WOODHEAD PUBLISHING IN MATERIALS

ADVANCED NANOCARBON POLYMER BIOCOMPOSITES

SUSTAINABILITY TOWARDS ZERO BIOWASTE

Edited by

MD REZAUR RAHMAN

MUHAMMAD KHUSAIRY BIN BAKRI

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Dedication

This work is dedicated to my amazing wife and daughters—Shirin Akther, Fahriah Rahman, and Faizah Rahman, who are very special to me and made it possible for me to complete this work.

–Ts. Dr. Md Rezaur Rahman

First, I would like to thank the Almighty God for the guidance, strength, power of mind, protection, and for giving us a healthy life. All of these we offer to you. Every difficult task needs self-effort as well as the guidance of elders, particularly those who are near to our hearts. I offer my humble dedications to my beautiful and loving father, mother, wife, and brothers, whose devotion, love, support, and nightly prayers have enabled me to work toward this significant achievement, along with all the dedicated, well-liked, and well-respected teachers and supervisors.

–Ts. Dr. Hj. Muhammad Khusairy Bin Bakri

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Preface

Integrating nanotechnology and polymer composites has emerged as a transformative paradigm in the rapidly evolving landscape of materials science and engineering, offering unprecedented opportunities to develop advanced materials with tailored properties and multifunctional applications. This book, *Advanced Nanocarbon Polymer Biocomposites*, represents a comprehensive exploration of the synergistic possibilities of the fusion of nanocarbons, polymers, and biocompatible elements.

Nanocarbon materials extracted from wood (pine and aspen) biomass (natural fiber, etc.) exhibit exceptional mechanical, thermal, and electrical properties. Harnessing the unique characteristics of these nanoscale entities and combining them with polymers, which provide flexibility, processability, and a wide range of functionalities, opens new frontiers in material design. Moreover, incorporating biocompatible components facilitates the development of materials that excel in mechanical, morphological, and chemical performance and demonstrate compatibility with living systems, paving the way for applications in biomedicine, construction and building, packaging, and sustainable technologies.

This book is crafted to provide a comprehensive overview of the fundamental and state-of-the-art research and developments in nanocarbon polymer biocomposites. Each chapter is meticulously crafted by experts in the respective areas, covering fundamental principles, synthesis methods, characterization techniques, and diverse applications. The chapters are organized to guide readers through the intricate landscape of nanocarbon polymer biocomposites, from theoretical foundations to practical applications, fostering a holistic understanding of this burgeoning field.

The multidisciplinary nature of this book makes it an invaluable resource for researchers, academics, and practitioners working at the intersection of nanotechnology, polymer science, and biocompatible materials. Whether delving into the fundamental science behind nanocarbon interactions with polymers or seeking insights into the practical applications of these advanced materials, this book serves as a roadmap to navigate the complexities and potentials of nanocarbon polymer biocomposites.

As editors, we would like to express our gratitude to the contributing authors for their scholarly contributions and dedication to advancing the knowledge in this field. We believe this compilation will inspire further exploration, foster collaboration, and contribute to the evolution of nano-carbon polymer biocomposites as a transformative technology.

Md Rezaur Rahman
Muhammad Khusairy Bin Bakri

CHAPTER FIVE

Aspen wood sawdust and its biocomposites applications

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5.1 Introduction to aspen wood

Aspen trees or quaking aspen trees are medium sized deciduous trees that are members of the Salicaceae family, which appear with distinctive leaves and smooth greenish white bark as shown in Fig. 5.1.There are six species of aspen trees found worldwide, excluding hybrid species, *Populus grandidentata*, *Populus tremuloides*, *Populus tremula*, *Populus davidiana*, *Populus sieboldii*, and *Populus adenopoda* (Rogers et al., 2020). It is native to cold regions such as North America, Scotland and Russia (Nesbit et al., 2023). Fig. 5.2 displays the distribution of aspen trees by species. Aspen trees can live for as long as 200 years; according to some studies, they may reach up to 450 years (Latva-Karjanmaa et al., 2007; Vehmas et al., 2009). Due to their crucial role in preserving biodiversity and supporting the ecosystem, aspen trees are particularly vital in colder regions. It provides a range of valuable services to the environment, including carbon storage in the soil, revegetation, serving as forage for livestock, offering shelter to shrubs and herbaceous plants, and even contributing to the production of innovative wood products like paddles, studs, furniture, surgical splints, solid wood, and strand board (Bates & Davies, 2018; Boča & Miegroet, 2017; Gamfeldt et al., 2013; Kivinen et al., 2020; Rogers et al., 2020).

Advanced Nanocarbon Polymer Biocomposites.
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Figure 5.1 Aspen wood trees. *From Nesbit, K. A., Yocom, L. L., Trudgeon, A. M., DeRose, R. J. & Rogers, P. C. (2023). Tamm review: Quaking aspen's influence on fire occurrence, behavior, and severity.* Forest Ecology and Management, 531. *https://doi.org/10.1016/j.foreco.2022.120752*.

In clonal colonies, aspen trees can grow to a height of up to 120 feet and have a diameter of 4 feet. Nonetheless, mature aspen trees are a bit shorter, typically measuring at an average height between 60 and 80 feet with a diameter at breast height (d.b.h.) of 11 inches (Mackes et al., 2001). Aspen trees are generally straight although in certain areas may be contorted, fairly with minimal taper and free of limbs. Aspen is a hardwood with diffuse pores, in which the pores are relatively small and spread evenly. The heartwood of aspen that is closest to the center of the tree is either white, light brown or creamy in color, while the sapwood, closest to the bark, is usually whiter than heartwood and it blends into heartwood with no discernible demarcation lines (Bajpai, 2018a; Mackes et al., 2001). Generally, the annual growth of aspen wood trees can be differentiated by the difference in their earlywood and latewood colors. Aspen tree normally releases a strong and pungent smell due to the presence of anaerobic bacterial colonization that causes the heartwood to become watersoaked. This condition is known as wetwood and it occurs in almost all *populus* species. As stated in the Wood Handbook (USDA, 1999), the average moisture content in the heartwood and sapwood of

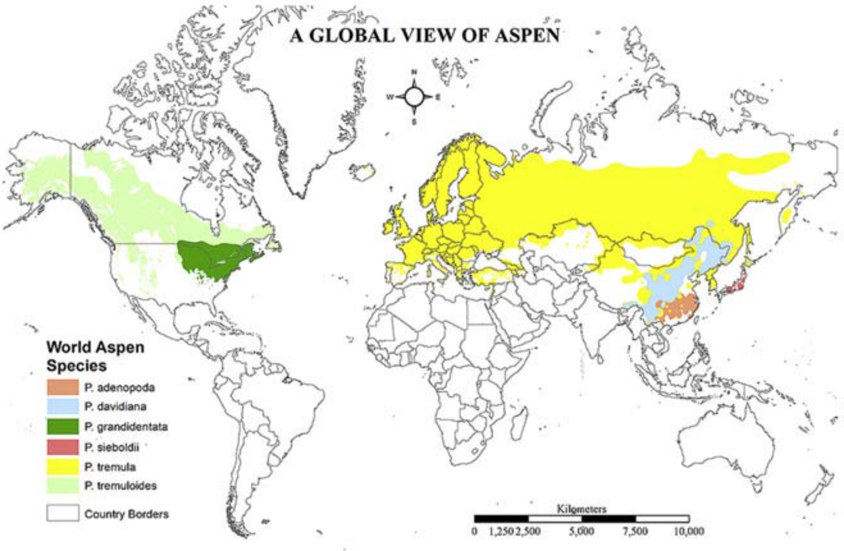

Figure 5.2 Distribution of aspen trees throughout the world based on their species. *From Rogers, P. C., Pinno, B. D., Šebesta, J., Albrectsen, B. R., Li, G., Ivanova, N., Kusbach, A., Kuuluvainen, T., Landhäusser, S. M., Liu, H., Myking, T., Pulkkinen, P., Wen, Z. & Kulakowski, D. (2020). A global view of aspen: Conservation science for widespread keystone systems.* Global Ecology and Conservation, 21. *https://doi.org/10.1016/j.gecco.2019.e00828*.

aspen trees is approximately 95% and 113%, respectively (Mackes et al., 2001). However, these values can differ depending on the season and the existence of wetwood. During summer, the moisture content in the sapwood of an aspen tree can be as low as 65% and increase to a range between 90% to 110% during winter (Wengert, 1967).

5.2 Physical and chemical properties of aspen wood sawdust

Aspen wood sawdust is a type of lignocellulosic biomass similar to those of various agriculture residues including coniferous wood. Aspen wood exhibits hygroscopic behavior and possesses an anisotropic pattern with a lumen structure resembling that of a honeycomb, resulting in high stiffness. The flexibility and stress resistant properties of aspen wood make it a suitable option for the fabrication of durable products. The aforementioned characteristics also make it well suited for the development of products that are subjected to changes in temperature and humidity. Unlike other woods, aspen wood is less likely to warp or crack under stress. The heterogeneous nature of aspen wood caused by differences in growth conditions and patterns of the tree has led to variations in its physical and chemical properties (Mackes et al., 2001). This means that the mechanical and physical properties of aspen wood can vary greatly depending on its age, species and location. Table 5.1 summarizes the mechanical properties of aspen wood based on three distinct species.

In general, a lignocellulosic material is composed of several chemical constituents, primarily cellulose, hemicellulose and lignin, all of which are interconnected network polymers, including small quantities of extractives and inorganics (Borovkova et al., 2022; Sahay, 2022; Wang et al., 2018; Wei et al., 2017).

Wood sawdust usually contains 40% to 45% of cellulose, 15% to 25% hemicellulose, 23% to 30% lignin and 19% to 26% pentosan that depending on their species (Figueiredo et al., 2010; Rowell et al., 2012). The distribution of chemical constituents is uneven within the wood cells due to the inhomogeneous nature of wood (Heidarian et al., 2017). Cellulose, the most abundant chemical constituent is formed through the repetition units of βD glucopyranose molecules which are covalently bonded between the equatorial OH group of C4 of one glucopyranose unit and the C1 carbon atom in the following glucopyranose unit to form a linear chain (Figueiredo et al., 2010). Cellulose is the main constituent of plant cell walls that plays a key role in providing strength and stiffness to plant tissues that influence the mechanical characteristics of the plant (Jakob et al., 2022).

In contrast to cellulose, hemicellulose consists of multiple varieties of sugar units such as dgalactopyranose, dxylopyranose, dmannopyranose, dglucopyranose, iarabinofuranose, dgalactopyranosyluronic acid and dglucopyranosyluronic acid. Hemicellulose of lignocellulosic biomass is identified based on its sugar content. Examples of such hemicellulose based on sugar content include glucuronoxylan, galactoglucomannan, arabinogalactan, arabinoglucuronoxylan, and glucomannan (Rowell et al., 2012). For aspen wood, its hemicellulose is referred to as glucuronoxylans, a typical type of hemicellulose found in all hardwood species (Li et al., 2013). This particular group of hemicellulose is characterized by a xylan backbone consisting of dxylopyranose units linked together by β(1 → 4) glycosidic linkages (Cunha & Gandini, 2010; Ebringerová, 2005; Rowell et al., 2012). For every ten xylose units, there are approximately seven acetyl groups attached at either the C2 or C3

Table 5.1 Mechanical properties of aspen wood tree from the Wood Handbook.

Properties	**Unit**	**Unknown Aspen wood species**	**Populus grandidentata**	**Populus tremuloides**
Moisture content	%	12%	12%	12%
Specific gravity	n/a	0.35	0.39	0.38
Bending impact		22 in	63000 KPa	58000 KPa
Static bonding properties	MPa	35	n/a	n/a
–modulus of rupture	MPa	5929	9900	8100
–modulus of elasticity	in–ibf/in^3	6.4	n/a	n/a
Work to maximum load				
Compression parallel to grain	KPa	14754	36500	29300
Maximum crushing stress				
Compression perpendicular to grain	KPa	1240	3100	2600
Stress at the proportional limit				
Shear parallel to grain	KPa	4550	7400	5900
Maximum stress				
Tension perpendicular to grain	ibf/in^2	230	–	1800
Maximum stress				
Side hardness	ibs	420	–	–

Source: From Green, D. W., Winandy, J. E. & Kretschmann, D. E. (1999). Mechanical properties of wood. In *Wood handbook: Wood as an engineering material.*

position of the xylose units (Bajpai, 2018b). Xylan rich hemicellulose has numerous possibilities for developing hydrogels and biofilms that can be applied in drug delivery systems, tissue engineering and pharmaceutical packaging. Besides, aspen wood sawdust also displays a notable combination of guaicyl (G) and syringyl (S) units in its lignin composition which comprised 18% to 25% of the total mass fraction (Wang et al., 2018). The distribution of chemical constituents in aspen wood varies across the cell wall. According to studies, the percentage of cellulose and hemicellulose increases progressively from the middle lamella to the primary cell wall followed by the secondary cell wall (Zeng et al., 2017; Zhang et al., 2022).

Conversely, the proportion of lignin decreases in the same direction, with the middle lamella containing the highest percentage. The three main chemical constituents in aspen wood, namely cellulose, hemicellulose and lignin (Fig. 5.3), are rich in hydroxyl groups. These hydroxyl groups are responsible for moisture sorption through hydrogen bonding. Apart from the three primary chemical constituents discussed earlier, the extractives present in aspen heartwood also serve as the chemical makeup for their cell wall. The extractives impact the scent, hue and durability of the corresponding aspen wood (Rowell et al., 2012). In addition, these extractives include fatty acids, fats, fatty alcohols, resin acids, waxes, steroids, phenol, terpenes, rosin, and other minor organic compounds. Previous studies have shown that the *populus* species is rich in biochemical compositions (Korkalo et al., 2020). However, these compounds are not well researched and limited information about them is available. Only a limited number of chemical compounds such as benzoate and salicylic based drugs have undergone comprehensive investigation for their pharmaceutical use (Devappa et al., 2015; Korkalo et al., 2020). Table 5.2 summarizes the mass fraction percentages of each chemical constituent of the aspen tree.

5.3 Aspen wood sawdust

Wood sawdust has been a source of significant concern when it comes to waste management owing to its large quantities and disposal issues. It is produced as a byproduct of wood processing activities such as milling, sawing, sanding and planing generated by industries and agricultural activities. The growing understanding of the detrimental effects that

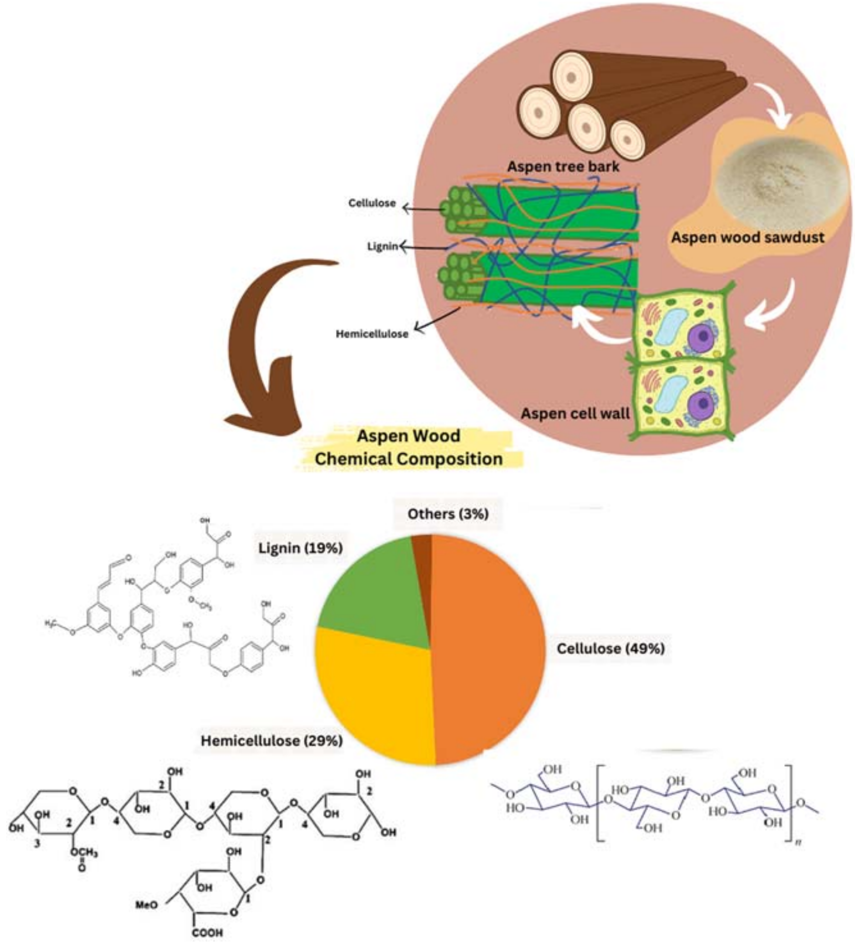

Figure 5.3 Illustration of aspen wood with its chemical composition structures.

industrial processes and products have on the environment and cause climate change has contributed to the idea of converting wood sawdust into valuable materials for various uses to manage the issue of excessive sawdust waste. Numerous applications of sawdust have been explored in this regard, including the production of activated carbon, the development of high-performance biocomposites, the development of sustainable water remediation technology and the preparation of oil-water separation remedies (Abdel-Salam et al., 2020; Croitoru & Patachia, 2014; Heidarian et al., 2017; Li et al., 2023; Mallakpour et al., 2021; Sungsee & Tanrattanakul, 2019).

Table 5.2 Chemical composition of aspen wood sawdust based on literature.

Chemical constituent	Mass fraction (%)			
Cellulose	49.0			
Hemicellulose	29.0			
• Xylan	18–20		Lignin	19.0
• Glucomannan/arabinan	Low	Pento sans	19.0	
Extractives	0.83			
1% NaOH solubility	18.0			
Hot water solubility	3.0			
Alcohol benzene solubility	3.0			
Ether solubility	1.2			
Ash	0.4			

Source: From Rogers, P. C., Pinno, B. D., Šebesta, J., Albrectsen, B. R., Li, G., Ivanova, N., Kusbach, A., Kuuluvainen, T., Landhäusser, S. M., Liu, H., Myking, T., Pulkkinen, P., Wen, Z. & Kulakowski, D. (2020). A global view of aspen: Conservation science for widespread keystone systems. *Global Ecology and Conservation*, *21*. https://doi.org/10.1016/j.gecco.2019.e00828.

5.3.1 Aspen wood fiber extraction

Numerous studies have discovered that natural woods regardless of species, have a relatively low mechanical strength in which their modulus of rupture (MOR) only ranges from 10 to 100 MPa (Ashrafi et al., 2021; Kotlarewski et al., 2016; Sikora et al., 2019). The mechanical strength of aspen wood, as measured by its MOR is only 35.16 MPa (5100 ibf/in^2) (Green et al., 1999). This value is considered relatively low for developing wood based biocomposite materials because the mechanical performance of aspen wood is insufficient for advanced engineering applications. The leading causes of this issue are attributed to cellulosic and noncellulosic components in the aspen wood, which imparts a highly hydrophilic character due to the abundance of hydroxyl groups (Karimah et al., 2021). Consequently, the interfacial bonding between hydrophilic aspen wood fibers and hydrophobic polymer matrix is adversely affected(Andrew & Dhakal, 2022; Hartley & Hamza, 2016; Lee et al., 2021). This represents a significant challenge in achieving optimal performance of wood based biocomposite as it significantly affects the overall properties of the material (James et al., 2022). Besides, the high hygroscopicity nature of aspen wood makes it more susceptible to moisture adsorption, limiting its long term use and further undermining the efficacy of wood based biocomposites (Hartley & Hamza, 2016; Rahman et al., 2011; Zelinka et al., 2022). Therefore, several treatment methods can be implemented to address the constraints associated with incorporating natural wood fiber for the development of biocomposites and counteracting the hydrophilic nature of aspen wood. These methods include pretreatment, physical, and chemical treatment (Girijappa et al., 2019; Sohn & Cha, 2018).

5.3.1.1 Pretreatment

Most natural fibers are suggested to go through multiple processing stages to separate the primary macromolecular which usually involves an initial pretreatment process. The selection of the pretreatment process is typically dictated by the specific type of natural fiber being used which is closely linked to its underlying chemical composition (Norrahim et al., 2021). Pretreatment is a simple and low cost method that modifies the structure of lignocellulosic biomass by weakening the connections between lignin and hemicellulose, which can impede its disintegration. This process amplifies the surface area of the cellulose, rendering it more accessible to enzymatic saccharification during the subsequent transformation process (Kucharska et al., 2018; Peral, 2016; Sindhu et al., 2015; Zhang et al., 2019). The following are some examples of pretreatment methods for aspen wood based on previous studies.

i. Thermal Pretreatment: A thermal pretreatment is an approach used to improve and preserve aspen wood fiber against biotic and abiotic factors by subjecting it to pyrolysis torrefaction in the presence of a low oxygen environment to produce biochar and prevent combustion (Hao et al., 2018). This treatment causes changes in the chemical composition and mass loss of the aspen wood, primarily through the degradation of hemicelluloses, which reduces the substrate available for fungi growth and the hygroscopic nature of the wood (Borrega et al., 2009; Ornaghi et al., 2021).

ii. Autohydrolysis Pretreatment: This technique has been widely considered in the industry due to its effectiveness in removing impurities without altering cellulose structure with minimal preparation and handling requirements (Norrahim et al., 2021). Autohydrolysis pretreatment relies on water as the reagent under high pressure to generate hydronium ions (H_3O^+) which will react with acetic groups released by the hemicellulose (Shah et al., 2021). The hydronium ions will act as a catalyst, leading to the breakdown and loosening of the natural wood structure (Lei et al., 2013). Most of the hemicelluloses are removed during this process, leaving the aspen wood as soluble saccharides. At the same time, lignin and cellulose are recovered in the solid phase with minimal losses (Wang et al., 2016). The removal of lignin via autohydrolysis is subjected to the breaking down of lignin βO4 linkages by acidolysis and homolytic cleavage reaction. However, a complete delignification is unlikely due to the lignin lignin condensation reaction during autohydrolysis. To address this issue, adding 2naphthol or NaOH could potentially prevent the lignin-lignin condensation reaction (Li & Gellerstedt, 2008).

5.3.1.2 *Physical treatment*

Physical treatment such as mechanical fibrillation treatment is a process that does not involve any chemical alterations to the composition of wood fibers (Menon et al., 2017; Sanchez-Salvador et al., 2022). Instead, it aims to enhance their digestibility by increasing their specific surface area (Keskin et al., 2019). This process is achieved by reducing the size of wood fiber particles via mechanical comminution such as crushing, chipping, grinding and milling (Ani, 2015; Baruah et al., 2018). This method isolates cellulose fiber from aspen wood pulp at high rotational speeds to produce cellulose with a high aspect ratio and specific surface area. Consequently, this leads to the creation of more reactive sites and improved cellulose accessibility for chemical treatment reactions. Although this method can increase the accessibility of cellulose by reducing the particle size of natural fibers, it has limitations in removing noncellulosic components such as lignin, hemicellulose and pectin. As a result, this can limit the access of enzymes to cellulose during subsequent processing. This approach also requires high energy consumption, which may impede its large scale implementation (Phanthong et al., 2018; Zhao et al., 2017).

5.3.1.3 *Chemical treatment*

Chemical treatment refers to the process of using chemical agents to alter the functional groups of wood fiber, particularly the hydroxyl groups. Besides, chemical treatment is also performed with the intention of removing noncellulosic constituents such as hemicellulose, lignin and pectin from aspen wood fiber to improve its strength, stiffness and durability (Mohammed et al., 2022; Rahman et al., 2010; Zwawi, 2021). There are a few chemical treatments that can be employed when dealing with aspen wood fibers, including:

i. Surface modification treatment Surface modification is an approach that introduces either covalent or noncovalent interactions to modify the hydrophilicity of wood fiber, which is abundant in hydroxyl (OH) groups on its surface. This approach is achieved by introducing new hydrophobic charged moieties or activating the hydroxyl groups to enhance the interfacial bonding between hydrophilic wood fibers and hydrophobic polymer matrix during biocomposite development. Table 5.3 summarizes the findings of several surface modification

Table 5.3 Surface modification treatments of wood fiber based on previous studies.

Wood species	Type of chemical treatment	Findings	References
Poplar, oak, basswood, red cedar sawdust	Alkaline treatment	Removal of noncellulosic constituents (lignin and hemicellulose) including excess waxes, oil and impurities from wood fiber using NaOH and Na_2SO_3 which collapsed the wood cell wall. Improved wood fiber wettability and enhanced the adhesion of wood fiber to other hydrophobic materials such as polymeric material. Improved wood fiber tensile strength, ballistic resistance, toughness and stability.	Song et al. (2018)
Poplar wood sawdust	Graft polymerization of 2 hydroxyethyl methacrylate (HEMA)/*N*,*N*′ methylenebis (acrylamide) (MBA)	The poplar wood is subjected to in situ modification via vacuum pressure impregnation with the reaction of HEMA and MBA. The results show a 61.13% improvement in the antiswelling properties of the wood fiber, as well as a lower rate of water adsorption and weight gain. The process of graft polymerization partially blocks the wood pores and modifies the presence of hydroxyl groups on the surface of wood fibers that result in improvements in the modulus of elasticity, stability, hardness and density of wood fiber. These enhancements have been verified through XRD analysis.	Hu and Wang (2023)

(Continued)

Table 5.3 (Continued)

Wood species	Type of chemical treatment	Findings	References
Poplar wood sawdust (Aspen wood)	TEMPO oxidation treatment using $NaClO_2$ (primary oxidant) and TEMPO (catalyst) in the presence of phosphate buffer at pH of 6.8	Successful fibrillate of freshly grounded aspen wood into fine grades of cellulose nanofibers. The use of chlorite in this treatment aids in the deglinification of aspen wood cellulose and the oxidation of its surfaces. The TEMPO oxidation treatment involves transferring negative charges to the surface of aspen wood fiber that improved the dispersion of aspen wood fibrils in water.	Jonasson et al. (2020)
Aspen wood sawdust	Acetylation treatment using acetic anhydride in the presence of formamide and pyridine	The results show that acetylation of aspen wood affects its solubility and water content, with treated aspen wood being only soluble in aprotic solvents (chloroform, DMSO) and having a low water content due to a decrease in hydrogen bonds as compared to nonacetylated aspen wood under the same conditions. Improved thermal stability of aspen wood	Gröndahl et al. (2003)

Wood fiber sawdust	Esterification reaction using anhydrides (e.g., maleic anhydride. acetic anhydride, succinic anhydride)	The results of various esterification methods indicate that wood fibers have exhibited enhanced hydrophobic behavior. This is attributed to the blocking effect of anhydrides which reduce the active sites of hydroxyl groups on the surface of the wood fibers. Enhanced wood fiber stability, fire resistance, hydrophobic behavior and durability	Teacă and Tanasa (2020)
Aspen wood sawdust	Sulfonation treatment	Sulfonation treatment introduced anionic charges on the surface of aspen wood which aid in improving wood fibrillation due to the presence of electrostatic repulsive forces. Sulfonation of sawdust caused a reduction in yield of approximately 5% to 6% and half of this percentage is subjected to the elimination of extractives from aspen wood fiber, which reduced the initial percentage of extractives from 4.7% to a range of 1.3% to 1.5%.	Robert et al. (1986)

techniques that have been studied on poplar species wood, including aspen wood. These approaches include alkaline treatment, acetylation, sulfonation, graft copolymerization, esterification and TEMPO mediated oxidation (Abe et al., 2020; Adamu et al., 2019; Islam et al., 2011; Liew et al., 2020; Mastantuoni et al., 2023; Oladele et al., 2020; Olsén et al., 2020; Rahman et al., 2013; Teacă & Tanasa, 2020; Yew et al., 2019).

ii. Densification This method involves the compression of wood fibers under high pressure which leads to a remarkable enhancement in their density, strength and stiffness. Densification allows cellulose fibers to be in close contact with one another, forming strong hydrogen bonds between the cell wall of neighboring fibers (Fang et al., 2020; Gondaliya et al., 2023). Adjusting the degree of densification enables the properties of the compressed wood to be tuned to meet specific functional and mechanical requirements. According to a study, densified wood composites produced via a combination step of delignification and compression process exhibit an exceptional tensile strength of 587 MPa which is 11.5 times better than natural wood and some polymer plastics like nylon 6, polycarbonate, epoxy and polystyrene (Song et al., 2018). Another study of densified aspen wood (*Populus tremula)* demonstrated that the density of the wood increased from 117% to 173% when it was compressed at a rate of 40% and a temperature of 180°C, thus, improving aspen wood hardness and strength (Pelit & Emiroglu, 2021). Additionally, the hygroscopicity of aspen wood also can be reduced via densification. According to a study, subjecting aspen wood to high densification temperatures decreases its ability to absorb water, thus corroborating the aforementioned claim.

5.4 Aspen wood biocomposite

Biocomposites are made up of two or more distinct materials, one of which is naturally derived from biological entities to form a new material with outstanding performance compared to the individual material (Abdulkhani et al., 2020; Christian, 2016; Gondaliya et al., 2023; Mondal et al., 2022). To produce wood based biocomposite, various techniques and stages have been reported in the literature, including injection molding, compression molding, resin transfer molding, filament winding, vacuum bag molding, pultrusion and extrusion (Barczewski et al., 2023; Dai & Fan, 2014; Kumar et al., 2020; Xia et al., 2019). This context involves the exploration of aspen wood potential as a material for the development of biocomposites, which serves as a means to transition towards more sustainable and environmentally friendly alternatives in order to reduce the reliance on conventional materials. A number of studies have shown that incorporating aspen wood sawdust into the development of biocomposites has the potential to be employed in multiple sectors, including construction, packaging, automotive, and manufacturing (Ahmad et al., 2022; Andrew & Dhakal, 2022; Beims et al., 2023; Hamid & Samy, 2022; Kamal et al., 2014; Ramesh et al., 2022). The following subsections will delve into the applications of aspen wood based biocomposites.

5.4.1 Aspen wood biocomposite in packaging industries

Packaging serves as a protective layer that is crucial in preserving the quality of the food, particularly during storage and food handling. Indeed, a significant number of packaging materials utilized by the industry are derived from petrochemical sources, and these materials pose negative environmental impacts. One of the primary concerns is their low recyclability and nonbiodegradability characteristics. To address this issue, there has been a growing interest in wood based biocomposite as an alternative to conventional plastic materials. Wood based biocomposites have eco friendliness, low cost, high hydration capacity, excellent shelf life, improved oxygen scavenging, antifungal and antimicrobial properties (Asgher et al., 2020; Elsheikh et al., 2022). Aspen wood, for instance, exhibits excellent gas permeability properties which makes it a desirable material for fabricating Modified Atmosphere Packaging (MAP) film (Wang et al., 2006). MAP film is suitable for packaging various types of food products, especially poultry meat and fresh cut vegetables and fruits. This is due to its ability to allow for gas exchange, such as oxygen and carbon dioxide including water vapor (Han, 2012; Tajeddin et al., 2018). The use of MAP can extend the shelf life of food without the need for any additional treatment (Han, 2012). However, it is important to consider factors such as temperature and the maximum efficacy of MAP in controlling microbial growth and preserving food quality. Extractives such as tannins, flavonoids, and essential oils found in aspen wood can be used as preservatives, therapeutic agents, and disinfectants (Bandau et al., 2021;

Filip et al., 2013; Okińczyc et al., 2018). These extractives demonstrate promising antimicrobial properties, further highlighting their potential utility. Based on a study, aspen wood flavonoid content varies by species, with Populus grandidentata species recording the highest value of 47 to 82 mg/g, followed by Populus tremuloides species of 12 to 62 mg/g, and Populus tremula species of 11 to 43 mg/g (Pietarinen et al., 2006). All of these extractives play roles in inhibiting the growth of pathogenic bacteria.

5.4.2 Aspen wood biocomposite in construction industries

The conventional structure of buildings which relies on reinforced concrete construction has a significant environmental impact (Trinh et al., 2021). This predicament has embarked on the need to utilize natural materials in order to achieve an environmentally friendly building construction (Ahmmad et al., 2017). Several conducted studies in the literature reported that the utilization of wood sawdust for biocomposite could become an alternative undertaken to achieve green technology in building constructions. An earlier study reported that wood biocomposite could be utilized to reinforce gypsum bonded sawdust composite for building construction. Mechanical testing of biocomposite in the study revealed that lightweight biocomposite could be obtained through water based epoxy treatment. Such treatment was able to produce 4.59 MPa of flexural strength and 13.25 MPa of compressive strength which suggested that the mechanism of sawdust induced gypsum performance is associated with water absorption (Dai & Fan, 2015). As informed by Kielė et al. (2020), the utilization of hardwood shavings could improve the flexural properties of alkali activated slag biocomposite. This indicated that the biocomposite from alkali activated slag blended with hardwood shavings had high commercialization potential in the construction materials industry (Kielė et al., 2020). Apart from that, wood sawdust also could be used to produce environmentally friendly bricks. A study informed that the production of bricks made from wood sawdust and rice bran with mycelium has an increase of 31% to 39% in average compressive strength as compared to the nonmycelium bricks, respectively (Ongpeng et al., 2020). Mycelium comprised of hyphae and root like plant structures that could allow the microorganism namely fungus to consume nutrients from its waste substrate (Jo et al., 2023). With the utilization of wood sawdust as the substrate, the study formulated and produced mycelium bricks that could meet environmental product standards as well as being comparable with construction building materials. It is evident from the latter studies that the utilization of wood sawdust could be proposed as an alternative biocomposite material in the construction industry (Ramage et al., 2017). This is due to the fact that the use of wood sawdust could achieve low cost production which is corrosion free as well as has low thermal conductivity (Ahmad et al., 2022). The application of aspen wood sawdust for building construction is yet to be reported despite the abundance of other conventional wood resources such as bamboo and coconut as biocomposite materials (Ahmad et al., 2022).

5.4.3 Aspen wood biocomposite in furniture manufacturing industries

The utilization of renewable resources derived from wood fibers has been evolved by manufacturing furniture with biocomposite based materials (Adeleke et al., 2021). These resources posed similarities in terms of chemical, physical, and mechanical properties in comparison to conventional materials (Schubert et al., 2023). Realizing this advantage, some furniture manufacturers tend to utilize renewable resources in order to develop environmentally friendly products. This includes biocomposites materials particularly plywood, medium density fiber board (MDF), particle board, and hardboard (Lee et al., 2022). Plywood is made of flat panel veneer layers that are arranged perpendicularly through resin spreading (Hua et al., 2022). It has several advantages in comparison to ordinary wood which are cracks resistance and durability (Yavartanoo & Kang, 2022). Additionally, the characteristics of plywood also include lightweight, easy to handle, strong, as well as having smooth surface textures (Xu et al., 2021). All these advantages have made plywood able to reduce shrinking and expansion under certain circumstances. To date, plywood is the most utilized biocomposite panels especially to manufacture doors, floors, and other furniture (Jones et al., 2020). MDF is also a wood based biocomposite material which contains panels composed of lignocellulosic compounds and synthetic resins such as urea formaldehyde and phenol formaldehyde (Hussin et al., 2022). Manufacturing MDF with wood based biocomposite could possibly replace the utilization of wood sawdust which is found to be poor resistant. Moreover, there is a high demand for particleboard as an alternative raw material for wood processing owing to low cost in comparison to conventional solid wood (Pędzik et al., 2021). Particleboard features a nonstructural interior product that is made of wood plastic byproducts (Kumar & Leggate, 2022). In order to manufacture particleboard, synthetic resins or binders are mixed with the wood particles in the essence of pressure and heat. Furthermore, the utilization of particleboard could potentially be expanded for manufacturing kitchen cabinets, shelves, and office furniture (Bakri et al., 2018). Another popular biocomposite material which had been discovered by the manufacturing industry is known as hardboard. Hardboard constitutes lignocellulosic fibers, wood chips and pulped wood waste that are combined using heat and steam (Oliaei et al., 2021). However, it is reported that hardboard could be easily damaged when being utilized for outside applications owing to hygroscopic properties (Giannotas et al., 2021). It is noticed that the wood processing industry experienced sustainability issues in terms of raw materials recovery (Xiong et al., 2020). Realizing this issue, the utilization of abundant wood wastes particularly aspen wood and oil palm wastes could mitigate such disputes. Although these materials are known as raw resources, some of them have shown promising applications as an alternative undertaken for the wood processing industry.

5.4.4 Application of wood biocomposite for wastewater treatment

Wood based biocomposites are an environmentally friendly and sustainable material for the future water treatment industry (Che et al., 2019). Wood based biocomposite features a combination of natural wood fibers and biopolymer matrices such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), and polybutylene succinate (PBS) (Dai & Fan, 2014). These biocomposites could be utilized as an alternative to various water treatment applications owing to their excellent mechanical properties, low cost, and biodegradability (Tu et al., 2021). The most common applications of wood based biocomposites in water treatment include adsorbent development (Bassyouni et al., 2022). In the water treatment process, adsorbents are used to remove contaminants from water sources through the adsorption process (Manyatshe et al., 2022; Rahman et al., 2023). By developing an adsorbent from wood based biocomposites, the adsorbent allows maximum removal of contaminants whereas its porous structure provides adequate space for coagulation and flocculation (Reguieg et al., 2022). This is due to the fact that wood based biocomposite poses a large surface area and porous structure. It was reported that the production of adsorbent from pine sawdust could remove ammonium ions from wastewater (Yang et al., 2018). The study reported that the adsorption capacity of the biocomposite was found to be 5.38 mg/g, which is significantly higher than other commercially available adsorbents. Additionally, wood based biocomposite could be utilized to develop and fabricate membranes for water filtration (Lustenberger & Castro-Muñoz, 2022). This is possibly due to wood based biocomposites being suitable for membrane development owing to their high mechanical strength, low cost, and biodegradability (Udayakumar et al., 2021). For instance, a wood based biocomposite membrane made from cellulose nanofibers and PLA could be proposed to remove salts from seawater (Rana et al., 2021). It was reported that the membrane posed a high water flux rate and high salt rejection rate. Another potential application of wood based biocomposite in water treatment also includes fabrication of biofilters (Augaitis et al., 2020). When water sources are treated with biofilters, the microorganism could break some contaminants through microscopic activities (Luo et al., 2022). Wood based biocomposite could be utilized as a substrate for the growth of microorganisms owing to high porosity and surface area. A wood based biocomposite made from sawdust and PLA was highly effective in removing nitrate from contaminated groundwater as well as able to maintain its efficiency for longterm applications (Sungsee & Tanrattanakul, 2019). This suggests that wood based biocomposites are a highly versatile and effective material for various water treatment applications due to their excellent performance. Realizing these advantages, the application of wood based biocomposites could be proposed as a sustainable water treatment system in the future (Chang et al., 2021).

5.5 Conclusion

Aspen trees are medium sized deciduous trees with distinctive leaves and smooth white bark. The lifespan of this tress typically ranges between 200 and 450 years, thus crucial for preserving biodiversity and contributing to producing innovative wood products. Aspen wood sawdust is a lignocellulosic biomass that acquires hygroscopic properties with high stiffness owing to its honeycomb like lumen structure. The tree is flexible and stress resistant, thus making it applicable for producing durable products that can withstand high temperature and humidity changes. Aspen wood sawdust is a byproduct of wood processing that contributes to waste management challenges. In order to mitigate this issue, aspen sawdust could be processed into valuable materials, particularly activated carbon, high performance biocomposites, and water treatment systems. Conventionally, aspen woods have low mechanical strength due to their hydrophilic nature caused by hydroxyl groups. This adversely affects the interfacial bonding with hydrophobic polymer matrices, subsequently limiting wood based biocomposites' efficacy. As such, it is suggested that the aspen wood undergo several treatment methods, such as pretreatment, physical, and chemical treatments, before being incorporated into a polymer matrix system to produce biocomposites. Such biocomposite could be produced by injecting molding, compression molding, and extrusion. Incorporating aspen wood sawdust into biocomposite could potentially be commercialized through several sectors, such as food packaging, construction, furniture manufacturing and wastewater treatment, which offers sustainable and environmentally friendly alternatives to conventional materials.

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The book covers the latest research findings on nanocarbon polymer biocomposites, their properties and manufacturing, as well as the possible ways to reduce waste and improve their sustainability.

Nanocarbon polymer biocomposites have gained increased attention from both researchers and manufacturers due to the significant improvement in their physico-mechanical, thermal, and barrier properties when compared to conventional materials. Their dimensions, biodegradable character, cost-effectiveness, and sustainability are among the main drivers for increasing demand. However, it is difficult to achieve uniform dispersion between the carbon filler and matrix as it easily forms agglomerations. Production of nanocarbon polymer biocomposites with high mechanical and thermal properties is also limited, but there has been rapid progress in processing possibilities to produce nanocomposites based on various biodegradable fillers. Advanced Nanocarbon Polymer Biocomposites collects all these novel scientific findings in one place. It discusses in detail their physical, chemical, and electrical properties and presents the latest research findings on nanocarbon polymer biocomposites with filler loadings and their improvement on compatibility. The book will be of great interest for those researchers who are concerned with the production and use of nanocarbon polymer biocomposites as a new innovative advanced material.

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- Emphasizes on nanoscale fillers and their improvement on compatibility
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About the Editors

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