Investigation on Leaching and Decay Resistance of Wood Treated with Nano-Titanium Dioxide

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ABSTRACT

Wood is naturally made and consists of carbon hydrates and lignin in its structure. It can be destroyed by different factors such as UV rays, fungi, beetles, ants, marine borers and chemicals. This fact decreases its durability in the wooden structures. The aim of this study is to evaluate the leaching and decay resistance of wood treated with nano-titanium dioxide (nano-TiO2). For this purpose, cottonwood (Populus deltoides) sapwood was cut into 19 mm cubes and conditioned at 20°C and 65% relative humidity. The nanomaterial was prepared as suspension at three concentrations, namely 1, 2 and 4%, and the sample impregnation was performed by full cell process according to AWPA E10-08 standard method. The leaching and decay resistance tests were done according to AWPA E11-06 and ASTM D 1413 standard methods, respectively. The results showed that the leachate amount was low for all nano-TiO2 treated samples and decreased over time and approximately no leaching occurred in all concentrations at end of test period (6 days). In addition, the samples treated with nano-TiO2 had high resistance against fungal decay compared to untreated samples and weight loss (WL) significantly decreased with increasing nanomaterial concentration. The minimum WL occurred in the samples treated with 4% nano-TiO2. Therefore, titanium dioxide nanoparticle can be used to protect the wooden structures that were placed in wet sites and exposed to the fungal agents.

INTRODUCTION

Treating wood with efficiently chemicals has been suggested to protect the wood against destructive factors. Due to increasing awareness regarding dangers of using toxic chemicals in the wood preservation, several limitations have been applied about production, trade and use of protective materials such as CCA (copper, chromium and arsenic) in European countries and United States [25]. When wood is used in the external applications and exposed to moisture, not removing the wood preservative is very important. Nano-materials are substances, which resist leaching and biological destruction, can easily penetrate wood fibers due to their various properties and particle size and cause hereby long-lasting protection [12]. Therefore, wood preservation with nanomaterial can be an incredible and important advance in improving wood durability and performance along with conservation of its beautiful appearance [6].

Recently, the effects of nanomaterial utilization on improvement of the wood resistance against different wood destructive factors have been investigated in several studies [1, 9, 10, 11, 17, 24, 29, 30, 36]. Nanoscale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers [7, 23, 32]. Freeman and McIntyre [17] reported that nano-metals with dimensions that are smaller than the wood pores (100 μm) and/or intercellular pores (400-600 nm), can penetrate the porous structure of wood and influence wood resistance against destructive factors. The UV region of solar radiation causes maximum damage on the wood surface, which is an excellent absorbing material due to having lignin [21, 27]. Nano-titanium dioxide (nano-TiO2) can absorb and prevent the transmission of UV radiations and its photocatalytic properties provide antibacterial coatings [15, 34]. Nano-TiO2 is used as a common catalyst because of its optical and electrical properties, high photocatalytic activity, chemical stability, non-toxicity, good abundance and availability, and no corrosion due to light [16, 22, 35]. Its anatase phase has bandgap and optical
activity. Optical activity means the ability of producing radical groups in the surface under sunlight [26]. Therefore, this phase can strongly absorb UV radiations.

Chen et al. [8] studied the antifungal properties of titanium dioxide by using Aspergillus Niger fungal cultivation and UV irradiation. The results showed that TiO$_2$ coated film in the presence of UVA (365 nm) irradiation exhibited antifungal capability. No visible growth was observed on specimens during the photo-process. Re-growth appeared in subsequent dark, indicating that the photocatalytic reaction was not sufficient for total disinfection against mold fungi but did suppress fungi growth. Saha et al. [29] used nano-titanium dioxide as a surface coating against UV radiations. The result showed that the titania embedded with UV absorber coating does not have a significant influence on wood color but addition of lignin stabilizer plays an important role in protection of wood against UV exposure as they mainly act as a radical scavenger.

Hochmannova and Vytrasova [20] researched about the antimicrobial effects of zinc oxide and titanium dioxide nanoparticles on formulation of the colors used in the interior applications. They expressed that nano-zinc oxide had the maximum antimicrobial efficiency against a broad spectrum of bacteria and fungi. Sun et al. [33] used nano titanium oxide to protect bamboo wood against mold and bacteria. The results showed that antibacterial properties of the samples treated with nano-titanium dioxide (Anatase phase) improved up to 99 percent.

Regarding antifungal properties of nano-TiO$_2$ mentioned above, the goal of this research was to study leaching and decay resistance of wood treated with TiO$_2$ nanoparticles for using in external applications along with minimum damage to the environment.

MATERIAL AND METHODS

Sample Preparation:

Cottonwood (Populus deltoides) sapwood obtained from the research forest in Shastkalateh, Golestan province, Iran, was cut into 19 mm cubes and conditioned at 20 °C and 65% relative humidity. The prepared samples were impregnated with nano-titanium dioxide (with 20 nm particle size). For this purpose, nanomaterial suspension was prepared in ultrasonic bath at 60 ˚C and three concentrations, namely 1, 2 and 4%, suspended in monoethylene glycol and distilled water. Then, the sample impregnation was performed by full-cell process according to AWPA E10-08 standard method [4] and untreated samples were used as control.

Leaching Test:

Leaching procedures were similar to AWPA E11-06 standard method [5]. Some samples were placed in a 500 mL glass beakers containing 60˚C water to accelerate leaching process and mildly agitated for 6 days. Leachates were collected after 6 and 12 hours and 1, 2, 4, and 6 days and analyzed for titania with ICP-AES and expressed as ppm titania for the average leach rate of the 3 blocks per treatment concentration.

Decay Test:

Decay test was performed according to ASTM D1413 standard method [3] with 6 replications for each treatment. Water holding capacity of the soil was 130%. The white-rot fungus *Trametes versicolor* (L.) Lloyd strain (CTB 863 A) was used to inoculate samples. The classification of resistance was done according to ASTM D2017 standard method [2].

RESULTS AND DISCUSSION

Nanomaterial retention:

The sample impregnation with different nanomaterial concentrations caused different retention, which increased with concentration increment (Table 1). With increasing concentration from 1 to 4%, the retention increased from 7.06 to 29.53 (more than 4-fold).

<table>
<thead>
<tr>
<th>Concentration (%)</th>
<th>Retention (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.06</td>
</tr>
<tr>
<td>2</td>
<td>15.06</td>
</tr>
<tr>
<td>4</td>
<td>29.53</td>
</tr>
</tbody>
</table>

Chemical Leaching:

The stability of chemicals in the wood is necessary to penetrate the cell wall and make chemical bonding with wood chemicals. As shown in Fig. 1, the leachate amount was low for all concentrations of nano-titanium dioxide and increased slightly with increment of nanomaterial concentration. In addition, the leachate amount and the difference between the concentrations decreased over time. Finally, the leachate amount in all concentrations reached approximately equal amount. In general, almost no leaching occurred for all concentrations of nano-TiO$_2$
at end of test period (6 days) compared to some preservatives such as zinc sulfate and boron that have been difficult to establish and can be easily washed and removed from the wood.

![Image](image_url)

**Fig. 1:** The leachate amount for three concentrations of nano-titanium dioxide.

**Fungal Decay:**
When wood is exposed to the white or brown rot fungi, its resistance and weight reduce significantly [13]. *Coniophora puteana* as a brown-rot fungus primarily attacks the cellulose and hemicellulose and prefers softwoods while *Trametes versicolor*, as a simultaneous white-rot fungus, attacks both lignin and carbohydrates and favors hardwoods [13, 14, 18, 19, 31]. It may justify more destruction and Weight Loss (WL) of the untreated samples prepared from poplar sapwood by *T. versicolor*. Higher degradation rate of mannans than cellulose and xylanes may lead to low destruction of hardwoods by *C. puteana* [28, 31].

<table>
<thead>
<tr>
<th>Concentration (%)</th>
<th><em>T. versicolor</em> Weight loss (%)</th>
<th>Degree of resistance (ASTM D2017)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>45.62</td>
<td>Non-resistant</td>
</tr>
<tr>
<td>1</td>
<td>4.86</td>
<td>Highly resistant</td>
</tr>
<tr>
<td>2</td>
<td>2.98</td>
<td>Highly resistant</td>
</tr>
<tr>
<td>4</td>
<td>1.28</td>
<td>Highly resistant</td>
</tr>
</tbody>
</table>

The results of Tukey statistical analysis test showed that there was a significant difference between WL of treated and untreated samples. WL was significantly more in the untreated samples and decreased with increasing nanomaterial loading as shown in Table 2. The sample resistance against the white-rot fungus significantly increased with increment of nano-TiO$_2$ loading and the minimum WL (high disinfection against decay factors) occurred in the samples containing 4% nano-TiO$_2$, while due to fungal decay, the untreated samples became white, very soft and feeble. Therefore, all treated samples were placed in highly resistant class, while the untreated samples with high destruction ratio were placed in non-resistance class according to ASTM D2017 standard method [2]. Improving decay resistance may be due to the antifungal properties of titanium dioxide nanoparticles [33].

**Conclusions:**
The leachate amount was low for all treated samples and it decreased over time. In addition, nano-titanium dioxide clearly was effective in the sample weight loss (WL) after exposing to wood destructive fungi. Sample WL decreased with increasing nanomaterial loading. The minimum WL occurred in the samples containing 4% nano-TiO$_2$ yielding high decay resistance. Nano-TiO$_2$ had good effects on preventing fungal decay along with high resistance against chemical leaching. Therefore, it can be used as a suitable preservative and filler in the wood composites. However, although the exploration of titanium dioxide nanoparticles based products is booming in the various directions of consumer products, their comprehensive toxicological impact still remains unclear and should be considered when used for wood.
REFERENCES


