

Production of transparent wood with UV assisted lignin modification using beech and oak wood

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Abstract

Transparent wood composites have received lot of attention in recent years due to their favourable optical, thermal insulation and mechanical properties. This new type of composite material has a wide range of applications, including building materials such as windows, furniture and solar panels. In this study, the lignin-modification time of beech and oak wood was investigated. The samples were modified with hydrogen peroxide. The modified process was accelerated by UV-A light. Experiments were carried out to produce transparent wood composites using polylactic acid and epoxy resin.

The process achieved complete bleaching in just 3 hours, which is faster than other lignin modification methods. The average mass loss for oak samples during the process was 19.67 %, while for beech samples it was 21.37 %. The in situ polymerization of polylactic acid caused the samples to turn dark brown or black. Further research is necessary in this area to prevent discoloration. The production of transparent wood yielded the best results through impregnation with epoxy resin. The lumens were completely filled with the resin, resulting in increased light transmission and reduced light scattering. These findings suggest that higher density hardwoods can be effectively utilized to produce transparent wood while preserving the natural texture of the wood.

Key words: lignin modification, brushing method, transparent wood, polylactic acid, in situ polymerisation

Introduction

The growing demand for sustainable and energy-efficient building materials has drawn attention to transparent wood as a possible solution. Transparent wood is particularly attractive because of its thermal insulation and optical properties, which make it ideal for buildings, solar panels and other optical applications. Traditionally, the removal of the lignin needed to produce transparent wood has required large amounts of chemicals and energy, which has created an environmental burden. In addition, the complete removal of lignin weakens the mechanical properties of wood and requires long processing times (Xia et al. 2021a).

To address these problems, researchers have recently focused on modifying the lignin structure and removing chromophore groups without completely removing lignin from the wood structure (Xia et al. 2021b). Such methods of modifying lignin allow for improving the optical properties of wood without compromising mechanical integrity. Innovations in the production of this type of transparent wood, such as solar-assisted chemical brushing, are particularly promising as they reduce the use of chemicals and energy while significantly shortening processing time and increasing production efficiency (Xia et al. 2021a).

The importance of our work in the present study lies in further optimising the transparent wood production process by applying a novel method of lignin modification using UV light. The UV-assisted bleaching method offers a faster and more environmentally friendly alternative, allowing for the production of transparent wood on a larger scale while improving the optical and mechanical properties of the product. The results presented here could open up new opportunities for transparent wood applications and contribute to the sustainable development of building materials.

Materials & Methods

Materials and Chemicals

Beech and oak veneers (40 mm x 40 mm x 0.6 mm) were used in this study. Hydrogen peroxide (H_2O_2 30% solution) and sodium hydroxide (NaOH 10% solution) were used to modify lignin. Lactic acid and epoxy resin were used to prepare the transparent wood. During the polymerization of lactic acid, tin (II) chloride dihydrate (SnCl_2) and p-toluenesulfonic acid (TSA) were used as catalysts.

Lignin Modification

The lignin modification process was carried out using two chemical reagents (NaOH and H_2O_2). These solutions were applied on the surface of the prepared wood samples by brushing method. The samples were treated following a two-phase protocol, with the first step being the application of the NaOH solution, followed by the application of the H_2O_2 solution. NaOH was applied by brush every hour while H_2O_2 was applied every half hour. After brushing, the samples were exposed to UV-A light sources (3 pcs UV-A light tubes, 30 W). The samples were placed 5 cm from the light source. After lignin modification, the samples were washed several times in distilled water. The samples were then washed in ethanol and stored in ethanol until further use.

Transparent Wood Production

The lactic acid monomer solution was first oligomerized in 3 cycles. In the first cycle, the melt was dehydrated at 75°C under 150 mbar for 75 min with continuous stirring. In the second cycle at the same pressure at 100°C for 100 min. In the third cycle, lactic acid was oligomerised at 130°C for 160 min. Before saturation of the lignin modified samples, 0.2 w/w% SnCl_2 and 0.2 w/w% TSA were added to the lactic acid oligomer. The samples were impregnated at 90°C by placing them in the oligomer. The saturated samples were polymerized between 2 glass plates at 120°C for 360 min and then at 103°C for 2 days to obtain the lactic acid oligomers.

In the case of samples prepared with epoxy resin, the resin and hardener were mixed at a ratio of 100:45 immediately before saturation. Saturated samples were placed between glass plates until the epoxy resin was fully cured.

Results and Discussion

Lignin Modification

When examining the effectiveness of lignin modification in oak and beech, it is worth observing the extent and time course of the response of each species to the treatment.

In the case of oak, the effect of the modification was more rapid. Significant fading of the samples was observed from the early stages. Uniform brightening also occurred more rapidly (120-150 min) and by the end of the process the colour had become almost uniformly light (Fig. 1 A). This suggests that oak responds rapidly to bleaching treatment, which may be advantageous in applications where minimizing treatment time is key.

Beech also started to lighten quickly (Fig. 1 B), but bleaching occurred in patches and took longer to achieve a uniform light colour (180 min). The bleaching of beech in patches and slower fading indicates that beech may be more resistant to certain treatments. Comparing the results from a

technological point of view and in order to reduce the colour deviation of the treated wood, it is appropriate to set the treatment time at 180 min.

In the study, the mass changes of oak and beech woods after the bleaching process were measured. The results showed an average mass loss of oak wood of 19.67 %, while beech wood, on average, suffered a mass loss of 21.37 %. Both woods showed significant mass loss, confirming that the bleaching process is effective in removing organic matter from the wood structure. These results provide important insights into the bleaching reactions of different wood species and may help in the development of further application-specific bleaching protocols.

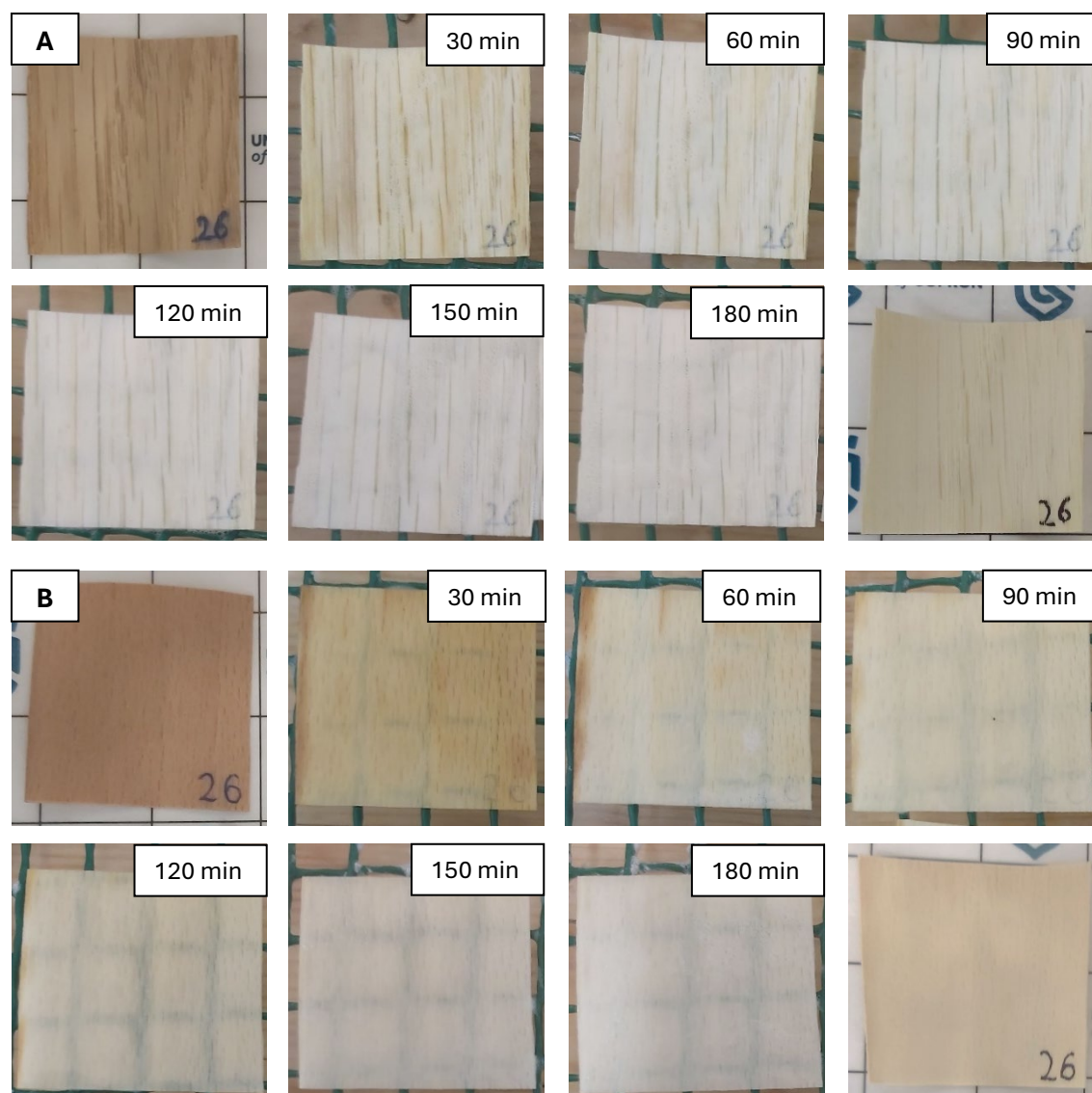


Figure 1. A sequence of images shows the effects of the lignin-modification process on oak (A) and beech (B) over time.

Transparent Wood Production

Samples of beech and oak wood samples were coloured dark brown or black during in situ polymerisation of lactic acid. During saturation, discolouration had already occurred on the samples. At first, only a faint browning started along the edge of the samples. After polymerisation at 120°C for 360 minutes, our samples were completely browned. After treatment at 103°C for 2 days, they were completely blackened (Fig. 2 A), but samples were cured. The

SEM images shown in Figure 2 B, that lactic acid penetrated the gaps between the wood cell walls and the vessels and filled them completely or mostly with polymer.

The beech and oak wood samples saturated with epoxy resin did not show the same discolouration as the previous samples (Fig. 2 C). The yellowish discolouration is due to residual ethanol and the omission of the toluene wash. Xia et al. (2021) report no discolouration.

Saturation with epoxy resin is a simple and rapid procedure.

In Figure 2 D, it can be observed that the epoxy resin completely filled the cavities between the cell walls and the vessels. The two glass plates allowed the epoxy resin to be evenly applied to the surface of our samples. The average epoxy coverage was 41.5 μm for beech and 79 μm for oak.

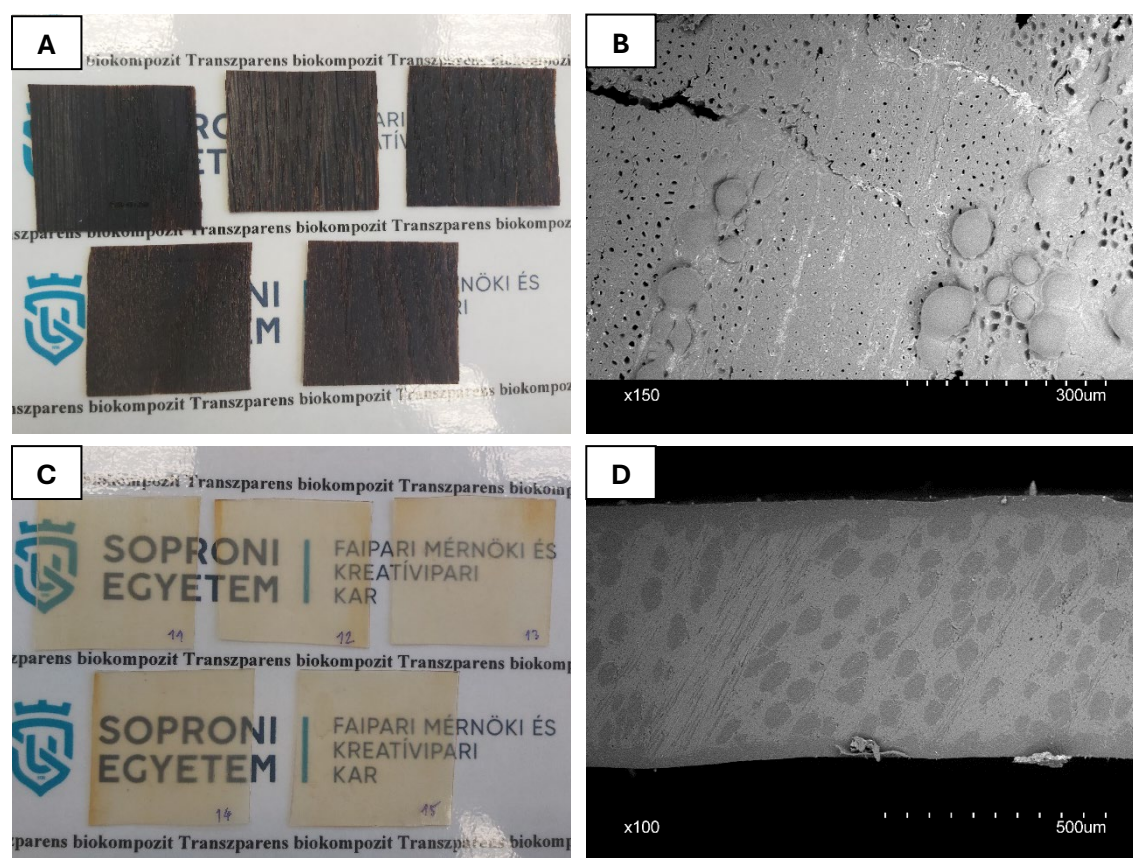


Figure 2. Samples of browned lactic acid lignin-modified oak (A), and saturation of these samples in SEM image (B). Samples of transparent wood beech prepared with epoxy resin (C), and saturation of these samples in SEM image (D).

Summary and Conclusions

In our research we have been working on the production of transparent wood composites. The results of the research showed that lignin modification was faster and more uniform for oak, while beech wood treatment required more time and resulted in patchy bleaching. In order to reduce the discolouration of the treated wood, it is advisable to set the treatment time at 180 minutes. Both woods suffered significant mass loss, confirming the effectiveness of the bleaching process in removing organic matter from the wood structure.

In the production of transparent wood, lactic acid in situ polymerisation caused dark discolouration, whereas no such problems were encountered when using epoxy resin. Samples impregnated with epoxy resin were found to be adequate as control samples.

Our research suggests that higher density hardwoods, such as oak and beech, can be used effectively to produce transparent wood while preserving the natural texture of the wood. The results also highlight the need for further research to focus on optimising polymerisation processes and preventing discolouration in order to make transparent wood composites more widely applicable in construction and other fields.

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