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Environmentally Sustainable Transparent Wood: A Fully Green Approach from Bleaching to Impregnation for Energy-Efficient Engineered Wood Components

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Abstract : Transparent wood is considered a promising structural material for the development of environmentally friendly, energy-efficient engineered components. To obtain transparent wood from natural wood materials two approaches can be used: i) bottom-up and ii) top-down. Through the second method, the color of natural wood samples is lightened through a chemical bleaching process that acts on chromophore groups of lignin, such as the benzene ring, quinonoid, vinyl, phenolics, and carbonyl groups. These chromophoric units form complex conjugate systems responsible for the brown color of wood. There are two strategies to remove color and increase the whiteness of wood: i) lignin removal and ii) lignin bleaching. In the lignin removal strategy, strong chemicals containing chlorine (chlorine, hypochlorite, and chlorine dioxide) and oxidizers (oxygen, ozone, and peroxide) are used to completely destroy and dissolve the lignin. In lignin bleaching methods, a moderate reductive (hydrosulfite) or oxidative (hydrogen peroxide) is commonly used to alter or remove the groups and chromophore systems of lignin, selectively discoloring the lignin while keeping the macrostructure intact. It is, therefore, essential to manipulate nanostructured wood by precisely controlling the nanopores in the cell walls by monitoring both chemical treatments and process conditions, for instance, the treatment time, the concentration of chemical solutions, the pH value, and the temperature. The elimination of wood light scattering is the second step in the fabrication of transparent wood materials, which can be achieved through two-step approaches: i) the polymer impregnation method and ii) the densification method. For the polymer impregnation method, the wood scaffold is treated with polymers having a corresponding refractive index (e.g., PMMA and epoxy resins) under vacuum to obtain the transparent composite material, which can finally be pressed to align the cellulose fibers and reduce interfacial defects in order to have a finished product with high transmittance (>90%) and excellent light-guiding. However, both the solution-based bleaching and the impregnation processes used to produce transparent wood generally consume large amounts of energy and chemicals, including some toxic or pollutant agents, and are difficult to scale up industrially. Here, we report a method to produce optically transparent wood by modifying the lignin structure with a chemical reaction at room temperature using small amounts of hydrogen peroxide in an alkaline environment. This method preserves the lignin, which results only deconjugated and acts as a binder, providing both a strong wood scaffold and suitable porosity for infiltration of biobased polymers while reducing chemical consumption, the toxicity of the reagents used, polluting waste, petroleum by-products, energy and processing time. The resulting transparent wood demonstrates high transmittance and low thermal conductivity. Through the combination of process efficiency and scalability, the obtained materials are promising candidates for application in the field of construction for modern energy-efficient buildings.

Keywords : bleached wood, energy-efficient components, hydrogen peroxide, transparent wood, wood composites
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