

FTIR and colour change of pine wood as a result of xenon irradiation

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Abstract: *FTIR and colour change of pine wood as a result of xenon irradiation.* The paper presents changes in colour and chemical composition of Scots pine wood surface, caused by exposure to UV-VIS light with a wavelength of 320-800 nm. Tested wood was exposed for 100 hours to a xenon lamp in order to simulate natural sunlight behind a window glass. Using the CIE Lab colour measuring system, wood surface discolouration was measured and ΔL^* , Δa^* , Δb^* and ΔE^* values were calculated. It was found that irradiation of pine wood caused its discolouration. Its surface grew darker and its colour became redder and yellower. It was found that the wood surface discolouration process was accompanied by slight changes in the structure of components found in subsurface layers, mainly lignin. The process of lignin degradation was accompanied by the formation of new carbonyl groups.

Keywords: color change, pine wood, xenon lamp irradiation, FTIR

INTRODUCTION

Wood colour naturally changes and the intensity of these changes depends not only on the wood species and its chemical composition, but also on the conditions, under which it is used and the method of its preservation. Sunlight is a significant factor causing wood discolouration (Papp et al. 2012, Teacă et al. 2013). As a result of light absorption reactions of degradation and autooxidation occur in certain compounds contained in wood.

Literature sources indicate that discolouration of wood is the effect of changes taking place both in major and extractive wood constituents. The most significant role is ascribed to lignin, which to the greatest extent absorbs ultraviolet radiation - at 80-95%. Lignin photooxidation mechanisms have been described in literature. Schaller and Rogez (2007) presented four mechanisms of the lignin photooxidation reaction:

- direct absorption of UV light by conjugated phenolic groups to form phenoxyl free-radicals,
- abstraction of phenolic hydrogen as a result of aromatic carbonyl triplet excitation to produce a ketyl and phenoxyl free-radical,
- cleavage of nonphenolic phenacyl- α -O-arylethers to phenacyl phenoxyl free-radical pairs,
- abstraction of benzylic hydrogen of the α -guaiacylglycerol- β -arylether group to form ketyl free-radicals, which then undergoes cleavage of the β -O-4 arylether bond to produce an enol and phenoxyl free-radical.

A much lesser absorption of UV radiation is found for carbohydrate components - at 5-20%, and extractives, at approx. 2%.

The aim of this study was to investigate resistance of pine wood to the effect of light emitted by a xenon lamp within the UV/VIS radiation range 320-800 nm and to determine changes in the chemical structure of wood, recorded by IR spectroscopy.

MATERIALS AND METHODS

The experimental material comprised wood of Scots pine (*Pinus Sylvestris* L.). Analyses were conducted on samples of 40 x 15 x 5 mm (± 1 mm) (long. x tang. x rad.). Sample surfaces were polished with sandpaper (400 P).

Chemical analysis of wood main components

Chemical analysis of pine included determination of extractive substances according to the T 204 cm-97 standard procedures (ethanol was used for extraction). For lignin quantification the T 222 cm-02 standard was used. Pentosans were determined according to the T 223 cm-01 standard procedure. Analysis of cellulose content was conducted according to Seifert (1956).

Light irradiation of samples and colour change assessment

After colour of control samples was measured, they were exposed to 100h irradiation in a SUNTEST CPS apparatus by Heraeus. The colour changes and colour coordinates of tested samples was recorded after 1, 5, 10, 25, 50 and 100 h in all cases. The light source for this study was Xenon light for interior applications (320-800 nm wavelength). The intensity of light projected onto the tested surfaces was 550 W/m², and the Black Panel temperature (BPT) was 38°C.

Colour of examined samples was measured before and after soaking in selected solutions and after 100-h irradiation using a Datacolor 600 spectrophotometer. Colour changes were analyzed based on the mathematical CIE Lab color space model developed by the International Commission on Illumination according to the following formula:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where: ΔE – color difference,

L^* – achromatic coordinate of colour (brightness). The values of the brightness coordinate L^* may range from 0 (black) to 100 (white).

a^* , b^* – chromatic coordinates of colour. The axis a^* corresponds to green ($-a$) and red ($+a$), while the axis b^* to blue ($-b$) and yellow ($+b$).

Analyses were conducted on three samples, on each of which three measurement points of 10 mm in diameter were marked.

Measurement of FT IRATR spectra

Control samples of pine and samples after 100h irradiation under a xenon lamp were analyzed using a Fourier transform attenuated total reflectance spectrometer Alpha produced by Bruker Optics GmbH. The spectral range measured was between 4000 cm⁻¹ and 600 cm⁻¹. The spectral resolution of the spectrophotometer was 4 cm⁻¹, each spectrum was computed as an average of 32 successive measurements in order to minimize the measurement error. Five measurements were performed on each sample.

RESULTS

Results of chemical analyses of pine wood are presented in Fig. 1. The content of lignin, a component exhibiting the greatest capacity to absorb natural sunlight, amounted to 29.66%. The content of extractive substances, i.e. compounds having a significant effect on wood colour, was 2.23%. The concentration of cellulose was detected at 47.69%, while that of pentosans was 11.89%.

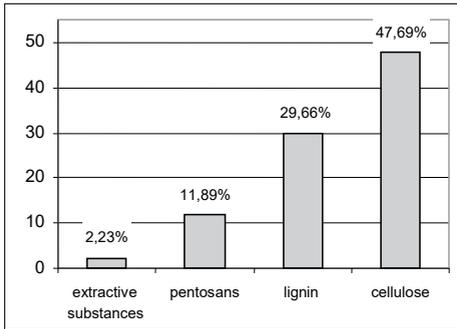


Fig. 1. Percentage contents of main components of pine wood

Values of colour changes (ΔE^*) and colour coordinates (ΔL^* , Δa^* , Δb^*) of pine wood after 100h irradiation under a xenon lamp, simulating solar radiation penetrating to interiors through a window pane, are presented in Fig. 2 .

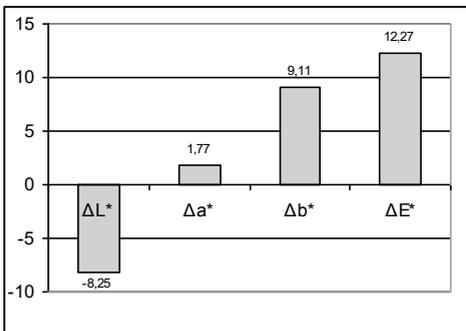


Fig. 2. Changes in colour and colour coordinates of pine wood after 100h irradiation under a xenon lamp (320-800 nm)

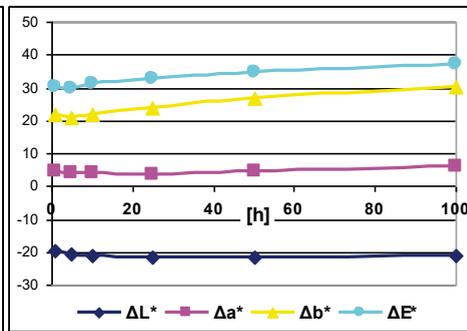


Fig. 3. Changes in colour and colour coordinates of pine wood after 1, 5, 10, 25, 50 and 100h irradiation under a xenon lamp (320-800 nm) (referred to the whiteness standard)

100h irradiation of pine wood samples caused a change in its colour (ΔE^*) by 12.27 units. The lightness parameter (ΔL^*) changed by 8.25 units. The recorded change in this parameter indicates that the surface of pine wood grew darker under the influence of UV/VIS light. The change in the value of the chromatic coordinate a^* shows that pine surface became redder and the change in the value of coordinate b^* indicates that the surface became yellower. When comparing values of changes recorded for chromatic coordinates a and b , amounting to 1.77 and 9.11 units, it may be stated that markedly greater changes in colour occurred towards the yellow rather than red colour.

Figure 3 presents changes in colour of pine wood, recorded after 1, 5, 10, 25, 50 and 100h irradiation. Changes in the lightness parameter (ΔL^*) indicate that the greatest changes took place in the first 25 h of irradiation (8.79 units). Further irradiation caused a slight decrease in the values of this parameter, up to 8.25 units after 100h irradiation. The value of parameter a^* within the first 25h irradiation was lower than that recorded for the control samples. After 50h irradiation an increase was found in the values of this parameter. Recorded changes show that within the first 25 hours of irradiation the surface of samples was less red and next it was becoming redder than that of the control samples. Changes in parameters ΔE^* and Δb^* during irradiation were similar. Their values during irradiation increased systematically.

Figure 4 presents FTIR ATR spectra of pine wood samples irradiated for 100 h and non-irradiated. Analyses of FTIR ATR spectra showed that they differ slightly.

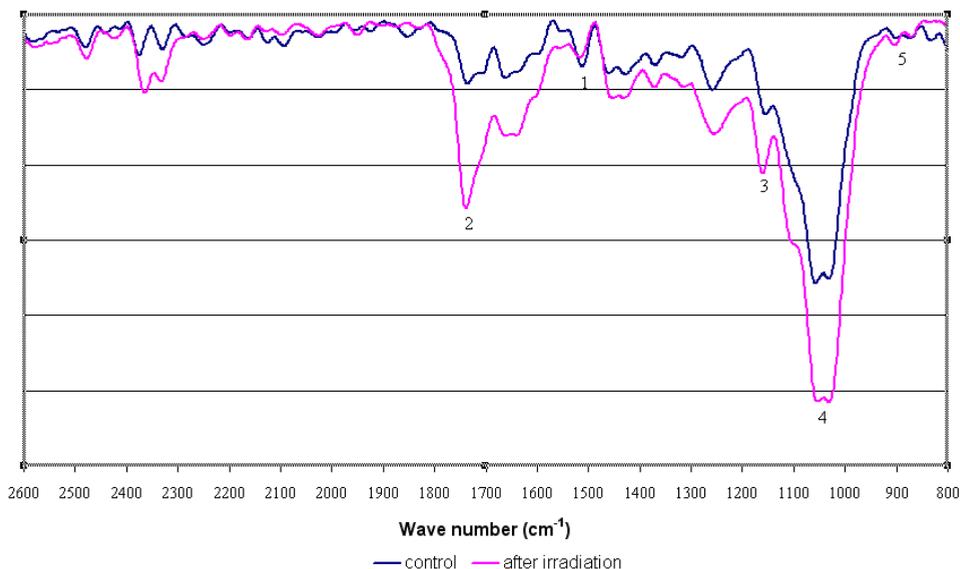


Fig. 4. FTIR ATR spectra of pine wood before and after 100h irradiation

The peak of absorption at 1512 cm^{-1} (1), originating from the vibration skeleton of the aromatic benzene ring is characteristic of lignin. A decrease in its intensity as a result of irradiation of pine samples indicates a certain degradation of lignin. The degradation of lignin was accompanied by a considerable increase in the peak intensity at 1735 cm^{-1} (2), which in turn indicates the formation of new, unconjugated carbonyl compounds as a result of irradiation. The increase of carbonyl absorbance with irradiation time in the wood sample was also presented in other studies (Wang and Ren 2008, Rosu et al. 2010). In the case of peaks at 1049 (4) and 898 cm^{-1} (5), connected with carbohydrate compounds, no changes were observed in their intensity. An exception in this respect was the peak at 1157 cm^{-1} (3), which intensity increased. When comparing the rate of formation for carbonyl compounds with the process of lignin degradation we may clearly see that the process of formation of new carbonyl compounds is faster than the degradation of lignin. It may be assumed that carbonyl compounds are formed not only as a result of oxidation of lignin, but also carbohydrate compounds. This is confirmed in literature data (Müller et al. 2003).

CONCLUDING REMARKS

Based on the conducted analyses the susceptibility of pine wood to the effect of a xenon lamp emitting radiation within the UV/VIS range (320-800 nm) was determined. It was found that as a result of irradiation pine wood became darker and underwent slight discoloration towards red colour and much greater towards yellow.

Moreover, based on the conducted analyses of FTIR ATR spectra it was stated that the process of discoloration is accompanied by slight changes in the structure of components found in pine wood. This confirmed literature reports concerning sensitivity of lignin to

photodegradation. The process of lignin photodegradation was accompanied by the formation of new carbonyl groups (at the 1735 cm^{-1} band (2)).

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Streszczenie: *FTIR i zmiana barwy drewna sosny podczas naświetlania lampą ksenonową.* W pracy przedstawiono zmiany w zabarwieniu i składzie chemicznym powierzchni drewna sosny zwyczajnej, spowodowane ekspozycją światła UV/VIS o długości fali 320-800 nm. Badane drewno zostało poddane 100h naświetlaniu lampą ksenonową emitującą naturalne światło słoneczne przenikające do pomieszczeń przez szybę okienną. Analizę zmiany barwy wykonano na podstawie matematycznego modelu przestrzeni barw CIE L^*a^*b , opracowanego przez Międzynarodową Komisję Oświetleniową. Stwierdzono, że w wyniku naświetlania drewno sosny uległo przebarwieniu. Jego powierzchnia ściemniała a barwa stała się bardziej czerwona i żółta. Stwierdzono, że procesowi przebarwienia się powierzchni drewna towarzyszyły nieznaczne zmiany w strukturze składników występujących w warstwach przypowierzchniowych, głównie ligniny. Procesowi degradacji ligniny towarzyszyło powstawanie nowych grup karbonylowych.

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