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SURFACE COATING OF ACRYLATE POLYMER ON SENGON WOOD (*Paraserianthes falcataria* L. NIELSEN) USING UV IRRADIATION

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ABSTRACT

SURFACE COATING OF ACRYLATE POLYMER ON SENGON WOOD (*Paraserianthes falcataria* L. NIELSEN) USING UV IRRADIATION. An experiment on surface coating of sengon wood (*Paraserianthes falcataria* L. Nielsen) using ultraviolet (UV) irradiation has been conducted. Epoxy acrylate and urethane acrylate resins were used as coating materials after addition of tripropylene glycol diacrylate and a photoinisiator, Darrocure 1173. Irradiation was conducted using UV light at the conveyor speed of 2, 3, 4, and 5 m/minutes. Parameters observed were glossyness, adhesion, hardness, abrasion resistance and chemical, solvent and stain resistance. The superior results of the epoxy acrylate films were obtained to show excellent adhesion on the surface of wood meeting with the standard because of greater remaining values than 50 % (ASTM 2571-71), together with the high degrees of abrasion, hardness, glossyness and torelance against chemicals, solvent, and stain except against 10 % NaOH solution.

Keywords : Sengon wood (*Paraserianthes falcataria* L. Nielsen), Coatings, Epoxy acrylate, Urethane acrylate, UV light

ABSTRAK

PELAPISAN POLIMER AKRILAT PADA PERMUKAAN KAYU SENGON (*Paraserianthes falcataria* L. NIELSEN) MENGGUNAKAN IRADIASI UV. Telah dilakukan percobaan pelapisan permukaan kayu sengon (Paraserianthes falcataria L. Nielsen) menggunakan radiasi ultraviolet (UV). Resin epoksi akrilat dan uretan akrilat digunakan sebagai bahan pelapis setelah dicampur dengan tripropilen glikol diakrilat dan fotoinisiator, Darocure 1173. Iradiasi dilakukan menggunakan sinar UV pada kecepatan konveyor 2, 3, 4, dan 5 m/menit. Parameter yang diamati adalah kilap, adhesi, kekerasan, ketahanan kikis, kimia, pelarut dan noda. Hasil yang diperoleh menunjukkan bahwa film epoksi akrilat mempunyai adhesi yang sangat baik pada permukaan kayu dan memenuhi standar karena nilai sisa tinggal lebih besar dari 50 % (ASTM 2571-71), tahan terhadap kikisan, kekerasan dan kilap yang tinggi, tahan terhadap bahan kimia, pelarut, dan noda kecuali terhadap larutan NaOH 10%.

Kata kunci: Kayu sengon (*Paraserianthes falcataria* L. Nielsen), Lapisan, Epoksi akrilat, Uretan akrilat, Sinar UV

INTRODUCTION

Sengon wood (*Paraserianthes falcataria* L. Nielsen) also known as the name of *batay,* is one of the most important pioneer multi purpose tree species in Indonesia. It is one of the tree species preferred for industrial forest plantations in Indonesia because of its very fast growth, ability to grow on a variety of soils, favourable silvicultural characteristics and acceptable quality of wood for the panel and plywood industries. Furthermore, *P. falcataria* plays an important role in both commercial and traditional farming systems in several sites in Indonesia [1]. However, *P. falcataria* is classified as low quality wood due to its low specific gravity of 0.33, strength class at IV-V, and durable grade of IV-V [2,3]. Thus, in terms of the expansion of the use of *P. falcataria* in industry, its quality needs to be improved.

In order to protect the product from defect and enhance the performance, most of finished products made from wood panels (furniture, audio-visual goods and building materials) should be surface coated. Conventionally, curing of coating is processed by addition of catalyst and can be speed up by heating. Recently, curing of surface coating by using UV radiation technique offers many beneficial, i.e., the outstanding performance of coating, avoidance of pollution by eliminating the use of solvents, energy savings, high capacity production, room temperature processing, and space saving [4-7]. Beside of surface coating, pretreatment using UV radiation can induce significant changes in physical properties of plywood. Increasing radiation intensities of UV light may increase pendulum hardness, adhesion strength, and percent gloss values [8]. A wide range of chemical compounds can be cured in acrylate formulations through radical addition reactions of double bonds but curing process is strongly effected by the intra molecular environment of the double bonds. An acrylate system was used in this study because it is currently the most common resin applicable in industries. It only requires moderate amount of energy to achieve complete curing and more useful for coating or adhesives on rigid substrates.

Epoxy acrylate as one of the acrylated oligomer is mainly based on bisphenol-A derivatives. The hydroksil groups are formed by the epoxy acid reaction, which markedly improves adhesion [9]. Approximately 95 % coating materials used for commercial purposes is acrylate compounds, and the polymerization process takes place through a radical polymerization reaction [10]. Research of the surface coating on wood has been done in Center for the Isotopes and Radiation Application, National Nuclear Energy Agency, Jakarta, Indonesia [11-15]. One of the formulation that used for coating of wood was epoxy acrylate containing 30 % tripropylene glycol diacrylate (TPGDA) and photoinisiator Darocure 1173 with concentration of 3 %. The resulted film showed high gloss, good adhesion, and resistance to chemicals, solvent and stain [14]. Among researches which use UV curing of surface coating, the surface coating of acrylate onto *P. falcataria* is still very few.

The purpose of the research is to improve the low quality of sengon wood by increasing its surface properties with a technique of UV curing of surface coating. In this research, the wood sample were coated with base coating epoxy acrylate and urethane acrylate and then irradiated at a conveyor speed of 3 m/min. Cured films were sanded with 320 mesh abrasive paper, then coated with top coat and cured by UV irradiation at a conveyor speed of 2, 3, 4 and 5 m/minutes. Epoxy acrylate and urethane acrylate were used as coating materials and parameters observed were viscosity, volatile matter content, hardness, adhesion, and chemical, solvents and stains resistance.

MATERIAL AND METODS

Materials

Aluminum plate with the size of 200 x 100 x 1 mm, and sengon wood with the size of 100 x 40 x 1.2 cm, that has been processed to prevent blue stain with water content of 10%, were purchased from PT. Inkari Albasia, Cianjur, West Java, Indonesia. Radiation curable material used was an aromatic epoxy acrylate resin with the commercial name of Laromer EA-81, urethane acrylate with the commercial name of Laromer-LR8739 and TPGDA monomer. The last three materials were obtained from BASF, Germany, and photoinisiator of 2-dimethyl-2-hidroxyacetophenone with the commercial name of Darocure 1173 was purchsed from Merck, Germany.

Equipment

Coating of samples were performed by using roller coater made in Ta Sane, Taiwan, with a width of 60 cm. Irradiation was conducted using one 10.4 kW UV lamp with intensity of 80 Watt/cm medium pressure lamp from IST Strahlen Technik, GmbH-Germany, equipped with a conveyor system.

Experiment

Surface of aluminum plate was swept by water followed by alcohol to clean the surface free of dust, particle, fat, etc. Sengon wood as a substrate was sanded with 240 mesh abrasive paper followed by cleaning with alcohol. Surface coating was conducted in two steps i.e. coating on aluminum plates to determine the optimum of the conveyor speed after assessing the gel fraction of cured films, and surface coating of sengon wood using epoxy acrylate and urethane acrylate resins. Coating of formulations onto aluminum plates were conducted using glass rod to get the thickness of around 100 μm.

Irradiation was carried out using 10.4 kWatt UV-lamp with the intensity of 80 Watt/cm. The wood samples were coated with base coating epoxy acrylate and urethane acrylate and then irradiated at a conveyor speed of 3 m/minute. Cured films were sanded with 320 mesh abrasive paper, then coated with top and cured by irradiation at a conveyor speed of 2, 3, 4 and 5 m/minutes [13,15]. with 3 replications, respectively.

The flow chart of the experiments was presented in Figure 1. The weight ratio of coating material components is illustrated in Table 1.

Measurement and testing

Viscosity of coating formulation was measured by viscometer (Visconic EMD-R, Tokyo Keiki Co., Ltd., Japan). Pendulum hardness was measured with Koenig methods using pendulum hardness Rocker type from Sheen Instrument Ltd., (United Kingdom) according to ISO 1522-1973 (E) and pencil hardness according to JIS standard (K 5401-70). Adhesion between coating and wood substrates was performed with a cross-cut according to ASTM Standard 2571-71. The specular gloss was determined with 60 ° geometry using Glossmeter (Gloss meter U, Toyoseiki, Japan). Chemical, solvent and stain resistant test were conducted according to ASTM Standard 1308-79**.**

Table 1. The weight ratio of coating material components.

Resin	Component	The weight component of base coating (g)	The weight component of top coating (g)
Epoxy Acrylate	Epoxy acrylate	60	70
	TPGDA	40	30
	Talc	10	-
	Photoinisiator	2.5	2.5
	Silicone oil	-	0.1
Urethane acrylate	Urethane acrylate	50	60
	TPGDA	50	40
	Talc	10	-
	Photoinisiator	2.5	2.5
	Silicone oil	-	0.1

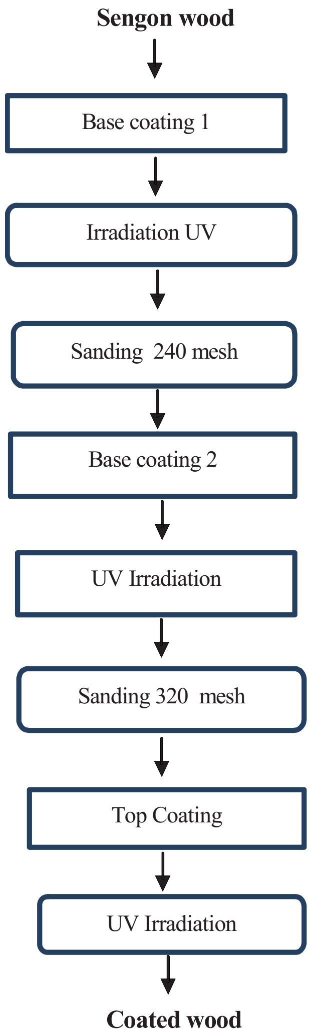

Figure 1. Flow chart of surface coating process on sengon wood.

RESULTS AND DISCUSION

The results of measurement properties of coating materials including density, viscosity, and volatile contents are presented in Table 2. It can be seen that there is no significant differences between the properties of the coating material replications-I, II and III. Volatile ingredients of epoxy acrylate coatings to the base coating and top coating, were 3.87% and 3.90% respectively, while the density were in the range of 1.10 up to 1.12 g/cm^3.

Viscosity of epoxy acrylate for top coat is lower if compared with urethane acrylate formulation, and it contains monomer TPGDA 40% or equal to 406 cp. A typical formulation of UV-curing consists of oligomers and monomers as reactive diluent together with photoinisiator. Appearance of the surfaces and final film properties were influenced and controlled significantly by viscosity of coating formulations. Viscosity should be considered in order to get a good properties. High viscosity is resulting in low surface appearance. In general, surface coating using epoxy acrylate coatings resulting in a good appearance.

In a previous study [14], the volatiles content of epoxy and urethane coatings materials is lower (3.90 %) compared with urethane acrylate coating material with a commercial name of Sinnacure 3132 (10,10 %). The content of volatiles expected to be as low as possible because of its influence on the environment and viscosity stability. Surface appearance of coating using epoxy acrylate was better than urethane acrylate, as indicated by evenness acrylate on sengon wood.

Table 2. Properties of resins for base coat and top coat (epoxy acrylate and urethane acrylate resin).

Resin	Type of coating	Replica tions	Density (g/cm^3)	Viscosity at 25°C (cp)	Volatile matter contain, (%)
Epoxy acrylate	Base coating	I	1.12	540	3.90
		II	1.11	540	3.87
		III	1.12	537	3.85
		Average	1.12	539	3.87
Epoxy acrylate	Top coating	I	1.10	386	3.95
		II	1.09	390	3.85
		III	1.11	388	3.90
		Average	1.10	388	3.90
Urethane acrylate	Base coating	I	1.10	586	3.95
		II	1.10	590	3.90
		III	1.11	585	3.93
		Average	1.10	587	3.93
Urethane acrylate	Top coating	I	1.12	400	4.00
		II	1.11	410	3.98
		III	1.11	408	3.99
		Average	1.11	406	3.99

Gel Fraction

The application of UV irradiation at higher doses on acrylate resins resulted in higher degree of crosslinking and relatively higher gel fraction coating materials of epoxy acrylate and urethane acrylate, respectively. Figure 2 shows the effects of the conveyor speed on the gel fraction base coat and top coat. It also resulted that the degree of crosslinking might be improved. The longer curing process during irradiation exposure of coated film, more free radical formed, the gel factions showed an increase [16]. The speed of conveyor at 5 m/min number of radicals formed is less, compared with the speed of 2 m/min and 3 m/min, respectively.

It will reduce gel formation of the fraction as a result of undesirable polymerization. Figure 2 shows that the effects of UV irradiation on gel fraction of epoxy acrylate and urethane acrylate film were 90% and 86%, respectively.

Gloss

The result gloss of the surface coated films formed after UV irradiation was measured by a Glossymeter and the results are presented in Table 3. Conveyor speed of 2 and 3 m/min, did not show the differences in gloss properties, but the higher conveyor speed 5 m/min, resulted in lower value. The irradiation dose absorbed by the coating at higher conveyor speed i.e. 5 m/min was lower, so that the formation of crosslinking is not perfect. Higher rate of polymerization or curing of the surface coating will impact a higher gloss coating [17] . In general, gloss properties decreased

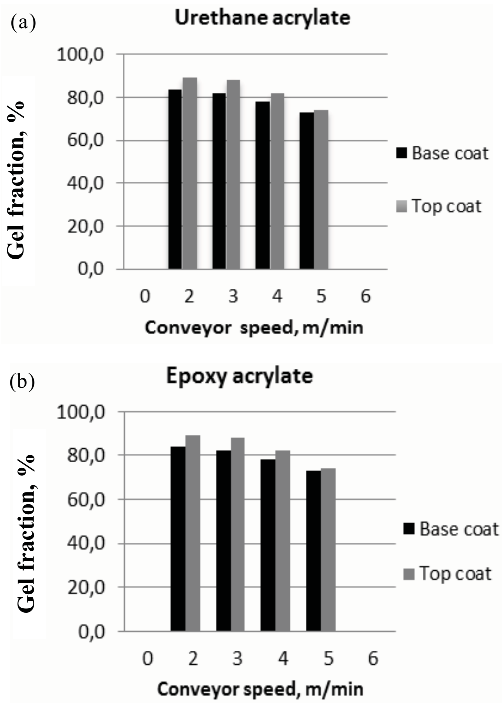

Figure 2. Effect of conveyor speed on gel fraction of base coat and top coat.

significanly by increasing the conveyor speed. As illustration, increasing of conveyor speed from 2 to 5 m/min, might reduce the gloss value from 86 % to 78 % for epoxy acrylate and 80 % to 74 % for urethane acrylate. All samples were categorized as belonging to the medium gloss because the values range were within of 74 - 86 %.

Adhesion

The adhesion between wood and acrylates after curing using UV irradiation is presented in Table 3. The data showed that the adhesion between base coat and top coat of acrylate polymers on sengon wood slightly decreased with increasing of conveyor speed. All samples showed excellent adhesion properties because remaining values were greater than 50% (ASTM-D 2571-71). It is almost the same with the adhesion of acrylate polymer coating on teak wood and polyester polymer coating on Randu wood (*Ceiba Pentadra* L. Gairtn) [13,18].

Hardness

Hardness testing is conducted using two methods, namely the standard Mitsubishi pencil in accordance with JIS K 5401-70 and Pendulum hardness according to the method of Koenig Hardness Rocker based on ISO 1522. Table 3 illustrates that crosslinking density of the polymer showed an increase as well as the hardness by increasing irradiation dose. Hardness of coating epoxy acrylate on sengon wood became slightly higher if compared with urethane acrylate. Seng [19] reported that the hardness will be affected by the substrate hardness if the coating thickness is smaller than 30 μm [19]. Pendulum hardness of epoxy acrylate varied in the range of 49 to 57 seconds and urethane acrylate coatings from 40 to 46 seconds, while pencil hardness was 3B. This indicates that there is an increase in hardness after the surface coated with epoxy acrylate and urethane acrylate on sengon wood. Pencil hardness of sengon wood before coating was 5B. The results of this study is almost equal with the hardness of the original meranti wood i.e 3 B [20]. Meranti wood that has been coated with epoxy acrylate using electron beam irradiation at the doses of 20 and 40 kGy were 2 B and 2 H.

Abrasion

The abrasion resistance of coated epoxy acrylate and urethane acrylate are presented in Table 3. It can be seen that abrasion resistance values of coated epoxy acrylate were in the range of 46% to 54%, while the values for urethane acrylate coatings was from 40% up to 49 %. The previous studies using acrylate polymer on wood surface concluded that the higher the crosslinking density, the higher of abrasion resistance and hardness. Abrasion resistance usualy has similar trend with hardness. At optimum condition of 3 m/min, the value of the epoxy acrylate and urethane acrylate hardness were 56 and 45 s, respectively.

Chemical, solvent, and stain resistance

Most of finished products such as furniture and building materials characteristics have certain chemical resistance, such as household chemicals Those chemicals are Na_2CO_3 1 %, CH_3COOH 5 %, H_2SO_4 10 %, NaOH 10 %, ethanol 50 %, thinner, and red, blue and black permanent marker. The chemical attack of a coating by these chemicals can result in the deterioration i.e., loss of gloss, spotting softening, whitening or swelling. Chemical, solvent, and stain resistance were tabulated on Table 4. If no deterioration caused by the chemical attacks, the coating films pass the test, as indicated by sign (+). Sign (-) shows the failure of test (slightly attacked), as indicated by spotting and a little reduction of gloss. In general, the samples tested were resistan to the chemicals used, except against NaOH 10 %.

From the characterization results, sengon wood acrylate coated polymer can be applied to the parquet floor and furniture. Fathermore, the optained results is expected to be developed by the furniture industry for audio-visual and partition.

CONCLUSION

It can be concluded that optimum conditions of UV irradiation was at conveyor speeds of 3 m/min. At this condition, gel fraction of epoxy acrylate and urethane acrylate films were 90 % and 86 %, while pendulum hardness varied between 56 and 45 s, respectively. Coating properties using epoxy acrylate oligomer is better than urethane acrylate, both in terms of gloss and appearance. All samples provide excellent adhesion and meet the standard requirement because percent remaining are greater than 50%. In general, cured coating resist to chemical (Na_2CO_3 1%, CH_3COOH 5%, H_2SO_4 10 %), solvent, and stains except against NaOH 10% solution.

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REFERENCE

[1]. H. Krirnawati, E. Varis, M. Kallio, M. Kanninen, *"Paraserienthes falcataria* (L.) Nielsen, *Ecology, Silviculture and Productivity*". *CIFOR,* Bogor, Indonesia, 1, 2011

Table 3. Effect of conveyor speed on the coating properties of epoxy acrylate and urethane acrylate on sengon wood.

Top coating	Conveyor speed, (m/min)	Gloss 60^o (%)	Hardness		Abrasion Resistance, (%)	Adhesion (%)
			Pendulum, (s)	Pencil		
Epoxy acrylate	2	86	57	3B	54	100
	3	86	56	3B	52	100
	4	80	51	3B	48	98
	5	78	49	3B	46	94
Urethane acrylate	2	80	46	3B	46	100
	3	80	45	3B	46	100
	4	78	40	3B	42	95
	5	74	40	3B	40	90

Description:
- The order of pencil hardness from soft to hard : 6B-5B-4B-3B-2B-B-F-H-2H-3H-4H- 7H
- Pendulum and pencil hardness of sengon wood before treatment were 18 s and 5B

Table 4. Chemical, solvent and stain resistance

Top coat	Conveyor speed m/min.	Chemicals, solvents and stains								
		A	B	C	D	E	F	G	H	I
Epoxy acrylate	2	-	-	-	-	+	-	-	-	-
	3	-	-	-	-	+	-	-	-	-
	4	-	-	-	-	+	-	-	-	-
	5	-	-	-	-	+	-	-	-	-
Urethane acrylate	2	-	-	-	-	+	-	-	-	-
	3	-	-	-	-	+	-	-	-	-
	4	-	-	-	-	+	-	-	-	-
	5	-	-	-	-	+	-	-	-	-

A = Na_2CO_3 1% , C = H_2SO_4 10 %, E = NaOH 10%, G = red markers, I = Black markers
B = CH_3COOH 5 %, D = ethanol50 %, F = thinner, H = blue markers, - = resistant, + = slightly attacked

[2]. A.T. Johannes, Fachmi, "Strong flexible wings beams cross section sengon wood and the play wood." *in Proc. Sym. Nat., Dept. of Forest Product,* IPB.Vol. 1, pp 254, 2009

[3]. F. Ishiguri, T. Hiraiwa, K. Lizuka, S. Yokota, D. Priadi, N. Sumiarsi and N. Yoshizawa, "Radial variation of anatomical characteristics in Paraserianthes falcataria planted in Indonesia". *J. IAWA* Vol. 30, pp 243-247, 2009.

[4]. H.Wensong, L. Baoping, Y. Hong, Z. Xueqin, "Synthesis and properties of UV-curable hyperbranched polyurethane acrylate oligomers containing photoinitiator". *Polym. Bull*. Vol. 68, pp 1009- 1013, 2012

[5]. R. Bongiovanni, M. Sangermono, G. Malucelli, A. Priola, " UV curing of photoinitiator-free systems containing bismaleimides and diacrylate resins: bulk and surface properties." *Prog. in. Org.coat*, Vol. 53, 46, 2005.

[6]. B. H. Lee H.J. Choi, H. J. Kim, "Coating performance and characteristics for UV-curable aliphatic urethane acrylate coatings containing norrish type I photoinitiators". *JCT Research*. Vol. 3, pp 221-226, 2006.

[7]. C. Mashouf, M. Ebraimi, and S. Bantani, "UV Curable urethane Coatings; Formulation experimental design approach". *Pigmen and resin technology*, [doi:10.1108/PRT-10-2012-0072]

[8]. M. Khan, R. A. Khan, B. S. Aliya, and Z. Nazreen, "Effect of the pretreatment with UV and gamma radiations on the modification of plywood surface by photocuring with epoxy acrylate". *J. Pol. Enviroment Vol.* 14, 11-15, 2006.

[9]. R. Holman and P. Oldring, "UV and EB Curing Formulation for Printing Inks. *Coating and Paints". Sita Technology*, London. 1988, 7.

[10]. R. Golden, *""Overview and trends in radiation curing technology." inProc. Rad - Tech*, *Europe* '89, *Frolence.* 1989, 11.

[11]. S. Danu, T. R. Mirzan, Darsono, S. Anik, R. N. Abdul, "Ultra Violet Curing of Pigmented Urethane Acrylate Coatings on Particle Board". *Indonesian J. Mat. Sci*. Vol. 10, No. 2 pp 117-123, 2009.

[12]. S. Danu, T. R. Mirzan, Darsono, S. Azis, *Proc.* "Optimation of photoinisiator concentration and its on UV curing of same wood panels." *in Proc. Rad-Tech Asia, Kuantan '*07, 2007, 149.

[13]. S. Danu, Darsono, S. Anik, "Pelapisan Permukaan Kayu Lapis Dengan Polimer Akrilat Menggunakan Radiasi Ultra Violet". *Indonesian J.Mat. Sci*., Vol 7, pp 45-51, 2006.

[14]. S. Danu and Darsono, "Pelapisan Parket Blok Jati (Tectona Grandis L.F.) Dengan Polimer Epoksi Akrilat Menggunakan Iradiasi Ultra Violet". *Indonesian J. Mat. Sci*. Vol. 10, N0. 1, pp 230-236, 2008.

[15]. Marsongko, "Pelapisan Permukaan Keramik Dengan Polimer Epoksi Akrilat Menggunakan Iradiasi UV*". Indonesian J. Mat. Sci*., Vol. 9, No. 1, pp 746-51, 2007.

[16]. S. Danu and Darsono, "Electron Beam Curing of Epoxy Acrylate Coatings on Medium-Density Fiberboard". *Indo, J. Chem*., Vol. 2, 207-214, 2008.

[17]. M.F. Yahya, N. G. N. Salleh, A. Hassan, A. N. Bakar, M. Mochtar, "UV/EB Nanocomposites with stratch and abration", *in Proc. Rad.Tech. Asia*, Kuantan, 2007, 166-171.

[18]. S. Danu, T. R. Mirzan, H. Dhedy, Darsono, Marsongko, "Densification of Kapok Wood (Ceiba Pentandra L. Gaertn) and Its Radiation Curing Of Surface Coatings Using Ultra-Violet." *Indonesian J. Mat. Sci*. Vol. 14, pp 222-228, 2013.

[19]. H. P. Seng, "Test methods for the characterization of UV and EB cured printing vamishes". *Part 1. Beta-gamma.* 1989, 3, 10.

[20]. Darsono, S. Danu, S. Anik, "Radiation curing of meranti wood using UV light." *Proc. PAIR-BATAN,* 1997, hal. 58- 64.