Improvement of Antibacterial Properties of Wood Surfaces

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Wood is a raw material that is renewable and has good mechanical properties, as well as being inexpensive and having abundant reserves. It has been extensively employed in furniture, construction, and other industries. In addition to being a material for furniture and interior decoration, it can have applications in high-tech sectors.

wood surface antibacterial hydrophobic

1. Introduction

Thousands of years ago, the Romans and Egyptians used alum and vinegar to reduce the combustibility of wood [1]. For the most part, lignin, cellulose, and hemicellulose make up the xylem of wood [2] (**Figure 1**). It is prone to thermal disintegration at medium and high temperatures, which releases a lot of heat, smoke, and hazardous fumes, starting fires and posing a major risk to human life [1][2][3]. The majority of researchers use added flame retardants [4] to make wood fire-resistant using straightforward physical techniques. Most researchers tend to apply additive flame retardants to make wood fire-resistant through simple physical methods. The most common types are intumescent flame retardants. The application range of traditional carbon sources is significantly constrained by their high hygroscopicity and propensity to precipitate on matrix surfaces during processing. Additionally, as petrochemical resources are consumed more, traditional carbon sources—mostly those derived from petroleum-cracking products—become more expensive and non-renewable. Biomass replaces traditional carbon sources with high carbon content, such as chitosan [5], cellulose [6], lignin [7], starch [8], etc. are often applied as char-forming agents. The traditional acid source promotes the dehydration of the char-forming agent into carbon, and the traditional melamine is applied as the gas source. Three fundamental components make up intumescent flame retardants.

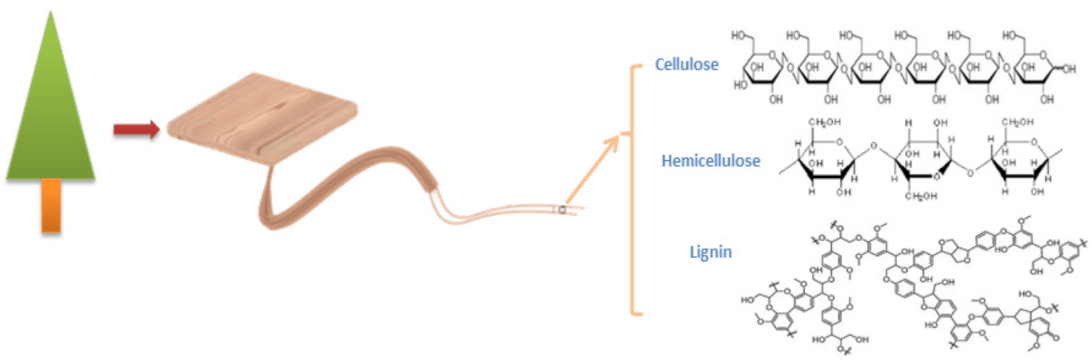

Figure 1. Xylem structure.

In the xylem, hydroxyl functional groups are found in cellulose, hemicellulose, and lignin, with -OH displaying the greatest hydrophilicity [9][10][11][12]. Wood is a common material applied in building, furniture, shipbuilding, and other sectors because it is organic, renewable, biodegradable, low-carbon, and environmentally beneficial [13][14][15][16][17]. However, because of its hydrophilicity, wood is easily cracked, molded, and degraded, which significantly reduces its useful life in the industry, limits its widespread application in industrial production and wastes resources [18][19][20]. Numerous investigations have demonstrated that the solution to this issue lies in the alteration of the hydrophilic hydroxyl groups on the surface of the wood. The majority of investigations typically employ metal ions to cross-link hydroxyl groups; however, wood surfaces can also be made hydrophobic using modified adhesives. On the one hand, the process of metal–ion crosslinking modification is straightforward, simple to apply, quick to react, has the low temperature required and has a high crosslinking density. On the other hand, the substrate's mechanical characteristics can be improved by changing the coating. The coating can effectively withstand the expansion and cracking deformation of the base due to its high tensile strength and strong elongation. The hydrophobicity of wood surfaces can be determined by measuring the contact angle (WCA) and rolling angle (WRA) between water and wood surfaces.

Generally, wood is less dense than metal. There are many holes on the surface and inside of wood. It is easily contaminated by various liquids and propagated bacteria [21][22]. On the one hand, bacteria and fungi can degrade and destroy cellulose, hemicellulose, and lignin in the wood xylem, resulting in wood discoloration, mildew, and warping, greatly reducing the mechanical properties and service life of wood [23][24]. On the other hand, bacteria, fungi, viruses, parasites, etc. also pose a major threat to human health, and wood is mainly applied in commercial spaces such as homes, offices, hotels, and restaurants. Wood, the most often applied raw material, is readily a breeding ground for bacteria on surfaces such as floors, tables, counters, cutlery, etc. [25] is generally impossible to remove with standard cleaning techniques. The introduction of hazardous microbes into wood products applied for certain locations or applications ought to be minimized [26]. Wood's xylem structure can be weakened by fungi, which also lessens the wood's mechanical qualities. For instance, some researchers have applied the selective degradation of wood cell wall components by the white-rot fungus as a delignification technique. The lignin is modified to produce a "sticky" lignin radical by white-rot fungal enzyme systems including peroxidase and laccase-mediator systems [27][28]. A simple and commonly applied method to improve the fireproof, waterproof, and antibacterial properties of wood and wood products is to spray functional coatings [29]. Gamini P. Mendis et al. [30] modified the epoxy resin covering to make it fire-resistant, which had a clear fire retardant impact on the wood surface. In addition, a layer-by-layer self-assembly technique [31] is used to form a fireproof, hydrophobic, or antibacterial layer [32] on the wood surface. By alternately depositing a substrate in a polyelectrolyte solution with an opposing charge, layer-by-layer self-assembly creates a multilayer polyelectrolyte film. Layer-by-layer self-assembly method was applied by Fu et al. [33] to generate a composite coating of chitosan, phytic acid, and TiO_2-CuO on a wood surface at 60 degrees Celsius.

The majority of plants in the natural world, including wood, are made of polymers. These polymers are employed as primary components in the creation of production equipment and everyday objects. Additionally, epoxy resin, polyurethane, and other coatings can be created chemically from polymer ingredients to offer wood surfaces functionalization using the coating modification approach.

2. Improvement of Antibacterial Properties of the Wood Surface

Wood is a common building material since it is an organic substance that is renewable. It will erode by fungi as a result of the temperature and humidity in the environment, leading to mildew and degradation [34]. Additionally, since wood is employed in the food business, health and safety concerns have naturally taken precedence. Growing attention has been shown in coating wood surfaces with antibacterial technologies [35][36].

Numerous studies have shown that a variety of dangerous microorganisms are presented on wood surfaces that people frequently come into contact with, especially furniture. In addition, because of the numerous pores in the structure of wood, bacteria can easily penetrate the surface of the wood and lurk there. This can have a significant impact on human health. Widespread interest has been shown in research on antimicrobial capabilities [36]. Gaurav Sharma et al. [37] made an antibacterial modification of the wood surface with the grafting method. Acrylonitrile (AN) and ethyl acrylate (EA) were grafted on the wood surface by changing monomer and initiator concentrations, temperature, time, pH value, etc., to make an antibacterial wood surface. The experimental results showed that the growth of E. coli on pine was inhibited (AN/EA). The largest inhibition zone was observed on an 8 mm or so strip, and the diameter of the inhibition zone was 21 mm.

Zhang et al. [38] applied a solvothermal method where nanoparticles (TiO_2 and Ag) were chemically bonded to the wood surface through a combination of hydrogen groups. The R% of Ag-doped TiO_2/wood (ATW) reached 99.0% and 90.5% toward E. coli and S. aureus, respectively. The researchers believed that tetravalent Ti ions in TiO_2 would be substituted by monovalent Ag ions, resulting in oxygen vacancies, which might be a benefit for the strengthening of the antibacterial properties of the wood surface.

Tran-Ly et al. [39] applied an antibacterial coating with fungal melanin and vegetable oil as a compound to prevent the corrosion of wood by bacteria and destroy the precious value of some wood products. The research results showed that plant essential oils had strong antibacterial effects, especially linseed oil and tea tree oil, and the antibacterial rate of the longitudinal section of wood was lower than 1%, even after two weeks, and the survival rate for streptococcus was still less than 10%.

Angelika Macior et al. [40] functionalized wood with poly(methylmethacrylate) (PMMA) and poly(2-(dimethylamino)ethyl methacrylate) (PDMAEMA) to yield wood grafted with PMMA-b-PDMAEMA-Br copolymers with antibacterial properties. The synthetic route is shown in **Figure 2**. Antibacterial tests revealed that no bacterial growth was observed in places with direct contact between the wood blocks and S. aureus and E. coli inoculum. It had good antibacterial properties.

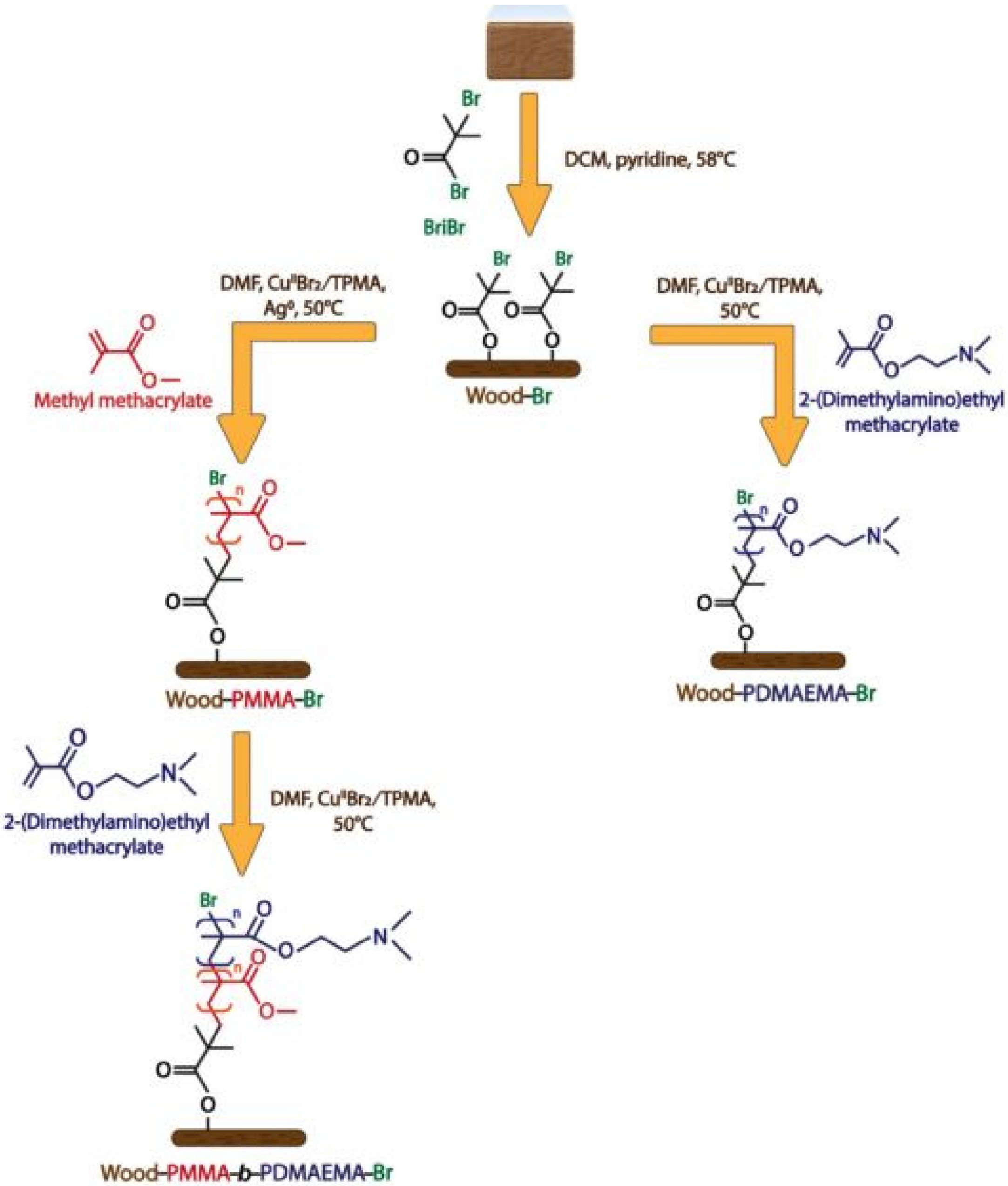

Figure 2. A two-step synthetic route for the preparation of a wood–polymer composite [40].

Wood's natural ability to absorb water makes it simple to foster the growth of fungus, which not only deteriorate wood and shorten its useful life but also release spores into the environment that pollute the environment and damage human health [41][42]. Qi et al. [43] prepared Nano-AgCu Alloy to treat wood surfaces. It had an antibacterial effect on Aspergillus niger, Penicillium citrinum, and Trichoderma viride. The diagram is shown in **Figure 3**. According to the findings, the antibacterial rate was above 75% and the leaching rate was just 7.678% when the concentration reached 1000 mg/L.

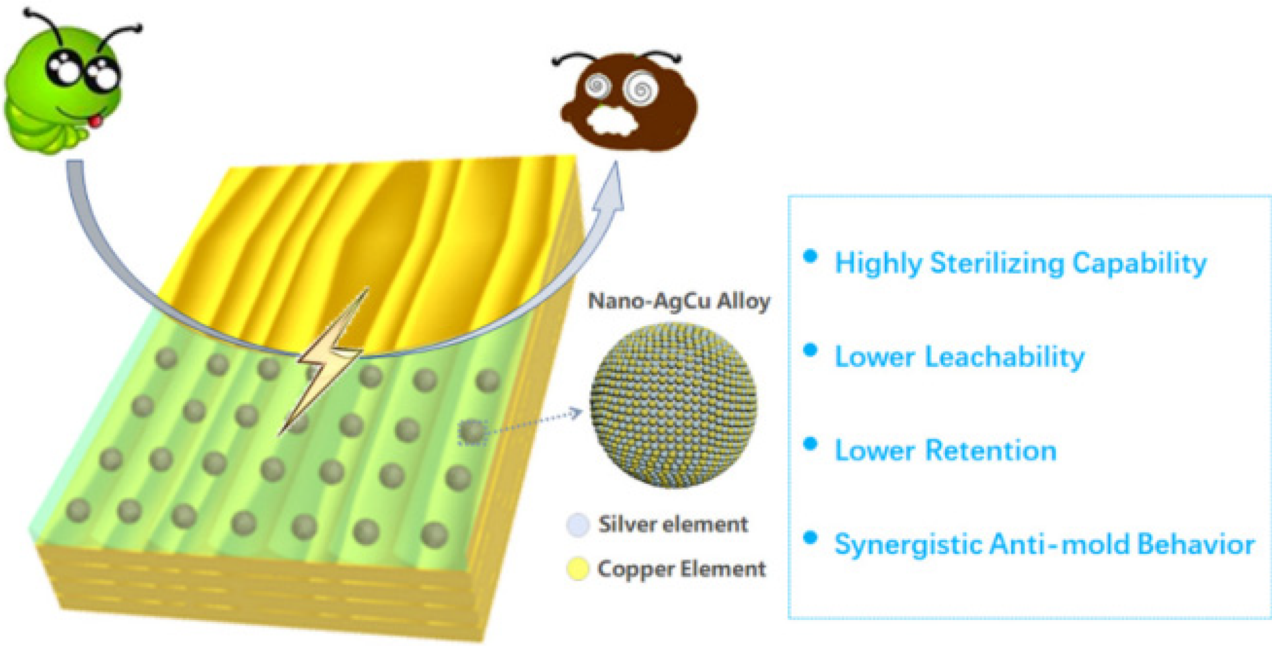

Figure 3. Schematic illustration of the nano silver-copper alloy (nano-AgCu) for mold resistance on the surface of wood [43].

Dai et al. [44] applied water-based nano silver to carry out antibacterial modification treatment on the surface of the wood and characterized its antibacterial properties. The experimental findings demonstrated that when the retention rate of silver reached 0.324 g·m^{-2}, the antibacterial rates of the wood surface for three kinds of molds, namely Aspergillus niger V. Tiegh, Penicillium citrinum Thom, and Trichoderma viride Pers. ex Fr, reached 80%, 75%, and 80%, respectively. The leaching rate of nanosilver is only 4.75%.

Bi et al. [45] prepared modified solvents with chitosan and cinnamaldehyde as raw materials. After treating wood with the modified solvents, they studied the inhibitory effect of cinnamaldehyde chitosan modified solvent on the growth of Aspergillus niger on the wood surface. The findings indicate that when the molar ratio of -CHO to -NH_2 in the modified solvent was 3:1, the antibacterial rate of the wood surface was the highest, at 95.8%. The results of the experiment demonstrated that the cinnamaldehyde chitosan solution increased the stability of cinnamaldehyde and significantly boosted the antibacterial rate of the wood surface.

Lazim et al. [46] prepared a starch-based anti-fungal coating with buttercup that greatly improved the antibacterial type of wood surface without changing other good properties of wood as much as possible. The characterization and analysis were carried out by TG, Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). The coating was evenly distributed on the surface of the wood, and the morphology was slightly rough. The antibacterial experiment showed that the mass loss rate of the uncoated wood samples reached 60% after 120 days of white-rot bacteria erosion, while the mass loss rate of the wood samples coated with antibacterial coating was only 10%. The coating had an obvious inhibition effect on white-rot bacteria.

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