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Research Article

Adhesion Strength of Wood Based Composites Coated with Cellulosic and Polyurethane Paints

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The objective of this study was to determine adhesive strength of particleboard and medium density fiberboard (MDF) finished with two types of paints. Samples were coated using cellulosic and polyurethane based paints. Adhesion strength and coating layer thickness of each sample were measured using pull-off testing method and PosiTector equipment, respectively. The highest adhesion strength value of 3.62 MPa was found for MDF samples coated with paint. Based on the statistical analysis type of substrate significantly influenced overall adhesion strength of the samples while type and layer thickness of paint as well as number of layers applied to the surface of specimens have not affected significantly adhesion resistance of the panels used in this work. It appears that pull-off test can effectively be used to determine and evaluate adhesion strength of the samples considered in the experiments.

1. Introduction

Wood composites such as particleboard and fiberboard, primarily medium density fiberboard (MDF), are prime products as substrate for thin overlays and direct finishing to be used in furniture and cabinet production. Their surface quality and type of the finishing material are two important parameters influencing overall quality of the final product. It is a well-known fact that hygroscopic characteristic of wood composite panels plays an important role in development of a good bonding between substrate and coating in a typical finishing process.

Although there are several major methods to enhance stability and appearance of wood composites finishing of such panels using varnishes, stains, and painting is still considered as the most popular one among the others. It is a fact that coating the surface of wood composites with different types of finishes will not only improve its appearance but also extend its service life. Unless there is a sufficient amount of adhesive strength of coating on the surface, service life of the finishing will not be very long and would result in a deterioration. Therefore it is important to evaluate such adhesive strength on the panels employing several techniques such as tape peeling, observing the cross cut, and pull-off test. The last one was effectively employed to evaluate adhesion strength of wood samples coated with different finishes in previous studies [1–7]. The adhesion strength of stained, bleached, and preservatively treated wood specimens from pine, chestnut, and beech was evaluated in a past study [5]. 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 [5]. In any kind of surface treatment of wood and wood based products, adhesion resistance is one of the major factors influencing the overall finishing quality and its effective service life. The finishing type and surface properties of the material where the surface treatment is applied as well as the number of layers used and layer thickness can also be considered as main parameters for a good finishing of the panels. Although there are various national and international standards of surface treatments in the form of finishing and their characteristics, evaluation of the coating characteristics including adherence between two members still remains at subjective perspective [8–10]. Therefore, in the majority of the applications, the surface treatments would cause an increase in the production costs and prevent achieving the desired surface performance

values due to lack of detailed information in this area [11–13]. As mentioned above although various methods have been developed to determine adhesion strength of wood composites pull-off test still keeps its popularity due to its practicality and precision. Adhesion mechanisms between the wood and wood composite panels and protective layers have been examined in several past studies [14–18]. Oak samples were coated with polyurethane base varnish which was investigated as a function of moisture content in previous study [19]. Various works have also been carried out to determine surface roughness of wood samples in relation to adhesion strength coated wood samples with different types of finishes [20].

Richter et al. concluded that rougher surface characteristics of radial and tangential grain orientations of three different hardwood species required higher amount of finishing material and overall quality of finishing was influenced by the surface roughness of the substrate [20]. In general it is expected that rougher surface of the substrate results in better bonding ability of peak and valley points of the surface. Therefore a typical particleboard would result in better adhesion strength than that of MDF. Also subjective numerical information on the surface quality of the wood composites would provide valuable information so that not only can amount of finishing chemical be controlled but also final product can be manufactured with a better quality. There are numerous studies carried out on surface quality specifically surface roughness and overlaying characteristics of both commercially and laboratory produced particleboard and MDF [7–9, 20]. However there is very little or no information on how cellulose and polyurethane based finishing materials would adhere to wood composite substrates as a function of coating thickness and panel type. Therefore it was the objective of this experimental study to evaluate adhesion strength of the particleboard and MDF coated with two types of paints. Such finished panel products can be used with a better efficiency in the form of higher quality value-added products [5, 9].

Table 1: Specifications of the finishing materials used for the experiments.

Paint type	Density (g/cm^3)	Solid content (%)	Viscosity (DIN6. sn)
Cellulosic base			
Primer coating	1.30	58	60
Top coat	0.98	44	130
Polyurethane base			
Primer coating	1.42	77	115
Top coat	1.18	50	290

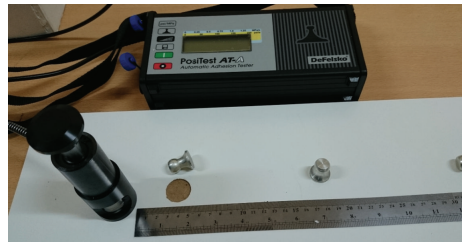

Figure 1: Adhesion resistance test setup used for the experiments.

Figure 2: Coating thickness measurement equipment.

2. Materials and Methods

Commercially manufactured particleboard and MDF panels were supplied by a local manufacturer. A total of 36 samples were cut into 1000 mm by 200 mm size having a thickness of 18 mm. Density levels of particleboard and MDF samples were measured using randomly cut specimens with 50 mm by 50 mm squares. Each sample was weighed and its dimensions were measured at an accuracy level of 0.1 g and 0.01 mm, respectively. Average density of particleboard was determined as 0.56 g/cm^3 while this value was 0.68 g/cm^3 for MDF samples. Table 1 displays specifications of commercially manufactured interior solvent-based cellulosic and polyurethane paints used as finishing materials. Samples were conditioned in a climate room having a temperature of 20°C and relative humidity of 65% until they reach a moisture content of 10% before they were coated with two types of finishes. Samples were coated employing a spray gun using a pressure of 0.80 MPa at a spread rate of 120 g/m^2. Sequential application of primer and top coat of the finishes was applied to the surface of each of the panels with an angle of 90 degrees. After each application the layer thicknesses of the coats were measured with PosiTector Probe 200. In the next step samples were conditioned for a week before adhesion strength tests were carried out using PosiTest AT-A Automatic Adhesion Tester based on ASTM D 4541, EN ISO 4624 standards [13, 21–23]. Table 2 displays sampling schedule. Minitab 16 software program and multiple variance analysis "ANOVA" test have been used for the statistical assessments of the results. The data was considered at the level of $\alpha = 0.05$ for determining the effect and significance levels of the factors examined. For the cases where the factor effects were significant with an error margin (Table 5), dual comparisons have been performed employing Tukey's test [14]. Figures 1 and 2 illustrate adhesion tester equipment and layer thickness measuring setup, respectively.

Table 2: Sampling schedule.

Panel type	Finish type	Number of samples	Finishing process
MDF	Cellulosic paint	3	Application 1 (primer + primer + top coat)
		3	Application 2 (primer + primer + top coat + top coat)
		3	Application 3 (primer + primer + top coat + top coat + top coat)
	Polyurethane paint	3	Application 1 (primer + primer + top coat)
		3	Application 2 (primer + primer + top coat + top coat)
		3	Application 3 (primer + primer + top coat + top coat + top coat)
Particleboard	Cellulosic paint	3	Application 1 (primer + primer + top coat)
		3	Application 2 (primer + primer + top coat + top coat)
		3	Application 3 (primer + primer + top coat + top coat + top coat)
	Polyurethane paint	3	Application 1 (primer + primer + top coat)
		3	Application 2 (primer + primer + top coat + top coat)
		3	Application 3 (primer + primer + top coat + top coat + top coat)

Table 3: Average coating thickness and adhesion strength values of the samples.

Panel type	Finish type	Application type	Average coating thickness (μ)	Average adhesion strength (MPa)
MDF	Cellulosic base	1	**179 (5.57)**	**3.62 (0.36)**
		2	**181 (11.68)**	**2.86 (0.15)**
		3	**236 (5.51)**	**2.78 (0.19)**
	Polyurethane base	1	**167 (2.08)**	**2.95 (0.31)**
		2	**239 (13.32)**	**2.37 (0.11)**
		3	**345 (8.33)**	**3.58 (0.21)**
Particleboard	Cellulosic base	1	**249 (13.89)**	**0.83 (0.04)**
		2	**322 (19.08)**	**1.54 (0.07)**
		3	**334 (6.81)**	**0.96 (0.13)**
	Polyurethane base	1	**199 (10.54)**	**0.85 (0.10)**
		2	**295 (3.06)**	**1.16 (0.09)**
		3	**363 (9.02)**	**0.97 (0.21)**

(Numbers in parenthesis are standard deviations values.)

3. Results and Discussion

Table 3 displays average adhesion strength and coating thickness of the samples finished with cellulosic and polyurethane based paints. The highest adhesion strength value of 3.62 (0.36) MPa was determined for MDF samples finished with application of cellulosic paint having two primers and one top coat. Particleboard specimens finished with the same type of paint having two primers and three top coats had the lowest adhesion strength value of 0.97 (0.21) MPa. Overall particleboard samples resulted in lower adhesion strength values in all applications as well as using two types of paint than those of MDF specimens as can be observed in Table 3. Statistically significant differences were found between adhesion values of two different panels products in all cases. In a previous study adhesion strength of MDF samples coated with polyurethane varnished before and after exposure to 85% relative humidity level resulted in similar values to those found in this work [7]. Once MDF samples were exposed to high humidity their surface quality became rougher and acted as a kind of barrier between coat and substrate reducing their adhesion strength characteristics [7, 24]. Although in this study no humidity exposure of the samples was used particleboard samples having relatively rougher surfaces as compared to that of MDF had lower interaction between the substrate and coatings without regarding any kind of finishing application processes employed in the experiments. Consequently such samples resulted in lower adhesion strength values. In both types of finishes statistical analysis also revealed that there was no significant effect of paint type and application process along the coating thickness on adhesion strength values of the specimens as can be seen in Table 4. It is clear that thickness of the finishes increased with increasing number of coats. For example, average finishing thickness of MDF specimens coated using application number 1 was 173 microns while corresponding value of finish in the case of particleboard samples was 224 microns. Higher thickness of finish in the case of particleboard samples can again be related to their rougher surface quality acting as a barrier to development of densified smooth coating on the substrate. As number of coatings increased similar trends were also determined in both types of finishing materials. Figure 3 also shows weak

Table 4: The analysis of variance for adhesion strength of the samples.

Source	DF	SS	MS	F value	P value
Panel type	1	35.3628	35.3628	370.84	0.000
Finishing type	1	0.1369	0.1369	1.44	0.242
Application type	2	0.0624	0.0312	0.33	0.724
Panel type ∗ paint type	1	0.0009	0.0009	0.01	0.923
Panel type ∗ application type	2	2.3954	1.1977	12.56	0.000
Finishing type ∗ application type	2	1.2465	0.6232	6.54	0.005
Error	26	2.4793	0.0954		
Lack-of-fit	2	0.8701	0.4350	6.49	0.006
Pure error	24	1.6093	0.0671		
Total	35	41.6842			

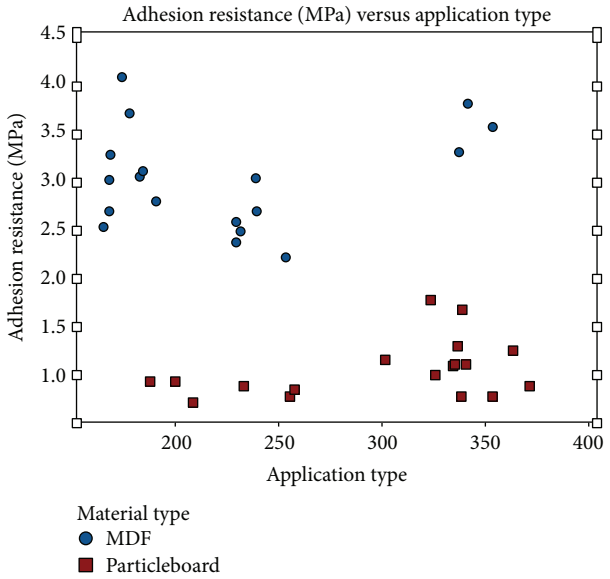

Figure 3: Relationship between layer thickness and adhesion resistance of two types of panels.

Table 5: Grouping analysis based on Tukey's test of adhesion resistance of the samples as a function of types of panel, paints, and applications.

	N	Mean	Grouping
Panel type			
MDF	18	3.033	A
Particleboard	18	1.051	B
Paint type			
Cellulosic	18	2.103	A
Polyurethane	18	1.980	A
Application type			
1	12	2.071	A
2	12	1.983	A
3	12	2.071	A

relationship between adhesion strength and layer thickness of the coats.

In the study, the material type, paint type, and application type, the factors whose effects on the adhesion resistance are examined, are evaluated by applying multiple variance analysis (ANOVA). In this analysis, the variable model explanation level is found as 94% (R-sq). The effect factors examined are evaluated separately with and without interaction.

4. Conclusions

Adhesion strength of MDF and particleboard coated with interior type of cellulosic and polyurethane finishes was tested in this work. Having densified and smooth surface of MDF specimens resulted in enhanced adhesion strength characteristics between finishing materials and substrate as compared to that of particleboard samples. In most cases lower average coating thickness resulted in relatively acceptable adhesion strength values in both particleboard and MDF samples. None of the failures took place in the fibers or particles on the panels. Preliminary data from this work would help to determine optimum amount of adhesion as a function of finish layer thickness for an effective finishing process to reduce overall production cost. In further studies determination of adhesion strength of such samples exposed to different relative humidity levels would give a better understanding of finished panel products during their service life under environmental conditions.

Conflict of Interests

The authors declare that there is no conflict of interests.

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