservative chemicals, stain, and varnish

While semitransparent alkyd-based brown stain (SABBS) and alkyd-based clear varnish (ABCV) were utilized as protective layers, chemicals A and B were used as wood preservatives. Preparation and application of wood preservative chemicals and protective coatings were according to manufacturer recommendations and American Society for Testing and Materials (ASTM) standard ASTM D 3023 (ASTM 1981a). Active ingredients and some physical properties of the wood preservative chemicals used in this study are given in Table 1 (Hickson 2000; Sadolin 2001).

While wood preservative A was applied to surfaces with a soft white cloth, a 15-min dipping method was utilized for wood preservative B. After the applications were finished, the excess chemicals were wiped from specimen surfaces. After 1 day of drying, SABBS and ABCV protective coatings were applied with a brush as 1 and 2 coats of topcoat. Stain and varnish amounts were determined with an electronic balance to the nearest 0.01 g. The coated specimens were conditioned at 20 ± 2 °C and 65 ± 3% relative humidity for 3 weeks.

Protective stain and varnish amounts were determined according to ASTM D 1644 (ASTM 2006) and are listed in Table 2. An average of 50 µm of dry film thickness was reached for each coat on a glass calibration panel. Layer thicknesses were measured with a comparator according to ASTM D 1005 (ASTM 1984).

After varnish application, the samples were dried and placed on outdoor exposure stands at 45° angles. The varnished surfaces were arranged facing south (Garlock and Sward 1972). The lowest sample on the stands was 50 cm higher than the floor. Plants (e.g., grass) and any other wastes capable of absorbing moisture were removed from around the stands (Sönmez and Özen 1996). The samples were exposed to outdoor conditions in the city of Ankara, Turkey, for 5 years (between 1 September 1998 and 31 August 2003) according to ASTM D 1641 (ASTM 1981b). The averages of the climatological data are given in Table 3 (Turkish State Meteorological Service 2012). The effects of outdoor exposure on the adhesion strength of varnish layers on preservative-treated wood were determined according to ASTM D 4541 (ASTM 1995).

Table 1. Active ingredients of wood preservative chemicals used in this study.

Wood preservative	A	B
Active ingredients	0.2% permethrin 0.5% 3-iodo-2 propynyl-butyl carbamate	0.5% tebuconozole 0.5% propiconazole 1.0% 3-iodo-2 propynyl-butyl carbamate 0.5% cypermethrin
Density (g cm^{-3})	0.81–0.84	1.03
pH	n/a	7

Table 2. Amounts of protective coating material applied.

Varnish type	pH	Solid content (%)	Applied varnish amount (g m^{-2})	Dry film thickness (µm)	
				1 coat topcoat	2 coats topcoat
ABCV	5.3	52.2	120	100	150
SABBS	4.9	41.2	152	100	150

Table 3. Average of climatological data (Turkish State Meteorological Service 2012).

Years	Temperature (°C)	Moisture content (%)	Rainfall (mm m^{-3})	Pressure (hPa)
01.09.1998	11.7	67.0	3.465	914.991
1999	13.0	61.7	3.720	913.351
2000	11.7	63.2	2.795	914.025
2001	13.6	58.3	3.499	912.860
2002	12.0	63.3	2.894	913.807
31.08.2003	12.6	60.9	2.569	913.216

The specimen surfaces were washed with cold water to remove dirt and dust and were dried with a soft cloth before the final conditioning period. The specimens were conditioned according to ASTM D 4541 (ASTM 1995) at 23 ± 2 °C and 50 ± 5% relative humidity for 24 h prior to the adhesion test. Experimental cylinders (20 mm in diameter) were attached to the conditioned surfaces (ambient temperature: 20 °C) to perform a pull-out test as outlined in the standard. A double-component, high-strength epoxy with no dissolving effect on varnish layers was used at a concentration of 150 ± 10 g m^{-2} as specified in ASTM D 4541 (ASTM 1995). The adhesion strength of the varnish layers was determined with a standard adhesion device (Budakçı and Sönmez 2011).

Adhesion strength (*X*) was calculated (in MPa) according to the following equation:

$$X = 4F / \pi \times d^2, \qquad (1)$$

where F is the rupture force (N) and d is the diameter of the experimental cylinder (mm) (ASTM 1995).

2.3. Statistical analysis

The MSTAT-C software package was used to evaluate data statistically. As a result of multiple analyses of variation (ANOVA) tests, the treatment method, wood preservative, varnish layer, and layer thickness factors and their mutual interactions in face-to-face adhesion strength were determined. Some comparisons were made by Duncan's test and least significant difference (LSD) critical values, and the reasons for and sources of the differences were examined.

3. Results

ANOVA analysis results of exterior weathering conditions on adhesion properties of varnish layers are given in Table 4. According to the results, B, D, AB, and CD interactions were not meaningful. The BD, ABC, ABC, and BCD interactions were not significant at the $P < 0.05$ level. Table 5 shows statistical interaction values of the treatment method, preservative chemical, varnish layer, and layer thickness obtained via the LSD critical value method and

Table 4. Multiple variance analysis.

Factors	Degrees of freedom	Sum of squares	Mean square	F value	P < 0.05
Method (A)	1	16.706	16.706	118.1088	0.0000
Preservative chemical (B)	1	0.352	0.352	2.4856	0.1171*
Interaction (AB)	1	0.239	0.239	1.6876	0.1960*
Protective coating (C)	1	1.307	1.307	9.2393	0.0028
Interaction (AC)	1	10.619	10.619	75.0787	0.0000
Interaction (BC)	1	5.937	5.937	41.9726	0.0000
Interaction (ABC)	1	0.002	0.002	0.0170	ns
Layer thickness (D)	1	0.197	0.197	1.3956	0.2394*
Interaction (AD)	1	0.710	0.710	5.0213	0.0266
Interaction (BD)	1	0.001	0.001	0.0051	ns
Interaction (ABD)	1	0.084	0.084	0.5919	ns
Interaction (CD)	1	0.348	0.348	2.4591	0.1190*
Interaction (ACD)	1	0.873	0.873	6.1736	0.0141
Interaction (BCD)	1	0.038	0.038	0.2674	ns
Interaction (ABCD)	1	3.522	3.522	24.9036	0.0000
Error	144	20.368	0.141		
Total	159	63.302			

*: Not meaningful at 0.05 level; ns: not significant.

Table 5. Interaction results of the treatment method, preservative chemical, varnish layer, and layer thickness according to one-way Duncan test (all values are MPa).

Factors		$\overline{x}$	HG	LSD±
Method	Control	3.260	A*	0.1174
	Exposed	2.614	B	
Preservative chemical	Wood preservative A	2.984	A	
	Wood preservative B	2.890	A	
Protective coating	SABBS	3.027	A	
	ABCV	2.847	B	
Layer thickness	1 layer	2.902	A	
	2 layers	2.972	A	

*: Highest adhesion strength value; $\overline{x}$: average value; HG: homogeneous group.

with the one-way Duncan test. According to the results, the highest adhesion strength was calculated for control samples and the SABBS varnish layer at the method and protective coating levels, respectively. Wood preservation chemicals and layer thickness did not have any statistically significant effects at $P < 0.05$.

Table 6 indicates pairwise comparison results of method versus protective coating analysis via the LSD critical comparison method. The highest adhesion strength was recorded for the control specimens coated with ABCV varnish. The preservative chemical and protective coating interaction results according to the LSD critical value method are given in Table 7.

SABBS varnish applied on preservative-A–treated wood gave the highest adhesion strength value. The mutual effects between the method and layer thickness are presented in Table 8. The highest adhesion property was found on the 2-coat ABCV control specimens, while 1- and 2-layer ABCV-coated outdoor exposed specimens gave the lowest.

Table 9 highlights a general comparison among all factors examined above. According to Table 9, the highest adhesion strength was recorded in a single-coat application of ABCV varnish on a preservative-B–treated wood surface without outdoor exposure.

Table 6. Average adhesion strength results for pairwise comparison of method compared with protective coating (all values are MPa).

Protective coating	SABBS		ABCV	
Method	$\overline{x}$	HG	$\overline{x}$	HG
Control	3.093	B	3.428	A*
Exposed	2.962	B	2.266	C
LSD ± 0.1660				

*: Highest adhesion strength value; $\overline{x}$: average value; HG: homogeneous group.

Table 7. Average adhesion strength values for pairwise comparison of preservative chemical compared with protective coating (all values are MPa).

Protective coating	SABBS		ABCV	
Preservative chemical	$\overline{x}$	HG	$\overline{x}$	HG
Wood preservative A	3.267	A*	2.701	C
Wood preservative B	2.788	C	2.993	B
LSD ± 0.1660				

*: Highest adhesion strength value; $\overline{x}$: average value; HG: homogeneous group.

Table 8. Average adhesion strength values for pairwise comparison between method and layer thickness (all values are MPa).

Layer thickness	1 coat		2 coats	
Method	$\overline{x}$	HG	$\overline{x}$	HG
Control	3.158	B	3.362	A*
Exposed	2.645	C	2.582	C
LSD ± 0.1660				

*: Highest adhesion strength value; $\overline{x}$: average value; HG: homogeneous group.

Table 9. Average adhesion strength values for multiple comparisons among method, preservative chemical, protective coating, and layer thickness (all values are MPa).

Interaction ABCD		SABBS				ABCV			
		1 coat		2 coats		1 coat		2 coats	
		$\overline{x}$	HG	$\overline{x}$	HG	$\overline{x}$	HG	$\overline{x}$	HG
Control	Wood preservative A	3.304	BC	3.276	BC	2.988	C	3.506	AB
	Wood preservative B	2.624	DE	3.168	BC	3.718	A*	3.498	AB
Exposed	Wood preservative A	3.288	BC	3.200	BC	2.224	F	2.086	F
	Wood preservative B	2.940	CD	2.420	EF	2.130	F	2.624	DE
LSD ± 0.3319									

*: Highest adhesion strength value; $\overline{x}$: average value; HG: homogeneous group.

4. Discussion

In the current research, the long-term (5-year) performance of 2 varnish systems, SABBS and ABCV, was evaluated in preservative-treated Scots pine (*Pinus sylvestris* L.) sapwood. According to the results, the adhesion strength of SABBS- and ABCV-coated surfaces was reduced by 4.2% and 33.9%, respectively, due to outdoor exposure. The outdoor exposure has a significant effect on adhesion. Layer thickness and preservative type did not show any statistical reduction in adhesion properties.

According to the results, after 5 years of outdoor exposure the ABCV protective layer showed faster degradation than the SABBS coating (Figure 1). This can be explained by the pigmented nature of SABBS varnish systems. These pigments helped to absorb harmful UV radiation, which slowed the photochemical degradation of SABBS varnish layers (Figure 2). This result has been reported in the literature (Sell and Feist 1986; Williams et al. 1987; Carll and Feist 1989; Feist 1990; Feist 1994; Kropf et al. 1994; Hemel 2007).

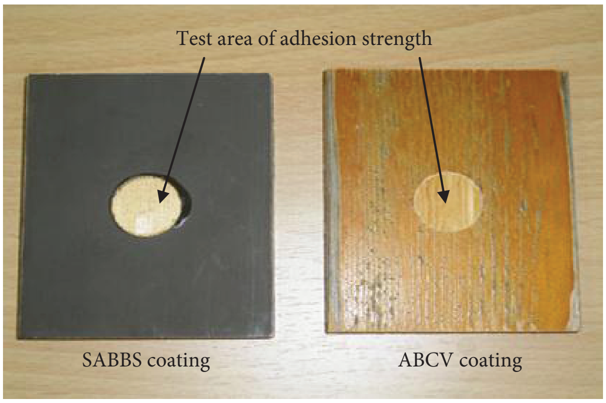

Figure 1. Degradation of coatings after 5 years of outdoor exposure.

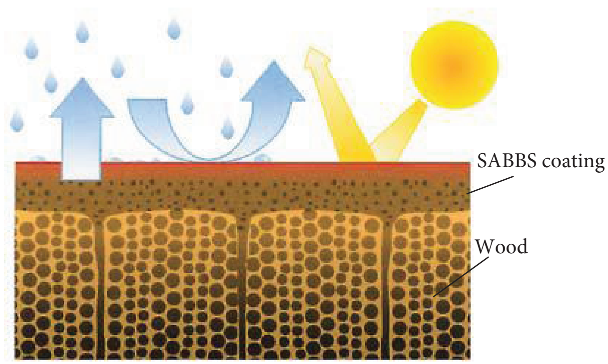

Figure 2. SABBS coating (Hemel 2007).

After 5 years of outdoor exposure, the single- and double-coat SABBS-applied surfaces did not show any blistering, peeling, or flaking (scaling) (Figure 3). This can be attributed to the better diffusion and adhesion properties of the SABBS system on lignocellulosic wood materials. This result has also been reported in the literature (Sönmez and Budakçı 1999).

The wood preservative chemicals used in this study did not have a detrimental effect on adhesion and long-term durability of the varnish systems used. The organic and water-based features of the wood preservative used may cause minimal interference in adhesion between protective varnish layers and the lignocellulosic wood texture. Oil-based diffusible wood preservatives caused a reduction in adhesion properties between treated wood surface and varnish and/or paint layers (Sönmez and Budakçı 2001). Varnish layer thickness did not exhibit any effects on adhesion properties. This is particularly important since it can reduce the raw material and labor required in finishing applications. The single-coat ABCV application, however, resulted in some failures on wood surfaces after 5 years of outdoor exposure, according to visual observations (Figure 4). Therefore, the authors recommend double-coat applications for treated wood if ABCV varnish is used outdoors.

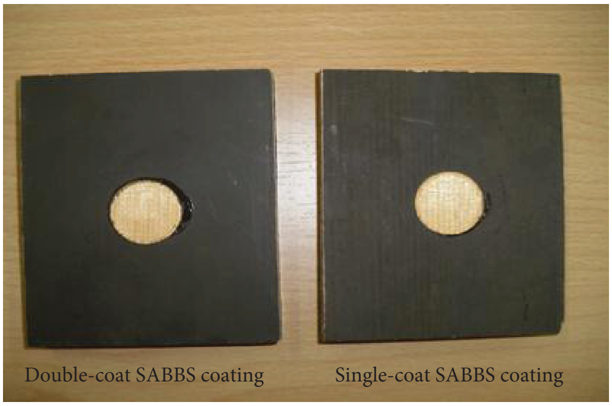

Figure 3. Double- and single-coat SABBS coatings.

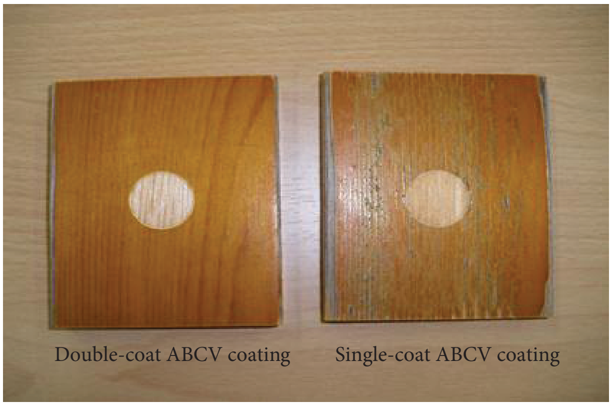

Figure 4. Double- and single-coat ABCV coatings.

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