University of Sopron
Faculty of Wood Sciences
Cziráki József Doctoral School of Wood Sciences and Technologies

Doktoral (PhD) thesis

Investigation of the steaming properties of poplar wood

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Introduction and objectives

This dissertation deals with the possibilities for expanding the application range of poplar (Populus x euramericana), specifically the Pannonia poplar (Populus x euramericana cv. Pannonia), through modification techniques. This work is pioneering as there is a lack of literature, both domestically and internationally, regarding the steaming of poplar wood, as well as limited understanding of the behavior of this wood material. This fast-growing, plantation-based tree species is relatively abundant in Hungary, yet its use has been limited to secondary wood industry applications (such as pallet and crate manufacturing) and for energy production. The advantageous color changes caused by modification processes could potentially elevate these secondary uses to primary applications. Steamed poplar wood, for instance, could be suitable for uses like paneling or sauna cladding. Considering the broader industrial application of other wood species (such as beech or black locust), it is worth investigating whether these species can enhance the advantageous properties of poplar wood when subjected to similar modification processes.

In summary, the main research question of the dissertation is: Is steaming an effective modification process for enhancing the industrial utility of poplar wood, and if so, under what conditions?

During the doctoral research, the following objectives and hypotheses were formulated:

- H1. The color of secondary use Pannonia poplar can be improved through steaming, resulting in a darker, browner color that is more pleasing to the human eye than the original color of poplar wood.
- H2. The optimal steaming temperature range and duration can be determined to achieve the desired color.
- H3. The color differences of the sapwood and heartwood can be homogenized through steaming.
- H4. The effect of co-steaming with beech and black locust auxiliary materials improves the color of poplar wood. Steam, as a carrier medium, can transport extractive substances into the poplar, resulting in significant color change.
- H5. Steaming can increase the weather resistance of poplar wood.

In addition to the hypotheses, the aim of the dissertation is to draw conclusions from the results and suggest cost-effective applications for practical use.

Materials and methods

During our research, we aimed to improve the unfavorable optical properties of Pannonia poplar (Populus x euramericana cv. Pannonia) by subjecting it to a steaming process. For the experiments, we prepared test specimens with a moisture content between 8-12%, determined by a mass measurement method. The samples had a cross-section of 30x25 mm and a length of 160 mm, tailored to fit the size of the steaming pot. To monitor the changes across the entire cross-section, we separated the poplar samples into sapwood and heartwood and steamed them at temperatures ranging from 90°C to 120°C for up to 20 days (the treatment lasted 9 days at 120°C). We tracked the color changes of both sapwood and heartwood using objective color measurement, presented in the CIE L*a*b* three-dimensional color coordinate system, where the L* coordinate represents the lightness of the sample, the a* coordinate the red hue, and the b* coordinate the yellow hue. The measurement results refer to the D65 light source, for an illuminated surface of 8 mm diameter, under 10° observation. A KONICA-MINOLTA 2600d type colorimeter was used for the color measurements.

In our further experiments, we steamed poplar samples in the same airspace with frequently steamed industrial wood samples of black locust (Robinia pseudoacacia) and beech (Fagus sylvatica) to enhance the color-modifying effect of steaming. We expected that the steam, acting as a carrier medium, could transfer extractive substances from the auxiliary materials (black

locust or beech) into the poplar, resulting in significant color change. The treatment temperatures used were between 90°C and 120°C, with the maximum duration of steaming being 20 days (only 9 days at 120°C), consistent with the parameters of our previous experiments. In the steaming pot, the volume ratio of the material to be improved (poplar) and the auxiliary material (black locust or beech) was always the same, adding 50% auxiliary material to the 100% material to be improved.
After altering the visual appearance of the poplar wood, we examined the durability of the new color created by steaming. For these tests, we used poplar wood that had been steamed for five days at temperatures of 100, 110, and 120°C, and then exposed it to UV radiation provided by a mercury vapor lamp. The color-changing effect of the treatment was measured after 7, 16, 36, 60, and 90 hours of exposure.

Results and evaulation

The results of the visual examinations indicate that steaming is a reasonable alternative for improving the color of poplar wood. The steamed wood became darker and browner, and the wood texture became more visible. This phenomenon was present throughout the entire cross-section.
The color change caused by steaming is described by the changes in individual color coordinates. The lightness value significantly decreased at all set temperatures. The greatest decrease in lightness, 44 units, was achieved with 9 days of steaming at 120°C. The results confirmed our hypothesis that

steaming is an appropriate method to produce a darker color in poplar wood. We found that during the first 5 days of steaming at 90-110°C, the change in lightness of the poplar wood was not temperature-dependent. This finding has practical significance in that strict temperature control is not necessary at these temperatures, implying that steaming equipment does not require a precise temperature control system.

The red color component (a* value) consistently increased over time during the steaming process at 90°C, 100°C, and 110°C. The increase reached 2.5-3 times the initial values in the first 5 days, followed by a more moderate increase. In the 120°C treatment, where changes occurred more rapidly, both the sapwood and heartwood showed a fourfold increase in the a* value after the first day, followed by a slower rate of change. For the sapwood, this slow change continued until the end of the treatment, while for the heartwood, the maximum a* value was reached on the sixth day and then showed a decrease until the end of steaming.

The increase in the yellow color component (b* value) was similar to the a* value. At 90°C and 100°C, the curves for sapwood and heartwood were close to each other. The 110°C treatment resulted in a significant increase in the yellow color for the sapwood and a slight increase for the heartwood. The most intense increase occurred in the first 5 days of steaming, followed by a moderate increase until the end. Similarly to the red color component, at 120°C, there was a significant increase in the yellow color component on the first day, followed by a slowdown. The b* values for both sapwood and heartwood reached their peak, the former on the fourth and the latter on the sixth day, and then showed a decrease until the end of the treatment.

As a result of 20 days of steaming at 110°C, the yellow color component value increased to 33.25 units, which is 1.9 times the initial value. Meanwhile, the greatest value for the red color component was 12.3 units, almost a fivefold increase from the initial value. Therefore, in percentage terms, the change in red coloration is greater. However, based on the unit changes in the color coordinates, the red color component showed an increase of 9.7 units, while the yellow color component showed an increase of 15.7 units. Thus, in absolute terms, the increase in the yellow coloration is more significant, further amplified by the differing initial values.

In examining color intensity, we determined that steaming at all tested temperatures enhances the saturation (C*) of the poplar. The highest saturation value achieved was 35.2, which is twice the initial value.

We found a high correlation between the lightness and hue angle values during the steaming of poplar wood, applicable to both sapwood and heartwood. The determination coefficients (R2) were high, ranging between 0.88 and 0.98, indicating a good linear correlation. The highest value was achieved at a treatment temperature of 100°C.

For the total color change, we calculated increasingly larger ΔE* values compared to untreated samples as temperature and time increased across all treatment temperatures. With a 100°C, two-day treatment, we already achieved a change of 6 units, which is very noticeable to the naked eye. The highest value was observed in the 120°C, 9-day treatment, with a 45-unit change for both sapwood and heartwood. In our case, the total color change does not provide additional information due to the significant decrease in lightness, as the L* value dominates in the ΔE* calculation. This results in the minor numerical changes in the red color component, which are significantly perceptible to our eyes, and the effects of the wood texture, being less pronounced. The total color change can be useful for measuring the color difference between the sapwood and heartwood, which is important information for the wood industry. It is important to consider that the wood's texture can affect the perceived result. The optimal treatment times for homogenization of heartwood and sapwood are as follows:

- At 90°C for 9 days. ΔE*=0.78. This is the smallest value experienced at all treatment temperatures, close to the imperceptible color difference. The disadvantage is the long steaming time.
- At 100°C for 5 days. ΔE*=1.78. In preliminary experiments, which also involved 100°C treatment, we obtained the same result, with the color points being closest to each other on the 5th day.
- At 110°C, it is not recommended, as no value was lower than the initial state. It might be that the material becomes more inhomogeneous at this temperature. At this temperature, we also observed the highest deviation of 5.78.
- At 120°C for 2 days. ΔE*=1.72

In the next group of our experiments, we steamed poplar samples in the same airspace with black locust (Robinia pseudoacacia) and beech (Fagus sylvatica) samples to enhance the color-modifying effect of steaming. Based on objective color measurement, we determined that the presence of the auxiliary materials did not affect the change in lightness at any temperature, and only enhanced the color change of the poplar above 100°C. The presence of both initiators caused a slight increase in red coloration in the poplar's sapwood compared to the poplar steamed alone. The presence of black locust caused a greater change in red coloration than the presence of beech, which can be explained by the higher extractive content in black locust. The effect of co-steaming becomes apparent in the first two days at 120°C, but later deteriorates due to the washing-out effect of the steam. This observation applies to both the heartwood and sapwood. The behavior of the b* (yellow color component) change was similar to that of the red color component in relation to the auxiliary materials. Above 100°C, beech as an auxiliary material had a mild effect on the sapwood of the poplar and a more significant effect on the heartwood. The greatest difference was achieved as a result of treatment at 110°C. The presence of black locust, similar to its effect on the red coloration, had a greater impact on the yellow coloration than the presence of beech. The effect of black locust on the sapwood was noticeable at 120°C, while on the heartwood, it caused a mild change below 100°C and a significant change above 100°C. In conclusion, the effect of the auxiliary woods on the colour change is observed at 110°C and 120°C.

After changing the visual appearance of poplar wood, we examined the durability of the new color created by steaming. For this purpose, we exposed steamed poplar wood to UV radiation. The effect of UV radiation on the lightness of poplar wood indicates that the steamed wood underwent less darkening during UV treatment compared to natural (unsteamed) wood. In terms of the durability of the red coloration, the red hue produced by steaming at 120°C remained stable against UV radiation. Additionally, poplar wood steamed at other temperatures was more resistant to UV radiation than unsteamed wood.

For the yellow coloration, the samples steamed at 120°C showed the greatest color stability, but not to the same extent as with the a* (red color) value. While the yellow coloration of natural wood increased by 2.3 times, the yellow coloration of the wood steamed at 120°C increased only by 1.3 times after 90 hours of UV exposure. The color changes of the other steamed samples were between these two values.

Finally, we examined the equilibrium moisture content of steamed poplar wood, which is an important factor in terms of durability and resistance. These experiments were conducted three years after treatment to determine the long-term equilibrium moisture content of the treated samples. During these three years, the steamed samples were stored under room-dry conditions. The moisture content of the steamed samples was determined using a mass measurement method. The results showed that all treatments resulted in a decrease in equilibrium moisture content. A continuous, moderate decrease in moisture absorption was observed in samples treated at 90-110°C. In contrast, the first two days of treatment at 120°C significantly reduced the absorbable water content, after which further steaming had no effect on the equilibrium moisture content of the samples.

Based on the results, we can state that with increasing treatment time or temperature, the poplar wood settles at a lower equilibrium moisture content. The effect of 20 days of steaming at 90°C resulted in a 0.5% lower equilibrium moisture content, and at 110°C, it was 1% lower. For the 120°C treatment, we observed a 2% decrease in equilibrium moisture content in the first two days. From the stagnant results after two days, we concluded that neither increasing the temperature nor the duration of treatment would be beneficial to further enhance this effect.

Thesis

1) I stated that the uncharacteristic greyish-white colour of Pannonia poplar can be improved by steaming. Steaming can produce a darker, browner colour that is more pleasing to the human eye, and the wood texture is highlighted and visible. I have shown that the right range of steaming temperature and duration can be determined to achieve the optimum colour desired. In the range 90-110°C, the change in lightness of poplar does not depend on temperature during the first 5 days of steaming.

2) I stated that steaming at all temperatures tested enhances the colour saturation of the poplar, which increases the esthetic value of the colour created.

3) I demonstrated that there is a linear correlation between the lightness and colour hue of the color points created during the steaming process. The steaming at 100°C produces the best correlation coefficient between colour hue and lightness for both sapwood (R2=0.94) and heartwood (R2=0.98).

4) I determined that the color differences between the sapwood and heartwood of poplar can be homogenized. This is achievable at different steaming temperatures: 9 days at 90°C, 5 days at 100°C, and 2 days at 120°C. After these periods, the colors begin to diverge. I also found that

treatment at 110°C is not suitable for homogenization, as the wood became more inhomogeneous throughout the entire steaming duration.

5) I found that steaming together with beech and black locust auxiliary materials improves the color of poplar wood. I discovered that beech and black locust, when steamed in the same airspace, do not affect the lightness change of poplar wood, but they do have an impact on its yellow and red coloration. I determined that the effect of the auxiliary wood materials on yellow and red color change occurs at 110°C and 120°C.

6) Steaming enhances the color stability of poplar wood against UV radiation compared to unsteamed wood. This resistance increases with higher steaming temperatures. Comparing the effects of 90 hours of UV radiation on the color coordinates of untreated and 120°C-steamed samples showed the following results: The decrease in lightness was 10 units for the untreated sample, but only 1 unit for the steamed sample. The value of the red coloration for the untreated sample increased by 2.9 times, while it did not increase for the steamed sample. The value of the yellow coloration for the untreated sample increased by 2.3 times, while it increased only by 1.3 times for the steamed sample.

7) I proved that steaming reduces the equilibrium moisture content of poplar wood. As the steaming time and temperature increase, the poplar wood reaches a lower equilibrium moisture content, with the effect being maximized at 120°C. After 20 days of steaming at 90°C, the equilibrium moisture content of the poplar samples decreased from 9% to 8.5%. At 100-110°C, this value drops to 8%, representing a 1% decrease. However, at 120°C, a 2% decrease is observed within the first two days, thus setting the wood's equilibrium moisture content at 7%.

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