Research Article

Uses of Nanostructures in Innovative Composite Wood Products and Their Applications

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Abstract | Composite wood products are the engineered products manufactured from wood saw dust and fibers with synthetic organic adhesive like urea formaldehyde and phenol formaldehyde. The uses of nanotechnology in present day are flourishing in many fields, because of its unique properties. Nanomaterials are those materials, which have a size in between 1-100 nm. Nano level sized materials show distinct physical and mechanical properties and incomparable chemical and biological properties. Nano based composite wood products are manufactured now a days by incorporating different nanomaterials in the synthetic adhesives. These nano based wood composites are highly hydrophobic, resistant to pesticides, promising physico-mechanical properties, UV resistance, eco-friendly and fire retardant etc. Nano-structures accelerate and enhance the durability and life span of building materials and furniture. The nanotechnology scavenges the volatile organic compounds (VOCs) emitted from the synthetic adhesive used in wood panels. Due to the vast scope of nanoparticle, it paves a way to use nano-structure in wood composite products for better industrial products manufacturing. The article aim is to review the current state of research regarding the use of nanomaterials in wood composite products.

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Introduction

Nanotechnology is a science in which matter are manipulated to a size of 1-100 nm. In this we incorporate science and technology with each other having diverse applications with the aims to develop and improve the various physical and mechanical properties (Wegner and Jones, 2006, 2009). Nano leveled materials exhibit distinguished and unique properties than that of original (Bajpai, 2016). Nanotechnology is a versatile field which has multipronged uses in the medical bio sensing and catalytic activates etc. (Lohcharoenkal *et al.*, 2021). Twenty first century is considered as the new era of nanotechnology for uplifting the bio economy of the country by the development of various nano based products (Rani *et al.*, 2020; Singh *et al.*, 2018, 2019). As it is evident that nanotechnology uses are multifarious, but in the present era its use has been focused in wood-based industries. The non-nano based wood products are generally less durable, unstable, carcinogenic, and less eco-friendly. The nanomaterial's make wood products more resistant to pests, decrease the surface hydrophylicity, fire resistant, durable, and UV absorption (Bueno *et al*., 2014; Cristea *et al*., 2011; De Filpo *et al*., 2013). These nanostructures also increase the preservation and decreasing the leaching of wood by limiting the penetration of agents to wood (Liu *et al*., 2002; Peteu *et al*., 2010; Salma *et al*., 2010). Nanoparticles are added to the wood based products by following methods like, direct addition to the adhesive or by post treatment of finished products by applying nano based coating (Pizzi and Mittal, 2017; Carvalho *et al*., 2012; Kim, 2009; Myers, 1989; Conner and Madariaga, 1996). The doped nanoparticles shows greater activity than its pure form like, samarium doped cerium oxide 10-20% greater than common ceria (Balamurugan *et al*., 2020). Nanostructures also indirectly put a good impact on climate by avoiding carbon emission to atmosphere through preserving wood decay. It is expected that steel, concrete and aluminum have high carbon footprint than that of wood and the CO_2 emission can be reduced by 14% using wood-based products in buildings (Global Status Report: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector, 2018). Hence the vast uses of nanoparticles in different fields it will increase the life span and durability of composite wood products.

Nanostructures used in composite/wood based products

So far different nanostructure either in pure or in doped form have been used in wood based products for better and efficient results like to increase durability, high physic-mechanical properties, fire resistance and hydrophobicity etc. The following are the important nanomaterials used in composite wood products.

Graphene oxide nanopatrticle

Graphene are mono layered carbon atoms with hexagonal structure having Sp^2 hybridization (Jagiełło *et al*., 2020). Mostly Hummer method is used for the preparation of graphene nanoparticles (Hummers and Offeman, 1958). Graphene nanoparticle improved the physical properties like water absorption, thermal conductivity and thickness swelling up to 19.5%, 39.79% and 50%, respectively. Similarly, the graphene oxide also improved the mechanical properties like modulus of elasticity (MOE), modulus of rupture (MOR) and internal bond up to 19.22%, 38.8% and 28.5%, respectively (Gul and Alrobei, 2021). The Table 1 show the properties of wood products when graphene oxide was incorporated as nanoparticle.

Iron oxide (Fe_2O_3 and Fe_3O_4) nanoparticles

In nature Iron exist in many forms but the two important ones are Fe_2O_3 and Fe_3O_4 (Cornell and Schwertmann, 2003). As compared to bulk form the nanostructure of iron oxide possesses unique magnetic, optical and electrical properties (Iriarte-Mesa *et al*., 2020). Pyrolysis method is used specially for the preparation of iron oxide nanostructure (Jia *et al*., 2011). By adding 1%Fe_3O_4 to the MDF increased 8.5% internal bonding (IB). Moreover, the shielding effect was increased significantly by adding 10% of Fe_3O_4 to MDF (Pourjafar *et al*., 2022). The Table 2 show the properties of wood products when Iron oxide was incorporated as nanoparticle.

Titanium oxide (TiO_2) nanostructure

Titanium oxide (TiO_2) nanomaterial's is prepared particularly by hydrothermal process (Meng *et al*., 2016). The various functionality in wood is enhanced by TiO_2 nanoparticle like fire resistance (Sun *et al*., 2010), prevent weathering (Mahltig *et al*., 2008; Rassam *et al*., 2012; Schmalzl and Evans, 2003), dimensional stability (Sun *et al*., 2010), and rot protection (Mahr *et al*., 2013). Apart from wood or wood based products TiO_2 nanostructure is also used for bio sensing purpose through caped ionic liquids. The Table 3 show the properties of wood products when Titanium oxide was incorporated as nanoparticle.

Table 1: *Effect of Graphene oxide (GO) and reduced graphene oxide (rGO) on properties of MDF (medium density fiber board).*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
MDF (Medium density fiber board)	Graphene oxide (GO) and reduced graphene oxide (rGO)	Thickness swelling, water absorption, thermal conductivity, internal bond and rupture modulus	Significantly improved	(Gul *et al*., 2023)

Table 2: *Effect of iron oxide (Fe2 O3) on properties of MDF (medium density fiber.*

Wood products	Type of nanoparticle	Properties	Effect (increase/ decrease)	Reference
MDF (Medium density fiber board)	iron oxide (Fe_2O_3)	Thickness swelling, water absorption, moisture content and density	Significantly improved	(Pourjafar *et al*., 2023)

Silica (SiO_2) nanostructure

Nano silica has novel and unique properties, due to which it is incorporated to the woody or non woody based materials to increase strength, hardness durability, modulus and decrease the rate of degradation (Li *et al*., 2004; Guefrech *et al*., 2011; Tobón *et al*., 2012). The nanosilica is prepared from its basic rice husk source through many steps (Yalcin and Sevinc, 2001). The Table 4 show the properties of wood products when Silica was incorporated as nanoparticle.

Zinc oxide (ZnO) nanostructure

Zinc oxide nanostructure is prepared generally by thermal decomposition method (Salavati-Niasari *et al*., 2008). Urea formaldehyde is a gluing agent in composite wood products. When zinc oxide nanostructure is mixed with urea formaldehyde in the manufacturing of MDF (medium density fiber board) increases and improves the water absorption and thickness swelling (Gul *et al*., 2021). 1% addition of ZnO to the wood based products increases modulus of elasticity (MOE) and modulus of rupture (MOR) (Candan and Akbulut, 2015). The Table 5 show the properties of wood products when Zinc oxide was incorporated as nanoparticle.

Silver nanoparticles (AgNPs)

Among various metallic nanoparticles silver nanostructure is the most important and fascinating ones for biomedical application, industries, food and optical sensor etc. (Mukherjee *et al*., 2001; Chernousova and Epple, 2013). Generally, the silver nanostructure is prepared by various methods like physical, chemical and biological method. Pyrolysis and spark discharging are the two main conventional physical methods which are used for synthesis of silver nanomaterials (Tien *et al*., 2008; Pluym *et al*., 1993). While organic solvents or water is used in chemical method for the synthesis of silver nanostructures (Tao *et al*., 2006; Wiley *et al*., 2005). To reduce the limitation of chemical method the silver nanoparticles is prepared by green synthesis using fungi, bacteria and plant extract (Ganaie *et al*., 2015). Addition of silver nanomaterials to the MDF shows better hardness at 6minute hot pressing. When hot press time increase it decrease the hardness of MDF because of De-polymerization (Taghiyari and Norton, 2014). The Table 6 show the properties of wood products when Silver oxide was incorporated as nanoparticle.

Table 3: *Nano fibrillated cellulose (NFC) and titanium dioxide (TiO2) effect on particle board properties.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
Particle Board	Nano fibrillated cellulose (NFC) and titanium dioxide (TiO2)	Thickness swelling, water absorption, moisture content, internal bond and rupture modulus	Significantly improved	(Ümit Yalçın, 2023)

Table 4: *Silica nanostructures impact on physical properties Particle Board, MDF and Ply wood.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
Particle Board, MDF and Ply wood	SiO_2	Thickness swelling, water absorption, and internal bond	Significantly improved only in case of MDF internal bond decrease	(Valle *et al*., 2020; Dukarska and Czarnecki, 2016; Khanjanzadeh *et al*., 2014)

Table 5: *Effect of ZnO on MDF properties.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
MDF	ZnO	Thickness swelling and water absorption	Significantly improved	(Gul *et al*., 2021)

Table 6: *Effect of silver oxide nanoparticle on MDF properties.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
MDF	AgO	Thickness swelling, hardness and water absorption	Significantly improved	(Taghiyari and Norton, 2014)

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Table 7: *Al2 O3 effects on properties of MDF.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
MDF	Al_2O_3	Thickness swelling, water absorption, internal bonding (IB), modulus of elasticity (MOE) and modulus of rupture (MOR),	Significantly improved	(Gul *et al.*, 2020)

Table 8: *Effects of Wollastonite on MDF properties.*

Wood products	Type of nanoparticle	Properties	Effect (increase/decrease)	Reference
MDF	Wollastonite	Density and gas liquid chromatography	Significantly improved	Taghiyari and Samadi, 2016

Alumina (Al_2O_3) nanostructure

Alumina (Al_2O_3) is considered the most vital ceramic materials have magnificent characteristics like high strength gigantic electrical insulation, good catalytic activity, colossal hot-hardness, high thermal conductivity, fabulous dielectric properties, chemical inactiveness, huge melting temperature and good stiffness etc. (González *et al.*, 2012; Song *et al.*, 2005; Qu *et al.*, 2005; Issa *et al.*, 2018). Several methods are reported for alumina nanoparticle preparation like hydrothermal (Qu *et al.*, 2005), sol-gel (Li *et al.*, 2006) and precipitation method etc. (Song *et al.*, 2005). By the addition of 4.5% alumina nanostructure to medium density fiberboard (MDF) increases and improves the modulus of elasticity (MoE), modulus of rupture (MoR) and internal bond (IB) to a level of 31%, 22.12% and 16.4%, respectively. By comparing to the controlled and normal MDF alumina nanostructure also increases water absorption and thickness swelling 37.53% and 40.15%, respectively (Alabduljabbar *et al.*, 2020). The Table 7 show the properties of wood products when Alumina was incorporated as nanoparticle.

Wollastonite nanofibers

Wollastonite chemically a calcium silicate minimizes the effects of various pathogens and flourishes the plant growth (Fernández-Puratich and Oliver-Villanueva, 2014). Due to the huge thermal conductivity of wollastonite (Taghiyari *et al.*, 2013) its nanofibers significantly improves the solid wood dimensional stability (Poshtiri *et al.*, 2014) and enhances the medium density fiberboard thermal conductivity coefficient (Taghiyari and Norton, 2014). Wollastonite nano fibers minimized the gas and liquid permeability to medium density fiberboard (MDF) significantly, So, its durability is increase (Taghiyari and Samadi, 2016). The Table 8 show the properties of wood products when Walsonite was incorporated as nanoparticle.

Application of nanotechnology

The nanomaterials have multidisciplinary uses including wood and wood composite materials (Wu *et al.*, 2011). In order to increase and fascinate the quality of wood based composites nanotechnology is introduced which also fulfill the demands for new products in the modern era. Various components like, moisture contents, pathogens and structure instability causes various wood drawbacks in its utilization. These limitations are caused due to many hydroxyl group and polymer nature of cell wall (Papadopoulos, 2010). Naturally wood is a hygroscopic material and the absorption capability of wood to moisture contents is directly related to the surface area exposed.

Properties enhancement of wood based panels by nanomaterials

Wood composites are the combination of various wood elements combined by adhesives (Kevin *et al.*, 2018). As compared to common wood the wood composite properties are generally regarded as stronger. Wood based products for specific purpose at various grade, size and thickness can be easily manufactured. The main limitations and disadvantages of the wood composite products are like that they require high primary energy for manufacturing prone to humidity and releases toxic formaldehyde as compared to the solid lumber. In order to overcome all the above mentioned limitations and disadvantages nanotechnology is implied in the wood based industries in this modern arena (Jasmani *et al.*, 2020).

Wood coating

Nano coating of wood-based products is less susceptible to various environmental factors because of the greater surface volume ratio of the coated nanomaterials. The coated nano materials interact with the adverse environmental factors to protect the wood-based product from decay and weathering (Fengel and Wegener, 2003; Hincapié *et al.*, 2015).

Nano additive as a durable enhancement

To increase the durability of wood and wood-based products nanostructures are added by appropriate way. This nano addition creates molecular level changes in the wood-based products. Pathogens like bacteria, fungi and other microorganism 'scant easily attack on the Nanocoated wood-based products. Different metal oxide nanoparticles such as Zinc oxide (ZnO), cerium oxide (CeO_2) and titanium oxide (TiO_2) were evaluated and find out significant antimicrobial activities (Okyay *et al*., 2015; Chakra *et al*., 2017; El-Naggar *et al*., 2016; Tomak *et al*., 2018). Graphene, silver and polyurethane Nanoparticles also inhabit the growth of microorganisms on the surface of wood and their products (Wang *et al*., 2018; Cheng *et al*., 2016, 2020).

Improvement of mechanical properties by nano addition

The inorganic nanoparticles immersed in the organic polymer increase the mechanical properties. These nanostructures act as a nano filer in the adhesives. nanoparticles like silica and nanocellulose increases hardness, modulus of elasticity (MOE) and modulus of rupture (MOR) significantly (Kong *et al*., 2019; Fallah *et al*., 2017).

Improvement of fire retardancy by nano addition

In the modern era, nanostructures are used in pure form or with conventional combination of fire retardants to reduce the ignitability of composite wood products. In this regard titanium oxide (TiO_2) nanostructure is reported which reduces the inflammability to larger extent as compared to simple and non-nano based wood products (Deraman and Chandren, 2019). Other nanoparticles reported as fire retardant are zinc-aluminum layered double hydroxide, Nano magnesium aluminum layered double hydroxide and graphene used in wood based products (Yao *et al*., 2019; Wang *et al*., 2018; Esmailpour *et al*., 2020).

UV absorption enhancement by nanoparticles

The UV light coming from the sun rays causes degradation of wood and wood based products and also decreases its water resistance power, because it destroy the polymeric structure of wood (Teacă *et al*., 2013). To improve the UV resistance of wood and wood based products different techniques have been applied among which the nanotechnology is promising. Different nanostructures such as TiO_2 and ZnO are reported which exhibit strong UV resistance properties and color stabilization (Zheng *et al*., 2015).

Eco-Friendly effects of nanostructures

The human and environment problem related with formaldehyde (HCOH) emission from wood-based panels causes a serious concern globally and many countries issues legislations for this to reduce volatile organic compounds related to wood based panels, the scientific community have to overcome this problem (Ulker *et al*., 2021). To scavenge formaldehyde emission from wood-based panels nanostructures was added these nanostructures increase the adhesion of formaldehyde (HCOH) in wood-based panels due to its large surface area (Mahrdt *et al*., 2016).

Conclusions and Recommendations

Nanotechnology use in wood and wood-based products is colossal and enormous. The fate of wood-based industries has been changed by incorporation of nanotechnology globally. Nanotechnology has many advantages such as eco-friendly and its recyclibity in many products. The applications of nanostructures are multipronged and versatile but the present review aim to dig out its use in forest products industries. The addition of nanomaterials to wood based products increase their physico-mechanical properties and increasing the scavenging quality of formaldehyde. The future perspective of nanotechnology is to make the nanocomposite with bio adhesives to eradicate the toxic synthetic polymers and developed the novel bio based nano adhesive for the wood-based products. This will indirectly conserve the forest by increasing the durability of wood-based products.

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Novelty Statement

Nanostructures are transforming composite wood products by enhancing their performance, sustainability, and functionality, thereby driving innovative applications in modern construction and manufacturing

Author's Contribution

Abdur Rahman Khan: Contributed to the conception and composing of manuscript Also served as corre-

sponding author.
Mansoor Ali Khan: Helped in composition of manuscript and assisted in physio mechanical properties of nanocomposite.
Abdur Rehman: Helped in cross checking for grammatical check.
Muhammad Umair Khan: Proof reading of article and composing of novel statement.

Conflict of interest
The authors have declared no conflict of interest.

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