

Investigation of light-irradiated wood with heat treatment by near infrared spectroscopy

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Introduction

Wood painting has mainly two objectives. One is coloring; the other is the protection of the surface. However, the emission of volatile organic compounds such as toluene and xylene from paint is a health concern. Colouring by light-irradiation and heat treatment emits no volatile organic compounds and is very simple. Therefore, this treatment is a new alternative for colouring wood.^{1,2} The colour of light-irradiated wood remarkably changes by heat treatment. It is thought that the remarkable change in colour is caused by the change in chemical component. This study discusses the changes in NIR spectra and wood colour resulting from heat treatment after light-irradiation. Such basic researches are available to materialise a new colouring method of wood without using paints.

Materials and method

Materials

Wood species used were Japanese cypress (*Chamaecyparis obtusa*), Japanese cedar (*Cryptomeria japonica*), Spruce (*Picea sitchensis*), Japanese beech (*Fagus crenata*) and Japanese oak (*Quercus mongolica*). The dimension of each sample was 50 mm in width, 50 mm in length, and 10 mm in thickness. The light-irradiations and heat treatment were applied to the widelong surface (i.e. flat grain). The three samples for each wood species were prepared. During the experimental periods, no significant changes in measurement values were observed. The following results are therefore presented as the average value of three measurements.

Method

Samples were irradiated with artificial sunlight from a xenon lamp at 180 W m^{-2} , in the range of 300–400 nm, for 100 hours, at 63°C (black panel) and 50%RH in a commercial chamber. After light-irradiation, the samples were treated in humid conditions at 90°C and 90%RH for 150 hours. The colour of the samples was measured with a colorimeter (NR3000: Nippon Denshoku Industries Co., Ltd). The sensor head was 10 mm in diameter. Measurements were made using a D_{65} illuminant and a 2-degree standard observer. The CIELAB colour parameter (L^* , a^* , and b^*) were computed, and the difference in the L^* (i.e.; ΔL^*) and chroma coordinates (i.e.; Δa^* and Δb^*) were calculated. In this study, the measured colours before light-irradiation for each sample were employed as the control. The colour of specimens before light-irradiation is shown in Table 1. NIR spectra were

Table 1. The colour of specimens before light irradiation.

Wood species	L^*	a^*	b^*
Japanese cypress	81.01 ± 1.03	10.17 ± 1.09	22.49 ± 1.17
Japanese cedar	69.82 ± 0.71	21.05 ± 1.23	17.85 ± 2.08
Spruce	77.58 ± 0.25	12.38 ± 0.95	20.25 ± 0.79
Japanese beech	77.44 ± 0.91	9.80 ± 3.33	21.59 ± 1.70
Japanese oak	66.65 ± 0.11	8.98 ± 1.48	20.35 ± 1.14

measured with a spectrophotometer (InfraAlyzer 500: Bran+Luebbe Co.). The wavelength of incident light varied from 1100 nm to 2500 nm at a step of 2 nm.

Results and discussion

Figure 1 shows original spectra of Japanese cypress before light irradiation, after light irradiation and heat treatment, respectively. NIR region includes some kinds of OH or CH absorption bands concerning to overtone or combination mode. It is suggested from Figure 1 that OH or CH absorption bands slightly decreased as each process was performed. To examine such variation in detail, we gave attention to the second derivative spectra at two NIR ranges (i.e. 1400–1600 nm and 1650–1750 nm) as follows.

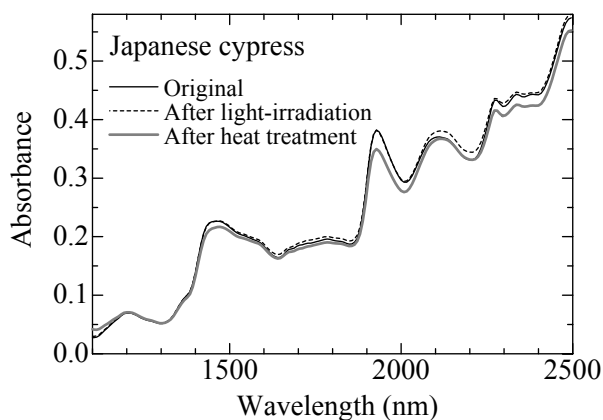


Figure 1. Original spectra of Japanese cypress before light-irradiation, after light-irradiation, and after heat treatment.

Figures 2 and 3 show the second derivative spectra of absorbances $d^2 A/d\lambda^2$ for Japanese cypress and Japanese beech, respectively. The absorption bands at $\lambda=1432$ nm, 1480nm and 1586 nm are assigned to the second overtone of OH groups in the amorphous, semi-crystalline, and the intramolecularly hydrogen-bonded crystalline regions due to the cellulose, respectively.^{3,4} It is known from this figure that OH groups in the amorphous region due to holocellulose (mainly composed of the cellulose and the hemicellulose) decrease by light-irradiation and heat treatment. However, OH in semi-crystalline and crystalline regions were not affected by such physicochemical process. The absorption band at $\lambda=1672$ nm and 1712 nm are assigned to the second overtone of CH stretching vibration in aromatic skeletal due to the lignin and them in furanose (or pyranose) due to

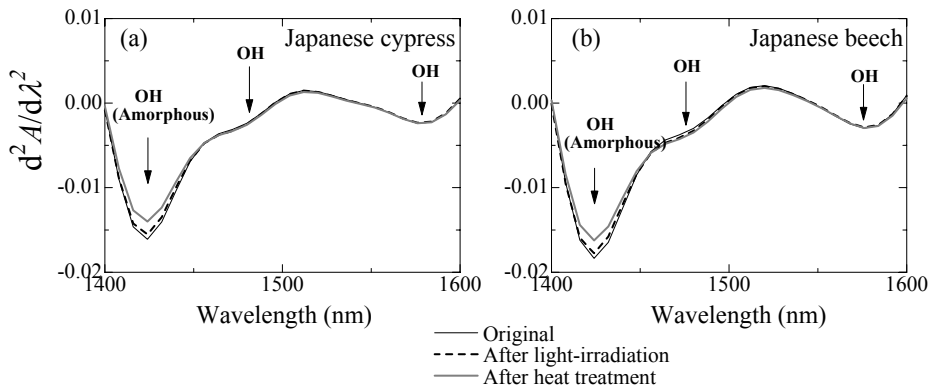


Figure 2. Second derivative spectra of absorbances $d^2 A/d\lambda^2$ ranging from 1400 nm to 1600 nm for spruce and Japanese beech.

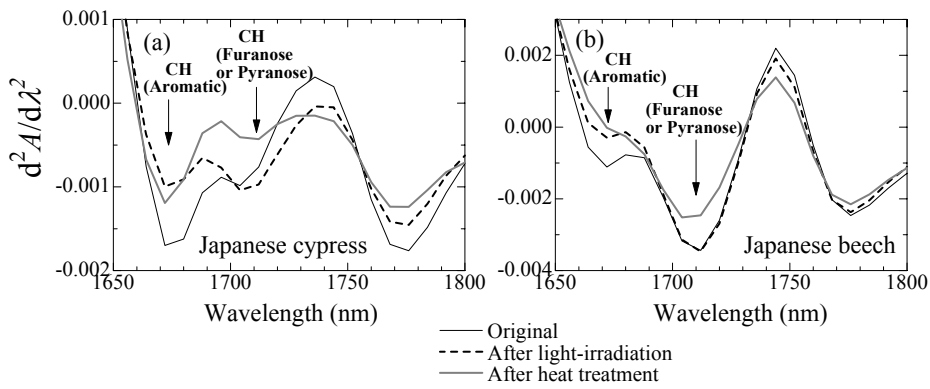


Figure 3. Second derivative spectra of absorbances $d^2 A/d\lambda^2$ ranging from 1650 nm to 1800 nm for spruce and Japanese beech.

the holocellulose, respectively.⁵ Both absorption bands characteristically changed as each process were performed. It is strongly suggested that the lignin and the hemicellulose mainly decreased by light-irradiation and heat treatment, respectively.

Figure 4 shows the change in colour parameter (ΔL^* , Δa^* and Δb^*) and the ratios of $d^2 A/d\lambda^2$ after light-irradiation or heat treatment to them before such procedure, V_λ .

That is,

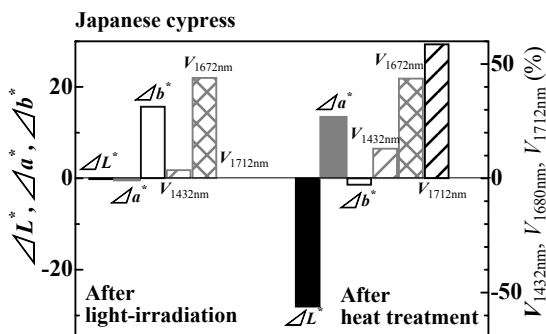


Figure 4. Variation of colour parameter and V_λ with light-irradiation and heat treatment.

$$V_\lambda = \left[1 - \left\{ \left(\frac{d^2 Ab}{d\lambda^2} \right)_{After} / \left(\frac{d^2 Ab}{d\lambda^2} \right)_{Before} \right\} \right] \times 100 \quad (1)$$

The change in the colour of wood with light-irradiation is related to the degradation of lignin, which was clear from the variation of absorption band at 1672 nm, V_{1672nm} . Some researchers reported that the change in the colour of wood with heat treatment is related to the degradation of hemicellulose.⁶ The variation of absorption band at 1712 nm, V_{1712nm} , with heat treatment directly supports such previous research.

Thus, NIR spectroscopy becomes a useful method for the detection of a change in chemical structure of light-irradiated wood with heat treatment.

Acknowledgements

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