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Review: Protection of Wooden Structures with Nano-Titanium Dioxide Coating

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Review: Protection of Wooden Structures with Nano-Titanium Dioxide Coating

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***Abstract*- Wood is widely used for various purposes with good performance. Wood works as the main material for furniture, monuments, decorations and constructions. which has the close relationship with human. Durability of wood is important in ensuring an appropriate life for the structure being designed. Wooden construction deteriorates easily due to UV radiation and weather conditions. Many of wood types need a preservative treatment. Several compounds are available for chemical protection, but not all are completely safe for human health. New technologies with low environmental impact and economically feasible are developed, which improves the life cycle of wood. Titanium dioxide is used widely in building materials and can help to make construction products and buildings more sustainable. It is used as a UV light absorber to protect wood matter from photodegradation. This review will focus on the use of titanium dioxide coating technology to protect wood from decay and the methods of applications in order to throw light on this field.**

***Keywords*- Wood, Protection, Nano-TiO_2, Structures.**

I. INTRODUCTION

By producing products with a wide range of unique properties, nanotechnology can improve the performance of construction materials and develop new applications with more sustainable features. Novel materials and products based on nanotechnology are used in coatings, insulating applications, and building matrices. In furniture and timber architecture, wood heat treatment is commonly used to address issues with poor dimensional stability, grey colour and decay. The wood's colour, durability, and dimensional stability are all greatly enhanced by heat treatment. As a result, heat-treated wood is widely used in indoor and outdoor applications, including furniture, fences, stairs, landscape boards, and other decorative cladding materials. Sunlight, temperature, and humidity variations in the outside environment have a major impact on the colour and chemical compositions of heat-treated wood. In the study of Shen et al. [1], a durable hydrophobic and UV-resistant layer was produced on the surface of thermally treated wood at room temperature after in situ deposition of titanium dioxide (TiO_2) nanoparticles and a polydimethylsiloxane (PDMS) coating. Fig.1 shows the two-step process of TiO_2 nanoparticles deposition and the coating of hydroxyl-terminated PDMS on the surface of thermally treated wood.

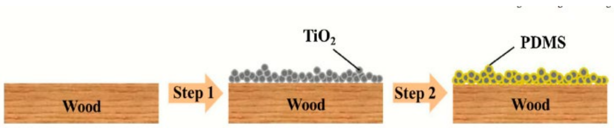

Figure 1. Illustration of the two-step process for preparation of antiweathering thermally treated wood surfaces, [1].

In the work of Xing et al. [2], the deposition of TiO_2/ZnO on heat-treated wood was prepared by a hydrothermal reaction and sol-gel method. Low surface free energy wood that is highly hydrophobic was successfully produced. As shown in Fig.2 the wood surface was significantly brighter when the TiO_2 or ZnO was applied, as shown by spectrophotometer and ocular inspection. SEM-EDS and FTIR examinations demonstrated that the TiO_2/ZnO particles were successfully loaded onto the wood's surface. In comparison to the control (uncoated), which had a contact angle of 88.9°, the contact angles of the wood modified with TiO_2 and ZnO were 123.9° and 134.1° respectively, Fig.3. The hydrophobic properties of the TiO_2/ZnO modified wood samples were directly related to spheres of particles and the shapes of clusters, which increased the roughness of the wood surface.

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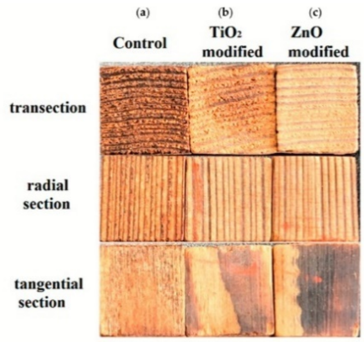

Figure 2. The visual and color changes of three sections of wood before and after being surface modified, [2].

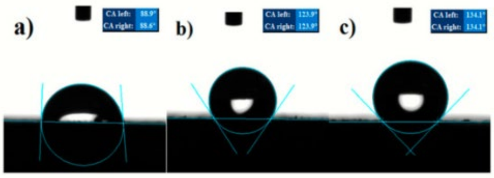

Figure 3. Water contact angles of (a) control; (b) TiO_2 modified wood; (c) ZnO modified wood, [2].

One popular technique for creating superhydrophobic surfaces on wood surfaces is the sol-gel method, which is a reaction process that produces nanoscale rough structures on the wood surface. In this method the TiO_2 nanoparticles were added to the perfluorooctyltriethoxysilane (PFOTS) solution. The hydroxyl group present on TiO_2 nanoparticle reacts with the hydrophilic head (-Si(OC2H5)3) of PFOTS molecule which functionalizes the TiO_2 nanoparticles [3]. This results in a uniform self-assembled coating on the wood surface, and the product adheres to the wood surface, leading to the hydrophobic end (C8H4F13) upward, giving the wood surface superhydrophobic properties, Fig. 4.

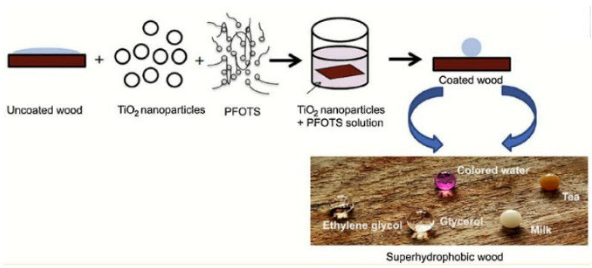

Figure 4. Schematic representation of synthesis of superhydrophobic wood surface, [4].

Because of its low cost, simple process control, and straightforward preparation method, the sol-gel process is well suited for large-scale industrial production. Wang et al. [5] summarized the research progress on wood superhydrophobic coatings. A detailed discussion is held regarding the preparation methods of superhydrophobic coatings on wood surfaces under various acid-base catalysis processes, using the sol-gel method with silicide as an example. Recent progress in preparing superhydrophobic coatings using the sol-gel process is discussed, and the future development of superhydrophobic surfaces is prospected

Ag–TiO_2 heterostructures with Ag nanocrystals and TiO_2 particles well-grown on wood substrate was obtained by Gao et al. [6] using a two-step protocol combining hydrothermal synthesis and silver mirror reaction. Photocatalytic activity study showed that when exposed to visible light, wood coated with Ag-TiO_2 composite film showed excellent photocatalytic activity compared with wood coated with pure TiO_2 particles for phenol degradation. The Ag/TiO_2 coated wood was further modified by (heptadecafluoro-1,1,2,2-tetradecyl) trimethoxysilane, which played a crucial role in improving the water resistance and imparting self-cleaning property to the wood products. The modified wood has strong antibacterial activity towards both Gram-positive and Gram-negative bacteria. The film coated on the wood surface shows good photodegradation of organic pollutants and strong hydrophobicity, leading to an important application in self-cleaning.

As a decorative material, bamboo offers many of benefits. It is a sustainable material that is rapidly renewable and has mechanical qualities similar to those of wood. Li et al [7] used chemical solution deposition and chemical modification in combination to create a strong and long-lasting superhydrophobic surface on bamboo timber substrate. The superhydrophobic surface resulted from micro-nanoscale binary-structured TiO_2 films and the assembly of low-surface-energy fluorinated components, which exhibited a water contact angle of 163 ±1° and a sliding angle of 3 ±1°. After 800 mm of mechanical abrasion against 1500 mesh SiC sandpaper at 1.2 kPa of applied pressure, the produced surface maintained superhydrophobicity, suggesting strong mechanical stability. Additionally, the superhydrophobic surface demonstrated strong chemical stability against both basic and acidic aqueous solutions (e.g. simulated acid rain). However, the resulting surface showed good long-term stability after being exposed to the atmosphere for approximately 180 days, with a contact angle of 155 ±2° and a sliding angle of 6 ±2°.

By adding triazine derivative organic UV stabilizers to inorganic titania particles using the sol-gel method, Saha et al. [8] developed UV protective coatings. The aim of the study was to delay the discoloration of heat-treated wood exposed to external conditions. The protective coatings were prepared in air at room temperature. The coatings were not further heat treated after application to heat sensitive materials. The heat-treated jack pine wood was coated. Then, coated and uncoated jack pine samples were used in accelerated aging testing. The results revealed that titania included with a UV absorbing coating has no significant effect on the colour of the wood but the addition of a lignin stabilizer plays an important role in protecting the wood from UV exposure as it essentially acts as a root scavenger. In

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addition, since wood is a porous material, the coatings lose their effectiveness if they are not thick enough.

Chen et al. [9], electrochemically deposited titanium dioxide (TiO_2) particles on the surface of heat-treated wood using a high-voltage electrostatic field. Natural and artificial weathering tests were performed to evaluate the anti-weathering properties after electrochemical deposition. Photodegradation of lignin was effectively mitigated during artificial and natural weathering. The stability of wood colour was remained.

Lin et al. [10] prepared wood-based Ag/TiO_2 nanocomposites by ultrasonic impregnation and vacuum impregnation methods. When compared with native wood, the anti-mold properties of wood-based Ag/TiO_2 nanocomposites were 14 times better. The nano-Ag/TiO_2, which was impregnated in the tracheid and attached to the cell walls, was able to reduce the number of hydroxyl functional groups on the wood surfaces. The resulting decrease in wood hydrophobicity and equilibrium moisture content destroyed the moisture environment necessary for mold survival. Ag/TiO_2 was deposited into the wood pores, reducing the number and size of pores and blocking the mold infection path. By cutting off the water supply and blocking the mold infection channel, the anti-mold qualities of the wood Ag/TiO_2 nanocomposite were enhanced, Fig.5.

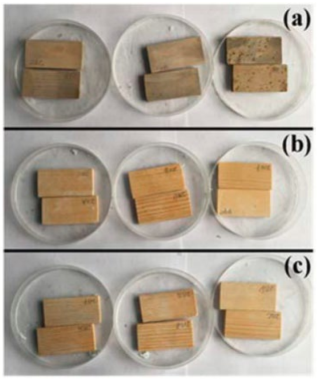

Figure 5. Mold infection of (a) original wood, (b) wood sample impregnated with Ag/TiO_2 nanoparticles via ultrasound and (c) wood sample impregnated with Ag/TiO_2 nanoparticles via vacuum assistance, [10].

The interactions between wood and TiO_2 coating as well as the coating efficiency were investigated by Svora et al. [11]. Two types of wood were selected for the experiments: pine (Pinus sylvestris) and beech (Fagus sylvatica), Fig.6. Molecular and physical modifications in coated and uncoated wood exposed to UV radiation were studied. TiO_2 coating has been shown to protect wood from photodegradation to a limited extent. Cracks were observed in the wood material around clusters of TiO_2 particles in beech wood.

Figure 6. Pine wood and beech wood specimens coated with 1 wt. % of TiO_2 acrylic dispersion, [11].

Fungi play a major role in the deterioration of cultural heritage, as their contamination leads to the decomposition of materials used in the manufacture of historical artefacts. Prevention of fungi, treatment of contaminated objects and their successive preservation are important elements for conservators. Filpo et al. [12] treated eight different wood species, some commonly used in the field of cultural heritage, with a solution of titanium dioxide nanoparticles and placed them in contact with two species of fungi, Hypocrea lixii (white-rot) and Mucor circinelloides (brown-rot), which are known to be responsible for a fast decay of wood. The results showed that the photocatalytic activity of titanium dioxide nanoparticles prevents fungal colonization of wood samples over a long period compared to untreated samples.

Moisture absorption and dimensional distortion are the main disadvantages of using timber as a building material. In the study of Sun et al. [13], poplar wood coated with a thin layer of titanium dioxide (TiO_2) was prepared by a cosolvent-controlled hydrothermal method. Then, moisture absorption and dimensional stability were examined. Scanning electron microscope analysis revealed that the wood substrate was closely and completely covered by the TiO_2 layer. After immersing in water for 90 days, the water absorption and swelling thickness of wood with TiO_2 coated layer increased very slowly and minimally. In addition, the weight change was reduced to 20.5% of untreated control wood, and that maximum cross-sectional relative swelling was only 1.2%. Samples were conditioned for 3 months at 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% relative humidity to determine the effects of relative humidity on moisture absorption and dimensional swelling of TiO_2-coated wood. The results revealed that weight did not change the relative swelling of the cross section was less than 0.3% for humidity less than 60% while there was a linear increase in weight above 60% relative humidity (maximum change was less than 6%), and the relative swelling also increased (The maximum change was about 3%.)

Sun et al [14] successfully fabricated wood materials with UV-resistant capacity by depositing sub-micrometre-sized rutile TiO_2 spheres on the wood surface using a facile, one-pot hydrothermal method. ATR-FTIR spectra showed that chemical bonds were formed at the interfaces between rutile TiO_2 and wood due to the presence of hydroxyl groups. Accelerated aging was used to measure the UV resistance of

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original wood, anatase TiO_2/wood, and rutile TiO_2/wood. Rutile TiO_2/wood showed greater UV resistance ability due to its high UV light absorption capacity, superior light scattering property, high photogenerated electron recombination, and sub-micrometer sized rutile TiO_2 spheres on the wood surface

Li et al [15] investigated the growth of anatase TiO_2 coating on wood surface through hydrolysis of tetrabutyl orthotitanate (TBOT) under different conditions, using a controlled hydrothermal method at low temperatures. Energy dispersive X-ray analysis and Fourier transform infrared spectroscopy confirm that the growth of TiO_2 coating on the wood surface is associated with hydrocarbon chains. Several reaction factors that affect the shape and amount of TiO_2 present on the wood surface have also been studied. It was observed from the scanning electron micrographs, the shape and content of TiO_2 grown on the wood surface can be controlled under appropriate reaction conditions.

When titanium dioxide is deposited as a thin layer, the high refractive index of titanium dioxide usually results in whiteness and opacity, which limits the use of titanium dioxide for material surfaces, for which long-term natural appearance is of great importance. Guo et al. [16] showed that in the presence of cerium ammonium nitrate, titanium dioxide can be converted from white powder to TiO_2/Ce xerogel via a facile bottom-up fabrication process. It has also been shown that the transparent TiO_2/Ce xerogel can reduce UV-induced surface degradation and maintain the natural appearance of the highly abundant biomaterial wood. Moreover, the TiO_2/Ce xerogel coating prevents the generation of free radicals on wood surfaces upon exposure to UV radiation.

In the study of Yang et al. [17], the pore structure of natural wood was introduced into the TiO_2 structure through a biological template fabrication strategy. The resulting structure showed improved absorption of formaldehyde and methylene blue from the solution. Photocatalytic degradation results showed that wood-coated titanium dioxide degraded 71.8% of formaldehyde in the solution within 100 minutes under visible light. In addition, the degradation efficiency of methylene blue was up to 97.9% within 60 min. The morphology and structure of titanium dioxide were characterized by SEM, TEM and X-ray diffraction. This revealed that the crystalline phases of the prepared titanium dioxide were anatase and rutile, and rutile titanium dioxide was attached to the surface of anatase titanium dioxide. Compared with TiO_2 without wooden template, TiO_2 prepared with wooden template showed obvious red-shift of absorption in the visible light region, resulting in significantly increased absorption.

Chu, Chuong and Tuong [18] manufactured TiO_2-treated hybrid acacia wood (Acacia mangium x auriculiformis) by combined pressure impregnation and subsequent hydrothermal treatment. In TiO_2-treated wood, the wettability, microstructure, and crystal structure of the titanium dioxide (TiO_2) gel were examined. Contact angle measurements of blank wood and TiO_2-treated wood indicated a significant increase in hydrophobicity, with contact angles exceeding 150o in the treated samples. Moreover, the waterproof property of the treated wood was quite stable, even after being immersed in boiling water. The results also showed that the microstructure and size of TiO_2 gels on the wood surface depend on the pH of the post-treatment solutions.

The effectiveness of a nanocoating containing titanium dioxide nanoparticles (TiO_2-NPs) as a finishing material for mangium wood was investigated by Rahayu et al [19]. The coating material compositions used were oil-based and water-based varnishes with TiO_2-NP concentrations of 1%, 5%, and 10% (w/v). Uncoated and coated specimens were exposed to weathering periods of 0, 2, and 4 months. Adding titanium dioxide nanoparticles to the varnish led to gradual colour changes after a weathering period, Fig. 7. The surface of the mangium wood also became smoother after being coated. However, the surface roughness increased with the duration of the weathering period. The wettability of the sample decreased after coating, indicating that the coated sample was more hydrophobic than the uncoated sample. The results of a photocatalyst test, which analysed the effectiveness of the coatings, showed that the best coating material were oil base-concentration 10% and water base- concentration 10%, as they degraded 75.21% and 71.03% of methylene blue content, respectively.

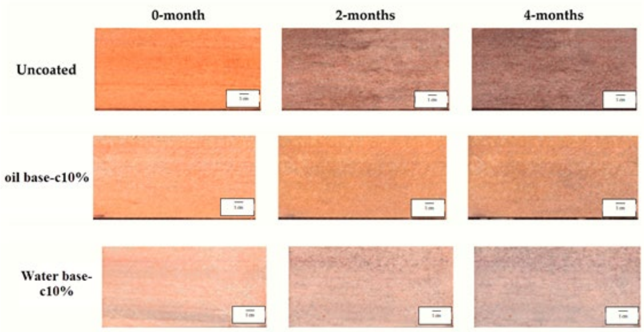

Figure 7. Colors of uncoated and coated mangium wood during the weathering test, [19].

In the work of Zanatta et al. [20], commercial titanium dioxide has been impregnated into Pinus elliottii wood, with the aim of increasing its durability against attack by the brown rot fungus Postia placenta and UV-induced photodegradation. The samples were placed under 8 bar pressure for 3h with different concentrations of TiO_2 (0.5%, 0.25%, 0.124% and 0%-control). The photodegradation was carried out by exposing a tangential section to ultraviolet radiation for 400 hours, and the colorimetric parameters were periodically evaluated. The treated wood remained practically unchanged, in contrast to the control in which the darkening was mainly accelerated in the first 50 hours.

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To enhance the resistance of wood against weathering, Wang et al. [21] modified Chinese fir (Cunninghamia lanceolata) wood through a two-step process by first growing titanium dioxide (TiO_2) nanocoatings on the wood substrate using a sol-gel process followed by low-surface free-energy treatment with hydrolyzed hexadecyltrimethoxysilane (HDTMS). The introduction of TiO_2 nanoparticles facilitated the generation of double-sized roughness on the wood substrate, and the long-chain alkyl groups of HDTMS were covalently attached to the particle surface. The water contact angle of the treated wood is significantly improved up to approximately 138° showing a high degree of water repellency. The TiO_2 coatings also showed strong UV absorption and imparted enhanced photostability to the underlying wood substrate, which was highly dependent on the TiO_2 loadings in the coatings.

Jnido, Ohms and Viöl [22] deposited titanium dioxide (TiO_2) layers on wood surfaces by an atmospheric pressure plasma jet using titanium tetraisoperoxide (TTIP) as a precursor to improve the stability of wood against ultraviolet (UV) radiation and its ability to resist moisture, Fig. 8. The results showed the presence of small globules of TiO_2 with some clustered areas on the surface of the coated wood. Hydrophilic wood surfaces were converted to become hydrophobic or superhydrophobic after coating with TiO_2, depending on the deposition parameters. Colour changes during UV exposure were measured for both uncoated and coated wood samples. Wood coated with TiO_2 became more resistant to discoloration after exposure to UV radiation compared to untreated wood.

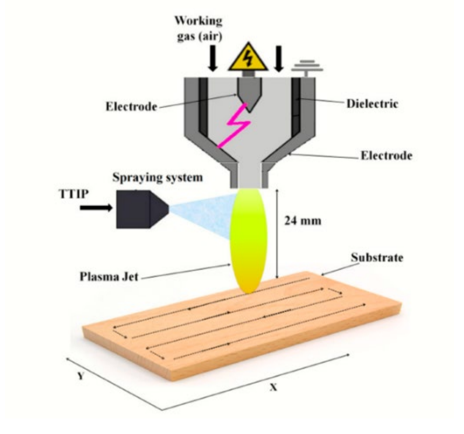

Figure 8. Schematic representation of the atmospheric pressure plasma jet (APPJ) system coupled with spraying system, [22].

II CONCLUSION

Wood has attracted wide attention in architecture, furniture design and other industries for its many advantages, such as its environmental friendliness and excellent mechanical properties. Weather conditions and UV radiation cause wooden structures to decay rapidly. This paper aims to provide an overview of research conducted on TiO_2 nanomaterial coatings on wood and their application methods. The review showed the possibility of applying the protective effect of titanium dioxide to wood coatings. With this knowledge, it can be concluded that TiO_2 treated wood is able to prevent fungi from penetrating the wood's cell wall, inhibit their growth, and create a barrier that protects the polymers from photodegradation, increasing its durability and emerging as a potential alternative for wood treatment. Currently, most coating methods use small-scale laboratory wood samples, which are not suitable for industrial process production. Hence, more studies in this area are required to apply these techniques to larger structures and longer time periods.

Conflicts of Interest: The authors declare no conflict of interest.

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