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Manufacturing of Kapur Wood (Dryobalanops spp.) Particle Board and Its UV-Radiation Curing of Surface Coatings

Pembuatan Papan Partikel Kayu Kapur (*Dryobalanops* spp.) dan Pelapisan Permukaannya dengan Pemadatan Menggunakan Radiasi-UV

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ABSTRAK

Pembuatan Papan Partikel Kayu Kapur (*Dryobalanops* spp.) dan Pelapisan Permukaannya dengan Pemadatan Menggunakan Radiasi-UV. Penelitian pembuatan komposit papan partikel kayu kapur (*Dryobalanops* spp.) dilakukan menggunakan bahan perekat campuran residu minyak cengkih dan tanin setelah dicampur senyawa fenol dan formaldehida. Pembuatan papan partikel dilakukan dengan pencetakan melalui penekanan dan pemanasan. Papan partikel yang diukur berdasarkan SNI 01-2105-1991 mempunyai sifat fisik yaitu, densitas, kandungan air, pengembangan tebal memenuhi standar sedangkan sifat mekaniknya, yaitu keteguhan lentur, keteguhan patah, keteguhan rekat internal, kuat pegang sekrup tidak memenuhi standar. Lapisan poliester hasil iradiasi UV pada permukaan papan partikel mempunyai kekerasan pensil 2B-2H, kilap menengah (36 – 58 %), adesi memenuhi ASTM D 2571-71, dan pola kerusakan terjadi pada bagian papan partikel. Pada umumnya lapisan poliester tidak tahan terhadap larutan natrium hidroksida 10 %.

Kata kunci : papan partikel, pelapisan permukaan, radiasi-UV

ABSTRACT

Manufacturing of Kapur Wood (*Dryobalanops* spp.) Particle Board and Its UV-Radiation Curing of Surface Coatings. Research on manufacturing the kapur (*Dryobalanops* spp.) particle board has been conducted using the mixture of clover leaf oil by products and tannin after being mixed with phenol and formaldehyde as adhesives. Particle board was prepared by molding process while pressing and heating. Particle board measured by using SNI 01-2105-1991 have physical properties i.e. density, water content, thickness swelling meet the standard whereas the mechanical properties i.e. modulus of elasticity, modulus of rupture, internal bond strength, and screw holding strength do not meet the standard. Ultra-violet cured polyester coatings on particle board have pencil hardness of 2B – 2H, medium gloss (36 – 58 %), adhesion meet ASTM D 2571-71, and most failure patterns occur on particle board part. In general, polyester coats do not resist against 10 % sodium hydroxide solution.

Key words : particle board, surface coating, UV-radiation

INTRODUCTION

Particle board is a panel manufactured from lignocellulosic materials (usually wood) combined with a synthetic resin or other suitable binder/adhesive and bonded together under heat and pressure [1]. Considering the fact that the raw materials

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especially in natural resouces sector is limited, the wood-working industry has made several efforts to ensure the sustainability of raw materials. Therefore, for providing wooden raw materials, special attention should be paid to wood wastes/residues from wood-working industries and agricultural residues, because the particle board industry is able to use and consume a wide range of wooden and non-wooden lignocellulosic wastes/residues. Wood wastes in the form of saw dust produced by other wood industries can be used as an alternative raw material for production of particle board [2].

In general, adhesive for particle board is made by using synthetic resins, such as urea formaldehyde, melamine formaldehyde and phenol formaldehyde. Those chemicals are derived from fuel oil and nonrenewable resources. Instead of synthetic resins, adhesive can also be prepared from natural resources which more environmental friendly and renewable. Tannin as one of the natural resin has been developed as an adhesive for manufacturing the particle board. For example, a blend of hydrolyzed tannin and cashew nut shell liquid has been found to posses better dimensional stability, whereas a blend of hydrolyzed tannin with urea formaldehyde resin can be used to reduce the formaldehyde emission level significantly [3]. The wheat straw panels produced from tannin-modified phenol-formaldehyde adhesive met the modulus of rupture, modulus of elasticity, internal bond strength and thickness swelling requirement for general uses according to European standards [4]. The condensed tannins are both chemically and economically interesting for the preparation of adhesive of particle board [5].

Most of the final products made from particle board (furniture, audio-visual goods and building materials) need surface coating process to protect the product surface from defects and to enhance its performance. In conventional process, curing of coating is performed by addition of catalyst and can be speed up by heating. In addition, curing of surface coating can be carried out using ultra-violet (UV) radiation. UV-curable coatings do not need solvents and it can be cured instantaneously (fast curing) without heating and addition of catalyst. Therefore, the UV-curing process is more friendly to the environment than conventional coatings. One of the radiation curable materials is polyester resin. Polyester resin is widely used for filler, sealer and top coating of wood [6,7]. This kind of resin is available locally, low cost and after being cured provides hard and transparent materials, but need high radiation exposure.

Kapur wood (*Dryobalanops* spp.) is widely used for furniture, column, shipbuildings, ribs and boards in house and bridge construction [8]. The wood wastes are abandon in the form of flakes, chips or saw dust as a residue from wood-working industries. This paper describes the manufacturing particle board made of kapur wood saw dust with the clover leaf oil residue and tannin formulation was used as adhesive. The particle boards were then coated with pigmented polyester resin using UV-curing technique. The objective of the research is to investigate the physical and mechanical properties of all manufactured particle board and the properties of polyester-coated particle board using UV curing.

MATERIALS AND METHOD

Materials. Kapur wood saw dust was obtained from PT Marem, Kebayoran Lama, Jakarta Selatan. Eugenol and isoeugenol residues from the clover leaf oil production were received from PT Djasula Wangi, Cileungsi, Bogor. Tannin formulation was received from Forest Products Research and Development Center, Bogor. Unsaturated polyester resin was produced by Justus Sakti Raya Corporation, Tangerang, whereas titanium dioxide (rutile type) in the polyester dispersion was used as pigment. Photoinitiator of 2,2-dimethyl-2-hydroxy acetophenone was purchased from Merck, Germany.

Equipments. Equipments used were sieve (20 mesh and 40 mesh), mats (27 cm x 27 cm x 2 cm) and press machine from Toyoseiki, Japan. Irradiation was conducted using one 10.4 kW UV lamp with intensity of 80 Watt/cm medium pressure lamp from IST Strahlentecknik GmbH, Germany.

Method. Saw dust was sun dried to get moisture content of 3 - 4 %. Adhesives used were the tannin formulation (after being added with phenol and formaldehyde) and the mixture of tannin formulation (TF) and clover leaf oil residue formulation (CLORF). CLORF is the mixture of eugenol and isoeugenol residues with the weight ratio of 1 : 1. Dried saw dust was mixed with adhesive (16 % b.w), blended manually, and then pressed at 40, 50 and 60 kgf/cm^2 and pressure temperature of 160^o C for 30 min. Physical properties (density, water content, thickness swelling) and mechanical properties i.e., modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB) and screw holding strength (SH) of particle board were measured according to Indonesian National Standard (SNI) [9]. The mechanical properties were measured using Universal Testing Machine (Instron). Based coating formulation was resin polyester after being mixed with photoinitiator at the concentration of 3 % b.w. Coating was conducted using roll coater, and then irradiated with UV at conveyor speed of 2 m/min. Top coating was performed using the mixture of polyester resin, pigment and photoinitiator. Properties of coating on particle board tested such as hardness, gloss, color value, adhesion, and chemical and solvent resistance were analyzed. Pendulum hardness was measured with a Koenig method using Pendulum Hardness Rocker from Sheen Instruments, Ltd., (United Kingdom). The 60^0 geometry specular gloss was determined using glossmeter from Toyoseiki, Japan. Evaluation of color was performed with Hunter Method using Chromameter CR 2006, Minolta, Japan. Adhesion between coating and wood substrates was carried out with a pull-off test using Elcometer Model 106 Adhesion tester. Instead of pull-off test, adhesion measurement was also conducted with a cross-cut method. Chemical and solvent resistance were performed with sulfuric acid, sodium carbonate, sodium hydroxide, acetic acid, ethanol, and thinner, using spot test method.

RESULTS AND DISCUSSION

Physical and Mechanical Properties of Particle Board

The moderate value (1.104 cp) of TF adhesive can be easily blended with saw dust. On the other hand, CLORF adhesive was very high-viscous liquid. In this case, blending should be done as homogenize as possible.

Table 1 shows the physical properties of particle board at various saw dust – adhesive ratio and pressure. For all pressures and saw dust – adhesive ratio, all samples follow the standard, except for 24-h immersion thickness swelling. Twenty-four hour immersion resulted in thickness swelling of 21 – 22 % (SNI $\leq$ 20 %). XIANGQUAN [10] reported that the thickness swelling can be reduced by increasing the time and temperature of post-heat treatment. The higher the pressure, the more dense the particle board resulted in the higher density. It was found that the density was in the range of 0.68 – 0.71 g/cm^3. According to SNI, the density of particle board is 0.5 – 0.9 g/cm^3. Density is affected by the operating condition, such as cold and hot press pressures, pressing time and moisture content of the raw materials which affected the properties of the particle board produced [11]. There was also a close relation between density and water content. The higher the density, the more dense the particle board, and as a consequences, the pores became smaller. Thus, water penetration can not easily enter the pores resulted in lower water content.

Table 1. Physical properties of particle board with the ratio of tannin/phenol/ formaldehyde as adhesive was 100/27/27. Temperature = 140°C

Saw dust/adhesive ratio	Pressure (kgf/cm^2)	Density (g/cm^3)	Water content (%)	Thickness swelling (%)	
				2 h	24 h
80/20	40	0.68	9.0	12	21
75/25	40	0.70	8.9	12	22
75/25	50	0.70	8.7	11	21
75/25	60	0.71	8.3	11	21

SNI 01-2105-1991 : Density = 0.5 – 0.9 g/cm^3; Water content: $\leq$ 14 %
Thickness swelling: < 14 % (2 h); 20 % (24 h)

The water content of samples were in the range of 8.3 – 9.0 %. The similar trend appeared for the thickness swelling property which correlated to the dimensional stability. Increasing the thickness swelling resulted in the lower dimensional stability.

Mechanical properties of particle board using TF adhesive were tabulated in Table 2. All of the mechanical properties did not follow the standard. For example, the standard while almost all of the thickness swelling properties did not meet the SNI value (Table 3). Increasing the concentration of wood particle/TF in the mixture with wood particle/ CLORF (A/B ratio) resulted in increases of MOE, MOR and SH. Its clearly that the use of TF was better than that of CLORF as adhesive.

Mechanical properties of particle board using TF – CLORF mixture adhesive

Table 2. Mechanical properties of particle board with the ratio of tannin/phenol/ formal- dehyde as adhesive was 100/27/27. Pressing time = 30 min; Temperature = 140 °C

Adhesive concentration (%)	Pressure (kgf/cm^2)	MOE (kgf/cm^2)	MOR (kgf/cm^2)	IB (kgf/cm^2)	SH (kgf/cm^2)
20	40	37.8	34.8	0.3	15.9
25	40	98.9	36.2	2.1	18.8
25	50	79.3	26.5	2.2	14.1
25	60	54.5	30.7	3.4	24.8

SNI 01-2105-1991 : MOE $\geq$ 10.000 kgf/cm^2 ; MOR $\geq$ 100 kgf/cm^2
IB $\geq$ 6 kgf/cm^2 ; SH $\geq$ 30 kgf/cm^2

maximum MOR and SH were 36.2 and 24.8 kgf/cm^2 respectively. Those values were still lower than SNI (MOR $\geq$ 100 kgf/cm^2; SH $\geq$ 30 kgf/cm^2). The lower values can be caused by several factors, such as : the improper of operating condition selection (pressure, temperature, pressing time) or the improper of adhesive component ratio.

Physical properties of particle board (density and moisture content) with the use of TF – CLORF mixture adhesive had met can be seen in Table 4. The table shows that only the use of ratio of A/B of 25/75 provide IB (9.4 kgf/cm^2) follows the standard while MOE, MOR and SH were out of standard. As stated in the discussion of the physical properties of particle board using TF adhesive (Table 3), the similar result was observed for the mechanical properties. It was found that TF gave better mechanical properties than that of CLORF. Based on the physical and mechanical properties data, A/B ratio of 25/75 was to be taken as the optimum composition. Particle boards manufactured at optimum composition have MOE of 54.3 kgf/cm^2, MOR 20.2 kgf/cm^2, IB 9.4 kgf/cm^2 and SH 18.6 kgf/cm^2.

radiation curable materials tend to form smoothless and waved surface resulted in low performance of coated particleboard. Many factors, such as particle size, particle-adhesive ratio, adhesive composition,

Table 3. Physical properties of particle board with the adhesive of TF and CLORF mixture. A : wood particle/TF (3 : 1); B : wood particle/ CLORF (5 : 1); CLORF/TF = 1/1; Pressure = 60 kgf/cm^2; Temperature = 140 °C; Time = 30 min.

Ratio A/B	Density (g/cm^3)	Water content (%)	Thickness swelling (%)	
			2 h	24 h
0/100	0.80	6.7	64.0	77.8
25/75	0.81	9.0	32.3	47.0
50/50	0.83	7.2	27.5	37.5
75/25	0.74	8.4	17.6	23.5
100/0	0.71	8.3	11.0	21.0

SNI 01-2105-1991: Density = 0.5 – 0.9 g/cm^3; Water content: $\leq$ 14 %
Thickness swelling: < 14 % (2 h); 20 % (24 h)

Table 4. Mechanical properties of particle board with adhesive of TF - CLORF mixture. A = wood particle/TF (3 :1); B = wood particle/CLORF (5 : 1); CLORF/TF = 1/1; Pressure = 60 kgf/cm^2; Temperature = 140 °C;Time = 30 min

Ratio A/B	MOE (kgf/cm^2)	MOR (kgf/cm^2)	IB (kgf/cm^2)	SH (kgf/cm^2)
0/100	11.4	5.5	3.0	7.0
25/75	50.7	16.2	9.4	18.6
50/50	23.7	14.4	5.1	15.3
75/25	29.2	18.9	1.6	17.6
100/0	54.3	20.2	2.0	16.5

SNI 01-2105-1991 : MOE $\geq$ 10.000 kgf/cm^2 ; MOR $\geq$ 100 kgf/cm^2
IB $\geq$ 6 kgf/cm^2 ; SH $\geq$ 30 kgf/cm^2

Coating Formulation

Density and viscosity of polyester formulation were tabulated in Table 5. Addition of pigment should be limited due to the absorption of UV light by pigment resulted in slower curing process [12]. The use of photoinitiator of up to 4 % b.w seem to have no influence on the density but the viscosity is increased. Two percent of photoinitiator could produce smoother film appearance than that the use of 3 or 4 % b.w of photoinitiator. High viscosity

pressure and temperature play an important role for the all properties of particle board produced. Therefore, the combination of the treatment should be developed to get the better results.

Cured Coating Properties

Pencil hardness and pendulum hardness of polyester cured coatings can be seen in Table 6. Combine treatment of 2 % b.w of photoinisiator and conveyor speed of 3 and 4 m/min gave soft and tacky surface,

Table 5. Density and viscosity of polyester coating.

Pigment concentration (%)	Photoinitiator concentration (%)	Density (g/cm^3)	Viscosity, 25ºC (cp)
0	0	0.99	1.10
	3	1.00	1.20
2	2	1.02	1.25
	3	1.02	1.80
	4	1.03	1.89

Table 6. Hardness of polyester coatings. Pigment concentration = 2 % b.w. Photoinitiator : 2-hydroxy-2-ethyl-1-phenyl propanone.

Photoinitiator concentration (%)	Conveyor speed (m/min)	Pencil hardness	Pendulum hardness[a] (s)
2	1	H	66
	2	HB	44
	3	*	*
	4	*	*
3	1	H-2H	78
	2	HB	36
	3	2B	23
	4	*	*
4	1	2H	79
	2	HB	46
	3	F	20
	4	2B	17

*soft/tacky
[a] ISO 1522-1973(E)

therefore the testing of sample can not be done. The higher the conveyor speed, the lesser the UV-radiation absorbed by coating materials, resulted in insufficient of cross-linked polymer produced for curing process. Therefore, the film still tacky and wet even after irradiation. Similar results were also observed for the effect of photoinitiator. Lower photoinitiator concentration causes of lesser radical formed, thereby cross-linked polymer production becomes insufficient for curing process. On the other hand, too high photoinitiator concentration produces an excess of radicals as compared to reactive sites. Consequently, the radicals do not drive reaction faster and may be slower if the termination step is more dominant [12]. This result is in line with the previous work, i.e., optimization of phoinitiator concentration and its application of UV-curing on some wood panels and UV-curing of pigmented epoxy acrylate coating on ceramic tiles [13,14]. Maximum pencil hardness was achieved at the photoinitiator concentration of 4 % b.w and conveyor speed 1 m/min. For this condition, pendulum hardness was 79 s.

Gloss and color value were shown in Table 7. Gloss of coatings are belong to medium-grade gloss (30 - 80 %). Gloss property usually correlates with the performance of coated products. Aesthetic feature of coated products is desired in the market either for low, medium and high gloss. The table shows the gloss at 60° geometry incident light of cured coating as a function of photoinitiator concentration and conveyor speed. The gloss is affected by the light absorbtion of the system i.e., the coating itself and the substrate [15]. The reflected light by the coating is base on specular gloss measurement. Reflected light by the coating is not measured precisely as the angle of incident light due to the scattering of light by pigment in the coating material. The scattering of light reducing the sharpness of the gloss and appearance, but increasing the haze of the coatings. As the table iindicates, the gloss slightly increases with an increase in photoinitiator concentration, and decreases with an increase of conveyor speed. All samples have medium-gloss grade (30 – 80 %).

Table 7. Gloss and color value of polyester coatings. Pigment concentration : 2 wt. %.

Photoinitiator concentration (%)	Conveyor speed (m/min)	Gloss[c] 60° (%)	Color value		
			L	a	b
2	1	38	68.4	0.4	0.8
	2	37	67.4	0.3	0.6
	3	*	*	*	*
	4	*	*	*	*
3	1	51	60.1	2.4	4.0
	2	36	60.3	1.8	1.5
	3	38	59.4	2.0	4.2
	4	*	*	*	*
4	1	58	69.3	0.8	2.9
	2	45	62.2	1.5	1.1
	3	44	59.2	2.0	2.6
	4	38	59.4	0.6	0.1

* Soft/tacky
[c] ASTM D 523-85
Uncoated particle board : L = 49.6; a = 12.7; b = 24.4

The color value of coated particle board was determined using the hunter system. In this system, measurement of white - based color will be dominated by L (lightness) axis, which 0 value representing black color. The a (red-green) and b (blue-yellow) axis will be less important. Uncoated particle board (brown color) has L = 49.6, a = 12.7 and b = 24.4. After coating, the higher L values (59 – 69) representing that the white color more dominant than a or b values. Photoinitiator concentration and conveyor speed do not affect very much to the color values. Visually, the coated particle board has brownish white, which originally brown color. The change in L values were higher than that of the change in a (0.3 – 2.0) or b (0.1 – 4.2).

The adhesion between wood surface and coating to substrate is measured using cross-cut and pull-off test method. In cross-cut method, the qualitative adhesion of a coating to substrate can be tested by

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observing the amount of scored coating which is removed from substrate by pressure sensitive adhesive, expressed by % remaining. It means that the higher % remaining, the higher the adhesion. Table 8 shows that all samples tested meet the standard because % remaining is > 50 %. Effect of photoinitiator concentration on % remaining is not evident. Nevertheless, adhesion of coatings meets the standard. Wide variation of the data can be observed either for cross-cut or pull-off test method. In the pull-off test, adhesion test measure the force required to remove a coating from the substrate. For interpretation of adhesion phenomena instead of absolute values of adhesion strength, the nature of failure (failure pattern) is important [16]. The adhesive strength and failure patterns were tabulated in Table 8. If the particle board is expressed with notation A, base coat with B, and top coat with C, the possibilities of value pattern can be categorized into the failure in the substrate (A), between substrate and base coat (A/B), between base coat and top coat (B/C), or their combination of failure. The adhesive strength decreases with an increase in conveyor speed. But, the photoinitiator concentration seems to have no influence on the adhesive strength. The greatest strength was observed for coating at photoinitiator concentration of 3 % b.w and conveyor speed of 1m/min, i,e., 3.5 lb/in^2. In general, the failure occurred in the substrate/particle board (100 % A). Another failure occurred between substrate and base coat (100 % A/B), between base coat and top coat (100 % B/C), and two samples provide the combination. Based on the failure pattern, it indicates that the adhesive strength between particle board and base coat (A/B) and between base coat and top coat (B/C) were higher than that of cohesive strength in the particle board itself. Several factors contribute to the variation of data, such as surface defects, un-uniform test conditions which tends to yield lower value. On the other hand, cleanliness of the surface such as free from dust, particle, fat etc., is very important to get excellent adhesion. The liquid coating which will be partly absorbed into the wood by capillary forces may remain uncured by UV radiation, resulted in poor adhesion [17].

Table 8. Adhesion of polyester coatings on particle board using cross cut and pull-off test. Pigment concentration = 2 % b.w.

Photoinitiator concentration (%)	Conveyor speed (m/min)	Cross-cut test[a)] (% remaining)	Pull-off test	
			Adhesive strength (lb/in^2)	Failure pattern
2	1	90	0	100 % A
	2	85	0	80% A, 20% A/B
	3	*	*	*
	4	*	*	*
3	1	92	3.5	100% A
	2	85	2.1	100% A
	3	100	1.1	100% A
	4	*	*	*
4	1	0	2.4	100% B/C
	2	55	2.8	100% A/B
	3	93	1.4	100% B/C
	4	10	1.1	90% A/B, 10 % B/C

* : soft and tacky A : particle board B : base coat C : top coat
[a] ASTM D 2571-71 : % remaining > 50 %

An increase of conveyor speed would lead to the decrease of exposure time. Decreasing of the exposure time decreases the formation of cross-linked polymer, resulted in weak adhesion in the interface. (=) respectively. It was found, that almost all of coatings resist to chemicals and solvent used except against 10 % sodium hydroxide solution as indicated by the swelling of coating.

Table 9. Chemical and solvent resistant of polyester coating.

Photoinitiator concentration (%)	Conveyor speed (m/min)	A	B	C	D	E	F
2	1	+	+	=	+	+	+
	2	-	+	=	+	+	+
	3	*	*	*	*	*	*
	4	*	*	*	*	*	*
3	1	+	+	-	+	+	+
	2	+	+	-	+	+	+
	3	+	+	=	+	+	+
	4	*	*	*	*	*	*
4	1	+	+	-	+	+	+
	2	+	+	+	+	+	+
	3	+	+	+	+	+	+
	4	-	+	+	+	+	+

* : soft/tacky
A : 10 % sulfuric acid
B : 1 % sodium carbonate
C : 10 % sodium hydroxide
D : 5 % acetic acid
E : 50 % ethanol
F : thinner
+ : no effect
- : gloss reduction
= : swelling

Adhesion strength reduced from 2.4 lb/in^2 (4 % photoinitiator concentration and 1 m/min conveyor speed) to 1.1 lb/in^2 (4 % photoinitiator concentration and 4 m/min conveyor speed).

Chemical resistance is important in the coated wood products,such as furniture, flooring and building materials. Chemicals attack of coating by acid, base, solvents, or any other chemicals used can result in loss of gloss, spotting, softening, whitening, swelling and other deterioration. Household chemicals, i.e. 10 % sulfuric acid, 1 % sodium carbonate, 10 % sodium hydroxide, 5 % acetic acid, 50 % ethanol and thinner were used for testing (Table 9). Visual scoring after testing were made in three categories, i.e.: resistant (no effect), slightly attacked (little gloss reduction) and attacked (swelling), as indicated by sign (+), (-) and

CONCLUSION

Particle boards made of kapur (*Dryobalanops* spp.) wood saw dust with tannin formulation (TF) adhesives provide physical properties (density, water content and thickness swelling) meet the SNI standard except for 24-h immersion swelling, while the mechanical properties (modulus of elongation, modulus of rupture, internal bond strength and screw holding strength) do not meet the standard. Physical properties of particle board prepared by using the mixture of TF and clover leaf oil residue formulation (CLORF) mixture follow the standard while most of thickness swelling do not follow the standard. Among the mechanical properties, only one of the sample follow the standard.

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Radiation-cured polyester coatings on particle board provide pencil hardness of 2B – 2H, pendulum hardness 17 – 79 s, medium gloss (60^0) 36 – 58 % and adhesion (cross-cut) meet the ASTM standard. Measurement of adhesion using pull-off test gives an information that the failure pattern occurs mostly in the particle board part. In general, the cured coatings are resist to household chemicals, except against 10 % sodium hydroxide solution.

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