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Change of Organic Phase of Wood to Transparent Wood

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Abstract:
Background*: Transparent wood (TW) structures are characterized as highly anisotropic or thick and isotropic but weak. Transparent wood laminates are investigated as load-bearing bio-composites with tunable mechanical and optical performances. Transparent wood has many applications such as solar cells, fabrics industry, Decorations and others.*
Materials and Methods*: In this prospective study, pine wood was used as a template to be a transparent wood. The method used for lignin removal is very simple and cheap, using sodium hydroxide and sodium sulphite water bath at high temperature to get rid of lignin which harden the wood.*
Results*: The transparent wood is characterized by elasticity comparing to hard one due to removal of lignin. Also, the transparent wood is light scattering and light permeable. Transparent wood exhibits a combination of high optical transmittance and haze, outstanding toughness, low thermal conductivity, low density, anisotropic optical and mechanical performance, etc.*
Conclusion: *The obtained transparent wood is very elastic and can be used in many applications.*
Key Word*: Bio-composite; Cellulose; Lignin; Phase change; Pine wood; Transparent wood.*

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I. Introduction

Wood is a widely used structural material that has excellent mechanical properties due to the unique structures from its natural growth. Depending on their types and geographical differences, different woods display an extraordinary variety of meso-structures. For example, softwoods typically have a more porous structure due to their fast growth. Hardwoods normally have a denser structure and a higher density compared to softwood[1,2].

Vertically aligned channels in wood are used to pump ions, water, and other ingredients through the wood trunk to meet the need for photosynthesis. The cell walls consist of cellulose nano-elementary fibrils of ≈3–5 nm in diameter, lignin, pectin, and others. The hierarchical structure and the strong interactions among cellulose, hemicelluloses, and lignin lead to excellent mechanical properties in wood[2,3,4,5].

Lignin is a class of complex organic polymers that form key structural materials in the support tissues of vascular plants and some algae. Lignins are particularly important in the formation of cell walls, especially in wood and bark, because they lend rigidity and do not rot easily. Chemically, lignins are cross-linked phenolic polymers. The composition of lignin varies from species to species. An example of composition from an aspen sample is 63.4% carbon, 5.9% hydrogen, 0.7% ash (mineral components), and 30% oxygen (by difference the formula $(C_{31}H_{34}O_{11})_n$. Lignin fills the spaces in the cell wall between cellulose, hemicellulose, and pectin components, especially in vascular and support tissues: xylem tracheid, vessel elements and sclereid cells. It is covalently linked to hemicellulose and therefore cross-links different plant polysaccharides, conferring mechanical strength to the cell wall and by extension the plant as a whole. It is particularly abundant in compression wood but scarce in tension wood, which are types of reaction wood[6,7,8,9].

There are different applications for transparent wood such as: smart buildings with photonic function, heat/shielding buildings/windows, smart windows, to save energy, load-bearing windows that never crack or shatter, transparent wood potentially transforms electronics, for example, it could manufacture solar cells, especially for large surfaces, provide electromagnetic interference (EMI) shielding by incorporating Ma nanoparticles into transparent wood; and finally transparent wood laser (entirely organic laser)[10].

This study aimed to obtained a clear transparent wood, in order to be applicable for different purposes. We apply the simplest method to obtain the transparent wood to change the organic phase of wood from hard to transparent.

II. Material And Methods

Study material: The wood materials used in this study is pine wood. Different rectangle-shaped wood shingles were obtained commercially.

Lignin Removal Protocol: This protocol is a modified basic version of comes from a paper[2]. The main purpose of this protocol is to remove lignin contents. The protocol was as follow: The wood slices were immersed in the lignin removal solution (1-liter water, 100 grams of NaOH, 50 grams of Na_2SO_3) and kept boiling for 12 h, followed by rinsing in hot distilled water three times to remove most of the chemicals. The wood blocks were then placed in the bleaching solution (1 bottle of H_2O_2 and heat for 2 hours, 2.5 mol/L) without stirring. When the yellow color of the sample disappeared, the samples were removed and rinsed with cold water. The lignin-removed samples were preserved in ethanol.

Polymer Infiltration: Epoxy resin was prepared by mixing the two liquid components (resin and non-blushing cycloaliphatic hardener) at a ratio of 2 to 1. Then the lignin-removed wood was placed at the bottom of a dish and immersed in the liquid resin. Finally, the dish containing the wood sample and resin was kept static at 30 °C for 12 h. The resin-infiltrated wood sample was peeled off from the dish after the resin was completely solidified).

Another method for coverage is by the incorporation of polyethylene glycol (70% PEG) in the transparent wood (TW). This method was described by[11].

Transparent wood characterization (SEM): The characterization of transparent wood (TW) and normal wood (NW) was applied using scanning electron microscopy (SEM) technique. The surface morphologies NW and TW samples were analyzed using a FEI Quanta 200 scanning electron microscope. Scanning electron microscopy (SEM) images were recorded with an accelerating voltage of 20 kV. All wood samples were coated with gold before SEM measurements.

III. Result

Pine wood is essential in many wood industries because it is inexpensive. It is one of the most common soft woods used in Egypt and is used in: Furniture and doors - floors - construction and armament - local counter manufacturing.

After chemical treatments and lignin removal, the wood become more elastic comparing to the control one (fig. 1). Also, the color and thickness change during all treatment steps, and the jar solution color change due to lignin removal from wood tissues (fig. 2).

The transparency of treated wood is clear and transparent to beyond writing due to large pore formation (fig. 3). While in the control wood, there is no transparency. In case of wood treated with PEG, the transparency is clearer than the one treated with epoxy. This could be due to the polymeric and viscous nature of epoxy. SEM image of transparent wood (fig. 4) indicating a cross section showing the empty pores free from lignin. These pores size is about 12.8mm in diameter.

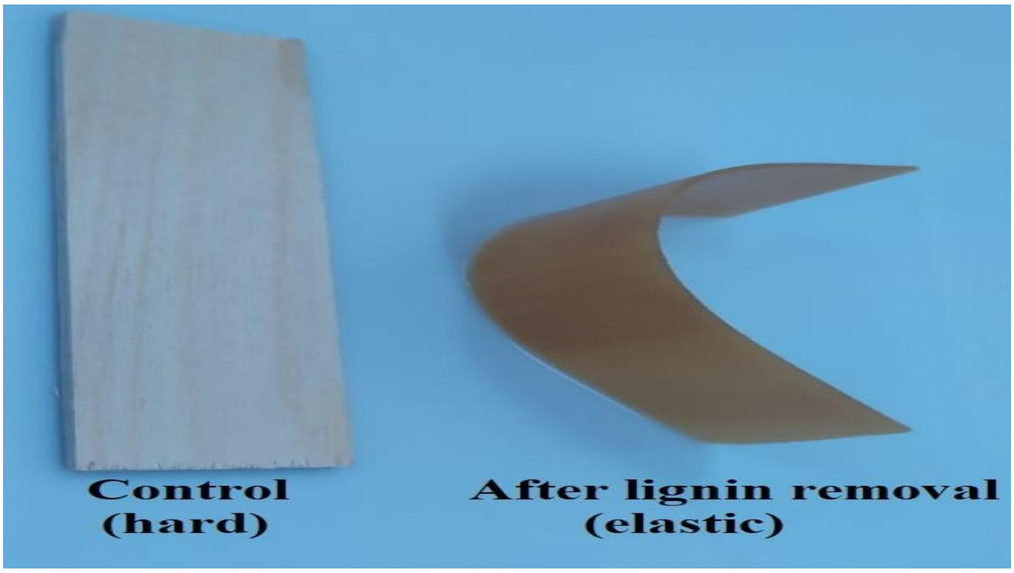

Fig. (1) Hardness and elasticity of wood before and after lignin removal

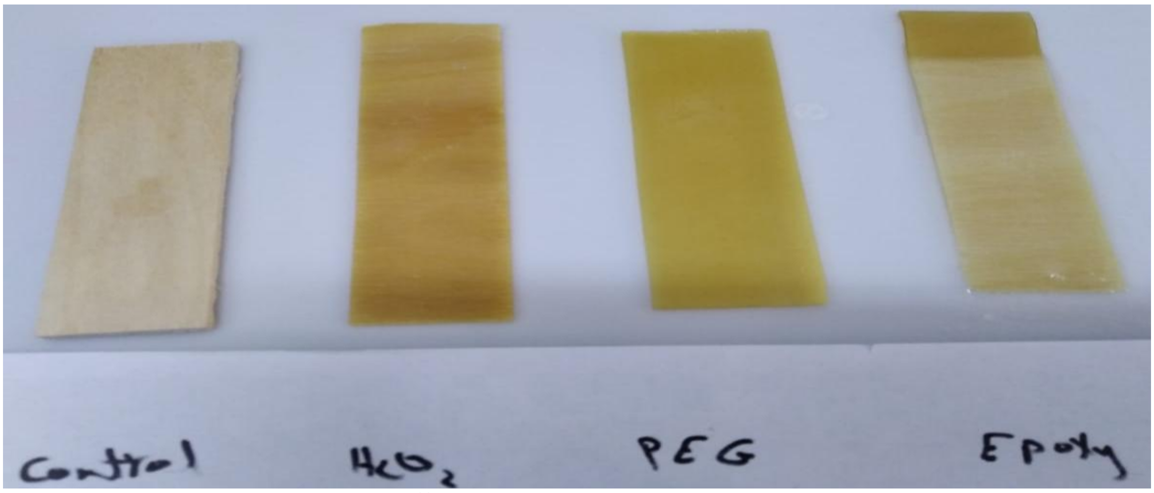

Fig. (2) Different stages to obtain transparent wood

Fig. (3) Wood transparency before and after lignin removal

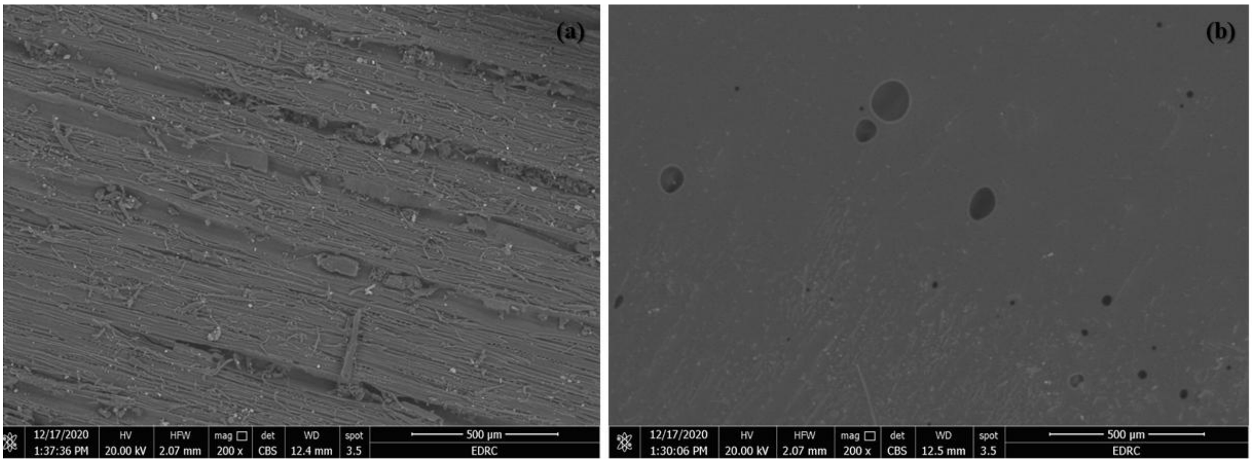

Fig. (4) Cross-sectional SEM images of wood; (a) wood before lignin removal, (b) transparent wood after lignin removal

Early efforts on transparent wood were not motivated by engineering considerations. It was first designed to facilitate wood anatomy studies. The interior wood structure becomes visible, and 3D reconstruction of the structure is possible. Similar concepts have been used for deep imaging of plant and animal tissue[12,13]. Recently, the mechanical performance of transparent wood was studied[14]. Since the material combines structural performance with functional (optical) properties (high transmittance and haze), this rare combination was emphasized. Most functional materials do not have load-bearing properties or are suitable for large-scale structures. Transparent building structure is one demonstration, where light transmittance can be designed so that artificial light can be partially replaced by sunlight. High haze can be used to ensure more uniform and soft nature of the transmitted light so that indoor privacy is preserved[15]. Another direction for transparent wood applications is as a structural material for photovoltaic devices such as solar cells and electrochromic devices[2,16]. Due to the high haze, transparent wood can be designed as a light diffuse layer. High haze means large scattering angles, which increase the length of the light path inside solar cells, so that efficiency is improved[17,18].

IV. Conclusion

Transparent wood is an interesting topic in the emerging field of wood technology and nanotechnology, both in academic and in industrial context. Noticeable progress has been achieved, including preparation of transparent wood with improved mechanical properties, improvement in making larger and thicker transparent wood structures, realization of transparent wood functionalization, and the demonstration of applications in smart buildings and photovoltaic devices.

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