# Solar Reflectance, Adhesion and Thermal Properties of $TiO_2$/Polyurethane Coating onto Wood/Natural Rubber Composite Sheet


**Natita Hamaviriyapornwattana, Teerasak Markpin, Narongrit Sombatsompop and Ekachai Wimolmala***

*Polymer PROcessing and Flow (P-PROF) Research Group,*
*School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi (KMUTT),*
*126, Pracha-utit Road, Bangmod, Thungkru, Bangkok, Thailand*

*Corresponding author: King Mongkut's University of Technology Thonburi (KMUTT),
126, Pracha-utit Road, Bangmod, Thungkru, Bangkok, Thailand
Email: ekachai.wim@kmutt.ac.th



## ABSTRACT

In this study, the effects of coating thickness and titanium dioxide ($TiO_2$) dosage in polyurethane (PU) coating on near infrared (NIR) reflectance, adhesion, crack resistance to bending, and thermal conductivity for wood/natural rubber (WNR) composite sheet before and after a prolonged UV ageing condition. The $TiO_2$ powder content to be added in the PU coating was varied from 0-15 parts per hundred (pph) of polyurethane. The PU coating thickness on WNR composite sheet was varied from 130 to 300 micrometers. The experimental results suggested that the solar reflectance slightly increased with increasing $TiO_2$ powder, but did not change with varying the PU coating thicknesses used in this work. Increasing $TiO_2$ powder into the PU coating resulted in a slight increase in thermal conductivity of $TiO_2$/PU coated WNR composite layer. Under UV accelerated weathering tester (QUV-UVB 313nm), the lightness of the PU coating slightly increased whereas the NIR reflectance, layer adhesion and crack resistance to bending test remained unaffected with increasing the UV ageing time.



**KEYWORDS:** Natural Rubber; Polyurethane; Titanium dioxide; Thermal conductivity.


## 1. INTRODUCTION

Generally, roofing materials should have resistances to sunlight, rain, hail, snow, atmospheric pollution and temperature variations [1]. The roofs made from polymeric materials have recently gained attentions due to readily process-abilities, good mechanical properties, favorable environmental profiles and cost savings [2]. The use Titanium dioxide ($TiO_2$) is of interest for various applications because of its photo-electrochemical, and photo-catalytic properties [3]. Some $TiO_2$-based self-cleaning products, such as tiles, glass, and plastics, have become commercially available [4]. There have been reported on utilizing $TiO_2$ as UV protector, usually in the form of pure inorganic coatings [5-6]. A study by Hong and Xiu [7] on the effect of the coating thickness on NIR reflectance of white $TiO_2$/PVC coating, and they found that the maximum NIR reflectance was 93% at the thickness of 134 micrometer [7]

Type of roofing materials, such as metal, clay, tile, wood and asphalt shingle, and the roof roughness are also expected to have effects on the solar reflectance [8-9]. However, such effects may become more complicated in composite materials. This paper was aimed to develop a solar-reflective roof from polyurethane coated wood/natural rubber sheet by focusing on the effects of coating thickness and titanium dioxide ($TiO_2$) dosage in polyurethane (PU) coating on near infrared (NIR) reflectance, adhesion and thermal conductivity under UV accelerated weathering test.

## 2. EXPERIMENTAL

***2.1 Materials & Chemicals***:

Natural rubber (NR, STR20) was supplied by Siam United Rubber Co., Ltd, Bangkok, Thailand and vulcanized in form of ebonite rubber. The formulation of the ebonite NR compounds was 100 phr NR, 33.4 phr zinc oxide (ZnO), 13.4 phr stearic acid, 3.4 phr mercaptobenzthiazole (MBT), 1.4 phrdiphenylguanidine (DPG), 40 phr wood particles, 45 phr precipitated silica, 0.1 phr UV stabilizer, 0.1 phr anti-oxidant, and 20.0 phr sulphur. Wood particles used had an average size of about 100-300 µm, and was supplied by V.P. Wood Co., Ltd., Bangkok, Thailand). The wood particles were chemically treated with silane coupling agents (KBM 603A by Kishimoto Sangyo Co., Ltd., Thailand). Titanium dioxide (Rutile type, Ti-pure R-902) was supplied by Dupont Co., Ltd., Bangkok, Thailand), and Polyurethane coating (Anti-UV coating type) was purchased from Sea Chief Enterprise Co., Ltd., Bangkok, Thailand).

***2.2 Preparation of WNR composite sheet:***

The WNR sheet was prepared by masticating the NR on a laboratory two roll mill (Yong Fong Machinery Co., Ltd., Thailand) for 5 min, before compounding with the desired content of the vulcanizing (ebonite formulation) agents and the prepared chemicals and additives (silica and wood) for further 35min. The NR compound was then compression-molded to a 90% cure using an hydraulic press (Lab Tech, Thailand) at a pressure of 170 $kg/cm^2$ with 160$^oC$ cure temperature to give vulcanized wood/NR composites.

***2.3 Preparation of $TiO_2$/PU coated WNR composite layer:***

To prepare PU coated WNR, $TiO_2$ powder was added into liquid PU at 0, 1, 3, 5, 7, 9 and 15 parts per hundred (pph) using a high speed mixer for 15 min and then the hardener was added for further 15 min. The liquid PU was then sprayed on the WNR using a spraying distance of 30cm with an air pressure of 6 - 6.5 kg/cm$^2$ and the coating thickness was varied by changing the number of spray coating. The PU thickness in this work was varied from 130 – 300 micrometer. The composition of $TiO_2$/PU coated WNR composite layer is given in **Figure 1**.

***2.4 Properties of $TiO_2$/PU coated WNR composite layer***:

1) Solar reflectance test in this work was expressed in terms of near infrared (NIR) reflectance (wavelength of 780-2100 nm), and this was carried out following ASTM E891 (1992).
2) Color index test was performed based on CIE System (Commission International de I' Eclairage); CIE (L* a* b*) for $TiO_2$/PU coated WNR composite layer using UV-VIS-NIR Recording Spectrophotometer (UV-3100, Shimadzu, Japan). Only lightness value of the PU coating was reported in this present work.
3) Adhesion between $TiO_2$/PU coating and WNR sheet was investigated in accordance with ASTM D3359 (2008).
4) Crack resistance to bending test followed ASTM D 522(2001) using cylindrical mandrel set (MG-1412, BYK-Gardner USA)
5) Thermal conductivity for $TiO_2$/PU coated WNR composite layer was measured in accordance with ISO/DIS 2207-2(2007) Thermal Conductivity Analysis (Hot Disk TCA).
6) UV weathering test for the PU coating on WNR sheet was carried out by aging the coated rubber sheets under UV accelerated weathering tester (QUV, Q-PANEL, USA) according to ASTM G154(2006). The cycle consists of 20 hrs of UVB (λ=310nm) radiation at 80$^o$C and 4 hrs of condensation at 80$^o$C. The irradiance intensity used was 0.62 Wm$^2$/nm at UV weathering period times of 168, 336, 504 and 672 hrs.

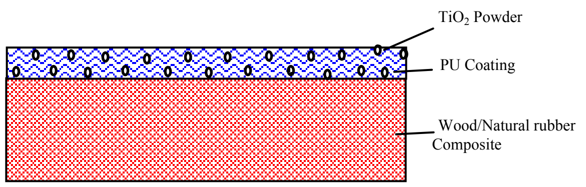



**Figure 1.** WNR layer coated with $TiO_2$/PU top-coat

## 3. RESULTS AND DISCUSSION

### *Effect of PU coating thickness and $TiO_2$ content*

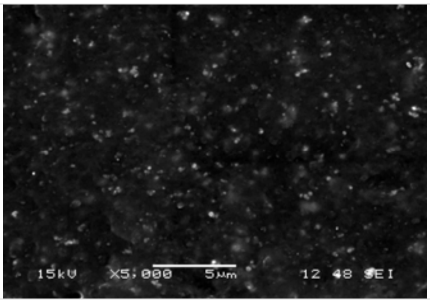
**Table 1** shows effects of PU coating thickness and $TiO_2$ content on NIR reflectance, adhesion, crack resistance to bending and thermal conductivity of WNR sheet coated with PU coating. It was found that the NIR reflectance increased marginally with increasing $TiO_2$ powder, but was unaffected by the PU coating thickness. The slight increase in NIR reflectance due to addition of $TiO_2$ was because the added $TiO_2$ interfered the transmission of the solar light. The more the $TiO_2$ particles added and distributed the more the NIR reflectance. This could be proven by the SEM results in **Figure 2** which shows $TiO_2$ distribution in the PU coating at 3 and 15 phr of $TiO_2$ and it was found that there was a good distribution of $TiO_2$ particles in the PU coating. The reason for unchanged NIR reflectance with varying the PU coating thickness suggested that the NIR reflectance was more affected by the addition of $TiO_2$ particles rather than the coating thickness [2-3].

**Table 1**. The properties of the PU/$TiO_2$ coating on WNR composite sheet

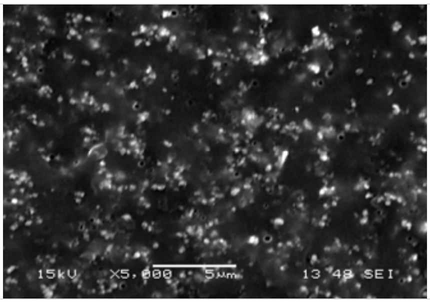
| PU coating on WNR | | Properties of PU/$TiO_2$ coating on WNR | | | |
|---|---|---|---|---|---|
| **Thickness of PU coating** (µm) | **$TiO_2$ powder content** (pph) | **NIR reflectance** (%) | **Adhesion of PU coating** | **Crack resistance to bending** | **Thermal conductivity** (W/m K) |
| 130 ± 10 | 0 | 27.99 | 5B* | Non cracks | 0.363 |
| | 1 | 27.28 | 5B* | Non cracks | 0.347 |
| | 3 | 29.78 | 5B* | Non cracks | 0.380 |
| | 5 | 29.78 | 5B* | Non cracks | 0.392 |
| | 7 | 36.20 | 5B* | Non cracks | 0.393 |
| | 9 | 37.61 | 5B* | Non cracks | 0.397 |
| | 15 | 40.11 | 5B* | Non cracks | 0.399 |
| 150 ± 10 | 15 | 40.20 | 5B* | Non cracks | N/A |
| 200 ± 10 | 15 | 40.48 | 5B* | Non cracks | N/A |
| 250 ± 10 | 15 | 40.47 | 5B* | Non cracks | N/A |
| 300 ± 10 | 15 | 40.40 | 5B* | Non cracks | N/A |

Remark: 0B is no adhesion and 5B is high adhesion, and N/A is not applicable

**Table 1** also shows that the thermal conductivity obtained for the PU coated WNR sheet ranged between 0.347-0.399 W/m K and the values slightly increased with $TiO_2$ content. This was expected since the $TiO_2$ has higher thermal conductivity than the PU. All PU thicknesses and $TiO_2$ contents used had no effect on adhesion and resistances to bending. The adhesion properties of the PU coating on WNR composite sheet in this work were satisfactory and passed an international standard peel test with no observations of cracks under a bending test.



(a) PU coating + $TiO_2$ 3 pph



(b) PU coating + $TiO_2$ Powder 15 pph

**Figure 2**. SEM micrographs of $TiO_2$ dispersion on PU coating: (a) 3 pph and (b) 15 pph

**Figure 3** shows color change in terms of lightness (L*) of the PU coating on WNR sheet by varying $TiO_2$ contents. It was found that the lightness of the PU coating increased significantly with increasing $TiO_2$ content. This is because the addition of $TiO_2$, whose lightness is 99.6, would result in PU surface fading and thus, the lightness increased with increasing $TiO_2$ loading.

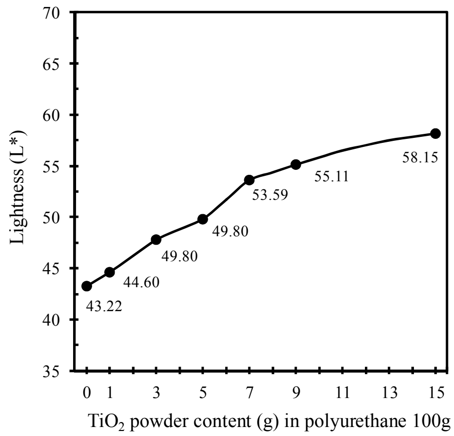



**Figure 3.** The lightness of PU coating on WNR sheet with varying $TiO_2$ contents

***Effect of UV ageing***

In this section, NIR reflectance, adhesion, crack resistance to bending, and lightness were investigated as a function UV weathering times from 0 to 672h. The selected $TiO_2$ content and PU coating thickness were 15 pph and 130 micrometers. It can be seen from **Table 2** that the UV light had no effect on NIR reflectance, adhesion and crack resistance to bending, but slightly increased the lightness of the PU coating of less than 4% as shown in **Figure 4**.

**Table 2**. The effect of UV weathering time on the properties of PU coating on wood/natural rubber sheet

| UV accelerated weathering time (hrs) | Thickness (μm) and $TiO_2$ content (pph) | Properties of PU/$TiO_2$ coating on WNR (After UV accelerated weathering aging) | | |
|---|---|---|---|---|
| | | NIR reflectance (%) | Adhesion of PU coating | Crack resistance to bending |
| 0 | 130±10 μm / 15 pph | 40.11 | 5B* | Non cracks |
| 168 | | 40.20 | 5B* | Non cracks |
| 336 | | 40.48 | 5B* | Non cracks |
| 504 | | 40.47 | 5B* | Non cracks |
| 672 | | 40.40 | 5B* | Non cracks |

Remark: 0B is no adhesion and 5B is high adhesion, and N/A is not applicable

## 4. CONCLUSIONS

$TiO_2$ filled PU coated wood/natural rubber composite layer was prepared and the NIR reflectance, thermal conductivity, crack resistance to bending and layer adhesion were studied. The experimental results suggested that the lightness and NIR reflectance increased with increasing $TiO_2$ content in the PU coating, but did not change with varying the PU coating thicknesses used in this work. The thermal conductivity obtained ranged between 0.347-0.399 W/m K and the adhesion properties of the PU coating on wood/natural rubber sheet have passed the standard peel test with no observations of cracks under a bending test. The after UV weathering tests for the PU coating on wood/natural rubber sheet suggested that the lightness slightly increased with UV aging time with no layer de-lamination and cracks under bending tests.

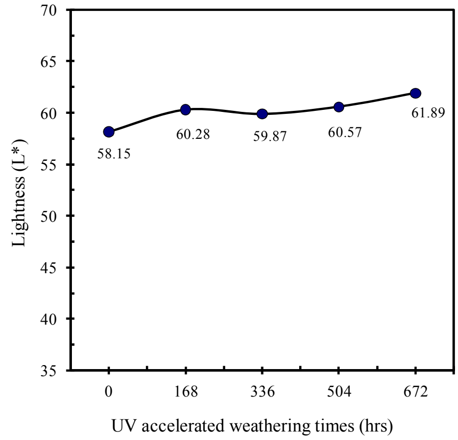



**Figure 4.** The lightness of PU coating on WNR sheet as a function of UV weathering time.

## 5. ACKNOWLEDGMENTS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