

Effect of Nitrocellulose on the Properties of PU–NC Semi-IPN Wood Coatings

Kun-Tsung Lu,¹ Cheng-Tzu Liu,¹ Hong-Lin Lee²

¹Department of Forestry, National Chung-Hsing University, Taichung, 402 Taiwan

²Taiwan Forestry Research Institute, Taipei, 100 Taiwan

Received 9 July 2002; accepted 25 October 2002

ABSTRACT: Wood coatings of PU–NC semi-interpenetrating polymer networks (semi-IPNs), made from blown castor oil (BCO), aromatic polyisocyanate (PTDI), and nitrocellulose (NC), were prepared by sequential polymerization method. To investigate the effects of NC on the properties of PU–NC semi-IPNs wood coatings, three different viscosities of NC ($\frac{1}{2}$ -sec, $\frac{1}{4}$ -sec, and $\frac{1}{16}$ -sec), and a PU catalyst [dibutyltin dilaurate (DBTDL)] were synthesized in this study. The results revealed that the PU–NC semi-IPNs with $\frac{1}{2}$ -sec NC-containing coating had the shortest drying time, and their films had the best tensile strength, elongation at break, lightfastness, and solvent resistance. Dynamic mechanical analysis showed that PU–NC semi-IPNs with $\frac{1}{2}$ -sec NC or $\frac{1}{16}$ -sec

NC had good interpenetration between PU and NC, whereas PU–NC semi-IPNs with $\frac{1}{4}$ -sec NC had a slight separation phase between PU and NC. In both PU–NC semi-IPNs with $\frac{1}{4}$ -sec NC and those with $\frac{1}{16}$ -sec NC, the addition of 0.2% DBTDL could effectively reduce the drying time of the coating and improve the film properties, including tensile strength, elongation at break, and lightfastness. In addition, the miscibility of PU and NC was examined in PU–NC semi-IPNs with $\frac{1}{4}$ -sec NC. © 2003 Wiley Periodicals, Inc. *J Appl Polym Sci* 89: 2157–2162, 2003

Key words: networks; polyurethanes; catalysts; coatings

INTRODUCTION

Interpenetrating polymer networks (IPNs), are a combination of two or more polymers in network form, with at least one such polymer polymerized and/or crosslinked on the immediate presence of the other network.^{1–2} The substrates, held together predominantly by the permanent entanglement of two crosslinked components rather than by covalent grafting between them, exhibit excellent film characteristics compared to other combinations of blocking or grafting copolymers.³ If both polymers of the IPNs are crosslinked, then they are known as full-IPNs. If only one of the two components is networked, then the other one is in the form of a linear polymer, and their composite is called a semi-IPN. The semi-IPNs can be obtained either by the crosslinking of a functionalized polymer with a linear polymer blend, or by the polymerization of a multifunction monomer dispersed in a linear polymer. Chemists have drawn attention to this type of polymer, since it can create new organic compounds through the aforementioned technique.⁴

The use of renewable resources has also been monitored by many researchers because of their high potential as substitutes for petrochemical derivatives. Castor oil, a naturally occurring triglyceride of ricin-

oleic acid, is a fine candidate for making IPNs.^{5–12} The hydroxyl functionality in castor oil can be used as a polyol to react with isocyanate and form polyurethane (PU) networks through a step-growth reaction. Compared to two-package PU for wood coatings, castor oil possesses several good properties in its films. However, the application of this wood coating still has numerous drawbacks, such as slow drying rate, limited pot-life, and lower hardness than PU.

Nitrocellulose (NC), a wood coating resin with a linear polymer formed by the nitration of cotton or wood pulp, has higher hardness, a faster drying rate, and excellent compatibility compared to other commonly used resins. Wood products finished by NC-containing coatings are appealing to most people. Although NC is an appropriate resin for wood coating, its films still have several drawbacks, such as yellowing, poor chemical and solvent resistance, poor thermal resistance, need to be improved.

The semi-IPNs, based on castor oil, PU, and NC wood coatings, have previously been investigated by the authors.^{13–14} The reports revealed that the drying time of PU can be effectively reduced, and an unlimited pot-life was observed after interpenetrating PU with NC. The formulation of PU–NC semi-IPN wood coatings, based on PU with molar ratio of NCO : OH of 1.2, and a PU : NC weight ratio of 70 : 30, can be conducted under the best conditions for compatibility, resulting in the best interpenetration between PU and NC and better coating and film properties for use as a wood finish.

Correspondence to: K. T. Lu (lukt@ms64.url.com.tw).

TABLE I
Constituents of Chemicals Applied in the Study of PU-NC Semi-IPNs

Materials	Description
NC	Nitrocellulose, viscosity = $\frac{1}{2}$ -sec, $\frac{1}{4}$ -sec and $\frac{1}{16}$ -sec (by falling ball viscometer); solid content = 50% (solvent MEK).
BCO	Blown castor oil, acid value = 2; OH value = 159.
PTDI	Aromatic adduct derived from toluene diisocyanate by reaction with trimethylpropane, solid content = $75 \pm 1\%$ (solvent BAc); NCO value = 12.4%.
DBTDL	Dibutyltin dilaurate, PU catalyst.
PU Thinner	MIBK : EAc : BAc : Xylene : Toluene = 10 : 20 : 20 : 20 : 30 (by wt.), Reagent grade.

The film and coating properties of the PU-NC semi-IPNs depend on the applied constituents of PU hardeners and catalysts, and on the molecular weight of NC. The effectiveness of PU hardeners, polyisocyanate and PU catalysts on the film properties of PU-NC semi-IPNs has been studied by the authors.¹⁵⁻¹⁶ To explore and better understand the application of PU-NC semi-IPNs as wood coatings, three different commercially used NC viscosities ($\frac{1}{2}$ sec, $\frac{1}{4}$ sec and $\frac{1}{16}$ sec) and a PU catalyst, dibutyltin dilaurate (DBTDL), added at 0.2% in blown castor oil (BCO) (w/w), were further investigated in this research.

EXPERIMENTAL

Materials

Table I lists the applied wood coatings, catalyst, thinner and their descriptions. The specimens tested for coating include hard maple (*Acer sp.*), veneered plywood, glass panels, Teflon panels, and white cardboard. They were treated according to different testing requirements.

Preparation of PU-NC Semi-IPNs

Reaction chemicals were maintained at a molar ratio of NCO : (OH + COOH) of 1.2, and at a weight ratio of PU : NC of 70 : 30. Three different kinds of PU-NC semi-IPNs coatings were prepared as follows. First, the calculated amounts of BCO and each of the $\frac{1}{2}$ -sec, $\frac{1}{4}$ -sec, and $\frac{1}{16}$ -sec NC samples were mixed in three 1000 mL sanded flasks at room temperature. Second, the mixture was stirred vigorously with a stirring device at room temperature for 30 min. Third, the calculated amounts of polyisocyanate (PTDI) and PU thinner were added dropwise into the above mixture and stirred for another 30 min. The solid content of the synthesized compounds was maintained at 50% during the reaction. Finally, a 0.2% PU catalyst of DBTDL (by weight of BCO) was added to the synthesized compounds and the mixture was stirred for 30 min.

The resultant coatings were kept at room temperature until all bubbling ceased and then finished on different kinds of substrates with film applicators. The

thickness of the wet films was adjusted to 200 μm and 100 μm for the drying time test. All finished specimens were conditioned at room temperature for one week before testing.

Characterization

Tests of viscosity for wood coatings were carried out on a Gardner bubble viscometer at 30°C. Drying time tests of coatings was performed on a three-speed B. K. drying time recorder at 30°C and 65% RH (relative humidity). The gel time of each coating was identified by its flowing characteristics at room temperature.

The adhesion properties of the tested films were determined by the cross-cut method according to CNS K 6800. The tensile strength of the tested films was determined on a Shimadzu Autograph S-500 instrument with a crosshead speed of 20 mm/min. All tested specimens were sized to 25 \times 150mm, and five samples were tested for each treatment. The hardness of the tested films was investigated on a König hardness tester (Braive Co.) according to DIN 53157, and at least five points were tested for each specimen.

The lightfastness of the tested films was determined using a SUGA Standard UV Long-Life Fade Meter. The light source was applied as a carbon arc, and its black panel temperature was adjusted to $63 \pm 2^\circ\text{C}$. After 100 h of exposure, the ΔL^* (brightness difference), ΔE^* (color difference), and ΔYI (change in yellowness) of the specimens were measured at five different points for each specimen using a color and color difference meter, a SUGA Color Computer SM-5. The data were further computed from the average of the five points for each specimen.

Thermal stability determinations of tested films were carried out on a thermogravimetric analysis (TGA) instrument, a Setaram model TGA92-12, in a nitrogen atmosphere from 25 to 650°C at a heating rate of 10°C/min. The weight of the tested samples was about 10 mg.

The chemical and solvent resistance of the films was measured by putting each weighted film into 100 mL of PU thinner for 48 h. In order to remove the remaining thinner, the soaked film was further dried in an 80°C oven for 24 h. The weight retention of tested film was calculated as the chemical and solvent resistance.

TABLE II
Properties of PU-NC Semi-IPNs Coatings

Sample Code	DBTDL (%)	Viscosity (Gardner, 30°C)	Drying Time (min)	Gel Time (d)
$\frac{1}{2}$ -sec NC	0	W	30	>30
	0.2	Y	30	0.5
$\frac{1}{4}$ -sec NC	0	P	170	>30
	0.2	P	30	0.5
$\frac{1}{16}$ -sec NC	0	H	190	>30
	0.2	H	45	0.5

Hot and cold cycle tests of the films were carried out on hard maple veneered plywood coated with different synthesized wood coatings. One test cycle of the specimens consisted of placing them in a -20°C refrigerator for 2 h, and then transferring them to a 50°C oven for another 2 h. Ten test cycles were performed on the coated specimens, and the gloss retention of the films was also measured during the test cycles. The cycle number was recorded if the films were cracked.

Dynamic mechanical analysis (DMA) of the films to determine glass transition temperature (T_g) and maximum loss tangent ($\tan \delta_{\max}$) was performed in a nitrogen atmosphere from -20 to 200°C on a Perkin-Elmer DMA 7e according to the tension method. The heating rate was set at $5^{\circ}\text{C}/\text{min}$, and the resonance frequency was adjusted to 1 Hz. The sample size was approximately $5 \times 15\text{mm}$.

RESULTS AND DISCUSSION

Coating properties

The properties of PU-NC semi-IPNs with different NC wood coatings are listed in Table II. Among all of the semi-IPNs without added PU catalyst, the $\frac{1}{2}$ -sec NC-containing coating showed the highest viscosity value of W, and the $\frac{1}{16}$ -sec NC-containing coating showed the lowest viscosity value of H, indicating that the viscosity of PU-NC semi-IPN coatings was apparently affected by the molecular weight of NC. As

reported, the molecular weights of the $\frac{1}{2}$ -sec NC, $\frac{1}{4}$ -sec NC, and $\frac{1}{8}$ -sec NC were 21,100–26,400, 13,200–18,500, and 10,500–13,200, respectively. Therefore, the molecular weight of the $\frac{1}{16}$ -sec NC was assumed to be below 10,000. Furthermore, after the addition of 0.2% DBTDL, the viscosity value of the $\frac{1}{2}$ -sec NC-containing coating was increased from W to Y, whereas the $\frac{1}{4}$ -sec NC, and $\frac{1}{16}$ -sec NC-containing coatings were unaffected.

Before the addition of 0.2% DBTDL, the drying time of the $\frac{1}{2}$ -in NC, $\frac{1}{4}$ -in NC, $\frac{1}{16}$ -in NC-containing films were 30 min, 170 min, and 190 min, respectively. After the addition of 0.2% DBTDL, the drying times of the $\frac{1}{4}$ -in NC and $\frac{1}{16}$ -in NC-containing films were reduced from 170 to 35 min, and from 190 to 45 min, respectively. However, the drying time was not changed in the $\frac{1}{2}$ -in NC-containing film, and its value remained at 30 min. The results indicated that the drying rate of PU-NC semi-IPNs with $\frac{1}{4}$ -in NC or $\frac{1}{16}$ -in NC could be reduced significantly with the addition of a PU catalyst.

In this study, all tested coatings, before the addition of a PU catalyst, could be kept at a flowing condition for more than 30 days. However, the tested coatings were galled at 12 h after the addition of 0.2% DBTDL. The results also indicated that PU-NC semi-IPN coatings had no pot-life limitation before the addition of a PU catalyst.

Mechanical properties

Mechanical properties of the PU-NC Semi-IPNs films are listed in Table III. The results revealed that the films of all PU-NC semi-IPN coatings, before or after the addition of a PU catalyst, possessed excellent adhesion properties. Among all of the PU-NC semi-IPN coatings before the addition of a PU catalyst, the highest tensile strength was observed to be $361.2 \text{ kg f cm}^{-2}$ from the $\frac{1}{2}$ -sec NC-containing coating, and its elongation at break was 5.5%. Moreover, the $\frac{1}{16}$ -sec NC-containing film showed a brittle phenomenon, resulting in the lowest tensile strength of $91.1 \text{ kg f cm}^{-2}$, and the lowest elongation of break of 1.3%. Among all tested films, the tensile strength and elongation at break could be im-

TABLE III
Mechanical Properties of PU-NC Semi-IPNs Films

Sample Code	DBTDL (%)	Adhesion	Tensile-Strength (kgf cm^{-2})	Elongation at Break (%)	Hardness (könig, sec)
$\frac{1}{2}$ -sec NC	0	10	361.2	5.5	141
	0.2	10	391.4	5.5	142
$\frac{1}{4}$ -sec NC	0	10	132.5	2.0	137
	0.2	10	355.6	4.8	144
$\frac{1}{16}$ -sec NC	0	10	91.1	1.3	144
	0.2	10	285.5	4.4	142

TABLE IV
Changes in Lightfastness of PU-NC Semi-IPNs Films After Exposure to Carbon Arc

Sample Code	DBTDL (%)	ΔL^*	ΔE^*	ΔYI
$\frac{1}{2}$ -sec NC	0	-28.44	37.78	84.02
	0.2	-27.87	41.37	99.79
$\frac{1}{4}$ -sec NC	0	-31.85	44.52	109.99
	0.2	-27.95	41.56	100.71
$\frac{1}{16}$ -sec NC	0	-31.08	44.39	109.16
	0.2	-25.52	39.97	99.62

Exposure lasted 100 h

proved after the addition of 0.2% DBTDL, especially when lower viscosity NC was used. For example, the tensile strengths of the $\frac{1}{4}$ -sec NC and the $\frac{1}{16}$ -sec NC-containing coating, before the addition of 2% DBTDL, were 132.5 and 91.1 kg f cm⁻², and after the addition of catalyst were 355.6 and 285.5 kg f cm⁻², respectively. The same tendency was observed in the film elongation at break. The results revealed that the properties of tensile strength and elongation at break of the PU-NC semi-IPNs with lower viscosity ($\frac{1}{4}$ -sec NC or $\frac{1}{16}$ -sec NC) could be improved after the addition of PU catalyst. However, similar results were not observed in the PU-NC semi-IPNs with higher viscosity ($\frac{1}{2}$ -sec NC).

By comparison with the hardness of the PU-NC semi-IPNs films before the addition of PU catalyst, the $\frac{1}{16}$ -sec NC-containing film had the highest value of hardness at 144, and no significant difference was observed among all tested films. Moreover, an obvious change in the hardness of PU-NC semi-IPN films with the addition of a PU catalyst was observed for the $\frac{1}{4}$ -sec NC-containing films, from 137 to 144, respectively. However, little change in film hardness was found in the $\frac{1}{2}$ -sec NC or $\frac{1}{16}$ -sec NC-containing films after the addition of 0.2% DBTDL.

Lightfastness

Table IV lists changes in the lightfastness (the ΔL^* , ΔE^* , and ΔYI values) of the PU-NC semi-IPNs with

different NC films after exposure to a carbon arc for 100 h. Of all PU-NC semi-IPNs films, before the addition of a PU catalyst and after exposure to a carbon arc for 100 h, the $\frac{1}{2}$ -sec NC-containing films showed the least change in lightfastness, and their values of ΔL^* , ΔE^* , and ΔYI were -28.44, 37.78, and 84.02, respectively. For all PU-NC semi-IPNs films after the addition of 0.2% DBTDL and exposure to a carbon arc for 100 h, different tendencies of change in ΔL^* , ΔE^* , and ΔYI values were observed among the $\frac{1}{2}$ -sec NC, $\frac{1}{4}$ -sec NC, and $\frac{1}{16}$ -sec NC-containing films. The ΔL^* , ΔE^* , and ΔYI values of the $\frac{1}{2}$ -sec NC-containing films changed from -28.44 to -27.87, 37.78 to 41.37, and 84.02 to 99.79, respectively. A slight decrease in ΔL^* values and an obvious increase in ΔE^* and ΔYI values was observed in the $\frac{1}{2}$ -sec NC-containing films. However, different results were obtained for the $\frac{1}{4}$ -sec NC and $\frac{1}{16}$ -sec NC-containing films, for which the ΔL^* , ΔE^* , and ΔYI values changed from -31.85 to -27.95, 44.52 to 41.56, and 109.99 to 100.71, as well as from -31.08 to -25.52, 44.39 to 39.97, and 109.16 to 99.62, respectively. The results revealed that the addition of 0.2% DBTDL affects the lightfastness values of the films of PU-NC semi-IPNs, and the lightfastness of the films can be improved in $\frac{1}{4}$ -sec NC and $\frac{1}{16}$ -sec NC, especially with the lowest viscosity ($\frac{1}{16}$ -sec) NC. It was hypothesized that lower molecular weights of $\frac{1}{16}$ -sec NC could interpenetrate between NC and PU, and that the NC moiety was shielded by the PU moiety, resulting in less photodegradation of the film when exposed to UV light.

Thermal properties

The weight loss percentages for PU-NC semi-IPNs with different NC were evaluated by TGA, as summarized in Table V. Among all of the tested films before the addition of PU catalyst, the $\frac{1}{2}$ -sec NC-containing film had the least weight loss of 6% at 220°C, whereas both the $\frac{1}{4}$ -sec NC and the $\frac{1}{16}$ -sec NC-containing films showed only 7% weight loss. Weight loss at 220°C from PU-NC semi-IPN films was less than that of NC

TABLE V
Weight Loss Percentage of PU-NC Semi-IPNs Films at Different Temperatures

Sample Code	DBTDL (%)	Temperature (°C)										
		200	220	250	300	350	400	450	500	550	600	650
$\frac{1}{2}$ -sec NC	0	0	6	9	21	40	53	65	73	74	74	74
	0.2	0	8	13	25	37	42	51	59	63	70	79
$\frac{1}{4}$ -sec NC	0	0	7	12	26	41	46	54	63	66	71	76
	0.2	0	7	11	23	37	42	48	55	59	66	73
$\frac{1}{16}$ -sec NC	0	0	7	12	24	38	42	51	59	63	70	78
	0.2	0	6	10	22	36	41	48	56	60	65	72

Determined by TGA

TABLE VI
Percent Weight Retention and Gloss Retention of PU-NC Semi-IPNs Films After 10 Hot and Cold Test Cycles

Sample Code	Percent Weight Retention		Gloss Retention	
	DBTDL (%)		DBTDL (%)	
	0	0.2	0	0.2
$\frac{1}{2}$ -sec NC	91.35	89.01	97	92
$\frac{1}{4}$ -sec NC	50.72	86.63	100	96
$\frac{1}{16}$ -sec NC	87.46	87.48	95	100

at 83%, as presented in our previous report.¹⁴ Theoretically, the weight loss of the films at 220°C is about 25% ($30 \times 83\%$) in the PU-NC semi-IPNs with the composition of PU : NC of 70 : 30. The results indicated that an entanglement occurred between NC and PU in all of the PU-NC semi-IPNs. Comparing the weight loss at 450°C of each PU moiety of the compound being decomposed,¹⁷ the lowest value was observed at 51% from the $\frac{1}{16}$ -sec NC-containing film, which suggests that a better thermal stability of the film could be achieved with lower viscosity NC. Moreover, the weight losses of all PU-NC semi-IPNs with 0.2% DBTDL were less than those without catalyst, indicating that thermal stability of the PU-NC semi-IPN films could be improved after the addition of a PU catalyst.

Solvent resistance and cycles test

Weight retention of films after dipping in PU thinner for 48 h are shown in Table VI. Among all PU-NC semi-IPN films prior to the addition of PU catalyst, the maximum weight retention was observed at 91.35% for the $\frac{1}{2}$ -sec NC-containing film, indicating that the best solvent resistance was achieved by this formulation. In addition, the worst solvent resistance was found at 50.72% from the $\frac{1}{4}$ -sec NC-containing film. This was probably due to its poor interpenetration between PU and NC, which makes it easy to dissolve in PU thinner.

For all films after the addition of 0.2% DBTDL exposed to a solvent resistance test, the weight retention of the $\frac{1}{4}$ -sec NC-containing film was 86.63%, apparently increased by 35.91% from the retention of 50.72% without 0.2% DBTDL. However, little or no change in weight retention was expected for the $\frac{1}{2}$ -sec NC and $\frac{1}{16}$ -sec NC-containing films after the addition of 0.2% DBTDL, and their values changed from 91.35% to 89.01%, and from 87.46% to 87.48%, respectively. The results revealed that the solvent resistance of the film could be improved effectively with the addition of a PU catalyst.

For all PU-NC semi-IPN coated films after ten hot and cold cycle tests, the gloss retention of all specimens, before or after the addition of PU catalyst, were retained at above 90% (as shown in Table VI), indicating that all of the PU-NC semi-IPN films had excellent durability.

DMA

The $\tan \delta_{\max}$ and T_g values for all PU-NC semi-IPN films, determined by DMA, are listed in Table VII. For the semi-IPN films without added PU catalyst, the $\tan \delta_{\max}$ values of films containing $\frac{1}{2}$ -sec NC, $\frac{1}{4}$ -sec NC, and $\frac{1}{16}$ -sec NC were 0.6129, 0.6691, and 0.6173 respectively. Among all tested films, the film containing $\frac{1}{4}$ -sec NC had the largest $\tan \delta_{\max}$ value, resulting from lower crosslink density and poorer interpenetration between PU and NC. Other evidence (Table VI) showed that the $\frac{1}{4}$ -sec NC-containing film displayed lower weight retention after PU thinner extraction. After the addition of PU catalyst, the $\tan \delta_{\max}$ value of the $\frac{1}{4}$ -sec NC-containing film decreased significantly, from 0.6691 to 0.6322, whereas both the $\frac{1}{2}$ -sec NC and the $\frac{1}{16}$ -sec NC-containing films only changed slightly, from 0.6129 to 0.6120, and from 0.6173 to 0.6200, respectively. The results suggested that the crosslink density of semi-IPNs with $\frac{1}{4}$ -sec NC increased after the addition of PU catalyst, which contributed to improved interpenetration between PU and NC. Similar evidence was observed regarding the weight retention of the $\frac{1}{4}$ -sec NC-containing film after the addition of PU catalyst. Its value increased from 50.7 to 86.6%, as shown in Table VI.

In DMA experiments, both the $\frac{1}{2}$ -sec NC and the $\frac{1}{16}$ -sec NC-containing films, prior to the addition of PU catalyst, had only one T_g value of 100°C, whereas the $\frac{1}{4}$ -sec NC-containing film showed two T_g values of 79°C and 104°C. The results demonstrated that PU-NC semi-IPNs with $\frac{1}{2}$ -sec NC or $\frac{1}{16}$ -sec NC had better interpenetration between PU and NC than those with $\frac{1}{4}$ -sec NC. After the addition of a PU catalyst, the values of T_g in both of the $\frac{1}{2}$ -sec NC and the $\frac{1}{4}$ -sec NC-containing films only changed slightly, to 104°C and 102°C, respectively. However, an apparent in

TABLE VII
Changes in $\tan \delta_{\max}$ and T_g of PU-NC Semi-IPNs Films

Sample Code	DBTDL (%)	$\tan \delta_{\max}$	T_g (°C)
$\frac{1}{2}$ -sec NC	0	0.6129	100
	0.2	0.6120	104
$\frac{1}{4}$ -sec NC	0	0.6691	79 104
	0.2	0.6322	102
$\frac{1}{16}$ -sec NC	0	0.6173	100
	0.2	0.6200	107

Determined by DMA

crease in the T_g value was observed in the $\frac{1}{16}$ -sec NC-containing film, from 100°C to 107°C after the addition of 0.2% DBTDL. Moreover, the two T_g values observed in the PU-NC semi-IPNs with $\frac{1}{4}$ -sec NC changed to only one T_g value of 102°C after the addition of 0.2% DBTDL, indicating that the compatibility of PU and NC in the PU-NC semi-IPNs could be improved with a PU catalyst.

CONCLUSIONS

In this study, three types of PU-NC semi-IPNs were prepared from different molecular weights of NC for application in wood coatings. Among all tested films, the PU-NC semi-IPNs with $\frac{1}{2}$ -sec NC films had the shortest drying time, the best tensile strength, the best elongation at break, the best lightfastness, and the best solvent resistance. The $\frac{1}{16}$ -sec NC-containing coating had the lowest viscosity, and its film showed the best thermal stability. All PU-NC semi-IPNs had a pot-life of more than 30 days, and their films showed an excellent adhesion as well as a great gloss retention. DMA showed that the films of PU-NC semi-IPNs with $\frac{1}{2}$ -sec NC or $\frac{1}{16}$ -sec NC had one T_g value, indicating good interpenetration between PU and NC. By adding DBTDL to the PU-NC semi-IPNs, the drying time of coating and the mechanical properties of the films, such as tensile strength, elongation at break, and lightfastness, could be improved in the $\frac{1}{4}$ -sec NC and $\frac{1}{16}$ -sec NC-containing coatings. In addition, an improvement in the miscibility of PU and NC was also observed in

the PU-NC semi-IPNs with $\frac{1}{4}$ -sec NC. Generally speaking, PU-NC semi-IPNs with $\frac{1}{2}$ -sec NC make appropriate wood coatings, and their films show excellent physical properties prior to the addition of a PU catalyst. The properties of coatings and films of the PU-NC semi-IPNs with both $\frac{1}{4}$ -sec NC and $\frac{1}{16}$ -sec NC could be improved after the addition of a PU catalyst.

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