Determining the degree of heat treatment of ~~the~~ wood by light polarization technique

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Abstract. Thermal modification of wood enables the use of non-durable wood species in exterior applications, but quality control methods are required to monitor the product variability. This study tests the potential of a light polarization technique where visible light (400- 500 nm) is directed through a linear polarizer to the surface of thermally modified wood to measure the reflectance. Besides an effect of the grain direction, the reflectance decreased with increasing temperature~~s~~ during the thermal modification process. The technique could be used -for quality control, but further studies are required to understand its modes of action.

1. Introduction

Thermal modification of wood is increasingly recognized as an environmental friendly technique to enable the exterior application of non-durable wood species. Thermal modification is based on exposing the wood to elevated temperatures (ca. 180-220°C) to induce chemical changes that improve the resistance to fungal decay and the dimensional stability at the costs of reduced strength and ductility (Hill~~,~~ 2006). However, the increasing production volume and ~~the~~ rising number of manufacturers in recent years necessitates the implementation of quality control systems. This requires methods that can rapidly quantify the changes of the wood caused by ~~the~~ temperature exposure to monitor the variability of thermally modified wood. A large number of quality control methods has already been evaluated. However, many of these methods require matched, untreated raw material, are destructive, or otherwise unsuitable for routine field quality control (Willems et al.~~,~~ 2015). Therefore, the development ~~for~~ of new quality control methods is still desirable.

One potential method is the determination of the change in the optical constant of thermally modified wood. In a previous article by Niskanen et al. (2012), the effective refractive index of unmodified and thermally modified wood was measured using an immersion liquid method. The method is based on matching the refractive index of small wood particles with that of an immersion liquid. A clear effect of the temperature applied during the thermal modification on the effective refractive index was found, which indicated a loss in birefringence. However, the immersion liquid method requires sample preparation, is slow to conduct and typically requires expensive and toxic immersion liquids. The purpose of this paper is to investigate if the change in optical properties of wood by thermal modification can be determined by measuring the changes in polarized light reflectance from the surface of solid wood using a polarimeter and spectrophotometer techniques. Set-~~-~~up ~~is~~ based on these techniques can be simple and inexpensive.

2. Materials and Methods

~~The~~ T~~t~~hermal modification of the samples ~~were~~ was performed according to the Thermowood® process. Sawn timber (Scots pine) was modified in a kiln with a capacity of 0.5 m^3. The timber with dimensions of 63 (H) x 75 (W) x 2000 (L) mm^3 ~~were~~ was treated at 160, 180, 200, 220, and 230^{0}C with heat treatment time of 3 hours ~~in~~ at the maximum temperature. The boards were sawn from trees that had grown in Central Finland, approximately between 64–65°N and 27–28°E and contained both heartwood and sapwood. Samples with dimensions of 4(H) x 20 (W) x 180 (L) mm^3 were cut from the heat-~~-~~treated boards. The samples were measured in the laboratory conditioned at 23.5°C and 50% relative humidity. Directly after measurements, density and moisture content of each samples were recorded. Dry mass for moisture content calculation was determined after 16 h of oven-drying at 105 °C. The experimental configuration is shown in Fig. 1. In the setup, a linear polarizer is adjusted to 45 degree with respect to xy-co-ordinate. The light source is a LED (Flash model 205 365) and optical power of 1.35W within the 400-500 nm wavelength range. The light passed through a linear polarizer towards the surface of a wood sample. The reflected light is detected by a spectrometer (ASEQ Instruments, model LR1). In the measurements, the incident angle was 60°, which~~. This~~ is close to the Brewster angle of the air/wood-interface (at the Brewster angle, the reflected beam is polarized). The reflectance was calculated by dividing the reflected light intensity by the incident light intensity. The samples were measured in the vertical (y-axis) and horizontal (x-axis) grain directions with respect to the polarization direction of the incoming light beam. This method may introduce significant difference between those polarization states if any for the sample being measured.

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3. Results and Discussion

Reflectance as a function of the wavelength in two grain directions is displayed in Fig. 2. The maximum reflectance is located at 447 nm for all thermal modification processes in both grain directions. The maximum reflectance was lower for the measurement in vertical direction (Fig. 2 a) compared to the measurement in horizontal direction (Fig. 2 b). This might be the result of the orientation of cellulose microfibrils in the wood cell wall, with an almost longitudinal orientation in the largest (S2) layer of the cell wall. However, irrespective of the grain direction the reflectance decreased by thermal modification, as evident from the data shown in Table 1. This decrease in reflectance is in line with a loss in birefringence of Scots pine wood by thermal modification observed as an increase in the effective refractive index by Niskanen et al. (2012). They explained the loss in birefringence by the penetration of the immersion liquid into cell wall pores created during thermal modification and by the crystal to amorphous deformation of the cellulose. However, crystalline cellulose is highly resistant to heat and only little cellulose degradation occurs below 230 °C in hydrothermal treatments (Garrote 1999). The preferential degradation of hemicelluloses even results in an increase in percentage of crystalline cellulose within the modified wood (Andersson et al. 2005). Therefore, other explanations should be considered for the decrease in reflectance.

Neither density nor the moisture content of the samples determined directly after the reflectance measurements (see Table 1) fully correlate with the monotonic decrease in reflectance. However, thermal modification is known to increase the number of chromophores in wood that absorb visible light (390-700 nm), with this increase being closely correlated to the temperature and duration applied. Chemical changes in both, the hemicelluloses and the lignin fraction, are involved in creating chromophores, but changes in the acid insoluble lignin fraction are believed to have the largest share in their formation (González-Peña and Hale 2009). The chromophores formed during thermal modification might also absorb the polarized light in the 400 to 500 nm wavelength range to decrease the reflectance, as

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measured in this study. Although further studies are required to understand the exact cause for the loss in reflectance, its simplicity, low costs, little~~ow~~ measurement time and high sensitivity to the process conditions applied make the polarized light reflectance measurement a promising candidate for routine field quality control of thermally modified wood.

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Table 1. Measurement results for thermally modified Scots pine.

Fig 1. Schematic illustration of the optical set--up:

Fig 2. Reflectance for different heat treatment degrees as a function of wavelength: (a) horizontal and (b) vertical grain direction.

Fig. 2b