

The Coating Performance of UV Curable Urethane Acrylate Coatings for Fancy Veneer Overlayed Plywood Flooring^{*1}

Byoung-Hoo Lee^{*2}, Hyun-Joong Kim^{*2†}, and Young-Kyu Lee^{*3}

ABSTRACT

The goal of study was to investigate the influence of the acrylated urethane oligomer on mechanical properties, the chemical resistance and thermal resistance of the UV curable urethane acrylate coatings for fancy veneer overlayed plywood flooring. The pencil hardness and abrasion resistance of the coated fancy veneer overlayed plywood floorings increased with increasing the acrylate functionality of the acrylated urethane oligomer.

In the case of the UV cured film containing hexa-functional acrylated aliphatic urethane oligomer, high discoloration of the coated fancy veneer overlayed plywood flooring was observed near the cracks at the beginning of the chemical treatment.

In this study, it was found that the degradation of the UV cured film caused by an alkaline reagent was higher than that of the UV cured film caused by an acidic treatment.

Keywords : UV curing, UV curable coating, acrylated urethane oligomer, fancy veneer overlayed plywood flooring, chemical resistance, thermal resistance

1. INTRODUCTION

In recent years, the coated fancy veneer overlayed plywood flooring is used to provide a comfortable indoor environment in house. In addition, the markets of UV curable coatings for building materials are expanding owing to a rapid growth in the area of the flooring materials such as wood and PVC, *etc.* in Korea.

The UV curable coatings are widely used for

surface coatings as filler, sealer, basecoat and topcoat for the fancy veneer overlayed plywood flooring. In particular, the UV curable urethane acrylate coatings are widely used for the topcoat of the fancy veneer overlayed plywood flooring and noted for their high performance.

The UV curable urethane acrylate coating system tends to be expensive, and this is reflected in the price of the acrylated oligomers. However, these coatings have gained widespread

^{*1} Received on March 15, 2003; accepted on June 29, 2004.

^{*2} Lab. Of Adhesion & Bio-Composites, Department of Forest Products, Seoul National University, Seoul 151-742, Korea

^{*3} Material Property Analysis Lab, National Instrumentation Center for Environmental Management Seoul National University

[†] Corresponding author : Hyun-Joong Kim (hjokim@snu.ac.kr)

Table 1. Characteristics of the oligomers

Oligomers	Viscosity ^c (mPa.s)	Molecular weight	Functionality	Isocyanate type
Ebecryl [®] 210 ^a	3900	1500	2	Aromatic isocyanate
Ebecryl [®] 270 ^b	3000	1500	2	Aliphatic isocyanate
Ebecryl [®] 9260 ^c	2000 ~ 40000	1500	3	Aliphatic isocyanate
Ebecryl [®] 1290 ^d	2000	1000	6	Aliphatic isocyanate

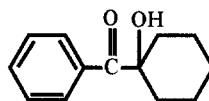
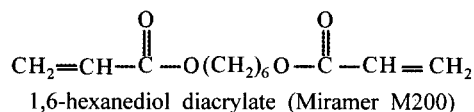
a: aromatic urethane diacrylate, b: aliphatic urethane diacrylate, c: aliphatic urethane triacrylate, d: aliphatic urethane hexaacrylate, e: Hppler viscosity at 60°C.

acceptance because of their overall balance of properties, high impact and tensile strength, abrasion resistance and toughness combined with the excellent resistance to chemicals and solvents (Ohata, 1991). The urethane acrylates or urethane methacrylates are formed by the reaction of an isocyanate group and hydroxyl group of an acrylic or methacrylic monomer (Holman, 1984; Hepburn, 1992; Mehnert *et al.*, 1998). In the case of the urethane acrylate oligomers, these can either be based on the aromatic isocyanates, or aliphatic isocyanates. The former type offers a better balance of reactivity, toughness and hardness, while the aliphatic type has the color stability and durability, despite the double bond, but is much more expensive (Holman, 1984).

The urethane acrylate oligomers are generally di-functional but they can be modified to increase or decrease functionality. By varying the backbone composition, *e.g.* the level of unsaturation, and other functionality parameters, hard or soft, rigid or flexible coatings can be produced (Holman, 1984).

In particular, when the coated fancy veneer overlayed plywood flooring is used in indoor, the applied coating must have resistance to alkali and acid, and good thermal stability associated with Ondol, the Korean traditional heating system.

Therefore, the goal of this study was to investigate the influence of the acrylated urethane oligomer on mechanical properties, the chemical resistance and thermal resistance of the UV cur-



1-hydroxy-cyclohexyl-phenyl ketone (Micure CP-4)

Fig. 1. Monomer and photoinitiator.

able urethane acrylate coatings used for fancy veneer overlayed plywood flooring.

2. MATERIALS and METHODS

2.1. Materials

The UV curable urethane acrylate system consisted of three main components: firstly, urethane diacrylate oligomers, secondly, reactive diluent monomer and thirdly, photoinitiator used to obtain the UV curable coatings. The four types of the urethane acrylate oligomers (Table 1) were the aromatic urethane diacrylate oligomer (Ebecryl[®]210, UCB), aliphatic urethane diacrylate oligomer (Ebecryl[®]270, UCB), aliphatic urethane triacrylate oligomer (Ebecryl[®]9260, UCB) and aliphatic urethane hexacrylate oligomer (Ebecryl[®]1290, UCB). The reactive diluent monomer and photoinitiator were 1,6-hexanediol diacrylate (Miramer M200, Miwon) and 1-hydroxy-cyclohexyl-phenyl ketone (Micure CP-4, Miwon) (Fig. 1).

Table 2. Formulations of the UV curable coatings

Components		Compositions (wt.%)				
		ArH-di	ArAlH-di	AlH-di	AlH-tri	AlH-hexa
Oligomers	Ebecryl 210 ^a	57	28.5			
	Ebecryl 270 ^b		28.5	57		
	Ebecryl 9260 ^c				57	
	Ebecryl 1290 ^d					57
Monomer	Miramer M200 ^e	38	38	38	38	38
Photoinitiator	Micure CP-4 ^f	5	5	5	5	5
Total (wt.%)		100	100	100	100	100

a: aromatic urethane diacrylate, b: aliphatic urethane diacrylate, c: aliphatic urethane triacrylate, d: aliphatic urethane hexaacrylate, e: 1,6-hexanediol diacrylate, f: 1-hydroxy-cyclohexyl-phenyl-ketone.

Table 3. Viscosities of the UV curable coatings

Viscosity (cP) ^a				
ArH-di	ArAlH-di	AlH-di	AlH-tri	AlH-hexa
644	604	578	500	250

a: measured by programmable viscometer Model DV-II+ at 25°C (spindle RV 4).

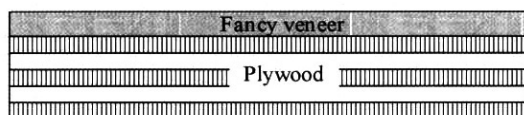


Fig. 2. Schematic fancy veneer overlayed plywood flooring system.

The UV curable coatings were formulated as shown in Table 2. Table 3 shows the viscosities of the prepared UV curable coatings.

2.2. Process of the UV Curing

The fancy veneer overlayed plywood flooring (14 cm × 7 cm × 0.8 cm) was coated in advance by UV curable epoxy acrylate intermediate coating, cured and then sanded out. Fig. 2 shows the schematic fancy veneer overlayed plywood flooring.

The UV curable top coating was coated onto the intermediate coated fancy veneer overlayed plywood flooring using a bar coater (No. 22)

and cured in a conveyer belt type UV curing machine equipped with a high-pressure mercury lamp (100 W/cm: main wavelength: 365 nm). For heat sensitive applications, a cold mirror was used as reflector. The UV dose used was a UV dose of 1360 mJ/cm². The thickness of the top cured film was ca. 60 μm.

To investigate the gel content and probe tack of the cured film, UV curable coating was coated onto a glass plate (15 cm × 6 cm × 0.3 cm) using a bar coater (No. 22). The sample was cured by over same procedure. The thickness of cured film was ca. 40 μm.

2.3. Pencil Hardness Test

This method is practiced by pushing a number of wood pencils which decreases in hardness along the coating (ASTM D 3363). To observe the pencil hardness of the coated fancy veneer overlayed plywood flooring, the coated fancy

veneer overlayed plywood flooring was placed on a level, firm, horizontal surface. The pencils used had a flattened end and they were held at an angle of 45° against the coated fancy veneer overlayed plywood flooring. The applied weight was 1 kgf. The hardness of the first pencil not to dig into or gouge the coated fancy veneer overlayed plywood flooring is used to denote the hardness of the coated fancy veneer overlayed plywood flooring. Pencils vary in hardness from 6B to 6H.

2.4. Adhesion Test

To observe the adhesion between top coat and intermediate coat, a lattice pattern with six cuts 2 mm apart in each direction was made in the coats on the fancy veneer overlayed plywood flooring (ASTM D 3352). After making the required cuts, the coated fancy veneer overlayed plywood flooring was brushed with a soft brush to remove any detached flakes or ribbons of coatings. The pressure sensitive tape over the lattice was applied using the 2 kgf-rubber roller. Then, the tape was removed by seizing the free end and was rapidly backed upon itself at as close to an angle of 180° as possible with the tensile mode of the Zwick Universal Testing Machine Z101. The crosshead speed was 1500 mm/min. The grid area for removal of topcoat from intermediate coat was inspected.

2.5. Abrasion Resistance Test

To observe the abrasion resistance of the coated fancy veneer overlayed plywood flooring, the coated fancy veneer overlayed plywood flooring was abraded under specified conditions. The abrasive rubber wheels were used, which is attached to an abrasion-testing machine known as a taber abraser (Taber 5130 abraser, Taber Industries).

The original weight of the coated fancy veneer

overlayed plywood flooring was measured. The coated fancy veneer overlayed plywood flooring was then placed on a taber abraser. A 1 kgf load was placed on top of two abrader wheels (CS-17), which allowed to spin for a specified number of revolutions. After a given number of revolutions, the coated fancy veneer overlayed plywood flooring was removed from a taber abraser. Then, the weight of the coated fancy veneer overlayed plywood flooring was measured to record the loss of weight of the coated fancy veneer overlayed plywood flooring.

The loss of the weight (L) of the coated fancy veneer overlayed plywood flooring was calculated as follows:

$$L = A - B$$

Where A is the weight of the coated fancy veneer overlayed plywood flooring before abrasion and B is the weight of the coated fancy veneer overlayed plywood flooring after a given abrasion cycles (ASTM D 4060).

2.6. Gel Content

The cured film was carefully peeled off from the glass plate, in order to measure the gel content. A known weight of the cured film was extracted in acetone at 32°C for 24 h. The residues were dried at 50°C to a constant weight. The gel content of the cured film was then determined by the following equation:

$$\text{Gel content (\%)} = W_t / W_0 \times 100$$

Where, W_t is the weight after extraction and W_0 is the weight before extraction.

2.7. Probe Tack Test

The probe tack test has been developed in an attempt to simulate and refine the commonly

used method of thumb or finger tack testing. The probe tack test was usually used in the PSA (pressure sensitive adhesives) industry, *etc.* (Satas, 2002). In general, the probe tack of the coating surface can be evaluated by bringing the smooth end of a cylindrical probe into contact with the coating surface and then plotting the curve of the force/distance produced when it is pulled away. The degree of tack is often expressed as the maximum debonding force value (Mizumachi, 2000). As shown in Fig. 3, a cylindrical probe is brought into contact with the coating surface to be tested under a defined contact pressure and for a well-defined contact time. During the separation of the probe from the coating surface, the tensile force is measured as a function of time (or distance) (Satas, 2002; Gay, 1999).

In this study, the probe tack test was conducted on using the adhesive test mode of the Texture Analyzer (TA-XT2i) with a polished stainless steel cylinder probe 5 mm in diameter at $24 \pm 1^\circ\text{C}$ and $50 \pm 2\%$ R. H. Measurements were carried out at a separation rate of 0.5 mm/sec under a constant pressure of 100 gf/cm^2 and with a dwell time of 1 sec.

2.8. Chemical and Thermal Resistance Test

In the case of the chemical resistance test, the coated fancy veneer overlayed plywood flooring was wet with 3 g of 1% sodium carbonate aqueous solution as an alkaline reagent or 3 g of 5% acetic acid aqueous solution as an acidic reagent for measuring the resistance to the chemical degradation at room temperature ($65 \pm 2\%$ relative humidity and $20 \pm 1^\circ\text{C}$), and then covered with a watch glass (diameter 5 cm) to protect the volatilization of the solution (KS F 3111).

After a given time intervals, the chemical reagent and watch glass removed from the

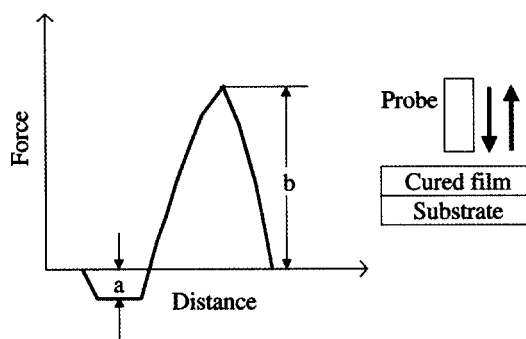


Fig. 3. Bonding and debonding process during a probe tack measurement (Satas, 2002). (a-contact force, b-probe tack)

sample surface and then the sample was dried at 80°C dry oven for 20 min and cooled at room temperature for 30 min and then measurement was taken out to record the extent of the degradation of the sample surface. The total treatment time was 252 h excepting for the dry and cool time of sample.

In the case of the thermal resistance test, the coated fancy veneer overlayed plywood flooring was heated at 80°C dry oven (KS F 3111). After a given time intervals, the coated fancy veneer overlayed plywood flooring removed from dry oven and then the coated fancy veneer overlayed plywood flooring was cooled at room temperature for 30 min and then measurement was taken out to record the thermal resistance of its surface. The total treatment time was 252 h excepting for the cool time of the coated fancy veneer overlayed plywood flooring.

2.8.1. Analysis

2.8.1.1. Gloss Measurement

The gloss at an angle of incidence/reflection of 20° was measured by a Tri-Microgloss (Sheen, England) to observe the surface degradation of the coated fancy veneer overlayed plywood flooring during the chemical and thermal treatment.

Table 4. Gloss, pencil hardness and adhesion of the coated fancy veneer overlayed plywood floorings

	ArH-di	ArAlH-di	AlH-di	AlH-tri	AlH-hexa
Gloss (20°)	87	84	83	88	83
Pencil hardness	3B	B	B	F	H
Adhesion ^a	10/25	0/25	0/25	0/25	1/25

a: 0/25 means 0% removal, 25/25 means 100% removal.

$$\text{Gloss retention (\%)} = (G_f / G_i) \times 100$$

Where G_i and G_f represent the initial gloss values and the current gloss values, respectively.

2.8.1.2. Contact Angle Measurement

The change of the contact angle on the coated fancy veneer overlayed plywood flooring surface during the chemical and thermal treatment was measured using SEO 300A contact angle measuring device (Surface & Electro-Optics Co., Korea) at $25 \pm 2\%$ relative humidity and $20 \pm 1^\circ\text{C}$. A 10 μl drop of the distilled water was placed on the coated fancy veneer overlayed plywood flooring surface. The measurement of the contact angle was taken 10 sec after the drop was placed on the surface of the coated fancy veneer overlayed plywood flooring.

2.8.1.3. Discoloration Measurement

The color difference (ΔE^*) of the coated fancy veneer overlayed plywood flooring was measured using a Spectrophotometer SP 820 λ (Techkon, Germany). The surface color difference was calculated using the CIE $L^*a^*b^*$ system.

$$\Delta L^* = L^*_f - L^*_i$$

$$\Delta a^* = a^*_f - a^*_i$$

$$\Delta b^* = b^*_f - b^*_i$$

Where L^* , a^* , and b^* represent the lightness, the yellowness, and the redness. L^* is the measure of lightness and varies from 100 for

perfect white to 0 for absolute black. $+a^*$ indicates redness and $-a^*$ indicates greenness. $+b^*$ indicates yellowness and $-b^*$ indicates blueness.

$$\Delta E^* = (\Delta L^{*2} + \Delta b^{*2} + \Delta a^{*2})^{1/2}$$

Where ΔL^* , Δa^* , and Δb^* represent the change between the initial (i) and the final (f) values. L^* , a^* , and b^* contribute to the color change (ΔE^*). A low ΔE^* corresponds to a low color change or color stability.

2.8.1.4. Surface Morphology Measurement

In order to observe the change of the surface morphology on the coated fancy veneer overlayed plywood flooring surface before and after the chemical and thermal treatment, scanning electron microscopy (SEM, JSM 5410LV) was used (magnitudes 350).

3. RESULTS and DISCUSSION

3.1. Gloss, Pencil Hardness and Adhesion

Table 4 shows the gloss, pencil hardness and adhesion of the coated fancy veneer overlayed plywood floorings. The pencil hardness increased with increasing the acrylate functionality of the acrylated urethane oligomer used. In the case of the isocyanate type of the acrylated urethane oligomer used, the pencil hardness of the UV cured film containing the acrylated aliphatic

Table 5. Gel content and probe tack of the cured film

	ArH-di	ArAlH-di	AlH-di	AlH-tri	AlH-hexa
Gel content (%)	95.6	95.7	96.2	97.2	-
Probe tack (gf)	8.7 (0.5)	8.6 (0.8)	7.9 (0.4)	7.6 (0.1)	7.4 (0.2)

() : standard deviation

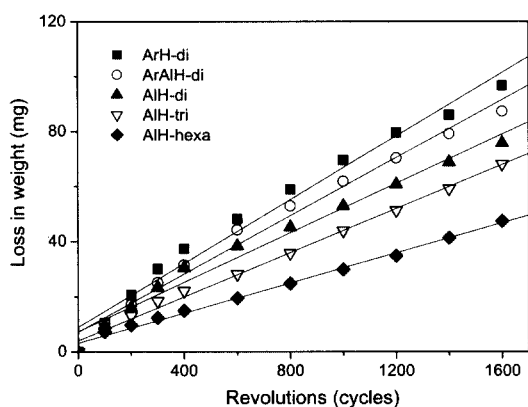


Fig. 4. Abrasion resistance of the coated fancy veneer overlayed plywood floorings.

urethane oligomer (AlH-di) was higher than that of the UV cured film containing the acrylated aromatic urethane oligomer (ArH-di). In addition, the adhesion of ArH-di was the worst.

Table 5 shows the gel content and the probe tack of the cured film. In this study, AlH-hexa produced brittle film because of the presence of hexa-functional acrylate groups in the acrylated aliphatic urethane oligomer used. After the UV curing, the UV cured film of AlH-hexa broke into pieces during peeling off the coating plate. The lower the probe tack means the higher the surface curing. As shown in Table 5, pencil hardness results are associated with smaller probe tack, higher surface curing and higher gel content of AlH-di (Wu and Soucek, 2000).

3.2. Abrasion Resistance

Fig. 4 shows the abrasion resistance of the coated fancy veneer overlayed plywood floorings.

The final loss of the weight and the slope of straight line decreased with increasing the acrylate functionality of the acrylated urethane oligomer, as shown in Fig. 4. In the case of the isocyanate type of the acrylated urethane oligomer, the UV cured film containing the acrylated aliphatic urethane oligomer (AlH-di) was higher abrasion resistance than that containing the acrylated aromatic urethane oligomer (ArH-di). These results are related to higher surface curing and gel content of AlH-di, as previously explained in the result of pencil hardness. In particular, the abrasion resistance of ArH-di was the worst. The reason of this result can be demonstrated by the lowest gel content of ArH-di.

The abrasion resistance of the coated fancy veneer overlayed plywood floorings was in the order: AlH-hexa > AlH-tri > AlH-di > ArAlH-di > ArH-di. This result was associated with the result of pencil hardness.

3.3. Chemical Resistance

Figs. 5-(a) and (b) show the gloss retention of the coated fancy veneer overlayed plywood floorings as a function of alkaline and acidic treatment time. As shown in Figs. 5-(a) and (b), the gloss retention of the coated fancy veneer overlayed plywood floorings depended on the acrylate functionality and isocyanate type of the acrylated urethane oligomer. As shown in Fig. 5-(a), the gloss retention of ArH-di, ArAlH-di, and AlH-di decreased sharply up to an alkaline treatment time of 60 h. The gloss retention of AlH-tri decreased progressively over the entire alkaline treatment time in this experiment. The

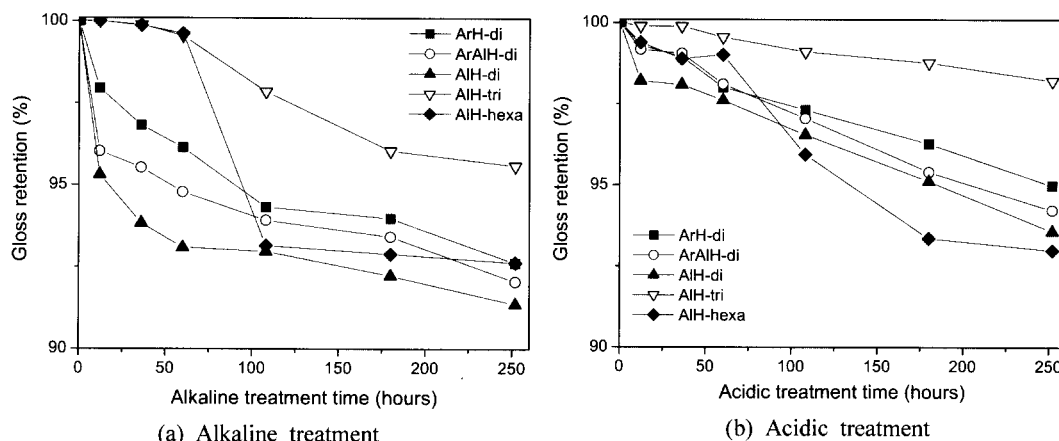


Fig. 5. Gloss retention of the coated fancy veneer overlayed plywood floorings as a function of chemical treatment time.

alkaline resistance increased with increasing the acrylate functionality of the acrylated urethane oligomer. The increased chemical resistance is associated with the increased crosslinking density of the UV cured film due to the increased acrylic double bond of the UV curable coating (Thames *et al.*, 1996; Hairdos *et al.*, 1999; Kim *et al.*, 2003). However, the gloss retention of AlH-hexa decreased sharply after a alkaline treatment time of 60 h. The reason for the dramatic decrease of the gloss retention of AlH-hexa is related to surface cracks which appeared on the coated fancy veneer overlayed plywood flooring after an alkaline treatment time of 36 h.

During the wetting and drying of an alkaline reagent on the coated fancy veneer overlayed plywood flooring, the permeability of the alkaline reagent, which is related to the absorption and swelling of the UV cured film, increased with increasing the treatment time and the development of cracks can be interpreted as the swelling and shrinkage of both UV cured film and fancy veneer overlayed plywood flooring caused by the alkaline resistance test (Kim and Lee, 1989). In general, higher crosslinked film exhibits lower solution absorption and higher gel content

(Wu and Soucek, 2000).

In this study, AlH-hexa produced the high crosslinked brittle film because of the presence of the hexa-functional acrylate groups in the acrylated aliphatic urethane oligomer. As alkaline treatment progresses, the amount of stress increases in the UV cured film. Also, the increased stress is due to the swelling and shrinkage of the coated fancy veneer overlayed plywood flooring caused by the alkaline reagent and moisture during alkaline resistance test. As a consequence, the surface cracks appear. In particular, the amount of stress of AlH-hexa was the highest, because of the highest its brittleness. Therefore, the stress of the UV cured film leads to cracking, channeling, and delamination. As shown in Fig. 5-(a), the gloss retention of AlH-di was the worst. However, all of the coated fancy veneer overlayed plywood floorings remained high gloss retention (> 90%) over the entire alkaline treatment time. The final gloss retention of the coated fancy veneer overlayed plywood floorings to alkaline reagent was in the order: AlH-tri > ArH-di \geq AlH-hexa > ArAlH-di > AlH-di.

Fig. 5-(b) shows the gloss retention of the coated fancy veneer overlayed plywood floorings

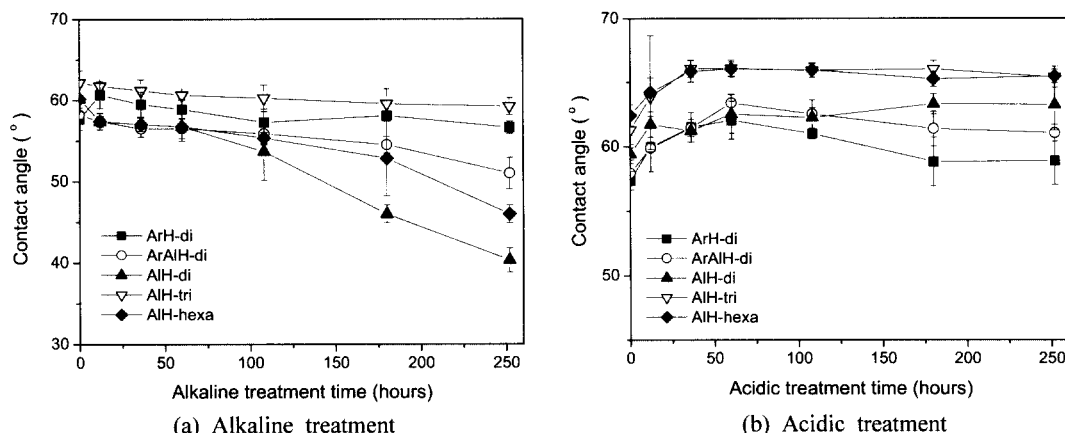


Fig. 6. Contact angle of the coated fancy veneer overlayed plywood floorings as a function of chemical treatment time.

as a function of acidic treatment time. The gloss retention decreased with increasing acidic treatment time. In the case of AlH-hexa, the surface cracks appeared on the coated fancy veneer overlayed plywood flooring after an acidic treatment time of 36 h. The gloss retention of AlH-hexa decreased dramatically after an acidic treatment time of 60 h. The final gloss retention of the coated fancy veneer overlayed plywood floorings to acidic reagent was in the order: AlH-tri > ArH-di > ArAlH-di > AlH-di > AlH-hexa. These results were similar to those obtained in alkaline treatment.

Figs. 6-(a) and (b) show the change of the contact angle of the coated fancy veneer overlayed plywood floorings as a function of alkaline and acidic treatment time. As shown in Fig. 6-(a), the contact angle of the coated fancy veneer overlayed plywood floorings decreased with increasing alkaline treatment time. However, in the case of the acidic treatment, the change of contact angle of the coated fancy veneer overlayed plywood flooring was not significant, as shown in Fig. 6-(b). In the case of the alkaline treatment, the contact angle of AlH-di decreased sharply after an alkaline treatment time of 60 h. In addition, the decrease of the

contact angle of AlH-hexa was the highest except AlH-di. The reason for this was elucidated as the development of the surface cracks on the coated fancy veneer overlayed plywood flooring, as previously explained in this study. However, in the case of AlH-hexa, the change of the contact angle was not significant during the acidic treatment. As a consequence, in the chemical treatment test of the UV cured films, the degradation caused by the alkaline reagent is found to be higher than that caused by the acidic reagent.

Fig. 7-(a) shows the discoloration of the coated fancy veneer overlayed plywood floorings as a function of alkaline treatment time. As shown in Fig. 7-(a), the discoloration of coated fancy veneer overlayed plywood flooring increased with increasing the alkaline treatment time. The discoloration of the coated fancy veneer overlayed plywood flooring decreased with increasing the acrylate functionality of the acrylated urethane oligomer used. The discoloration, due to the presence of chromophores and auxochromes, is associated with the chemical structure of the UV cured film and wood material (Turner, 1988). In particular, the discoloration of AlH-hexa increased sharply up to an alkaline treatment

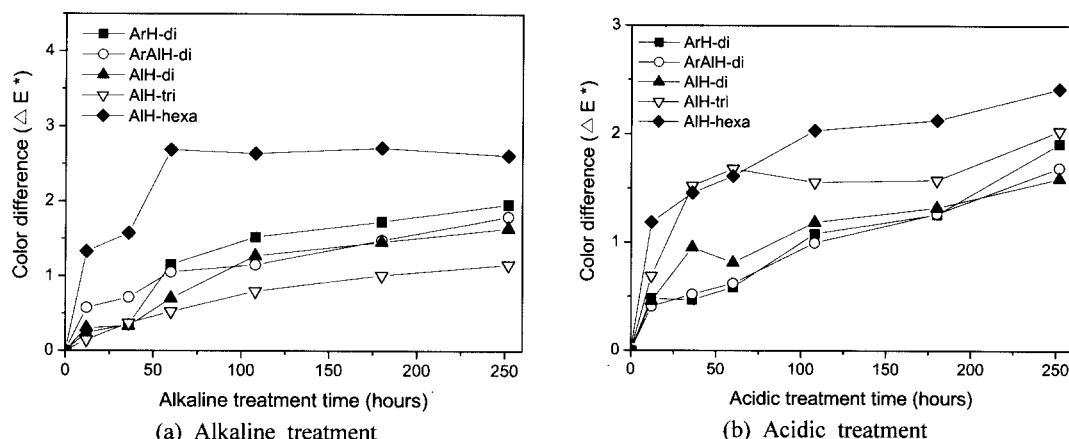


Fig. 7. Discoloration of the coated fancy veneer overlayed plywood floorings as a function of chemical treatment time.

time of 60 h. The discoloration of AlH-hexa was the highest. The reason for this result can be elucidated as the development of the surface cracks on the coated fancy veneer overlayed plywood flooring, as previously explained in this study. The discoloration of the coated fancy veneer overlayed plywood flooring was observed in the vicinity of the crack at the beginning of the chemical treatment. The discoloration could be observed by the naked eye. Most of the discoloration is due to the chemical reaction between the wood material and the chemical reagent, which penetrated through the cracks, though a little discoloration of the cured film its may also exists. The discoloration of the coated fancy veneer overlayed plywood flooring is related more to the alkaline effect on the wood material than that of the cured film, because the discoloration is observed in the vicinity of the crack at the beginning of the chemical treatment. In previous study (Hon and Shiraishi, 1991), it was known that the alkaline stain is the discoloration caused by the reaction of alkaline chemicals to wood materials (Turner, 1988).

In the case of the alkaline treatment, the discoloration of AlH-tri was the lowest. The

final discoloration of the coated fancy veneer overlayed plywood floorings to alkaline reagent was in the order: AlH-hexa > ArH-di > ArAlH-di > AlH-di > AlH-tri.

In the case of the acidic treatment, the discoloration result of AlH-hexa was similar to that of AlH-hexa obtained in alkaline treatment, as shown in Fig. 7-(b). However, the discoloration could be not observed by the naked eye in the vicinity of the crack. The discoloration of the coated fancy veneer overlayed plywood floorings increased with increasing the acrylate functionality of the acrylated urethane oligomer. The final discoloration of the coated fancy veneer overlayed plywood floorings to acidic reagent was in the order: AlH-hexa > AlH-tri > ArH-di > ArAlH-di > AlH-di.

3.4. Thermal Resistance

Fig. 8-(a) shows the gloss retention of the coated fancy veneer overlayed plywood floorings as a function of thermal treatment time. In the case of the di-functionality, the gloss retention of ArH-di containing the acrylated aromatic urethane oligomer was lower than that of AlH-di containing the acrylated aliphatic urethane oli-

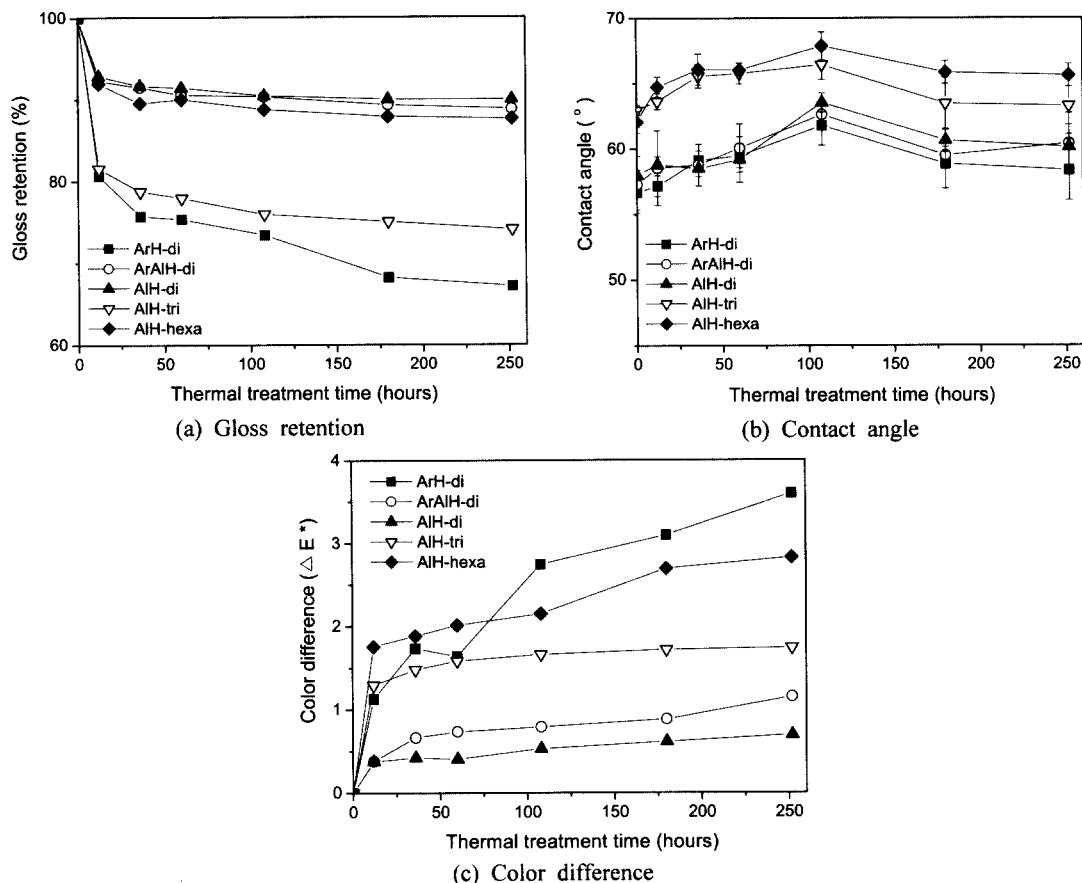


Fig. 8. Influence of the coated fancy veneer overlayed plywood floorings as a function of thermal treatment time.

gomer. Fig. 8-(b) shows the change of the contact angle of the coated fancy veneer overlayed plywood flooring as a function of thermal treatment time. The contact angle of the coated fancy veneer overlayed plywood flooring increased with increasing the acrylate functionality of acrylated urethane oligomer used. However, there was no significant change of contact angle during the thermal treatment. Fig. 8-(c) shows the change of the discoloration of the coated fancy veneer overlayed plywood floorings as a function of thermal treatment time. As shown in Fig. 8-(c), the discoloration of the coated fancy veneer overlayed plywood floorings increased

with increasing thermal treatment time.

The discoloration of AlH-di containing the acrylated aliphatic oligomer was lower than that of ArH-di containing the acrylated aromatic oligomer. In addition, the discoloration increased with increasing the acrylate functionality of the acrylated urethane oligomer. The trend of the discoloration is similar to that of gloss retention.

3.5. Morphology on Chemical and Thermal Treatment

Fig. 9 shows the surface morphology of the

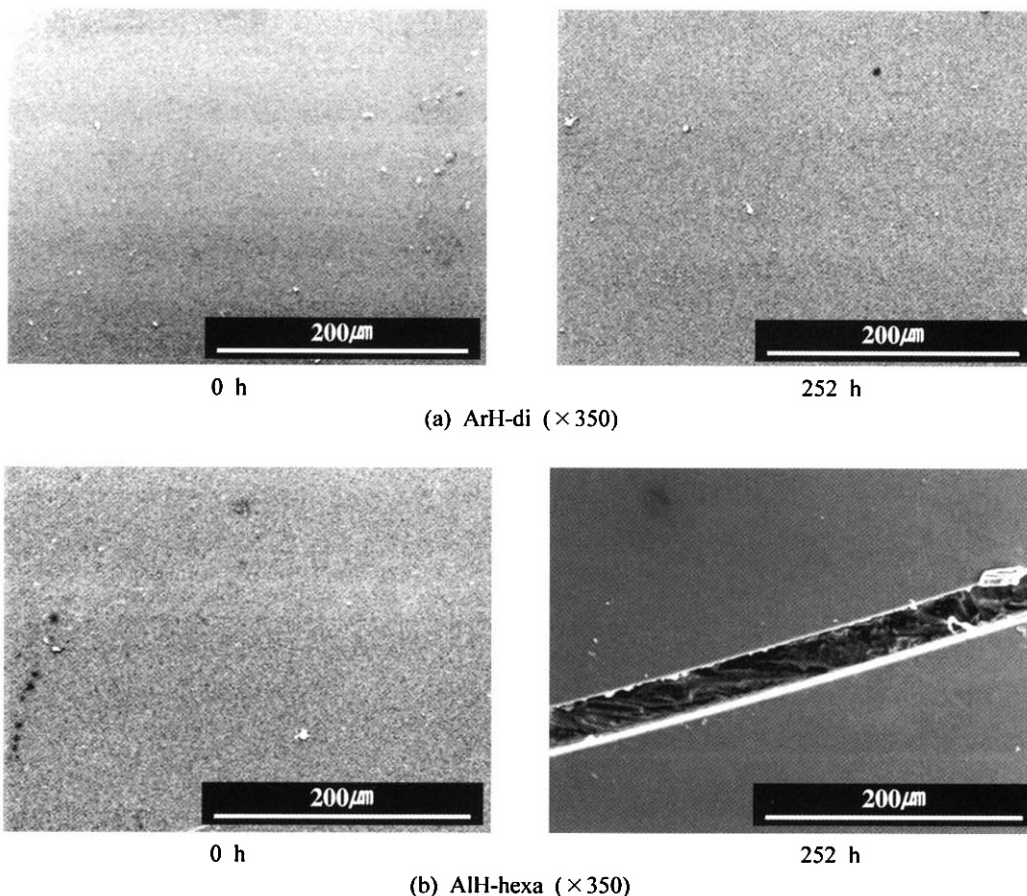


Fig. 9. Surface morphology of the coated fancy veneer overlayed plywood floorings before and after alkaline treatment.

coated fancy veneer overlayed plywood floorings before and after 252 h of the chemical and thermal treatment. As shown in Fig. 9-(a), the surface morphology change of ArH-di was not significant before and after chemical treatment. This result is associated with high gloss retention. However, in the case of AlH-hexa, the cracks appeared on the coated fancy veneer overlayed plywood flooring surface after 252 h of the chemical treatment, as shown in Fig. 9-(b). As explained in previous result, the surface crack is associated with low gloss retention and high discoloration.

4. CONCLUSION

The purpose of this study was to investigate the influence of the acrylated urethane oligomer used on the chemical resistance and thermal resistance of the UV curable urethane acrylate coatings used for fancy veneer overlayed plywood flooring.

In this study, the pencil hardness and abrasion resistance increased with increasing the acrylate functionality of the acrylated urethane oligomer. The abrasion resistance was associated with the degree of the surface curing and the gel content

of the UV curable coating. The adhesion between the intermediate coat and the top coat of ArH-di was the worst. In the case of the chemical resistance test, AlH-di and AlH-hexa exhibited higher chemical degradation than the others. In particular, high gloss change and discoloration of AlH-hexa were observed in the case of AlH-hexa, due to the surface cracks which appeared during the chemical treatment.

In the case of AlH-hexa, discoloration of the coated fancy veneer overlayed plywood flooring was observed near the cracks at the beginning of the chemical treatment. Most of the discoloration was due to chemical reaction between the wood material and the chemical reagent, which penetrated through the cracks, though a little discoloration of the cured film itself may also exist.

In the chemical treatment test of the coated fancy veneer overlayed plywood flooring, the degradation caused by an alkaline reagent was found to be higher than that caused by an acidic reagent. In the case of the thermal resistance, the gloss change and discoloration of ArH-di was the highest.

ACKNOWLEDGMENT

The study is also partially supported by the National Instrumentation Center for Environmental Management (2003-2085).

REFERENCES

1. ASTM D 3359. 2002. Standard Test Method for Measuring Adhesion by Tape Test.
2. ASTM D 3363. 2000. Standard Test Method for Film Hardness by Pencil Test.
3. ASTM D 4060. 2001. Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber.
4. Gay, C. and Leibler, L. 1999. Theory of Tackiness. *Physical Review Letters*. The American Physical Society. 82(5): 936~939.
5. Hepburn, C. 1992. *Polyurethane Elastomers*. Second Edition. Elsevier Applied Science, London. pp. 7~90.
6. Hirose, M., J. Zhou, and F. Kadowaki. 1999. UV Curable Polyurethane-Based Microspheres. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 153: 481~485.
7. Holman, R. 1984. U. V. and E. B. Curing Formulation for Printing Inks, Coatings and Paints. SITA Technology, London. pp. 1~170.
8. Kim, H. K., Y. B. Kim, J. D. Cho, and J. W. Hong. 2003. Synthesis and Characterization of Radiation-Curable Monomers for Antistatic Coatings. *Progress in Organic Coatings*. 48: 34~42.
9. Kim, H.-J. and P. W. Lee. 1989. Studies on the Cracking of Nitrocellulose Clear Lacquer Coated Films on Solid Woods of *Quercus acutissima* and *Betula platyphylla* var. *Japonica*. *Mokchae-konghak*. 17(1): 55
10. KS F 3111. 2001. Plywood Flooring Board Overlayed Fancy Veneer.
11. Mehnert, R., A. Pincus, I. Janorsky, R. Stowe, and A. Berejka. 1998. UV & EB Curing Technology & Equipment. SITA Technology Ltd, John Wiley & Sons, London. pp. 1~247.
12. Mizumachi, H. 2000. Adhesive Tack in Bonding and Debonding. Nitto Technical Report, 38(2): 1~10.
13. Ohata, M. 1991. Study on Physical Properties of UV Curable Wood Finishes. In: Conference Proceedings of RadTech Asia '91, Osaka, Japan, April 15~18 : 116~121.
14. Satas, D. 2002. Handbook of Pressure Sensitive Adhesive Technology and Applications. Satas & Associates, Warwick, Rhode Island. pp. 36~61.
15. Thames, S. F., H. Y. Thomas, P. Schuman and M. D. Wang. 1996. Acrylated Lesquella Oil in Ultraviolet Cured Coating. *Progress in Organic Coatings*. 28: 299~305.
16. Turner, G. P. A. 1988. Introduction to Paint Chemistry and Principles of Paint Technology. Third Edition. Chapman and Hall, New York. pp. 77~78.
17. Wu, S. and M. D. Soucek. 2000. Crosslinking of acrylic latex coatings with cycloaliphatic diepoxide. *Polymer*. 41: 2017~2028.