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Wood Polymer Composites

Recent Advancements and Applications

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Editors are honored to dedicate this book to their parents

Preface

Wood polymer composites have generated great interest among material scientists due to their eco-friendly nature and good thermo-mechanical performance. Wood polymer composite is an emerging area which possibly may replace traditional polymer composites in many applications. Polymer composites with synthetic fibers are used for automotive, aerospace, construction and building, etc. However, these materials will not degrade, and also, most of the synthetic fibers used are not recyclable. Therefore, the need of replacing synthetic materials with biodegradable wood is highly appreciable. So this book summarized many recent developments in the field of wood polymer composites. The advances in wood polymer composites and replacement of traditional materials with wood polymer composites in the field of materials and polymer science to achieve sustainable practice are described to the readers. This book also offers a good knowledge of wood polymer composites to the readers with numerous methods, illustrations and results for graduate students, researchers and industrialists. Academics, researchers, scientists, engineers, industrialists and students in the field of wood polymer composites will benefit from this book.

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Dr. Sanjay Mavinkere Rangappa is currently working as Research Scientist at King Mongkut's University of Technology North Bangkok, Bangkok, Thailand. He has received the B.E. (Mechanical Engineering) from Visvesvaraya Technological University, Belagavi, India, in the year 2010, M.Tech (Computational Analysis in Mechanical Sciences) from VTU Extension Centre, GEC, Hassan, in the year 2013, Ph.D (Faculty of Mechanical Engineering Science) from Visvesvaraya Technological University, Belagavi, India, in the year 2017 and Post Doctorate from King Mongkut's University of Technology North Bangkok, Thailand, in the year 2019. He is a Life Member of Indian Society for Technical Education (ISTE) and Associate Member of Institute of Engineers (India). He is a reviewer for more than 75 international journals (for Elsevier, Springer, Sage, Taylor & Francis, Wiley), book proposals and international conferences. In addition, he has published more than 150 articles in high-quality international peer-reviewed journals, 4 editorial corner, 30+ book chapters, one book, 15 books as Editor and also presented research papers at national/international conferences. His current research areas include natural fiber composites, polymer composites and advanced material technology. He is a recipient of DAAD Academic exchange-PPP Programme (Project-related Personnel Exchange) between Thailand and Germany to Institute of Composite Materials, University of Kaiserslautern, Germany. He has received a Top Peer Reviewer 2019 award, Global Peer Review Awards, Powered by Publons, Web of Science Group. He has been recognized by Stanford University's list of the world's Top 2% of the Most-Cited Scientists in Single Year Citation Impact 2019 and ranked 97th among 187 THAI Scientist in the list.

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He won the Outstanding Researcher Award in 2010, 2012 and 2013 at KMUTNB. His research interests are in polymer processing and composite material. He is Editor-in-Chief: KMUTNB International Journal of Applied Science and Technology and the author of more than 250 peer-reviewed journal articles. He has participated with presentations in more than 39 International and National Conferences with respect to materials science and engineering topics. He has recognized and ranked among the world's top 2% scientists listed by prestigious Stanford University.

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Introduction to Wood Polymer Composites

R. Ruban, H. Mohit, P. Ramesh, V. Arul Mozhi Selvan, and G. H. Kumar

Abstract In the recent year, the needs for environmentally-friendly, low-price, and recyclable with higher strength laminates have been improved significantly. In this regard, the wood fillers based polymer laminates have fascinated the investigators owed to their lower price and eco-friendliness as they are formulated from waste wood fillers and better physical and mechanical characteristics. These laminates were fabricated by reinforcing the waste wood fillers in the polymeric resin using different manufacturing techniques like compression molding, hand layup, injection molding, three-dimensional printing, and extrusion. A considerable quantity of research investigation has been examined on the characterization and testing of wood-based polymer composites for different applications. This chapter presents the thermal, water absorption, and mechanical characteristics of thermoplastics, biopolymers, and thermosets have been discussed. The present chapter's conclusion offers a better understanding of the wood laminates, which will inspire the investigators for further research investigations and advancements of new wood laminates for the developed applications.

Keywords Chemical surface modification · Mechanical properties · Thermal properties · Water absorption · Wood polymer composite

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1 Introduction

The attention to fillers reinforced in plastics has been determined for elastic characteristics enhancement (Liang 2012). The developing awareness in the utilization of plant fibers (Dong 2018; Mohit and Selvan 2018) recognizes the olive wood fillers of main economic and ecological interests. Certainly, among the crops from fruit, olive is mainly generated around the Mediterranean regions. During the process of oil extraction, a considerable quantity of solid and liquid waste offers possible issues of pollution to the environment. Besides, this type of wood used for the fabrication of handicraft components develops a tremendous amount of waste consisting of lignin and cellulose as the major constituents (Naghmouchi et al. 2015; Bouhamed et al. 2020).

Moreover, while comparing with carbon and glass fabrics, different polymers have been examined as potential materials for plant fibers because of their lower price, higher biodegradability, and lower density (Amar et al. 2011). Still, different classical plastics are consistently influencing the region of polymers for wood basic polymer laminates. Certainly, the recent investigation was performed in the scheme of bio-based materials. On the other hand, the investigated wood-based polymer laminate depends on the polymer resin; in another part, wood fibril particles are comprised as a capacity for improving the strength of the obtained laminate. This type of wood-based polymer composite material boosts the query about the properties and control techniques either during the fabrication or even after a specific period. Besides, such a wood-based polymer laminate is forecasted to exhibit the viscoelastic characteristics observed from the mechanical testing process and can be compared with the non-destructive examination. The non-destructive examination may be feedback to these queries gratitude to the right to select specimen structure, information availability, and the capability to collect a higher range of precision, low price, and testing speed. In principle, the utilization of non-destructive testing techniques for the mechanical properties of materials is diverse improving (Bouhamed et al. 2020). These techniques are substitutes for the traditional destructive mechanical properties evaluation.

From the non-destructive methods, the ultrasound technique can be applied to determine the examined specimen's elastic characteristics. Lefebvre et al. (2018) applied the Fabry–Perot resonance method to inspect the bulk and shear modulus of the viscoelastic plastic; El-Sabbagh et al. (2013) investigated the influence of plant fibers concentration on the velocity of ultrasound in a laminate material fabricated from polymeric resin. Castellano et al. (2014) has carried out the bio-based laminate mechanical testing from ultrasound measurements. The examination of transversal and longitudinal wave velocity is a useful measurement technique to isotropic elastic composites (Simonetti et al. 2005), primarily for differentiating the mechanical properties and then for evaluating the elastic modulus essential for the explanation of the mechanical characteristics (Scalerandi et al. 2012). The mechanism of this technique depends on the period for the measurement of flight. This examination can also be carried out in the spectral region using Fourier transform infrared spectra spectroscopy. It is well established that the longitudinal velocity of sound is a formulation of the composites' characteristics, which corresponds to the quality of adhesion and fiber concentration (El-Sabbagh et al. 2013).

Solid wood is a premium flexible material and has been broadly applied in different applications, including the following fields as sporting goods, furniture, and civil construction. It has greater strength to weight proportion, lower acoustic, thermal conductivities, and renewable sources as an essential characteristic. Furthermore, the qualified woods (particularly from forests) have more absorbed because of improper resource and utilization planning. For this reason, there is a high contribution to individual fast-breeding plants like pines. Generally, fast-breeding plants create a considerable proportion of young wood when cultivated in tropical regions, which presents an excellent problem for developed growing schemes for maintaining the quality of wood. Principally, a forest can be set in the method that a decreased gap between trees is used in the initial years of the tree life, which reduces the production of new types of cells from the cambial and thus relived the output of young wood. Palmero et al. (2013), the Pinus Elliott wood initiates to create mature timber at the twentieth year of span if cultivated in dense forest regions. Similar scientists have investigated old trees (35 years) with a diameter of 25 cm and explored that the central part of the trunk with a diameter of 15 cm made up of young wood. Under the ultrastructural level, while comparing the mature wood, the young wood has small cell walls, higher grain angle, lower tangential cells, a smaller ratio of latewood, and higher microfibril angle (Mcdonald and Hubert 2002). Thus, most of the biological, mechanical, photochemical, and hygroscopic properties of the young wood are lesser than the mature wood (Li et al. 2011). Insemination utilizing different polymers preliminary to in situ polymerization is the method to enhance many unfavorable characteristics in the wood. In this step, permeable and lightweight solid woods are inseminated with polymers of higher reactivity, lower viscosity, and a lower molecular weight that must be efficient of inter or intracellular voids in wood or chemically bond themselves to different lignin and polysaccharides available in the wood cell wall (Islam et al. 2014). Presently, various patented components were constructed from this principle and are abundant on the market, such as Ligeia, Vecowood, Indurite, epoxy, styrene, furfuryl alcohol, and methyl methacrylate are some already applied polymers in published literature (Acosta et al. 2020).

Among the plant fibers based polymer laminates, wood flour has been broadly applied to fabricate wood polymer laminates. LLDPE (Linear low-density polyethylene) is a standard selection to fabricate wood-based polymer composites (Government et al. 2019) because of its outstanding flexibility. Generally, polymers are hydrophobic, which leads to poor interfacial bonding with the hydrophilic wood flour, which restricts their mechanical characteristics (Zhou et al. 2015). The interfacial adhesion between the polymer and wood flour can be improved to utilize some crosslinking agents and chemical treatment of matrix/fibers (Arora et al. 2012). Currently, radiation is used to enhance the polymer matrix and fiber interfaces (Güven et al. 2016). Gamma radiation can influence the polymer design of wood fillers and matrix, creating active regions that may share to enhance interaction between polymer and wood (Niang et al. 2017). Gamma irradiation of polymer laminates became more general as no heat was generated during the process (Kismet 2017). This outcome in the crosslinking and degradation of polymers concerning the utilized dose (Ndiaye et al. 2014).

Wood is involved; renewable, durable material consists of various biomacromolecules and biomolecules (Guo et al. 2015). As a biodegradable material, it can be applied from the prehistoric period for a wide range of applications containing tools, transportation, fortifications, funerary objects, dwelling, and weapons (Moise et al. 2019). The necessity of cultural heritage conservation has been controlled and recognized internationally. Preservation of wood components is one of the practices within the rehabilitation of a heritage component. It is assigned to the preservation of both archaeological and historical features of the wood. The necessary regulations are mainly targeted at better conserving the individuality of the component. Many of these techniques are dependent on radiation methodologies like gamma biocide modifications for cultural heritage, polymerization under gamma irradiation, consideration of wooden artifacts from radiation curing polymers. One technique of preserving wooden products is radiative insemination with plastic (Schneider 2016). Although the principle can be freely prepared from general woodworking processes, it can also be fabricated from the typical polymer using injection molding and extrusion and produced from additive production methods via fused deposition modeling (FDM) (Ray and Rathore 2015). They are generally applied as an alternative for ordinary wood, which is involved in fencing, decking, and flooring, and their utilization is beneficial in humid working conditions or ever in close contact with fluid; the hydrophobic resin separates and shields the hydrophilic wood fillers, and hence leads to improves durability and needs lower maintenance interferences up to certain level (Chen et al. 2017). Remarkably are also their utilization in automotive and acoustics (Sawpan 2016). The significant benefits of wood as a filler reinforcement are decrement in cost and an enhancement in the finally developed laminate's environmental features. The erstwhile is utterly evident, as wood fillers are generally low-price components, usually impending from industrial or agricultural waste. The recent investigation is also fair since a significant proportion, sometimes as large as 70 wt% of a non-biodegradable matter of fossil region, is being replaced by an eco-friendly component (Kootsookos and Mouritz 2004). A higher environmental benefit can be collected if the applied resin is also from biodegradable polymers obtained from bioresources (Wang et al. 2018; Quan et al. 2018).

Considering the mechanical characteristics of the laminate, strength, and stiffness are adequate only if expensive coupling agents are reinforced during the formulation of the material: these additives are essential for enhancing the compatibility between the polymer and wood flour, which would not contribute any significant chemical correlations (Prusty et al. 2017). These objectives produce an efficient load movement interface between the covering resin and natural fillers. However, since wood plastic composites are generally brittle, their correlation usually consists of strengthening components like thermoplastic elastomers, ethylene propylene diene rubber, and styrene-butadiene rubber (Zhang et al. 2012). To boost as much potential from the previous benefits, an approximately higher wood flour concentration, more than 50 wt%, is more desirable. In the same manner, a higher quantity of reinforcement improve the viscosity of the resin melt noticeably, hence producing flow and thus making the process relatively complicated. This issue is again engaged by comprising useful additives such as lubricant, which may advertise wall slip and thus reduce the fabrication's energy needs. Note, certainly which the general method of reducing melt viscosity by rising temperature is not possible because of thermal degradation. Available lubricant applied for the improvement are ethylene or esters, thermoplastic silicones, and stearates.

For perfectly designing the preparing equipment, a discreet feature of the molten wood plastic composite is essential. This is not entirely genuine, mainly due to the non-newtonian behavior of these fluids. Even though a considerable quantity of research articles, an extensive review is still absent in the literature, and this chapter is targeted by considering specific aspects. In the upcoming sections, the concept behind the physical, mechanical, and thermal characterization techniques applied before showing the outputs of the scientific articles were outlined. In the final section, the conclusions were drawn and recommended a few discussions on the applications.

2 Fabrication Methods of Wood Plastic Composites

The proper manufacturing technique for wood-based polymer composites is a challenging practice based on the polymer type, the product's geometry, surrounding circumstances, the weight percentage of wood fillers in the matrix, and overall price. The type of polymeric resin, such as thermoplastic and thermosetting, is the highest affecting factor for the chosen manufacturing technique. The traditional manufacturing techniques like injection, extrusion, hot press, compression molding, and wet layup are generally utilized production techniques applied by various investigators as explained in the published article (Chaharmahali et al. 2010; Komal et al. 2020). In recent decades, three-dimensional printing is being used to produce wood polymer-based plastic composites as advanced manufacturing technology. In the current scheme, rapid prototype methodologies have been applied in construction, medical, and manufacturing fields.

Furthermore, three-dimensional printing has also been applied for generating the polymer-based laminates. In this technique, the primary three-dimensional model of reliable components is created in the modeling software, and the produced three-dimensional model was separated into the compilation of individual layers as per the printer's capacity. The solid component is engraved as layer by layer deposition of the composite laminate. This method is efficient for the rapid prototyping of components in producing and examining the product's design without the materials loss and expensive tool (Schwarzkopf and Burnard 2016). This method's primary benefit is straight generating the components in one process using the information from CAD. Selective laser sintering (SLS), fused deposition modeling (FDM), stereolithography, three-dimensional inkjet printing, and three-dimensional plotting are general printing methods for polymer-based fabrication laminates. Other methods are under the advancement region so far (Wang et al. 2017).

Further SLS and FDM 3D printing methods are applied for the development of wood polymer composites. The FDM three-dimensional printing method is a composite extrusion method that involves the produced filaments of wood polymer composites. The filaments are passed into the heating chamber, where the wood polymer composites were melted into semi-liquid form and deposited layer by layer from the nozzle in the regulated condition on the platform's surface. The FDM method's restriction is based on the polymer type applied at the melting temperature below the decomposition temperature of wood fillers applied in the wood polymer composites. However, this technique is restricted to the thermoplastic polymer composites (Schwarzkopf and Burnard 2016; Wang et al. 2017; Martikka et al. 2018; Kain et al. 2020). The SLS three-dimensional printing method utilized the powder that softens at various temperatures and is blended from laser radiation. The SLS method for producing wood polymer composites is under the phase of advancement (Schwarzkopf and Burnard 2016). All the three-dimensional printing methods of the progress of wood polymer composites developed prominently in recent decades. Because of the restrictions such as relatively higher processing price, limitations of materials, higher energy consumption, harmful emission, and slower processing, three-dimensional printing methodology is restricted in the area of wood polymer composites so far. Still, it will be sustainable for producing all kinds of wood polymer composites in the upcoming future. To date, a very restricted survey corresponded to the examination and advancement of three-dimensional printed wood polymer composites were abundant. The FDM method of three-dimensional printing has been applied to promote wood polymer composites components precisely in a unique way. Martikka et al. (2018) estimated three-dimensional printed wood fillers' mechanical characteristics based on PLA laminate. The impact and tensile strength of developed laminates were 53 and 58% reduction than the pure PLA. The mechanical characteristics of three-dimensional printed wood polymer composite components are also based on the pattern of printing, the diameter of the nozzle, the thickness of the layer, build a style of laminate, and speed of feed (Kariz et al. 2018).

3 Mechanical Characteristics of Wood Polymer Composites

The mechanical characteristics of wood polymer composites based on the mechanical and physical features of the wood fillers, characteristics of polymeric resin, particles geometry, content of fillers, wettability, compatibility and interfacial adhesion. The stress concentration, lower filler weight proportion, and good interfacial adhesion outcomes in the higher aspect ratio, good wettability of fillers with polymer, higher tensile strength and weight proportion of wood fillers improved the tensile modulus of laminates. The fiber pull out, higher energy absorption and interfacial adhesion enhanced the impact strength of wood polymer composites (Chand and Fahim 2008). The upcoming sections explain the flexural, tensile, hardness, and impact characteristics of different kinds of wood polymer composites as observed from the recent literature.

3.1 Thermoplastic Wood Polymer Laminates

Thermoplastic based polymers are generally softening at a higher range of temperature and can be formed into any shape or structure, and amorphous or semi-crystalline. The semi-crystalline structured polymers show the variation in crystallinity, and amorphous polymers contain molecular networks that are randomly oriented. The amorphous and crystalline polymers act variously under higher temperatures. Amorphous resin does not interpret the genuine melting but softens to the viscous flow (Wolcott and Englund 1999). These resins have a broad compatibility with the traditional fabrics like carbon and glass, need lower processing energy, ease of manufacturing, softer density, and economical (Espert et al. 2004). Universally, polypropylene and polyethylene were applied to advance thermoplastic polymer laminates that can be utilized for the external components because of better protection from moisture and its availability as waste (Chaharmahali et al. 2010). It has been well-established that few thermoplastic resins were applied for the advancement of wood polymer composites due to the preferred resin should have the softening temperature lower than the thermal decomposition of wood fillers (may be lower than 200 C) (Poletto et al. 2012). Thermoplastic resin-like high-density polyethylene, low-density polyethylene, polyethylene, polypropylene, polyvinyl chloride, and polystyrene have better compatibility with wood (Wolcott and Englund 1999). Polypropylene resin has been generally applied because of lower service temperature, higher mechanical characteristics, and lower cost. The studies of mechanical features for these laminates are performed for different weight concentration of wood fillers, structure of the chemical, size and aspect ratio of wood fillers, and laminate manufacturing method. Nourbakhsh et al. (2010) examined and compared the mechanical characteristics of particles of polypropylene laminates containing different aspect ratios and size of wood fillers for 30% weight proportion of general wood addition. They achieved that mechanical characteristics of laminate improve with the increment of wood particles aspect ratio and size. Chaharmahali et al. (2010) investigated the mechanical characteristics of reused particle sawdust reinforced high-density polyethylene laminate. It was found that the impact and flexural strengths of laminate reduced with an increment in the concentration of filler, and the flexural modulus also enhanced. Perez et al. (2012) collected that the strain at fracture, fracture toughness, and tensile strength of red pine wood fillers polypropylene laminates was reduced with an increment in the concentration of wood filer, and also the tensile modulus of the laminate was improved. The incorporation of MAPP coupling agent with the red pine wood fillers improved the tensile characteristics, but the influence on fracture toughness was insignificant. In another investigation, the tensile modulus, strength, and elongation at break of wood fillers polyvinyl chloride composites are more significant than the bamboo-based wood polymer composites because of uniform homogeneity within the matrix (Ge et al. 2004). Nikmatin et al. (2017) observed the influence of rattan nanofillers size on the mechanical, physical, and thermal characteristics of polypropylene-based laminates and compared their characteristics with the glass fiber reinforced and pure polypropylene laminates. The advanced laminate acquired an excellent surface finish and greater hardness value when compared with other laminates. The reinforcement of 40% of wood fillers in the polypropylene resin improved the tensile modulus and strength of laminate by 108% and 48%, respectively, and the elongation at break and impact strength reduced by 86% and 42%, respectively (Ichazo et al. 2001).

3.2 Thermoset Wood Polymer Laminates

Thermosetting polymers do not soften on external heating. The polyvinyl ester, epoxy, polyester, formaldehyde, phenolic, and polyurethanes are generally applied polymers to advance wood polymer composites. These resins acquire higher characteristics than the thermoplastic resins in mechanical characteristics, filler wettability, durability, thermal and electrical insulation, viscosity, molecular cross-linking, resistance from creep, and chemicals. Epoxy resin is commonly favored for laminates advancement among the abundant polymers because of many benefits such as lower viscosity, thermal stability, higher mechanical characteristics, good interfacial adhesion between the fillers and matrix, good resistance from chemicals, and after curing, lower shrinkage. Many scientists have studied the mechanical characteristics of thermosets wood laminates. Lette et al. (2018) studied the flexural and tensile characteristics of cedarwood fillers phenolic resin laminate and rice husk reinforced phenolic laminate. It was observed that 33 and 1% of higher flexural and tensile strengths of cedarwood fillers phenolic laminates were 29 and 11% higher than the flexural and tensile modulus of the rice husk phenolic laminates. Vignesh and Selvam (2015) analytically found that the tensile modulus, tensile, flexural, impact strength, and hardness of teak wood fillers polyester laminate were examined as higher when compared with the similar rubber and Sal based wood fillers polyester laminate. The flexural and tensile strength of wood shell (apple) particles epoxy laminate were improved with the incorporation of particle concentration, and the density of laminate reduced because of the lower weight of wood shell fillers (Shakuntala et al. 2014). Kumar et al. (2014) studied the flexural and tensile characteristics of wood dust (sundi) fillers epoxy laminates for seven different variations in weight% relating to three different speeds of crossheads, and the laminate with ten weight% reported higher flexural and tensile strength under crosshead speed of 1 mm/min and higher modulus under crosshead speed of 2 mm/min.

3.3 Biopolymer Wood Polymer Laminates

Our surroundings are getting influenced due to non-biodegradable polymers have been generally applied in different industries as packaging, furniture, automobile, and construction. The new strategies for environmental problems target to boost the application of components produced from bio-degradable materials that offer a driving load for advancing the new type of biodegradable materials, which can have a detrimental effect on the ecology environment. The new bio-based resin as green laminates is generated as a substitute material because it is recyclable, renewable, emit low greenhouse gas, and biodegradable. Biopolymers like polyester amide, polylactic acid, cellulose acetate, starch blends, polyhydroxyalkanoates, and polyvinyl alcohol and natural fillers, particles or whiskers collected from the waste of animal minerals and proteins, and plant waste are being applied as reinforcement and polymeric materials, respectively, for the advancement of green laminates (Teymoorzadeh and Rodrigue 2015). The scientists are frequently employing the sustainable improvement of bio-based wood polymer laminates. Ge et al. (2006) fabricated and mechanically characterized the bio-based bamboo wood fillers reinforced polypropylene carbonate laminate. The tensile strength of laminate was 16% greater than the pure polymer. The morphology interpreted dispersion of bamboo wood fillers in the polypropylene composite uniformly. Nagarajan et al. (2016) fabricated biochar fillers reinforced PLA-based bio-laminates and investigated the mechanical characteristics for various wood fillers' sizes. Agnantopoulou et al. (2012) measured the tensile characteristics of several types of wood fillers (general, spruce, beech, and pine) added thermoplastic starch laminates. The tensile modulus and strength of these laminates were observed from 0.85–0.95 GPa and 13.3–17.3 MPa, respectively.

3.4 Enhanced Mechanical Characteristics of Wood Laminates by the Treatment Process

The inappropriate interfacial adhesion between hydrophilic wood polymers incorporation and hydrophobic resins tends to the non-uniform transfer of stress by that decrement in the mechanical characteristics of wood-based polymer laminates (Hosseinaei et al. 2012). To improve the mechanical aspects of polymer-based wood polymer laminates, various kinds of surface modification techniques such as silane, maleated coupling agent, bleaching, benzoylation, acylation, etc.; physical surface modifications such as plasma, gamma, corona, etc.; compatibilizers such as metal oxides, nanoclay, etc.; and surface enhancements such as coating, roughing, and cleaning was used over the components of wood-based polymer laminates (Ichazo et al. 2001; Lee and Wang 2006). Many investigators have studied the influences of treatment techniques on the mechanical characteristics of wood polymer composites. Kord (2011) empirically evaluated the consequences of maleic anhydride polypropylene coupling agents on the impact, flexural, and tensile characteristics of sawdust reinforced polypropylene laminates. For two wt% of maleated coupling agents, the impact strength, tensile modulus, strength, flexural modulus, and laminate strength were improved by 11%, 5%, 11%, 6%, and 8%, respectively. Dairi et al. (Dairi et al. 2015) exhibited that flexural and tensile characteristics of maleated coupling agent modified pine wood fillers reinforced polyethylene-terephthalate/polypropylene laminate enhanced because of uniform interfacial bonding, which flattened the transfer of stress from fillers to the polymer resin. Kajaks et al. (2015) examined significant enhancements in impact, hardness, and flexural characteristics of pine wood fillers reinforced high-density polyethylene laminates after modified with maleated coupling agents. In another investigation, influences of chemical surface modifications such as cellulose palmitate, stearic acid, benzoylation, and maleated coupling agents on the mechanical characteristics and correlation of polypropylene depended wood laminates were performed (Danyadi et al. 2010).

The examination exhibited that incorporating nano-clay in the wood-based polymer laminate decreased the elongation at break, impact, and tensile strength but improved the modulus of laminates (Gu et al. 2010). The flexural and tensile strengths of wood fillers high-density polyethylene laminates were produced when mixed with TiO2 nanofillers, and flexural and tensile modulus were improved by 34.5% and 151%, respectively (Deka 2001). Kim et al. (2010) examined the influences of silane modifications over the Picea abies wood fillers polypropylene laminates, and Each silane modification displayed enhancements in the impact, flexural and tensile strength than the untreated wood fillers laminate. The silane modification based on VTMS exhibited higher enhancement in the impact (11%), flexural (78.4%), and tensile (85%) strength of the laminate.

3.5 Enhanced Mechanical Characteristics of Wood Laminates from Hybridization

The mixing of more than two wood fillers of different constituents and extents in individual polymers outcomes in a hybrid laminate counteract each kind of wood fillers' capacity. Usually, the need for hybridization reduces the demerits and boosts both kinds of wood fillers' merits. Finite published literature is found on the influences of hybridization of wood fillers on thermal, crystalline, water uptake, and wood polymer composites' mechanical properties. Saxena and Gupta (2018a, b) investigated the thermal, water uptake, and mechanical characteristics of hybrid mango and sal wood fillers reinforced epoxy laminates and examined the potential effect of hybridization mechanical attributes at the equal ration of each kind of wood fillers were combined. The hybrid shoresa and mango robust wood fillers reinforced epoxy laminate exhibited higher crystallinity than the single wood fillers reinforced epoxy laminate (Saxena and Gupta 2018a, b). Khan et al. (2019) studied the impact, flexural, microhardness, and tensile characteristics of hybrid shoresa robusta and pine fillers reinforced epoxy laminates for dissimilar weight ratios wood fillers. The hybrid laminate with an identical fraction of wood fillers exhibited higher mechanical characteristics than the similar collected for single wood filler laminates. The flexural strengths of hybrid laminate were observed 56% and 200%, tensile strengths 28% and 54%, impact strengths 14% and 18%, flexural modulus 3% and 6%, and microhardness 52% and 14% greater than the individual shorea robusta and pinewood fillers reinforced epoxy laminates, respectively.

4 Water Absorption Characteristics of Wood Laminates

The investigation of wood-based polymer laminates' water absorption characteristics is essential because the hydrophilic wood fillers are prone to water and moisture. Usually, wood polymer-based laminates were lower prone to absorption of moisture and acquired higher dimensional accuracy than the plant cellulose fiber-filled polymer laminates (Caulfield et al. 2005). The water absorption is based on various factors such as manufacturing technique, wood fillers wettability with the polymer resin, shape, size and concentration of wood fillers, wood's chemical structure, temperature, and concentration of voids (Caulfield et al. 2005). The hydrophilicity and hygroscopicity principle negatively influence the mechanical characteristics of wood polymer composite and stimulate fungal decay. The laminate initiates swelling when disclosed to moisture tend to the regional strain in polymer that outcome to micro-level cracks; subsequently, decreases the mechanical characteristics of laminates (Joseph and Thomas 1995). The wood fillers attain their original size and shape when preserved, whereas the polymer does not achieve its size and shape because of bounded strain tend to the limited debonding between the matrix and fillers. This principles a poor interfacial adhesion that damages the mechanical characteristics (Stark and Gardner 2008). Bhaskar et al. (2012) studied pine wood flour's water absorption capacity reinforced in original and recycled polypropylene laminate. The water absorption improves with an increment in the concentration of wood flour. The results found that recycled laminate exhibited 15–20% of lower water absorption capacity than the original polypropylene laminate. The maleated coupling modified recycled polypropylene laminate exhibited 15–20% lower water absorption than the original polypropylene laminate. The maleated coupling agent changed recycled polypropylene laminate exhibited decrement in water absorption up to 70% while comparing pure recycled polypropylene.

In contrast, the swelling of thickness was observed lower that further decreased to 0.43 to 0.55% with the addition of a maleated coupling agent. The water absorbed from cedar wood fillers based phenolic laminate was observed 57% higher than the rice husk phenolic laminate (Lette et al. 2018). The maleated coupling agent enhanced the resistance from water absorption of pinewood fillers based on polyethylene-terephthalate/polypropylene laminate (Dairi et al. 2015). The resistance of moisture from wood polymer composites can be enhanced through different kinds of chemical surface modifications on wood fillers as benzoylation, peroxide, esterification, acetylation, and alkaline treatment. The chemical surface modification of reinforcements changes the wood fillers' chemical constituents by eliminating the lignin, unwanted concentrations, and hydroxyl group (Kalia et al. 2011). The addition of wood fillers with polyvinyl chloride reduces the laminate's moisture-resistant characteristics (Jullianelli et al. 2010). The outcomes displayed that pine filler reinforced polypropylene laminate occurs higher resistance from moisture than the beech polypropylene laminates because of their higher lignin and hemicellulose content beech wood fillers while comparing with pinewood fillers (Ayrilmis et al. 2017). It was empirically examined that water absorbed by hybridization of charcoal and wood flour polypropylene laminate reduced with an increment in the charcoal concentration. The wood flour based polypropylene laminate soaked 38% extra moisture than the charcoal-based polypropylene laminate (Ayrilmis et al. 2015).

The mixing of TiO3 nanofillers with wood fillers reinforced high-density polyethylene laminates evaluated a 40% reduction in water absorption capacity due to the TiO2 played as a protective shield for water sorption characteristics (Deka 2001). Tazi et al. (2018) observed in their investigation that water absorption of spruce-based high-density polyethylene laminates was improved by adding the fusa bond coupling agent. The resistance to crystallinity and water absorption of beech wood fillers reinforced polypropylene laminate was potentially influenced by the organoclay insertion and maleated coupling agents (Ge et al. 2004). Danyadi et al. (2010) investigated the influences of different kinds of chemical surface modifications such as stearic acid, benzoylation, cellulose palmitate, and maleated coupling agent on the water absorption resistance of spruce wood fillers polypropylene laminate. The maleated coupling agent did not influence the resistance from water absorption of laminate, whereas the cellulose and benzoylation modifications exhibited a potential effect on laminates' water-resistance characteristics. The wood polymer-based composites have better resistance from wood.

Furthermore, the lower water absorption capacity of wood polymer composites, while comparing with the pure polymer, is the limitation of wood polymer composites that generated the decrement in mechanical characteristics and dimension instability. The hybridization of wood fillers has significantly enhanced the water-resistance features compared with the single wood filler based laminates. The investigators have applied various kinds of chemical surface modifications and compatibilizers for improving the moisture absorption resistance of laminates.

5 Thermal Characteristics of Wood Polymer Laminates

The thermal investigation contains the studies of storage and loss modulus, glass temperature transition, melting point, crystallization temperature, specific heat capacity, thermal conductivity, and damping of the laminates. The differential scanning calorimetry, dynamic mechanical analysis, thermogravimetric analysis, thermal imaging methods, and differential thermal analysis have been generally applied for the laminates' thermal properties. The dynamic automated study evaluates the laminates' viscous characteristics as the formulation of frequency and temperature and reports the loss, storage modulus, damping, and glass transition temperature. The storage modulus presents the higher quantity of energy stored in every cycle of oscillation in the laminate, whereas the loss modulus signifies the quantity of energy consumed from laminates in the conveyance as heat. The proportion of storage to loss modulus determines the damping characteristics of laminate that presents molecules' movement in the laminates. The above characteristics are necessary for the constituents applied in industrial, structural, and automotive applications, followed by dynamic loading (Sewda and Maiti 2013). Compared to the polymer and single filler incorporated laminates, a higher glass transition temperature and storage modulus were observed for hybrid shorea robusta/pine laminates. A flat cole–cole graph of hybrid laminate showed uniform and homogeneous hybrid wood fillers in the epoxy polymer (Khan et al. 2019). The dynamic mechanical analysis explained that mixing applewood fillers in the epoxy polymer appropriately increases the storage modulus, signifying the improvement in laminates' viscoelastic characteristics (Ayrilmis et al. 2015). Vimalanathan et al. (2016) examined that the damping parameter, glass transition temperature, and storage modulus of Shorea robusta/polyester laminate were enhanced significantly up to 20 wt% of the addition of fillers. The plain cole-cole curve of laminate employed uniform dispersion of wood fillers in the polyester resin. Ge et al. (2006) affirmed that the glass transition temperature and storage modulus of biodegradable bamboo wood fillers incorporated polypropylene laminate improved with bamboo reinforcement wood fillers. The thermal deterioration of wood ensued under the lower range of temperature around 200 °C (Poletto et al. 2012). Hence it is needed to forecast and examine the thermal characteristics of wood polymer composites. The thermal stability of wood polymer composites is based on the decomposition of wood fillers' structural components in terms of lignin, cellulose, hemicellulose, ashes, other extractives, and waxes (He et al. 2019). The awareness of the thermal degradation of these components assigned to their chemical structure. The hemicellulose drops their thermal stability nearly 200 to 300 °C due to their arbitrary amorphous design (John and Thomas 2008; Yang et al. 2006). The thermal decomposition of cellulosic initiates about 350 °C due to the crystalline nature (Yang et al. 2006). The lignin structure is entirely dissimilar from the cellulose and hemicellulose, which contains three kinds of propane-benzene groups that are immensely cross-linked and acquires greater molecular weight, which tends to higher stability. Hence, lignin's thermal decomposition starts near 300 to 500 °C (John and Thomas 2008; Poletto et al. 2012; Yang et al. 2006; Kim et al. 2006). Usually, spruce wood's thermal stability is greater than the pinewood due to the presence of a higher concentration of hemicellulose in the hardwood (He et al. 2019; Shen et al. 2010). Deka (2001) performed the thermal examination of TiO2 nanofillers mixed with wood fillers high-density polyethylene laminate.

The melting temperature and thermal stability of laminate were improved by 13% and 12.64%, respectively, compared with the unmixed laminate primarily because of the higher thermal diffusivity of TiO2 nanofillers. The crystallization temperature of each silane and alkali modified laminate was enhanced by approximately 5%, but the melting temperature was uninfluenced (Ichazo et al. 2001). The thermal degradation temperatures of silane (MPS, VTMS, and APTES) coupled with modified Picea abies wood fillers polypropylene laminates were enhanced for all kind of silane agent. The highest five wt% degradation temperature was examined under 308.7 °C for laminates modified with APTES agent. The similar temperature was 306.2, 306.6, and 297.5 °C for the VTMS, MTS changed and untreated laminates. Furthermore, the influence of silane agent for 50 wt% degradation temperature was observed insignificant (Kim et al. 2010).

6 Applications of Wood-Based Polymer Composites

The first profit-making application of wood polymer composite was initiated with Rolls Royce automotive (Gordon 2019). The particular utilization of wood polymer composites contains fabrication of distinct kinds of automotive components (Peaez-Samaniego et al. 2013; Ayrilmis et al. 2017) such as door panels, dashboard, rear storage, noise insulation panels, engine cover, headliner panels, bumper, wheel box, etc.; cabinets and casing of electrical and electronics equipment, interiors of buildings, packaging of other furnishings, lower price rehabilitation, and other useful household components. The wood polymer composite based components have excellent market possibility in Europe and North America with an annual expansion rate of 14% and 18%, respectively (Ashori 2008; Gupta et al. 2007). The automobile sectors explored the wood polymer laminates because of the government's higher interest towards the protection of the environment that granted the automobile sectors to use the biodegradable and recyclable constituents such as wood fillers in the advancement of automobile components. As per the European Commission regulations, around 85% of the entire automobile should be fabricated from recyclable materials (Ashori 2008).

After the successful advancements of biomass nanofillers, utilizations of their bio nanocomposites have shown interest. The bio-based nanocomposites are being applied in construction and building, electronics, packaging, cosmetics, automotive, and other film and coating industries (Sharma et al. 2019). The bio-based nanocomposites were periodically applied in biomedical utilizations like antibacterial activity, tissue engineering, drug delivery, body implants, and disease diagnostics because of their biodegradability, cytocompatibility, and hemocompatibility characteristics. A drug delivery scheme is a schedule in which an essential quantity of drugs is discharged at a particular period for the human being's specific organ. For this reason, different nanocellulose bio-based resin films were applied in the capsule form coated from different pharmaceutical industries (Jackson et al. 2011). Nontoxic behavior, porosity, lower price, network-like structure, biocompatibility,