



The effect of heat treatment on thermal conductivity of paulownia wood

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Abstract

The thermal conductivity properties of wood of Paulownia Clones in Vitro 112 were investigated after heat treatment at temperatures of 180 °C, 200 °C and 220 °C. After the treatment, the density decreased by 5.6, 8.9, and 14.1% for the samples heat-treated at 180 °C, 200 °C and 220 °C, respectively. The decrease in the thermal conductivity was 0, 2.6 and 15.7%, respectively. The thermal conductivity of kiri wood after thermal treatment at 220 °C was 0.064 W/mK, which is almost the same as that of thermal insulation materials.

1 Introduction

An increasing number of kiri wood (*Paulownia* sp.) plantations have been established worldwide in recent decades. Under suitable conditions, a 5–7-year-old tree can produce up to 1 m³ of wood material annually. The kiri tree has a wide range of possible uses: it is used to manufacture boxes, cabinets, chairs and tables, doors, windows, ceilings, and it can also be used for paper manufacturing. Intensive research on its use as a biofuel and in fiberboards is also taking place. Due to its rapid growth, large amounts of kiri wood will be harvested in the next few decades. It is expected that the uses of kiri wood will widen and additional tests are required to reveal its properties.

The thermal conductivity of wood is generally within the range of 0.1–0.2 W/mK perpendicular to the grain. Akyildiz and Kol (2010) investigated kiri wood and found thermal conductivities of 0.089–0.117 W/mK for the density range 263–357 kg/m³. Kaygin et al. (2009) measured the changes in the physical properties of the heat-treated paulownia (*Paulownia elongata*), whereby the density, EMC and shrinkage gradually decreased with increasing treatment duration and temperature.

In the present study, the thermal conductivity properties of Paulownia Clone in Vitro 112 were investigated after heat treatment at various temperatures.

2 Materials and methods

The Paulownia Clones in Vitro 112 ‘Oxyfa’ from Spain (Barcelona) were examined in this study. Three 9-year old trees were cut and a section, 2.4 m from the base of the trunk and free of knots, was used to produce the samples.

The initial size of the samples made of heartwood was 200 × 200 × 20 mm (grain × tangential × radial directions). The design of the specimens ensured that the heat transfer was perpendicular to the grain. The specimens were stored at 20 °C and 65% RH for 2 weeks prior to the measurements. The thermal conductivity measurement was taken by means of the hot plate method (MSZ EN ISO 10456 2012); the difference between the cold and the hot side was 10 °C. To ensure parallel heat flow, 35 cm wide EPS insulation was used to frame the specimens. The measurement started when the specimen was in steady state condition, which was accepted when the standard deviation of fifty serial measurements was less than 0.001 W/mK. The measuring instrument records one measurement per minute, and the average of hundred measurements in the steady state was taken as the final result.

Eight specimens for each treatment were studied. Three different target temperatures were used: 180 °C, 200 °C and 220 °C. According to the heating schedule, the specimens were heated from 25 °C to 95 °C in 5 h, then from 90 °C to

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130 °C in 7 h, and the target temperature was achieved after an additional hour. Holding time of the target temperature was 5 h. Upon cooling, the thermal inertia of the specimens and the chamber was used, so the specimens were cooled to 25 °C in about 15 h.

The thermal conductivity and density were measured on each specimen before and after the treatment, so the differences due to the wood anatomy could be excluded. To assess the influence of the heat treatment on the properties of the paulownia samples, Student's t-tests and post hoc Duncan tests were performed using the Statistica 13 software.

3 Results and discussion

The average initial density was 239.52 kg/m³ in the range of 226 and 252 kg/m³, and the average thermal conductivity value was 0.072 W/mK in the range of 0.066–0.086 W/mK. Detailed data related to the samples of the different treatment groups are listed in Table 1, where the averaged values of 8 samples per treatment are shown. The initial values of thermal conductivity were about 15% lower than those reported by Akyildiz and Kol (2010) for *Paulownia tomentosa*: 0.089–0.117 W/mK. The reason for the difference may be that different species were tested, which had a higher density: 263–357 kg/m³.

The density decrease after the heat treatment was statistically significant compared to the initial values. The mean values are significantly different.

The thermal conductivity of heat-treated kiri wood (0.0711, 0.0678 and 0.0640 W/mK) is in the upper range of that of standard insulation materials like rockwool or polystyrene foam. While the heat treatment at 180 °C also caused a decrease in density, it did not change the thermal conductivity. At 200 °C and 220 °C, the thermal conductivity decreases parallel to the decrease in density. The treatment at 200 °C and 220 °C caused a statistically significant change in thermal conductivity, compared to the initial values. The post hoc test does not show significant differences between the treatments. However, the different treatments separate the samples into three groups.

This paulownia clone had a significantly lower initial density value compared to other wood species. The low density

results from its anatomical structure: a large amount of parenchyma around vessels is characteristic for kiri wood, and parenchyma cells have large lumens and thin cell walls. The fibers also have relatively large lumens and thin walls. Since the density has a significant effect on the thermal properties, the initial thermal conductivity was also lower compared to other wood species. The porosity in the kiri wood is between 75 and 85% (Kiaei 2013), which explains the low initial heat conduction.

This result is somewhat contradictory to the experience with other wood species. Pásztor et al. (2017) have shown a decrease in the thermal conductivity with the duration of heat treatment in spruce and poplar wood at 180 °C, but even this treatment affected the thermal conductivity of spruce and poplar wood. For Caucasian fir and beech, different temperatures (170°, 180°, 190°, 200°, 212 °C) at constant times were used and a decrease in density and heat conduction was observed after the heat treatment (Kol and Sefil 2011) even below 200 °C. Due to its low thermal conductivity, kiri wood showed higher heat resistance during heat treatment compared to wood with higher density, resulting in a lower or shorter heat load on the inner parts of the material, which could explain why there was no detectable change in heat conduction at 180 °C.

4 Conclusion

The kiri tree is a fast growing tree species with low wood density. The wood of kiri is not suitable for wood constructions but might be used as insulation material. For this purpose, the density and the thermal conductivity of kiri wood were examined before and after thermal treatment. The treatment at 180 °C did not produce any change in thermal conductivity, while the density decreased by 5.6%. The treatments at 200° and 220 °C resulted in a thermal conductivity of 0.068 W/mK and 0.064 W/mK, respectively, with values that are 2.6% and 15.7% lower than the initial values. The lowest thermal conductivity achieved by thermal treatment is within the range of standard thermal insulation materials. The thermal conductivity of this paulownia clone after thermal treatment is almost 50% lower than that of conventional coniferous building materials.

Table 1 Initial and post-treatment density and thermal conductivity average values of kiri wood

Treatment temperature (°C)	Before treatment		After treatment		Differences (%)	
	λ (W/mK)	ρ (g/cm ³)	λ (W/mK)	ρ (g/cm ³)	λ %	ρ %
180	0.0711	239.9	0.0711 ^{AB*}	226.4 ^B	0	-5.6
200	0.0695	237.3	0.0678 ^{BC}	216.2 ^C	-2.6	-8.9
220	0.0762	241.3	0.0640 ^C	207.4 ^D	-15.7	-14.1

*Letters ranking per Duncan's multiple range test for significance level of 0.05 for the eight samples. Differences between mean values with same letter are not significant. Initial values are in the group A

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