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Research Article

Adhesion Strength of Cellulosic Varnish Coated Wood Species as Function of Their Surface Roughness

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The objective of this study was to evaluate adhesion strength of four wood species, namely, beech (*Fagus orientalis* Lipsky), alder (*Alnus glutinosa* subsp. *barbata* Yalt.), spruce (*Picea orientalis* L. Link), and fir (*Abies nordmanniana* subsp.) coated with cellulosic varnish. Samples were prepared in tangential and radial grain orientations from the above species. Surface quality of the specimens was also measured employing stylus type equipment after samples of all four types of species were sanded with 80- and 180-grit sandpaper prior to coating process. Surface roughness of the specimens sanded with 80-grit sandpaper resulted in significantly higher mean peak-to-valley height (R_z) values based on the measurement employing stylus type profilometer. The highest adhesion strength values of 2.39 N/mm^2 and 2.03 N/mm^2 were found for beech and alder samples, respectively. It appears that overall higher roughness characteristics of the specimens exhibited enhanced adherence between substrate and varnish resulting in higher adhesion strength values.

1. Introduction

Hygroscopic characteristics of wood products play an important role in their effective utilization. Although there are many methods to enhance stability and appearance of wood, finishing is still considered as the most popular one among the others. Coating the surface of wood with different types of finishes will not only improve its appearance but also extend its service life. Final quality of coating applied to the surface of wood is influenced by various parameters; namely, species, roughness, porosity, density, and interaction between coating and the substrate [1–3]. Wood, being a nonhomogeneous material, sapwood, and heartwood ratio will also affect overall quality of coating [3].

Adhesive strength of coating on the surface can be evaluated with several techniques such as tape peel, observing the crosscut, and pull-off test. The last one was effectively employed to evaluate adhesion strength of wood and wood products coated with different finishes in previous studies [4–6]. The adhesion strength of stained, bleached, and preservative-treated wood specimens from oak and beech was evaluated in a past study [7]. It was found that bleaching had an adverse influence on adhesion strength of coated samples while stained samples had an average adhesion strength of 1.58 N/mm^2 [7]. Oak samples were coated with polyurethane base varnish and the effect of moisture content was also investigated in another study [8]. Various works have also been carried out to determine surface roughness of wood samples, in relation to their adhesion strength, coated with different finishes [8–11].

Another past study evaluated surface characteristics of radial and tangential grain orientations of three different hardwood species and concluded that rougher surfaces required higher amount of finishing material and overall quality of finishing was influenced by the surface roughness of the substrate [10]. Adhesion strength of oak and beech specimens coated with polyurethane varnishes was studied by Jaic and Zivanovic [4]. It was found that 10.3% moisture content of the samples resulted in the highest adhesion values for both species [8]. Burdurlu et al. compared adhesion strength of pine wood finished with polyurethane and sheen stain and found that polyurethane coating resulted in better

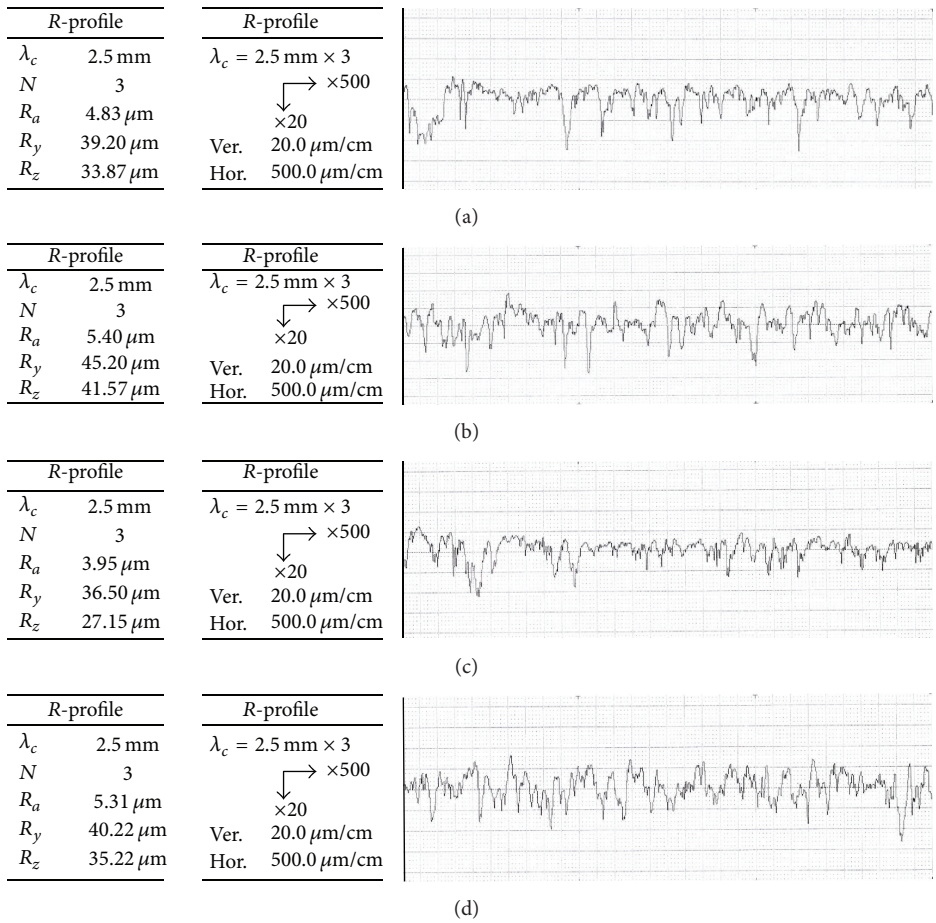


Figure 1: Typical roughness profiles of two species (from top to bottom; alder, 180-grit; alder, 80-grit; fir, 180-grit; fir, 80-grit).

strength values [8]. In general it is expected that rougher surface of the substrate results in better bonding ability of peak and valley points of the surface. As it is well known, surface roughness of the substrate will also influence the amount of finishing used controlling overall production cost. Therefore, subjective numerical information on the surface quality of the wood would provide valuable information so that not only amount of finishing chemical can be controlled but also final product can be manufactured with a better quality.

Almost all physical and mechanical properties of four species considered in this work were studied [12]. However, there is little or no information on how cellulose based varnishes adhere to their surfaces as function of their surface roughness. Therefore, it was the objective of this experimental study to evaluate adhesion strength of the samples from four species along with their surface roughness so that these species can be used with a better efficiency and higher quality to manufacture value-added products.

2. Experimental

2.1. Materials and Methods. A total of 240 defect-free, 60 for each species were prepared from beech (*Fagus orientalis* Lipsky), alder (*Alnus glutinosa* subsp. *barbata* Yalt.), spruce (*Picea orientalis* L. Link), and fir (*Abies nordmanniana* subsp.) for the experiments. Samples with dimensions of 400 mm by 100 mm by 200 mm were conditioned in a climate room having a relative humidity of 65% and a temperature of 20°C until they reach equilibrium moisture content of 12%. Conditioned specimens were sanded with 80-grit and 180-grit sandpaper using a commercial drum type sander. Although there are various roughness measurement techniques including pneumatic, laser, and light scattering methods to evaluate surface quality of wood and wood products, stylus type of profilometer is the most commonly used one due to its practicality and providing numerical result with an accuracy. Therefore, Mitutoyo SJ-301 profilometer was employed to measure roughness of the samples. Figure 1 illustrates typical roughness profiles of the samples sanded with 80- and 180-grit sandpapers.

Equipment has stylus with 0.5 μ radius and 90° contact angle running at a speed of 0.5 mm/s. A total of 25 random measurements with a span of 15 mm were taken from the surface of each radial and tangential sample across the grain orientation. Mean peak-to-valley height (R_z) which is well accepted roughness parameter was used as an indicator of the surface quality of the samples [13, 14].

Table 1: Roughness and adhesion strength test results.

Species grit size	Roughness value (R_z) (μm)				Adhesion strength (N/mm^2)			
	Tangential		Radial		Tangential		Radial	
	80	180	80	180	80	180	80	180
Beech (0.680 g/cm^3)	35.10 (3.82)*	29.85 (3.38)	34.39 (4.64)	32.85 (3.44)	2.42 (0.19)	2.36 (0.25)	2.18 (0.23)	2.13 (0.25)
Alder (0.520 g/cm^3)	37.66 (5.62)	33.69 (3.40)	35.81 (3.66)	30.81 (4.83)	2.15 (0.28)	1.92 (0.12)	2.01 (0.18)	1.96 (0.29)
Spruce (0.420 g/cm^3)	36.98 (3.98)	32.10 (8.61)	35.13 (4.33)	26.05 (3.03)	2.06 (0.40)	1.92 (0.25)	2.00 (0.22)	1.93 (0.16)
Fir (0.680 g/cm^3)	37.00 (4.39)	27.53 (6.68)	36.68 (4.42)	24.03 (3.69)	2.06 (0.32)	1.91 (0.29)	1.89 (0.15)	1.86 (0.18)

*Values in parentheses are standard deviations.

The specimens were coated with cellulosic varnish with 35% solid content having viscosity of 300 sec. DIN cup/4 mm and density of 0.95 g/cm^3 using a pressurized spray gun at a spread rate of 120 g/m^2. Coating was applied to the samples in two sequential steps, namely initial coating and the final coating. After the initial coating, samples were dried in room temperature and sanded with sandpaper having 220-grit sandpaper. In the next step, the final coating was applied and dried specimens were also sanded using aluminum oxide sandpaper with 400-grit sandpaper. Erichsen Adhesion-525 MC pull-off type tester was employed for adhesion strength evaluation of the specimens. Twenty random measurements were taken from the surface of the samples by gluing steel head with 20 mm diameter using epoxy resin on the samples. The equipment was run at a constant speed of 100 mm/min and applied the force to the surface layer by pulling the coating from the surface. Adhesion strength value of the finishing is recorded in N/mm^2 on the display of the pull-off testing unit. Figure 2 shows pull-off test setup used for the experiments. From each sample, 20 mm by 200 mm by 30 mm specimens were cut to measure their density. These small samples were weighed and their dimensions were measured at accuracy of 0.1 g and 0.01 mm, respectively. Variance analysis (ANOVA) and Duncan tests were used to analyze the test results.



Figure 2: Pull-off test setup used for the experiments.

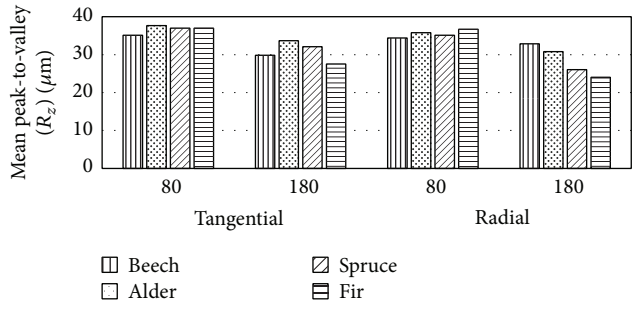


Figure 3: Mean peak-to-valley values of the samples.

3. Results and Discussion

Table 1 and Figure 3 show test results of the samples. The highest R_z value of 37.66 μm was found for alder samples sanded with 80-grit sandpaper in tangential direction followed by fir specimens sanded with the same grit size having the corresponding value of 37.00 μm. Once these samples were sanded with 180-grit sandpaper their average R_z values reduced ranging from 10.5% to 25.5%.

Both spruce and fir also resulted in similar R_z values to those of the other two species considered in this work. In a previous work, R_z value of beech control specimens was found to be 39.94 μm which is similar to the results in this work [10]. Spruce and fir species had smoother surface quality than those of beech and alder when they were sanded with higher grit size sandpaper. This could be related to low density of both softwood species. Based on the ANOVA analysis, no significant difference was found between R_z values determined from the tangential and radial surfaces for all four types of species as displayed in Table 2.

The highest adhesion strength value of 2.42 N/mm^2 was determined for beech samples sanded with 80-grit size sandpaper in tangential direction. Alder had 2.15 N/mm^2 for corresponding value as can be seen in Figure 4. Both spruce and fir resulted in 2.06 N/mm^2 and 2.05 N/mm^2 adhesion

Table 2: Statistical analysis of the roughness and adhesion strength test results.

Source	Sum of squares	df	Mean square	F value	Significance level
		Surface roughness			
Effect of species (A)	519.576	3	173.192	7.814	$***$
Effect of grain orientation (B)	313.361	1	313.361	14.137	$***$
Effect of sanding (C)	4197.226	1	4197.226	189.359	$***$
$A \times B$	340.698	3	113.566	5.124	$**$
$A \times C$	867.98	3	289.323	13.053	$***$
$B \times C$	35.058	1	35.058	1.582	NS
$A \times B \times C$	231.369	3	77.123	3.479	$*$
Error	8511.533	384	22.165		
Total	**446911.543**	**400**			
Source	Sum of squares	df	Mean square	F value	Significance level
		Adhesion strength			
Effect of species (A)	5.650	3	1.883	30.206	$***$
Effect of grain orientation (B)	0.896	1	0.896	14.367	$***$
Effect of sanding (C)	0.746	1	0.746	11.965	$***$
$A \times B$	0.520	3	0.173	2.783	$*$
$A \times C$	0.064	3	0.021	0.343	NS
$B \times C$	0.183	1	0.183	2.933	NS
$A \times B \times C$	0.081	3	0.027	0.431	NS
Error	18.953	304			
Total	**1374.395**	**320**			

NS: nonsignificant; *significant at the $\alpha = 0.05$ level; **significant at the 0.01 level; ***significant at the $\alpha = 0.001$ level.

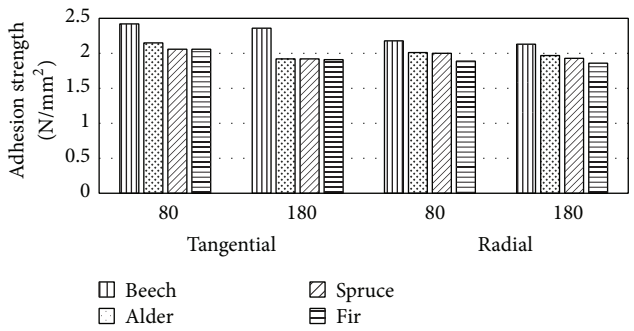


Figure 4: Adhesion strength values of the samples.

strength values when they were sanded with 80-grit size sandpaper. It is a well-known fact that anatomical structure is one of the major parameters influencing overall interaction between coating and substrate. Both alder and beech being semiporous structure would result in better absorption of the varnish causing higher magnitude of interaction between the two elements.

No significant difference was found between adhesion strength values of two softwood species based on ANOVA and Duncan test as displayed in Tables 2 and 3. Even though they were sanded with finer sand paper, their strength values did not go down in contrast to alder and beech. It seems that varnish had deeper penetration due to more porous structure than that of spruce and fir samples as mentioned above. In another study, ash which is also porous species had enhanced adhesion strength characteristics as it is sanded with coarse sand paper.

4. Conclusions

In this study, adhesion strength of cellulosic varnish coated wood samples was determined as function of their surface roughness. Based on the findings in this work, it seems that adhesion strength of the samples improved when they were sanded with higher-grit sandpaper with increasing their surface roughness characteristics evaluated using a stylus type of equipment. Tangential and radial grain orientations of the specimens did not make any significant differences in their roughness and adhesion strength values. Anatomical structure of the species would be considered one of the factors influencing roughness as well as development of bonding between coating and the samples. Softwood species having lower density levels resulted in smoother surface when they were sanded with rougher sandpaper. Preliminary data determined in this experimental work could possibly be used as quality control tool to improve overall finishing application of the members manufactured from these four species. In further studies, it would be desirable to investigate wettability of the varnished samples to have a better understanding of

Table 3: Duncan test results of the samples.

Strength properties	Factors	LS mean	Homogenous groups*
Surface roughness	Wood species		
	Beech	33.053	b
	Alder	34.498	a
	Spruce	32.571	bc
	Fir	31.313	c
	Grain orientation		
	Tangential	33.744	a
	Radial	31.974	b
	Grit size		
	80	36.099	a
	180	29.620	b
Adhesion strength	Species		
	Beech	2.277	a
	Alder	2.012	b
	Spruce	1.981	b
	Fir	1.936	b
	Grain orientation		
	Tangential	2.105	a
	Radial	1.999	b
	Grit size		
	80	2.100	a
	180	2.004	b

*Different letters indicate statistically significant difference between the groups.

their behavior along with exposure to different conditions having fluctuating relative humidity levels.

Conflict of Interests

The authors declare no conflict of interests.

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