**Application of Nanotechnology in wood coating**

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**Introduction**

People have used wood ever since civilization began as it is readily available, naturally regenerates, and has a broad range of applications (Mantanis, 2017). Even if steel and concrete have been used in structural applications at a higher frequency over the last 150 years, wood remains an essential component of our infrastructure (Sandberg, 2016). It is one of the materials that may be replenished over time. However, in recent years there has been a greater focus on the performance and sustainability of wood products (Mantanis, 2017). As a result, wood has been transformed into products with a wide variety of uses. The prospect of using different types of wood that are easily accessible and relatively inexpensive as alternatives to traditional timber-producing species is something that researchers are constantly investigating. To satisfy the ever-increasing need for wood, researchers are looking at the viability of short-rotation plantation species as a viable alternative to long-rotation trees. According to Moya and Munoz (2010), the dimensional instability, susceptibility to decay, and lack of strength properties of plantation wood are caused by the wood's lower density, a higher proportion of juvenile wood, a lower percentage of heartwood, and larger growth rings. Because of these defects, it is seldom used for applications like furniture, handicrafts, building, and other similar fields. For wood to be useful in technically created applications generated by industry, it must first be treated with additional materials or compounds derived from various sources, referred to as additives.

Nanoscience and nanotechnologies are relatively new branches of science and technology aiming to regulate the structure and behaviour of materials on an atomic and molecular size. Nanomaterials are materials that are between one and one hundred nanometres in size. "Nano" refers to 109 (Wegner & Jones, 2009). Nanotechnology is an interdisciplinary field combining the study of technology to produce new and improved materials that are better in their functional, physical, and chemical properties. According to Jasmani et al. (2020), the properties shown by compounds at this scale are unique from those exhibited by the same substances at their distinct dimensions. As a result, research into the unconventional applications of nanotechnology might benefit various industries. Health, information society, industry, energy, transportation, and space exploration are just some areas that use hundreds of different products that incorporate nanomaterials. Nanotechnology significantly boosts innovation in previously established processes and products, particularly in construction and cultural heritage. Their application contributes to their propagation in specific architectural settings worldwide. According to Blee & Matisons (2008), the building industry is one of the essential industries in which nanotechnology is now experiencing tremendous development. However, it is crucial to keep in mind that the majority of research has concentrated on materials in concrete and metallurgy. Several nano-products are now available to preserve wood, but relatively little attention has been dedicated to reinforcing wooden buildings (Marzi, 2015).

Coatings with nanoscale structures are the subject of the most interest and research. In addition to satisfying the standard performance criteria (longevity, durability, resistance to the elements, good adhesion to the substrate, transparency, eco-friendliness of the manufacturing process, etc.), they also add features such as self-cleaning, photocatalysis, resistance to water, fire, scratches, graffiti, and bacteria. This is in addition to the fact that they meet all of the standard performance criteria (Elvin, 2007; Marzi, 2015). Recent research into using nanoparticles to enhance wood's characteristics has been limited. However, nanoparticles have shown great promise in improving the mechanical, combustion, hydrophobic, and other features of various polymers, papers, and textiles (Chen & Yan, 2012; Jiang et al., 2011; Textor & Mahltig, 2010; Sun et al., 2007; Wang et al., 2006). It was further observed that using nanoparticles to enhance wood characteristics has only favourable outcomes. Various nanoparticles may increase UV protection, mechanical features, and durability and decrease moisture absorption (Mahltig et al., 2008; Rassam et al., 2012; Yu et al., 2011) also provide opportunities to enhance fire resistance (Mullins-Jaime & Smith, 2022; Rabajczyk et al., 2021). The findings above have shown new opportunities for application in wood science and technology. Full cross-section treatments, in addition to surface treatments, may extend the useful life of wood goods. This chapter will focus on the current advancement of nanotechnology applications in wood-based sectors, particularly wood coatings primarily used to enhance the wooden product's performance and durability.

**Nanotechnologies for wood in the construction field**

Around 100 nanometres thick, a nano-thin layer is deposited onto the substrate during the nano-coating process, which may improve the already present characteristics or introduce new ones. Nano-coating might benefit a more substantial material with a vast surface area. When used in situations where its stability is a limiting factor, wood coated with nanocomposite materials may have improved performance and functionality, which may help it survive longer. On the other hand, it has been brought to people's attention that some standard wood preservation technologies and treatments now available on the market are harmful to human and environmental health. As a result, there is a need for novel non-toxic products. It is possible to apply a variety of nano-impregnations on wood, and nanomaterials are often included in either aqueous, organic, or polymeric coatings. Spreading them evenly over a suitable medium is necessary to prevent nanoparticle aggregation. Due to the high surface-to-mass ratio of these materials, even a meagre percentage of accumulation in coatings may have a discernible impact on the chemical, thermal, and physical properties of the coatings (Jasmani et al., 2020). In recent years, there has been a meteoric rise in nanotechnology coatings. This is due to improved techniques that enable nanoscale control of the structure of coatings (Jasmani et al., 2020; Marzi, 2015). Marzi (2015) researched the present state of nano-based wood coatings available in markets worldwide, shown in Fig. 1. The ability to withstand water and the effects of UV radiation are two of the most important applications for these goods. It is essential to consider that the world is teeming with nanoparticles, each with a unique and valuable characteristic. There is often more than one choice of nanomaterials for a given application; however, some nanomaterials, such as silica (SiO2) and titania (TiO2), may be used in various contexts.



Fig 1: The primary uses of commercially available nano-based coatings for wood, including those that are waterproof (Clay, SiO2, CeO2, TiO2), UV-protective (TiO2, ZnO, SiO2, CeO2, Fe2O3, clays), biotic decay-protective (Ag, ZnO, Cu), fire-resistant (SiO2, Clay, TiO2), self-cleaning/photocatalytic (TiO2, ZnO), anti-scratching (TiO2, Al2O3, SiO2, clays, lime) (Marzi, 2015)

**Nano-additives improving water absorption**

Water and moisture pose a severe hazard to wood as the chemical constituents of wood are prone to wetness. Because of its interaction with water, wood is subject to biodegradation, dimensional instability, and fast weathering. As a result, nanotechnology is being used as an alternative way to modify and functionalize wood. Increasing the amount of water wood absorbs by incorporating nanoparticles into polymeric coverings is possible. Utilizing hydrophobic (water-repellent) nano-coatings is one of the most interesting technological developments made in recent years to preserve wood from the weather and boost its performance in facade treatments. The majority of these products are composed of silica nanoparticles. This may be used to produce a barrier that is impermeable to water while yet allowing air to pass through it (Fig. 2). It is important to point out that this nano-structured coating is entirely free of volatile organic compounds (VOCs) and has essential water-repellent characteristics. According to Papadopoulos & Kyzas (2019), the nanoparticles may be integrated into the coatings by either a solution mixing technique or an in-situ addition procedure. In their research, Wu et al. (2020) created a super-hydrophobic coating on the surface of poplar wood by applying a waterborne UV lacquer product (WUV) modified with ZnO nanoparticles and stearic acid. This coating had a contact angle of up to 158.4 degrees. Since the zinc stearate/waterborne UV lacquer super-hydrophobic coating (ZnSt2/WUV) has a greater resistance to water than WUV, it is an excellent choice for the preparation of super-hydrophobic coatings in a way that is both practical and beneficial to the environment. Researchers employed a varnish of water mixed with titanium dioxide nanoparticles (TiO2) (Moya et al. 2017). This allowed them to compare the finishes of nine different tropical wood species. The varnish that had not been changed with the addition of TiO2 nanoparticles broke down entirely after one year of exposure to the elements. On the other hand, the modified varnish layer remained intact since adding TiO2 decreased the water absorption values. Before polymerization can begin, the in-situ addition process, also often called a chemical operation, requires the addition of chemicals directly to monomers. The nanoparticles may be created in situ using a variety of chemical processes on the surface of the wood, including hydrothermal procedures and sol-gel deposition. Gao et al. (2016) developed a super-hydrophobic, conductive wood surface with increased oil repellency using AgNPs treated with fluoroalkyl silane. This multifunctional coating has various applications, including biomedical electronics and self-cleaning surfaces. According to the findings of another study by Li et al. (2015a), the ZnO nanosheet networks were produced hydrothermally onto the bamboo surface and were afterwards modified using fluoroalkyl silane. The successfully treated bamboo exhibited several remarkable characteristics, including high super-hydrophobicity, tolerance to ultraviolet radiation and cold, and durability in an acid rain simulation. According to Li et al. (2015b), the hydrothermal deposition of anatase TiO2 nanoparticles and the subsequent modification with octadecyl trichlorosilane resulted in bamboo wood with better properties in a comparable manner. Other methods for preparing super-hydrophobic wood surfaces include spray coating of a waterborne perfluoroalkyl methacrylic copolymer (PMC)/TiO2 nanocomposites onto the PDMS pre-coated surface, layer-by-layer assembly of polyelectrolyte/TiO2 nanoparticles multi-layers and hydrophobic modified with perfuoroalkyltriethoxysilane (POTS) (Lu & Hu, 2016). A biomimetic approach that uses soft lithography to build a SiO2 super-hydrophobic bamboo surface that resembles a lotus leaf was also examined by Wang et al. (2017).



Figure 2: The lotus effect and waterproofing provided by silica nanoparticle-based nano-coatings on wood surfaces (Marzi, 2015)

**Nanoadditive for improvement of Ultra-violet ray (UV) absorption**

A chain reaction starts when the wood is exposed to sunlight: the wood absorbs the light, changes colour, and erodes. According to Teaca et al. (2013), the structural components of wood (lignin, cellulose, and hemicellulose) are prone to photochemical deterioration. During the photodegradation process, wood and other materials often lose part of their inherent water resistance, speeding up the process by which they biodegrade in the open air. Using light-stabilization technologies, surface coatings, or exchanging these materials with ones more resistant to UV radiation may minimize the severe damage caused by the UV component of solar radiation (Andrady et al. 2011). Nanoparticles with functional coatings that provide UV-blocking capabilities provide good UV radiation protection without reducing the surface's transparency. Nanoparticles are far more effective in blocking UV radiation than natural materials (Jasmani et al., 2020). This is due to nanoparticles' large surface area to volume ratio and their microscopic size. Lignin may be protected from the damaging effects of sunlight by coatings that absorb UV radiation. Nanoparticles of TiO2 and ZnO are frequently used as UV absorbers, significantly reducing the photo discolouration of the wood surface, and the system remains chemically stable (Wallenhorst et al., 2018). Coatings for the outside of bamboo that are made of acrylic and include nanoparticles of benzotriazole (BTZ) and zinc oxide (ZnO) have been studied by Rao et al. (2019). They reported that the formulation with a ratio of 2:1 had the most synergistic effects among the BTZ-ZnO coatings. Covering the bamboo surfaces minimized discolouration when the surfaces were exposed to light. A combination of benzotriazoles hindered amine light stabilizers (HALS) and nanoparticles made of TiO2 and ZnO is one of the most effective treatments for maintaining the colour stability of wood when exposed to UV and VIS light (Panek et al., 2018). Zheng et al. (2016) applied rutile TiO2 and a variety of methyltrimethoxysilane and hexadecyltrimethoxysilane to wood samples, and the ensuing protection against weathering, surface colour change and weight loss was observed. When wood is subjected to UV radiation without applying water spray, the TiO2 coating seems to increase its capacity to maintain its colour. However, the photocatalytic activity of TiO2 caused the surface of the wood to degrade in the surrounding area (Zheng et al. 2016).

**Nanoadditive for improvement of wood durability**

Nano-coating, in which nanoparticles are used, can potentially improve the durability of wooden and non-wooden materials at the molecular level. Coatings may inhibit the growth of microorganisms like bacteria and fungi. Nanoparticles of metal oxides, such as zinc oxide (ZnO) (Chakra et al. 2017; Okyay et al. 2015), titanium oxide (Chakra et al. 2017), and cerium oxide (CeO2) (Tomak et al. 2018), have been shown to exhibit strong antibacterial properties. Graphene's ability to stop the spread of pathogens is also quite noteworthy. To improve mould resistance and antibacterial activity, bamboo-based outdoor products may be coated with reduced graphene oxide and nano-ZnO using a two-step dip-dry and hydrothermal process (Wang et al., 2018). Weththimuni et al. (2019) found that hydrothermally generated nano-structured ZnO was also effective in preventing biodeterioration of wood surfaces. Waterborne polyurethane coatings (WPU) with nanocrystalline cellulose (NCC) and silver nanoparticles (AgNPs) improved the antibacterial characteristics of wood boards (Cheng et al. 2020). AgNPs have an excellent reputation as antibacterial agents, although they tend to aggregate while manufactured. Thus, NCC enhanced AgNPs' compatibility with WPU and other coatings. In addition, NCC performed admirably as a reinforcing agent to improve the mechanical properties of nanocomposites. To suppress the growth of black-stain fungus on wooden surfaces, AgNP-containing acrylic latex coatings were also synthesized through micro-emulsion polymerization (Boivin et al. 2019). Antibacterial characteristics of silver and zinc oxide nanoparticles in acrylic coatings for processing commercial wood composites like particleboard and medium-density fibreboard were investigated (Izdinsky et al. 2018). Ag and ZnO nanoparticles were less effective against Gram-positive *Staphylococcus aureus* and more effective against Gram-negative *Escherichia coli* (Jasmani et al., 2020). As a biocidal agent, colloidal nanosilver has been on the market for over a century (Nowack et al., 2011; Rai et al., 2009). When exposed to water, silver ions are released from silver-containing compounds, but nanosilver particles, which may serve as a catalyst, are protected by a polymeric matrix and coating. When leaching out of paints, nanosilver is often transformed into less toxic compounds like silver sulphide (Kaegi et al., 2010), reducing health risks. Nanosilver has been applied to wood to reduce biodegradation (Fig. 3) and improve termite resistance (Marzi, 2015).



Figure 3: Silver nanoparticles against the microbial activity of wood (Marzi, 2015)

Nanotechnology-based treatments may be used to make wood more durable against biodegradation agents and the elements (Mantanis et al., 2014; Papadopoulos et al., 2019). Incorporating nano-products into wood increases its longevity in use (Goffredo et al., 2019). In contrast, complete system penetration allows for the homogenous dispersion of nano-products (Papadopoulos et al., 2019). There are several nano-products (nano preservatives) on the market for protecting wood, and many more are in different phases of research. The two most frequent types of wood protection nanotechnology are nanocapsules and nanomaterials.

**Nanoadditive for Fire Retardancy Improvement**

Wood and non-wood products have been restricted from numerous applications due to fire safety concerns. Careful consideration must be given to the flame-retardant properties of wood and non-wood materials to solve their inherent inadequacies and ensure their safe usage. Nanoparticles have been used in the creation of fireproof nanocomposites recently. Reduce the combustibility of wood by using nanoparticles or, in addition to, conventional fire retardants. Due to their nano size and high surface area, nanomaterials offer significant commercial and economic advantages over traditional chemicals. TiO2-coated wood was shown to be less flammable and to have less flame spread when compared to untreated wood (Deraman & Chandren 2019). ZnO-TiO2 double-nanostructures were synthesized on a bamboo substrate (Ren et al., 2018). ZnO-TiO2 coating significantly enhanced its flame-retardant properties, as shown by an increase in the oxygen index from 25.6% to 30.2%. Layered double hydroxides are a robust flame retardant because they absorb large amounts of heat during breakdown, reduce the concentration of flammable gas, and soak up dangerous acid gases (Yao et al. 2019). When Yao et al. (2019) applied nano magnesium aluminium layered double hydroxide (Mg-Al LDH) to bamboo in a single-step technique, they found that both the total heat release and the total smoke production were reduced by 33.3% and 88.9%, respectively. Wang et al. (2018) found that when Zn-Al LDH nanostructures were incorporated into the wood, the peak heat release rate (PHRR) was reduced by 55%, and total smoke production was reduced by 47% compared to untreated wood. Surface protection against fire in wood and wood composites was proven possible using graphene and other nano-structured carbon compounds (Esmailpour et al., 2020). Thin film fire retardant coatings of nanoparticle-based titanium and silicon dioxide might improve fire safety. These chemicals, meant to extinguish fires and lessen smoke, may be sprayed using regular airless sprayers. They deprive the flames of oxygen and extinguish the fire when exposed to heat. A thick char must be formed to prevent the surface from catching fire (Bertolini et al., 2010). Due to their high thermal conductivity, nanosilver coatings have also been investigated for their potential to improve fire resistance and heat transfer in wood (Taghiyari, 2012). According to the available data, Nanosilver treatment of solid wood products may improve their fire resistance. Such a coating might delay thermal degradation and carbonization by reducing heat accumulation. Wollastonite nano-fibres were also discovered to significantly enhance the fire-retardant properties of solid woods and wood composite products (Poshtiri et al., 2014). Nano-sized wollastonite acts as a fire retardant because it creates a physical barrier between the flames and the wood (Taghiyari, 2012).

**Conclusion**

The use of nanotechnology in the field of wood-based goods has tremendous promise. The potential for nanotechnology to revolutionize the market for wood-based goods has international and domestic implications. Wood materials have a low resistance to the degrading influence of UV light; hence, many studies have focused on colour preservation techniques. Nanometal oxides have equalled or exceeded the quality of organic absorbers in the UV range. However, we feel that the genuine long-term stability that inorganic absorbers should be able to attain still needs to be validated. In the present and the future, in particular, safety and health laws will impact how well people are protected against microbes. There are several methods for keeping wood from weathering its natural colour when used outdoors, but few are sustainable or effective in the long run. UV protection systems based on nanoparticles might be the answer to this issue. They're versatile enough to be utilized as a filler in film-forming, penetrating surface treatments, or even on their own. - a layer developed in situ on the wood's surface. In addition to protecting against photodegradation, they often have additional benefits such as a fungicide / biocidal activity or a water-repellent function.

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