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Measurement of photodegradation-caused roughness of wood using a new optical method

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ABSTRACT

The aim of this study was to clarify the intensity of the surface roughening of wood caused by light radiation using a fast optical method. The samples were irradiated by mercury lamp and the roughness change was monitored traditionally using a perthometer. The infrared (IR) diffuse reflectance spectrum was measured and the baseline shift was found to be a proper parameter to monitor the roughening effect of photodegradation. Linear correlation was found between the traditionally measured roughness and the baseline shift. This newly developed optical method is able to detect the degradation difference between earlywood and latewood. Some of the samples were immersed in distilled water for a day after an all light irradiation period of two days. This new baseline shift method was able to visualise and determine the small change in roughness caused by the leaching effect of water.

1. Introduction

Wood is a chemically highly complicated natural product. The basic component is the cellulose biopolymer surrounded by a lignin matrix. The components are naturally arranged into tubular structures and eventually form a cylindrically layered composite. This structure is sensitive to biotic and abiotic degradations. The chemical components of solid wood are sensitive to light irradiation. The main factor that causes the greatest change during exposure to sunlight is the ultraviolet (UV) radiation [1]. Chemical analyses showed that the deterioration is primarily related to the decomposition of lignin [2–7]. The chromophoric groups of lignin are strong UV light absorbers. The energy of the absorbed UV photons is large enough to create free phenoxyl radicals. These free radicals react with oxygen to produce carbonyl chromophoric groups [2–8].

Within the cell structure, the middle lamella between two cell walls is mostly destroyed by light irradiation [9]. This degradation increases the roughness of the wood surface. Temiz et al. [10] and Nzokou et al. [11] examined the roughness change of preservative-treated and finished wood samples during periodic light irradiation and water spray. They reported a considerable increase of the surface roughness of the control (the unfinished and untreated samples) during photodegradation and water spray. Ozgenc et al. [12] also examined the protective effect of vegetable oil treatments and concluded that the roughening of oil-treated samples was significantly lower than those of untreated controls during photodegradation and water spray cycles.

The earlywood is more degradable by light radiation than the latewood [13]. This fact causes roughening that is clearly visible and differentiated on the surface of wooden construction, especially those being left outdoors for a long time such as that shown in Fig. 1. This photo taken in Japan shows the weathered cross section of a fence part that was left outdoors for approximately 500 years. The photo clearly shows the degradation difference between earlywood and latewood. The surface roughness of timber is an important parameter for further processing and it is sensitive to the modification processes [14–16]. Some authors also mentioned roughness change due to the alteration of light scattering on the irradiated surface [17–19]. Light scattering is wavenumber dependent. The baseline shift of the infrared (IR) reflectance spectrum is usually caused by such scattering. This problem can be minimized by baseline correction in spectroscopic practice.

The aim of this study was to find a simple optical method to monitor the roughness change of wood caused by photodegradation. The baseline shift increases during photodegradation due to light scattering. When this change is calculated, then the correlation between roughness change and the baseline shift can be determined.

2. Materials and methods

Samples of three hardwood and two softwood species were used for this study. The hardwood species were black locust (*Robinia pseudoacacia* L.), oak (*Quercus petraea* Liebl.), and poplar (*Populus*

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Fig. 1. The photodegraded cross section of an old temple fence part. (Myajima island, Japan).

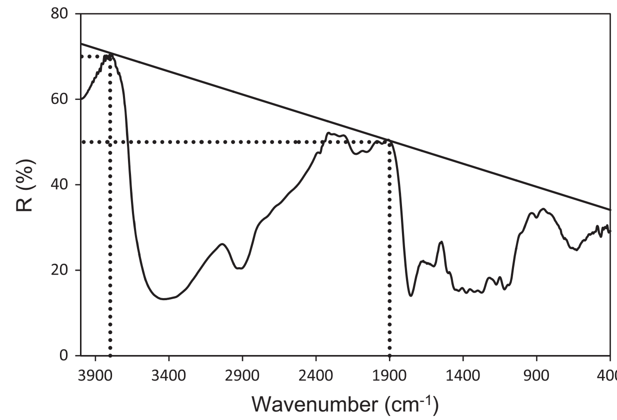

Fig. 2. The diffuse reflexion spectra of oak wood indicating the baseline shift.

tremula L.). The softwood species were Scots pine (*Pinus sylvestris* L.) and spruce (*Picea abies* Karst.). The dimensions of the samples for roughness measurement were 40 × 40 × 20 mm. Five replicates were prepared for all wood species selected. For the IR diffuse reflectance measurement, the sample dimensions were 40 × 10 × 2 mm and six replicates were prepared. It was necessary to prepare a different size for each of the two types of measurement because the spectrophotometer required thin samples while the perthometer needed thicker and wider samples to be able to fix these samples in the same position. The traditional roughness measurement was carried out using the perthometer on the radial surface of the sample along 10 parallel lines. The distance between the lines was 0.5 mm and the place of measured lines was always the same after each individual treatment period. The unfiltered P profile was computed from the traced profile (EN ISO 3274). The surface roughness parameters (P_z; P_t; P_a; P_{max}) can be applied also for this profile [20]. The roughness parameters were calculated by the Curve Cutter program from the unfiltered P profile.

A strong UV light emitter, mercury vapour lamp provided the light irradiation. The total electric power of the applied double mercury lamps was 800 W and the samples were located 64 cm from the lamp. An irradiation chamber set for 70 °C ensured ambient temperature conditions. The total irradiation time was 15 days in all cases. The irradiation was interrupted (two-day intervals were applied) for measuring the changes. After measuring the roughness and the IR spectra, the irradiated samples were soaked in distilled water for a day to imitate the leaching effect of the rain. One series of samples was not leached by water to determine the effect of UV radiation separately.

All the IR measurements were performed on the tangential surfaces of the specimens. The sample surface contained only one type of tissue which was either earlywood or latewood. The diffuse reflectance infrared Fourier transform (DRIFT) spectrum of the samples was measured before and after irradiation and also after water leaching. Measurements were carried out with an IR spectrophotometer (JASCO FT/IR 6300), applying a diffuse reflectance unit. The resolution was 4 cm^{-1} and 64 scans were obtained and averaged. The same area of the samples was always measured. The background spectrum was determined against an aluminium plate.

Wood had no absorption at 1900 and 3800 cm^{-1}. It meant the reflexion should be 100% at these places. But the reflexion was less than 100% because of the light scattering; this is called the baseline shift in IR spectroscopy (Fig. 2). Calculating the absorption spectrum, these reflexion values are lifted up to 100% (lifting up the whole spectrum) to eliminate the scattering effect. This is the baseline correction, which is regularly used in diffuse reflectance IR spectroscopy. The scattering depends on the roughness of the surface. It means the baseline shift gives information about the surface roughness. We gave the baseline shift as the quotient of two reflexion intensities.

$$\text{Baseline shift} = R(3800)/R(1900)$$

where $R(3800)$ is the reflection intensity at 3800 cm^{-1} and $R(1900)$ is the same at 1900 cm^{-1}. Applying this definition, the correlation between baseline shift and roughness was calculated.

3. Results and discussions

The roughness parameters were recorded after five days of UV light irradiation, which was followed by two-day intervals. There was a total of five irradiation periods. The samples were soaked in distilled water for a day after each irradiation period. The necessary parameters were measured right after subjecting the samples to light irradiation. The data presented below are the average of the five samples. The selected roughness parameters increased continuously during UV irradiation for all examined species. Figs. 3 and 4 show the results for black locust and spruce, representing the hardwoods and softwoods, respectively. The increase was linear for poplar, Scots pine and spruce. For black locust the increase was a little higher during the first 6 days compared to the later period.

Parallel with conventional roughness measurement, the IR reflexion spectra were also recorded. After calculating the baseline shift parameters (reflexion intensity at 3800 cm^{-1} divided by reflection intensity at 1900 cm^{-1}), the correlation between roughness and baseline shift was tested. The results are presented in Fig. 5 for black locust, Scots pine and spruce wood species. The

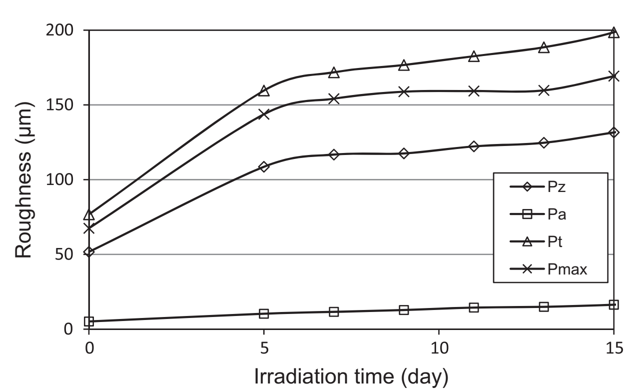

Fig. 3. Selected roughness parameters of treated (light and water) black locust wood, measured after light irradiation.