

# Effects of UV Curable Urethane Acrylate Resins Treatments on the Physical Properties of Medium- and Small-Diameter Softwoods

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**ABSTRACT:** This study analyzed the effects of ultraviolet curable urethane acrylate resin (UV resin) treatments on surface homogeneity, dimensional stability, and change in colors of medium- and small-diameter softwoods produced in Taiwan. The UV resins were formulated with urethane acrylate oligomer/methyl methacrylate (MMA) monomer by the weight ratio of 50/50, 60/40, 70/30, 80/20, and 90/10, and 3% of photoinitiator (benzil dimethyl ketal) by the total weight of UV resins was added, respectively. Four kinds of softwoods, including Taiwanina, China fir, Taiwan incense cedar and Japanese fir with a diameter of 10–15 cm were obtained from Hui-Sun Forest Station, Taiwan. Results show that the oligomer derived from 2-hydroxyethyl methacrylate (2-HEMA) and polymeric toluene diisocyanate (PTDI) by the molar ratio of  $\text{NCO}/\text{OH} = 1.0$  could be readily synthesized and the prepared UV resin were also easily applied to the woods

at room temperature and normal pressure. The surface hardness and moisture excluding efficiency (MEE) of woods were markedly enhanced and correlated with the increased in oligomer content of the UV resins as well as the homogeneity of softwood surfaces were also improved. According to the antiswelling efficiency (ASE), the increased in dimensional stability of woods were achieved; especially for the lower specific gravity China fir had the greatest improved efficiency of 60.68% at oligomer/MMA ratio of 80/20. In addition, a massive, colorful, and warm feeling in sense of sight on UV resin-treated wood, which would appeal to most people, was also obtained. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 121: 1647–1653, 2011

**Key words:** medium- and small diameter softwood; oligomer; resins; surfaces; urethane acrylate

## INTRODUCTION

Wood is an excellent and environment-friendly material which possesses a high ratio of strength to weight and easy to process for every demand. Because of grain patterns and colors, wood is an esthetically pleasing material; and dry wood has good insulating properties against heat, sound, and electricity. In addition, wood resists oxidation, acid, salt water, and other corrosive agent; has a high salvage value; has good shock resistance; and combines with almost any other material for both functional and esthetic uses.<sup>1</sup> Through the unique characteristics and comparative abundance of wood, the natural material have been used for building, structures, furniture, and other objects that lives up to the demands of people in the modern world.

However, the domestic timber yield in Taiwan merely accounts for 0.6%–0.7% of its timber consumption, which determines that the timber raw materials

are almost completely imported. In view of this, the relevant policy shall be formulated to raise the self-sufficiency of domestic timber, such as enlarging planting area and increasing the utilization of medium- and small-diameter woods, which is a necessary channel for Taiwan to maintain the sustainable development of its forestry industry.

Medium- and small-diameter wood refers to the trees which are small in diameter and forest age is not old enough to reach maturity. They are usually of low mechanical strength and the annual ring is comparatively wide but not obvious. They are small in specific gravity and light in weight. They tend to warp after being dried. Because of the lowness in material quality and the high proportion of juvenile wood, they are more heterogeneous than the mature materials in terms of quality, thus tending to swell or shrink as a result of absorption or desorption of moisture. In addition, they are inclined to discolor and deteriorate.<sup>2–4</sup> Generally speaking, it is of low use value. Therefore, it is necessary to expand the application and increase the economical value of the heterogeneous medium- and small-diameter woods by pretreatment to improve the dimensional stability and turn them into the homogeneous industrial materials for furniture making or other utilization.

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In consideration of the rapidness in the growth of softwood, Taiwan vigorously popularized forestation and enjoyed considerably abundant amount of growing stock in softwoods such as *Cunninghamia lanceolata* (China fir), *Taiwania cryptomerioides* (Taiwania), *Cryptomeria japonica* (Japanese fir), and *Calocedrus formosana* (Taiwan incense cedar). However, the timber of these softwoods has not been properly utilized yet. In our previous reports,<sup>5–8</sup> a high-performance polyurethane (PU) resins were synthesized and applied them onto the surfaces of medium- and small-diameter softwoods including China fir, Taiwania, and Japanese fir at room temperature and normal pressure. Through the simple treatment, the PU resins on wood surface could be hardened into a film so as to achieve the purposes of enhancing surface homogeneity, as well as the dimensional stability of the medium- and small-diameter woods.

Although the PU pretreatment has a superior improved efficiency on dimensional stability of wood, the longer drying time of this resin (about 2–4 h) could not be suited to the mass production of lumber for manufacture into furniture or other wood products. In this research, we attempt to synthesize an ultraviolet curable urethane acrylate resin (UV resin) and to analyze the improved efficacy on the homogeneity, dimensional stability as well as the change in colors of medium- and small-diameter softwoods by these UV resin treatments. The UV resin exhibit many advantages, including high solid content (i.e., less volatiles), low viscosity, instantaneous cure at ambient temperature via exposure of ultraviolet, energy saving and space facility, excellent film quality, easy application using conventional equipment and readily used for heat-sensitivity substrate (e.g., wood). In the views of economic benefit and environmental protection, it is in a good agreement with the needs of modern society.<sup>9,10</sup> At present, the oligomer which belongs to acrylate system of free radical polymerization is widely applied in UV resin.<sup>10</sup> This type of UV resin absorbs ultraviolet to produce free radical by photo-fragmenting or hydrogen-donating photoinitiator and simultaneously initializes crosslinking between double bonds of oligomer and monomer, which advantage is rapid curing (i.e., only several seconds). This study further explored the synthesis of acrylate oligomer as well as analyzed the effects of the oligomer/monomer ratios on the physical properties of medium- and small-diameter softwoods treated by UV resin.

## EXPERIMENTAL

### Materials

Polymeric toluene diisocyanate (PTDI) of solid content of 75% was supplied by Ann Feng Company, Taiwan. 2-Hydroxyethyl methacrylate (2-HEMA) was

provided by Sigma Aldrich. Dibutyl tin dilaurate (DBTDL) was purchased from Deuchen Co. Ltd., Taiwan. Methyl methacrylate (MMA) as a monomer was supplied by Kanto Company, Japan. Benzil dimethyl ketal (2,2-dimethoxy-2-phenylacetophenone, commercially denoted as Irgacure 651) was as a photoinitiator and obtained from Ciba Co. Four kinds of thinning medium- and small-diameter softwoods, with a diameter of 10–15 cm including Taiwania (*Taiwania cryptomerioides*, specific gravity of 0.49), China fir (*Cunninghamia lanceolata*, specific gravity of 0.39), Taiwan incense cedar (*Calocedrus formosana*, specific gravity of 0.57), and Japanese fir (*Cryptomeria japonica*, specific gravity of 0.59) were cut from Hui-Sun Forest Station of Experimental Forest of National Chung Hsing University in Nan-Tou County. The specimens with the dimension of 15.0 cm × 5.0 cm × 1.0 cm and 3.0 cm × 3.0 cm × 1.0 cm (longitudinal × tangential × radial direction) were prepared and conditioned to 10% moisture content. Before UV resin treatment, the specimens were sanded with sanding paper by the sequence of #180 and #400.

### Synthesis and characterization of urethane acrylate oligomer

By the molar ratio of NCO/OH = 1.0, i.e., with molar ratio 2-HEMA/PTDI = 3 the calculated amount of PTDI of 292 g was dissolved in ethyl acetate and put in a 1000-mL four-necked round-bottomed flask mounted with a motorized stirrer. The solution was heated to 40°C within 30 min. Then, the mixture of 2-HEMA of 132 g and DBTDL of 1.92 g was added into the flask drop by drop within 30 min and kept stirred for another 60 min. Finally, the ethyl acetate was removed by distillation under reduced pressure and the urethane acrylate oligomer obtained. The speed of stirrer was kept at 200 rpm throughout the reaction. The Fourier transform infrared spectroscopy (FTIR) analysis was used to examine the chemical functionality of the urethane acrylate oligomer.

### Preparation of UV resins

The UV resins were prepared by mixed urethane acrylate oligomer and MMA monomer with different weight ratios of 90/10, 80/20, 70/30, 60/40, and 50/50, and 3% of photoinitiator (Benzil dimethyl ketal) by the total weight of UV resins was added, respectively, and five kinds of UV resins were obtained.

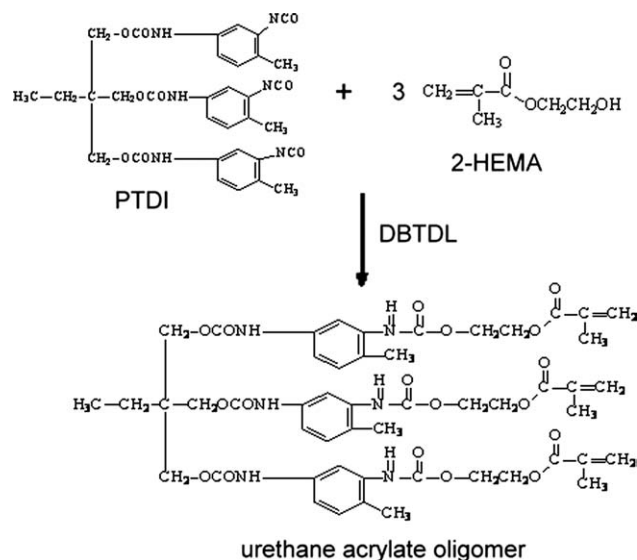
### UV resin treatment and characterization of UV resin-treated wood

The specimen with the dimension of 15.0 cm × 5.0 cm × 1.0 cm for hardness test was coated with UV resin by film applicator and the thickness of wet

film was 100  $\mu\text{m}$ . For moisture absorption test and water-soaked test the specimen with the dimension of 3.0 cm  $\times$  3.0 cm  $\times$  1.0 cm was dipped into UV resin for 10 s at room temperature and normal pressure, and then drawn out for weight measurement. The amount of resin adsorbed averaged 230–240 g/m<sup>2</sup>. After the treatment, the specimens were setting for 5 min to obtain a level wet film and then were irradiated by UV equipment (C-SUN Mfg. Ltd. Taiwan, UVC-362W) with medium pressure mercury lamps (120 W/cm, the major wavelength was 365 nm). The irradiation distance was kept at 10 cm, conveyer speed was 8 m/min and the numbers of irradiation was 1 time, corresponding irradiation time of 9 s. All of the film properties were measured after 24 h.

The hardness of the UV resin-treated wood surfaces was investigated using a König hardness tester (Braive Co.) according to DIN 53157. Ten points were tested with the values averaged for each specimen and a coefficient of variation was also calculated. In moisture absorption tests, the specimens were first placed into an oven at the temperature of 103°C  $\pm$  2°C. After being oven dried, the specimens were moved into a chamber of constant temperature (40°C) and humidity (65% RH and 95% RH) chamber for 72 h, respectively. The equilibrium moisture content (EMC) and moisture excluding efficiency (MEE) were calculated as follows: EMC (%) =  $(W_E - W_o) \times 100/W_o$ , where  $W_E$  = the weight of the specimen at a certain relative humidity, and  $W_o$  = the oven-dried weight of the specimen. MEE (%) =  $(E_c - E_t) \times 100/E_c$ , where  $E_c$  = the EMC of untreated specimen, and  $E_t$  = the EMC of UV resin-treated specimen. The measurements were made in triplicate with the values averaged.

In water-soaked tests, the specimens were oven dried with the volume and weight measured. The specimens were soaked in distilled water under reduced pressure for 30 min, and then under normal pressure for 1 h, and again under reduced pressure for another 30 min. Following that, the pressure was restored to normal for 1 day and the distilled water was replaced. The above-mentioned procedures were repeated for 7 days after which the volume and weight of specimens after wetted with water were measured. The water absorption percent (WAP), volumetric swelling coefficient ( $S$ ), and antiswelling efficiency (ASE) were calculated as follows: WAP (%) =  $(W_w - W_o) \times 100/W_o$ , where  $W_w$  = the weight of specimen after wetted with water, and  $W_o$  = the weight of oven-dried specimen before wetting.  $S$ (%) =  $(V_w - V_o) \times 100/V_o$ , where  $V_w$  = the wood volume of specimen after wetted with water, and  $V_o$  = the wood volume of oven-dried specimen before wetting. ASE (%) =  $(S_c - S_t) \times 100/S_c$ , where  $S_c$  = the  $S$  of the untreated specimen, and  $S_t$  = the  $S$  of the UV resin-treated specimen. The measurements were also made in triplicate with the values averaged.



**Figure 1** Urethane acrylate oligomer produced from PTDI and 2-HEMA.

The changes in color of the specimens after UV resin-treated were measured with a spectrophotometer (CM-3600d, Minolta, Osaka, Japan) fitted with a D<sub>65</sub> light source with a measuring angle of 10° and a test-window diameter of 8 mm. The tristimulus values X, Y, and Z of all specimens were obtained directly from the colorimeter. The CIE  $L^*$ ,  $a^*$ ,  $b^*$  color parameters were then computed, followed by calculating the brightness difference ( $\Delta L^*$ ), chroma difference ( $\Delta C^*$ ), and hue difference ( $\Delta H^*$ ) directly from the Minolta MCS software system. Six points were tested with the values averaged for each specimen.

## RESULTS AND DISCUSSION

### Synthesis of urethane acrylate oligomer

The synthesis of urethane acrylate oligomer was performed by urethane linkage (—NHCOO—) through addition polymerization between a —OH group in 2-hydroxyethyl methacrylate (2-HEMA) and —NCO group in polymeric isocyanate (PTDI). A simplified schematic depicting this reaction scheme is provided in Figure 1. The FTIR analysis (Fig. 2) showed that the absorbance of 2281 cm<sup>-1</sup> (—NCO group) in PTDI and 3425 cm<sup>-1</sup> (—OH group) in 2-HEMA disappeared in urethane acrylate oligomer spectrum. In the meantime, the relative absorption of urethane linkage (—NHCOO—) including 1073 cm<sup>-1</sup> (C—O stretching vibration), 1227 cm<sup>-1</sup> (C—O stretching vibration), 1533 cm<sup>-1</sup> (N—H bending vibration), 1732 cm<sup>-1</sup> (C=O stretching vibration), and 3327 cm<sup>-1</sup> (N—H stretching vibration) were detected in urethane acrylate oligomer, meaning that the oligomer obtained by reacting PTDI with 2-HEMA. Furthermore, the 975 and 1650 cm<sup>-1</sup> peak representing the double bond of

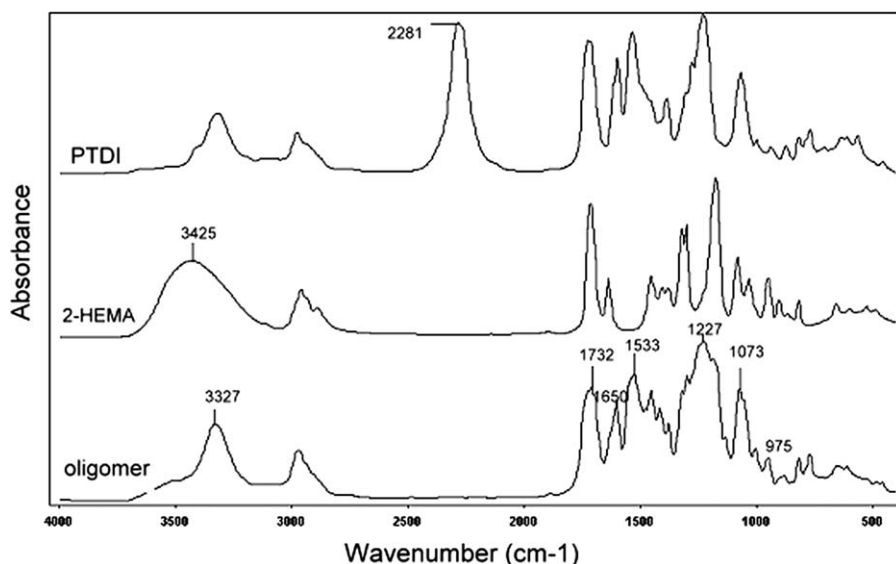


Figure 2 FTIR spectra of PTDI, 2-HEMA, and urethane acrylate oligomer.

methyl-acryloyl [ $\text{CH}=\text{C}(\text{CH}_3)\text{CO}-$ ] were also found in the oligomer. The similar reaction for the preparation of functional oligomers using the reaction between a hydroxyl and functional isocyanate well was described.<sup>11–13</sup> The UV resin system and then was developed by curing a double bond of acryloyl group of oligomer and MMA monomer through free radical polymerization via UV radiation and the reaction scheme is provided in Figure 3.

#### Surface hardness and dimensional stability of UV resin-treated woods

The surface hardness of various UV resin-treated woods is shown in Table I. The hardness of untreated Taiwania, China fir, Taiwan incense cedar, and Japanese fir were 47, 47, 60, and 50 s, respectively, and were remarkably enhanced by UV resin treatments and well also increased with increasing the urethane acrylate oligomer content of the UV resins. Take Taiwania for instance, when compared to the control specimen, the increase in hardness were from 38 to 242% which were proportioned to the oligomer/MMA ratios of 50/50 to 90/10. As seen in Table I, the specimen of oligomer/MMA = 90/10 treated one for all of the woods had the highest surface hardness, attributed to the fact that a more oligomer content of UV resin has higher viscosity and less penetrate to the cell wall and the wet film is easy cured completely by UV irradiation.

The coefficients of variation in surface hardness of UV resin-treated woods were lowered than that of untreated woods. To be more specific, the coefficient of variation for Taiwania decreased from 25.53% to 9.93%–16.84%; from 34.04% to 12.63%–20.83% for China fir; from 18.33% to 6.54%–15.71% for Taiwan

incense cedar; and from 52.00% to 8.72%–20.00% for Japanese fir. Although there was no regularity in decreasing coefficient of variation with proportion to the oligomer/MMA ratio, the results revealed that more homogeneous wood surface would be obtained by UV resin treatments. Generally speaking, the oligomer/MMA ratios of 80/20 and 90/10 had a superior improved efficiency on the homogeneity of medium- and small-diameter softwood surfaces.

The equilibrium moisture content (EMC) and moisture excluding efficiency (MEE) of UV resin-treated woods at 65% RH and 95% RH tests are listed in Table II. The EMCs of untreated woods were higher than those of the UV resin-treated woods at 65% RH. For instance, the EMC of the untreated Taiwania was 10.11%; after UV resin treatments, the EMCs of the treated wood were reduced to 8.06–4.27% as well as the MEE increased from 20.28% of untreated wood to

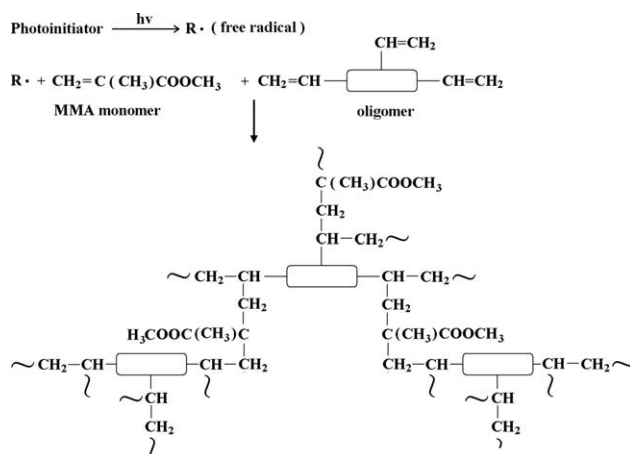


Figure 3 Photopolymerization process.



**TABLE I**  
Surface Hardness and Percentage of Increase in Hardness of UV Resin-Treated Woods

Oligomer/MMA (by wt %) <sup>a</sup>	Taiwania		China fir		Taiwan incense cedar		Japanese fir	
	Hardness (%)	Increase in hardness (%) <sup>b</sup>	Hardness (%)	Increase in hardness (%)	Hardness (%)	Increase in hardness (%)	Hardness (%)	Increase in hardness (%)
Control	47 (25.53) <sup>c</sup>	–	47 (34.04)	–	60 (18.33)	–	50 (52.00)	–
50/50	65 (15.38)	38	68 (20.59)	45	70 (15.71)	17	65 (20.00)	30
60/40	95 (16.84)	102	95 (12.63)	102	109 (11.93)	82	119 (15.38)	138
70/30	112 (15.18)	138	96 (20.83)	104	141 (12.77)	135	127 (16.54)	154
80/20	148 (12.84)	214	135 (15.56)	187	153 (6.54)	155	143 (12.59)	186
90/10	161 (9.93)	242	153 (15.69)	226	170 (9.41)	183	172 (8.72)	244

<sup>a</sup> 3% Photoinitiator was added by the weight of UV resin.

<sup>b</sup> Increase in hardness (%) = (Surface hardness of UV resin-treated wood – Surface hardness of untreated wood) × 100 / Surface hardness of untreated wood.

<sup>c</sup> Figure in bracket means coefficient of variation (%) = Standard deviation × 100 / Average.

57.76% of UV resin-treated ones and with proportion to the oligomer/MMA ratios of 50/50–90/10, i.e., the higher oligomer content the lower EMC and a superior MEE were observed. The similar trends were found for the other softwoods. The results indicated that UV resin could be hardened into a film on the surface and void of the wood and the higher oligomer content resins could obtain a good cross-linking film just mentioned above, thus delaying and reducing moisture absorption. The EMCs and MEEs of the UV resin-treated wood in the high-humidity environment of 95% RH showed the same trends as

those in the environment of 65% RH, but it had a higher EMC and lower MEE values. The high MEE value of UV resin-treated softwoods were comparable to the other thermosetting resins such as phenol formaldehyde (PF), melamine formaldehyde (MF), urea formaldehyde (UF),<sup>14</sup> and polyurethane (PU)<sup>8</sup> treated softwoods ones.

The dimensional stability of UV resin-treated woods is evaluated by the water-soaked tests, after the tested the film adhered to the wood and no demolition occurred, and the water absorption percent (WAP), volumetric swelling coefficient (S), and

**TABLE II**  
EMC and MEE of UV Resin-Treated Woods

Wood	Oligomer/MMA (by wt %) <sup>a</sup>	65% RH		95% RH	
		EMC (%)	MEE (%)	EMC (%)	MEE (%)
Taiwania	Control	10.11	–	19.46	–
	50/50	8.06	20.28	16.08	17.37
	60/40	7.29	27.89	15.65	19.58
	70/30	7.58	25.02	15.10	22.40
	80/20	5.78	42.83	13.29	31.71
	90/10	4.27	57.76	12.25	37.05
China fir	Control	9.79	–	17.74	–
	50/50	7.11	27.38	13.54	23.68
	60/40	6.99	28.60	13.47	24.07
	70/30	6.25	36.16	11.71	33.99
	80/20	4.80	50.97	11.23	36.70
	90/10	5.57	42.33	12.62	28.86
Taiwan incense cedar	Control	10.36	–	19.33	–
	50/50	8.31	19.79	15.72	18.68
	60/40	8.05	22.29	15.85	18.00
	70/30	7.43	28.28	15.06	22.09
	80/20	7.67	25.96	15.30	20.85
	90/10	4.33	58.20	12.18	36.99
Japanese fir	Control	9.96	–	19.83	–
	50/50	7.98	19.90	17.10	13.77
	60/40	7.27	27.01	16.00	19.31
	70/30	7.20	27.71	15.29	22.89
	80/20	5.42	45.58	13.27	33.08
	90/10	5.20	47.79	13.47	32.07

<sup>a</sup> 3% Photoinitiator was added by the weight of UV resin.

antiswelling efficiency (ASE) are shown in Table III. As can be seen, the lower the specific gravity of wood, the higher WAP of untreated wood was obtained, such as the WAP of 220, 174, 156, and 121% for China fir (sp. gr. of 0.39), Taiwania (sp. gr. of 0.49), Taiwan incense cedar (sp. gr. of 0.57) and Japanese fir (sp. gr. of 0.59), respectively. After UV resin treatments, the WAPs and S of all specimens were decreased, while there was no clear trend observed in oligomer/MMA ratios. However, the results also showed that comparing with the other UV resin-treated woods, the China fir had a higher ASE value in the same oligomer/MMA ratios of 50/50, 60/40, 70/30, and 80/20, meaning that it had a greater improved efficiency on dimensional stability after UV resin treatments. These are attributed to the fact that the more MMA monomer content possesses a lower viscosity and it is easy penetrate to the wood cell wall or void with low specific gravity to a greater extent. Because of the different cellular structure, each wood had the highest ASE in an adequate oligomer/MMA ratio, for instance, ASE value of 30.89 and 60.68% for Taiwania and China fir, respectively, in the ratio of 80/20; of 25.91% for Taiwan incense cedar in the ratio of 50/50; and of 55.01% for Japanese fir in the ratio of 90/10.

Because of the esthetically pleasing character of wood must be kept or enhanced for practical utiliza-

**TABLE III**  
WAP, S, and ASE of UV Resin-Treated Woods

Wood	Oligomer/MMA (by wt) <sup>a</sup>	WAP (%)	S (%)	ASE (%)
Taiwania	Control	174	14.46	–
	50/50	99	12.63	12.66
	60/40	94	11.30	21.85
	70/30	103	12.42	14.11
	80/20	75	9.98	30.98
China fir	90/10	94	11.95	17.36
	Control	220	17.65	–
	50/50	123	11.99	32.06
	60/40	114	9.67	45.21
	70/30	76	9.87	44.08
Taiwan incense cedar	80/20	131	6.94	60.68
	90/10	93	12.42	29.63
	Control	156	13.97	–
	50/50	119	10.35	25.91
	60/40	97	10.70	23.40
Japanese fir	70/30	76	10.79	22.76
	80/20	114	11.87	15.03
	90/10	88	11.87	15.03
	Control	121	16.36	–
	50/50	96	13.62	16.75
	60/40	90	15.39	5.93
	70/30	126	11.44	30.07
	80/20	112	12.59	23.04
	90/10	41	7.36	55.01

<sup>a</sup> 3% of photoinitiator was added by the weight of total of UV resin.

**TABLE IV**  
 $\Delta L^*$ ,  $\Delta C^*$ ,  $\Delta H^*$ , and  $\Delta E^*$  of UV Resin-Treated Woods

Wood	Oligomer/MMA (by wt) <sup>a</sup>	$\Delta L^*$	$\Delta C^*$	$\Delta H^*$
Taiwania	50/50	–5.62	9.19	–1.89
	60/40	–5.76	7.61	–1.98
	70/30	–2.96	6.24	–1.39
	80/20	–11.80	4.74	–4.20
	90/10	–10.74	5.14	–4.06
China fir	50/50	–5.33	7.74	–0.87
	60/40	–5.51	7.33	–1.39
	70/30	–5.75	7.93	–2.10
	80/20	–4.01	7.13	–1.06
	90/10	–5.60	11.02	0.28
Taiwan incense cedar	50/50	–4.82	8.65	–1.14
	60/40	–6.99	6.78	–5.09
	70/30	–4.04	4.56	–1.97
	80/20	–7.21	11.25	–2.23
	90/10	–3.63	7.42	0.48
Japanese fir	50/50	–7.83	6.12	–2.03
	60/40	–10.82	4.55	–4.65
	70/30	–6.74	8.94	–0.14
	80/20	–5.09	8.20	1.50
	90/10	–4.17	7.12	0.65

<sup>a</sup> 3% of photoinitiator was added by the weight of total of UV resin.

tion, the change in colors of wood after UV treatment must also be examined. The brightness difference ( $\Delta L^*$ ), chroma difference ( $\Delta C^*$ ), and hue difference ( $\Delta H^*$ ) of woods after UV resin treatments are listed in Table IV. Although there was no regularity in the oligomer/MMA ratios, all  $\Delta L^*$  of specimens were negative value, meaning it reduced the brightness of wood after UV resin treatments and it exhibited a massive feeling of UV resin-treated wood as well. In addition, all  $\Delta C^*$  of specimens were positive value, the increase in chroma representing a vivid feeling in the sense of sight on the UV resin-treated woods. Owing to the different nature color of the softwoods in this study, except the  $\Delta H^*$  of UV resin-treated China fir, Taiwan incense cedar, and Japanese fir with the oligomer/MMA ratio of 90/10 and Japanese fir with the 82/20 one, were positive value, meaning a slight yellowish color obtained. Most of the UV resin-treated woods had a minus  $\Delta H^*$  value, indicating the woods exhibited a deeper red color and the warm feeling of the wood could be enhanced after UV resin treatments.

## CONCLUSIONS

In this study, the urethane acrylate oligomer could be readily synthesized and the prepared UV resin with different oligomer/MMA ratios were also easily applied to the medium- and small-diameter softwoods at room temperature and normal pressure. The surface hardness and MEE of woods were markedly enhanced and correlated with the increased in oligomer content of the UV resins as well as the homogeneity of medium-

and small-diameter softwood surfaces were also improved. According to the ASE, the increases in dimensional stability of woods were achieved; especially for the lower specific gravity China fir had the greatest improved efficiency. In addition, darker, colorful, and reddish tone of UV resin-treated wood, which would appeal to most people, was also obtained.

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