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COATING SYSTEMS BASED ON ACRYLIC RESINS WITH UV ABSORBERS - DETERMINATION OF SOME PHYSICAL, CHEMICAL AND MECHANICAL PROPERTIES

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Abstract:
The adhesion strength of coatings depends on various factors including wood type, the application method of the coating on wood surface. The aim of this study is to determine the highest adhesion strength from among eight varnish systems based on acrylic resin using varnish viscosity, film thickness and SEM images. Oriental spruce (Picea orientalis L.) was used in the evaluation of the properties of adhesion strength. Spruce wood surfaces were coated with varnish using a brush. Film thickness and viscosity values demonstrated that varnishes with better penetration provided an improved adhesion, and better adhering varnishes had an increased level of cohesive failure in the coating. Differences in the adhesion strength of varnish systems were also observed on SEM images.

Key words: *adhesion strength; film thickness; varnish viscosity; scanning electron microscope (SEM); wood coating.*

INTRODUCTION

In wood-based production, the finishing processes are of great importance for the technical, economical and aesthetical evaluation of the wooden materials. Wood surfaces coated with varnishes are protected from certain adverse situations such as moisture, changes in dimensions and deterioration by microorganisms and fungi (Sonmez *et al.* 2009). However, the final quality of the finishing method is influenced by the wood's properties such as its porosity, chemical structure, and the interaction between the finishing and the wood surface (Ozdemir and Hiziroglu 2007). During water absorption by wooden materials, hydroxyl groups (OH) of cellulose and lignin hold water molecules until saturation. This phenomenon is important for varnish, which is cured by polymerization. Existing or subsequent moisture level plays a critical role in the success of the wood finishing processes. It is a fact that porosity, which is typically the void volume of wood ranging from 55-70%, depending on its specific gravity and moisture content, is one of the significant factors affecting the adhesion strength value of bonded samples (Zavarin 1984). Moreover, the wettability and capillarity of the surface influence an effective penetration of the coating. Penetration is a function of species and, its anatomical structure. For example, ratio between late wood and early wood is one of the most important parameters that affect the penetration of a coating (Kollmann et al. 1975).

In addition, a suitable level of roughness provides a greater actual surface available for adhesion mechanisms (Ozdemir and Mengeloglu 2009; Ozdemir *et al.* 2013).

The adhesion strength of a finishing is determined by using various methods, namely the axial pull-off tests, shear test with torque system, block shear test, and semi-quantitative cut or cross hatch test (Bardage and Bjurman 1998; Williams *et al.* 1990).

There are currently no significant studies, which use such methods about spruce samples coated with varnishes including different resins and UV absorbers. In this study, the axial pull-off test was used to determine the adhesion strength of samples coated with varnishes manufactured from eight different formulations. The effect of film thickness and coating penetration on the adhesion strength were also analysed with SEM micrographs.

EXPERIMENTAL PROCEDURE

Wood samples and coating systems

A total of 24 flat grained samples were cut from spruce with average densities of 0.42g/cm^3 (3 wood samples per each coating systems). These samples were planned to the dimensions of 150 (mm) x 100 (mm) x 20 (mm) and conditioned in a controlled room with a temperature of 20°C and a relative humidity of 65%. Prior to the application of the coatings, the specimens were also sanded with 120- and 180- grit sizes. A water-based impregnation agent, which had active ingredients of 1.20% propiconazol and 0.30% iodopropynyl butylcarbamat, was used as a primer for the protection of the samples against biological deterioration, including soft rot and blue stain. The primer was applied to the samples with a brush at a spread of 120g/m². Two types of absorbers were used: the UV screener TiO_2, as an inorganic UV absorber (UV2), and the UVA of the hydroxyphenyl-striazines class, as an organic UV absorber (UV1). Commercially produced finish, which had had two acrylic resin with different copolymer dispersions, was used in eight

different coating formulations. The BASF Company synthesizes these acrylic resins and UV absorbers. A small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate, a coalescing agent was added in the topcoat formulation to reduce the effect of other additives on the photo stabilization performance (Table 2). The oriental spruce (*Picea orientalis* L.) was used in this study. Two layers of topcoats were also applied to each sample with a brush at a spread rate of 100g/m², before applying the second layer of topcoat. After applying the coating, wood samples was dried a controlled room with a temperature of 20°C and a relative humidity of 65%.

Table 1

Two different acrylic resins and UV absorbers in formulations

Acrylic resin and UV absorber	BASF code
Acrylic Resin (A)	Acronal DS 6266
Acrylic Resin (B)	Acronal DS 6277
Organic UV Absorber	Tinuvin DW 400
Inorganic UV Absorber	Tinuvin DW 477

Table 2

The formulation of eight different coating systems

Coating systems	A*	B*	C*	D*	E*	F*	G*	K*
1	73.7	73.7	-	-	60.0	60.0	-	-
2	-	-	73.7	73.7	-	-	60.0	60.0
3	20.9	20.9	20.9	20.9	34.6	34.6	34.6	34.6
4	0.7	0.7	0.7	0.7	0.7	0.7	0.67	0.7
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
7	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
8	-	1.8	-	1.8	-	1.8	-	1.8
9	1.8	-	1.8	-	1.8	-	1.8	-

*percent by weight;1: Acrylic resin (A); 2: Acrylic resin (B); 3: Distilled water; 4: Coalescent; 5: Defoamer; 6: Thickener (A); 7: Thickener (B); 8: Organic UV absorber; 9: Inorganic UV absorber

Test methodology

The viscosity of the eight different coatings applied in this study was determined by using DIN cup/4mm/20 ^{0}C (ASTM D 1438, 1971). After applying the coating, dry coating thickness was determined by Erichsen P.I.G. 455 with a dry film thickness apparatus (ASTM D 4541, 1978). For each variation, 3 repetitions were made.

Pull-off methods were used to evaluate adhesion strength between the wood surface and the coating (Bulian and Graystone 2009). Two random measurements with a contact area of 20mm circles were taken from the side of three samples for each of the coating formulations. Erichsen Adhesion-525MC with a head glued to the surface of the samples was used for the tests. The equipment ran at a constant speed of 10cm/min and applied tension forces to the surface layer by pulling the coating from the surface. The adhesion strength value of the coating was the limiting value of the tension force applied, which was registered on the display screen of the equipment in N/mm^2. For each variation, 6 repetitions were made.

For SEM (Zeiss Evo LS10, Germany), test samples were oven-dried and coated with gold under the vacuum to increase conductivity (Emitech SC7620, France). The microscope was operated at 5kV. The coating layer on the wood surface was investigated by using SEM.

RESULTS AND DISCUSSION

Dry film thickness

In this study, the effects of dry film thickness and varnish viscosity on adhesion strength were investigated. A summary of the dry film thickness and varnish viscosity are presented in Table 3.

Table 3

The dry film thickness of coating applied to wood surfaces and the viscosity of coating formulations

Formulations	Dry Film Thickness (µm)	Viscosity (s)
A	60±2.4	98
B	57±1.8	90
C	55±1.4	30
D	58±1.7	33
E	68±2.0	145
F	60±2.2	40
G	62±2.1	138
K	63±2.5	45

According to the results of this study, there was a significant effect between the dry film thickness and varnish viscosity. Low viscosity varnish constituted low dry film thickness on the surface of the wood. Compared to high viscous varnishes, low viscous varnishes have higher penetration within the wood. (Ozdemir et al. 2013). The results obtained in Table 3 show different results from the literature. Although the viscosity is very low in K and F varnishes, the dry film thickness is very low. It is estimated that the anatomical structure of the spruce wood affects the penetration negatively. The aspiration of bordered pits in the anatomical structure of spruce wood can reduce varnish penetration (Yildiz et al. 2012).

Pull-off strength

Adhesion strengths of the coatings were determined by using pull-off tests. According to Fig. 1 and Table 3, the interaction of varnish viscosity and dry film thickness on the adhesion strength was found to be quite significant. The highest adhesion strength was obtained with low viscosity varnish (C, D and F), while the lowest was with high viscosity varnish (B, A and G).

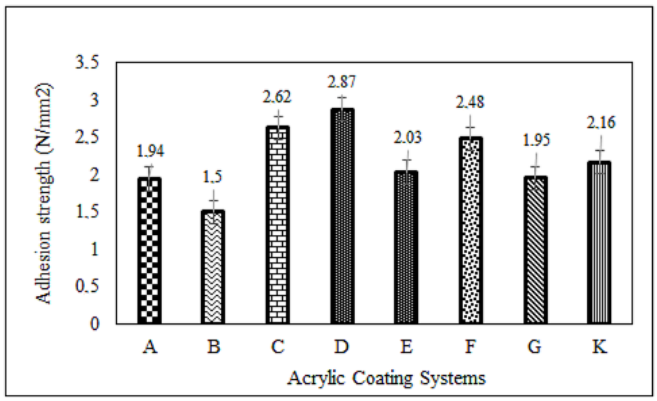

Fig. 1.
The average adhesion strength of coated spruce samples.

The varnish systems (D, K) containing organic UV absorber and acrylic resin (A) type have the lowest viscosities. The varnish D is also the highest adhesion strength. According to these results, it affects the adhesion strength as well as the viscosity value and the content of the varnish.

Scanning electron microscopy (SEM)

The layers of coating bonding the surface of the wood with high adhesion strength can be seen on SEM micrographs (Figs. 2, 3 and 4). SEM micrographs confirmed that the upper cells were often filled with coating. SEM analysis also demonstrated that surfaces, which could be penetrated in numerous ways, tended to have thinner films. The average film thickness was 58±1.7µm for (D) varnish, 55±1.4µm for (C) varnish and 60±2.2µm for (F) varnish.

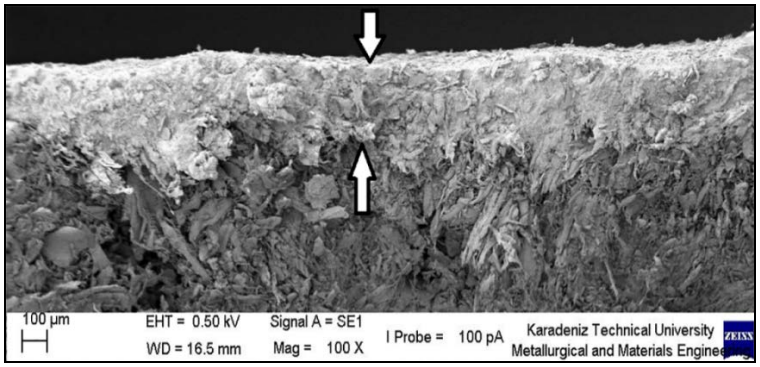

Fig. 2.
SEM micrographs of the dry film thickness of (C) varnish.

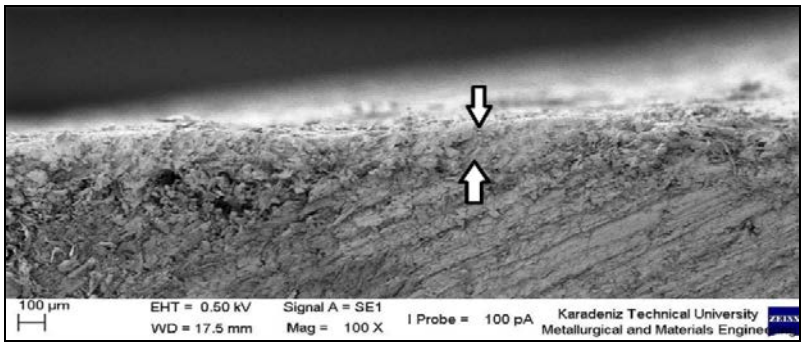

Fig. 3.
SEM micrographs of the dry film thickness of (D) varnish.

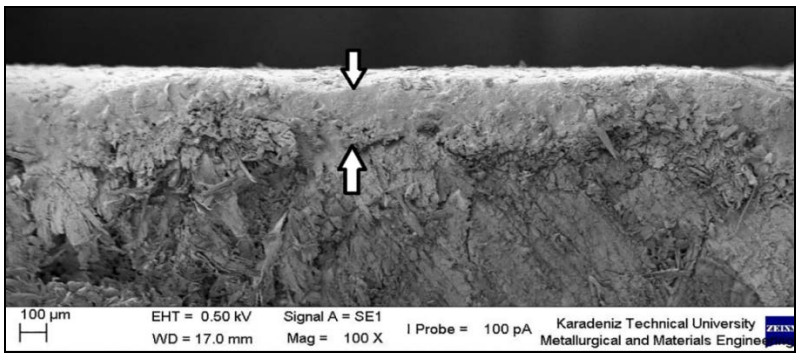

Fig. 4.
SEM micrographs of the dry film thickness of (F) varnish.

Adequate adhesion is a fundamental requirement for good coating performance and affects the properties of resistance and durability. An important factor, which affects adhesion, is the internal tension of the film derived from its volume contraction due to drying and curing. Loss of volatiles involves considerable shrinkage; moreover, the cross-linking mechanism of chemically drying coatings reduces the free volume, further increasing internal stress. Thick film can resist more stresses than thin films. In addition, viscosity is effectively the resistance of a liquid to deformation, by increasing the rate of deformation and adhesion strength (Bulian and Graystone 2009).

CONCLUSIONS

Based on the results of this experimental study, it can be concluded that both varnish viscosity and dry film thickness have significant effects on adhesion strength. Regarding the coating film, for which high adhesion strength is desired, the penetration of the coating into the wood's surface should be high. Improvement in adhesion strength between the coating film and surface of the wood was observed on the SEM micrographs. Particularly, the varnish-containing components influence adhesion resistance. The varnish type (D) with organic UV absorber and acrylic resin (A) has low viscosity and high adhesion strength. In addition, SEM images show that the D varnish is quite good for wood. In future studies, it is considered to investigate the development of D varnish type and its adherence to different tree species.

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