

## **WOOD SURFACE DISCOLOURATION OF THREE HUNGARIAN HARDWOOD SPECIES DUE TO SIMULATED INDOOR SUNLIGHT EXPOSURE**

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### **ABSTRACT**

Colour changes of wood caused by sunlight exposure in indoor applications are a major down-grading factor and have a substantial economical impact on high valuable wood products. In this study, the most traded wood species in Hungary, two hybrid poplars, namely Poplar I 214 and Poplar Pannonia, and Robinia were exposed to simulated indoor sunlight irradiation and the wood surface discolouration was analysed. The samples were exposed for a maximum irradiation time of 96 hours to a xenon-arc lamp equipped with a 3 mm window glass filter in order to simulate natural sunlight behind a window glass. Colour measurements were performed by means of a colorimetric device. Using CIE-L\*a\*b\* colour measuring system wood surface discolouration was measured and calculated according to  $\Delta L^*$ ,  $\Delta a^*$ ,  $\Delta b^*$  and  $\Delta E^*$  values. An impression of the different behaviour of these wood species and how they relate to each other is now given.

**KEYWORDS:** poplar I 214, poplar Pannonia and Robinia, simulated indoor irradiation, xenon-arc lamp, window glass filter, colour changes, surface discolouration

### **INTRODUCTION**

At the beginning of the 20<sup>th</sup> century, due to the increasing demand for the light and homogeneous woods, efforts were initiated to breed improved varieties of wood species. Thus,

several poplar hybrids were bred according to the market demands, the two hybrid poplars investigated being some of the most important. Currently, I 214 poplar (*Populus x Euramericana I 214*) and Pannonia poplar (*Populus x Euramericana Pannonia*) are some of the most prevalent poplar hybrids in Europe. Their growing rates are extremely fast and currently occupy the largest areas in Hungary among the poplars, with an area of 1.5 million ha (9.6 % of the total forest area) and yield 1.3-1.5 million m<sup>3</sup> of wood annually (23-25 % of the total harvest) (Molnár and Bariska 2002). Another wood species, which plays an important role in the Hungarian forest management, is Black locust (*Robinia pseudoacacia L.*), which covers approximately 23 % of the forested area and provides about 19 % of the annual timber output of the country (Rédei et al. 2008). Due to its rapid growth rate (Chow et al. 1996), easy regeneration, and favourable wood qualities black locust is considered a valuable species across the majority of cultivated range (Stringer and Olson 1987).

An important issue in the woodworking area still remains to be the colour information of the wood surfaces. Compared to the physical, mechanical and chemical properties of wood, the colour and other visual properties are not so systematically known (Katuščák and Kučera 2000). The colour of wood surfaces differs with and within the wood species (Hon and Shiraishi 2001) and together with the structural texture represents the aesthetic value of wood (Straže et al. 2008). According to Hon and Shiraishi (2001), wood colour may range from almost white, as in the sapwood of many species, to almost black, as in the heartwood of black ebony. Even though the natural variation of wood colour surfaces and wood structure is most of the times appreciated, processing steps such as steaming (Tolvaj et al. 2000, Németh et al. 2007, Straže et al. 2008, Tolvaj and Németh 2008), drying and heat treatments (Kretschmann et al. 1999, Kärki 2002, Stenudd 2004, Keey 2005) can positively change the colour of wood.

It is generally known that ultraviolet light is one of the most effective environmental factors which cause severe changes in wood surface discolouration (Browne and Simonson 1957, Tolvaj and Faix 1995, Tolvaj and Mitsui 2005) besides moisture, temperature, oxygen and air pollutants (Hon and Chang 1982). Wood discolouration is considered a superficial phenomenon due to the fact that UV radiation cannot penetrate very deeply into the wood. However, the penetration of light into wood was pointed out to be correlated to its wavelength (Kataoka et al. 2007).

The light-induced degradation of wood was usually investigated under artificial conditions, due to the fact that constant conditions are provided during exposure and less duration time are needed, when compared to natural indoor sunlight exposure. However, only few studies are available regarding indoor exposure (behind a window glass) of wood surfaces to simulated sunlight (Chang and Chang 2001, Wu et al. 2002, Oltean et al. 2008).

The present research work tries to provide information concerning the surface discolouration of the most used hardwood species in Hungary exposed to simulated indoor sunlight. Detailed information according to CIE-L\*a\*b\* colour values was provided after 12 hours and 96 hours of irradiation, according to the overall discolouration  $\Delta E^*$ , but also according to  $\Delta L^*$ ,  $\Delta a^*$ , and  $\Delta b^*$  values. In this study, an attempt was made to provide information about the different behaviour of these wood species and how they relate to each other.

## MATERIAL AND METHODS

### Material Preparation of the Samples

Three wood species, two hybrid poplars, poplar I 214 (*Populus x euramericana I 214*), poplar Pannonia (*Populus x euramericana Pannonia*) and Robinia (*Robinia pseudoacacia*) were selected

from the most used species in Hungary. In the case of the two hybrid poplar species, heartwood as well as sapwood was investigated. Fresh boards were selected from the specified trees and cut over 1.3 m above ground. The boards were conventionally kiln dried at 45 °C and 73 % relative humidity, until they reached 12 % moisture content. From the dried boards free of defects samples were prepared with the dimensions of 60 mm x 60 mm x 10 mm. The number of samples used is given in Tab. 1. The surface was sanded with a sanding grid paper of 150. In the case of Robinia and the sapwood of both poplar hybrid species, the colour measurements were performed on the radial surface (45 ° inclined on the standing annual rings). In the case of the heartwood of the poplar species, the colour measurements were performed on the tangential surface. All specimens were conditioned in a climate chamber at 20 °C and 65 % RH to constant weight.

Tab. 1: Number of samples of specified Hungarian hardwood species used for the simulated indoor sunlight exposure

Wood species	Botanical name	No of samples	
		Sapwood	Heartwood
Poplar Pannonia	<i>Populus x euramericana Pannonia</i>	5	5
Poplar I 214	<i>Populus x euramericana I 214</i>	5	5
Robinia	<i>Robinia pseudoacacia</i>	5 <sup>1)</sup>	

1) as a mixture of heartwood and sapwood

## Light irradiation

In this study, the samples of the three Hungarian wood species were exposed to simulated indoor sunlight for 96 hours, according to ÖNORM EN ISO 11341 (1994). In these experiments a SUNTESTER CPS (Heraeus Instruments Hanau Germany) was used, and the irradiation light source was a xenon-arc lamp equipped with a window glass filter. In order to properly simulate indoor sunlight, a 3 mm window glass filter was used, which eliminates wavelengths shorter than 320 nm. The samples were exposed to a maximum radiation intensity of 765 W.m<sup>-2</sup> resulting in a wood sample surface temperature of approximately 45 °C (black panel temperature), according to the manufacturer specifications (ATLAS Material Testing Solutions, Linsengericht Germany, www.atlasmtt.com).

## Colour measurements

Colour measurements were performed using a colorimetric device Chroma Meter CR-410 (Konica Minolta, Tokyo, Japan), with a measuring diameter of 50 mm. The samples were exposed for 96 hours of simulated indoor sunlight, and colour measurements were performed at several steps of irradiation, namely, 30, 60, 90, 120 minutes and 3, 6, 9, 12, 24, 48, 72 and 96 hours, the latest being the maximum period of light irradiation. In order to have the same surface initial conditions of the samples (i.e. constant surface temperature but no light irradiation), all samples were covered with aluminium foil and exposed to simulated indoor sunlight for 20 hours, after which the colour was measured. This step was considered as a control for the colour measurements. Thereupon, the samples were exposed continuously to simulated indoor sunlight for 96 hours, and at the specified steps colour measurements were performed on the wood surfaces. Following the CIE-L\*a\*b\* colour measuring system, based on D65 light source (according to CIE Commission Internationale de l'Eclairage), L\*, a\* and b\* parameters were measured and ΔE\* calculated.

In the CIE-L\*a\*b\* system, the L\* axis represents the lightness (which can vary from 100 for white and 0 for black), and a\* and b\* are the chromaticity coordinates (+a\* is for red, -a\* for green, +b\* for yellow, -b\* for blue). L\*, a\* and b\* values are used to calculate the overall colour changes of the wood surface using the following formula (1):

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

where  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  are the differences between coordinates values of exposed and unexposed (control samples which were initially covered with aluminium foil) areas of L\*, a\* and b\*, respectively. A low  $\Delta E^*$  corresponds to a low colour difference. The colour measurements were always performed immediately after the irradiation step in order to provide consistent conditions of the samples.

## RESULTS AND DISCUSSION

During the first 12 hours of exposure to simulated indoor sunlight, a rapid colour change was observed for all wood species investigated (Fig. 1), continuing to increase up to 72 hours, reaching almost plateau after 96 hours of irradiation. However, Robinia showed the highest colour changes in the first 12 hours of exposure, with continuous somewhat less but consistent changes up to 96 hours. Similar trends in colour changes were observed for both, the heartwood and sapwood parts of the two poplar hybrids investigated, Poplar I 214 and Poplar Pannonia. However, higher values in the overall discolouration ( $\Delta E^*$  values) were recorded for the sapwood samples of both wood species during the whole period of time of simulated indoor sunlight exposure, when compared to the heartwood samples.

Regarding the correlation between the natural sunlight exposures and the simulated UV light exposure there are different statements reported in the literature (Chang and Chang 2001, Wu et al. 2002, ToLvaj and Mitsui 2005). However, due to different parameters, such as wood species tested, duration of irradiation, type of lamp used with or without the filter, the results were difficult to compare, thus a more general comparative analysis was desirable. Tolvaj and Mitsui (2005) reported that in the case of simulated irradiation by means of a suntester equipped with a xenon lamp and quartz glass filter has an accelerating effect about three times higher compared to outdoor sunlight exposure, without water spraying. According to ATLAS Material Testing Solutions (Linsengericht Germany), with the device and settings used, accelerated exposure for 26 days is equivalent to one year of exposure to natural light behind a window glass in Central Europe.

In this study it could be observed that for the wood species tested under the same conditions, the trends of overall discolouration ( $\Delta E^*$ ) with time (Fig. 1) almost reached plateau after 96 hours of exposure. Similar results were recorded in a previous study (Oltean et al. 2008), where Robinia and Black poplar (*Populus nigra*) wood species were exposed to simulated indoor sunlight with similar experimental design (same type of lamp and window glass filter used). A similar trend of discolouration was recorded, with a fast initial increase in colour changes in the first 24 hours of exposure, Robinia showing a higher discolouration when compared to Black poplar wood species, while after a longer exposure time an almost plateau was reached. At the intermediary step of 72 hours, the overall colour changes recorded were of about  $\Delta E^* = 13.06$  for Robinia and  $\Delta E^* = 6.30$  for Black poplar, respectively (Oltean et al. 2008). These values are higher when compared to the current data values, at the intermediary

step of 72 hours. These values are  $\Delta E^* = 17.17$  for Robinia, for the heartwood and sapwood of poplar I 214  $\Delta E^* = 10.93$  and  $\Delta E^* = 18.11$ , respectively, while for the heartwood and sapwood of poplar Pannonia the values were  $\Delta E^* = 12.32$  and  $\Delta E^* = 18.77$ , respectively. This might be explained by the difference in the control samples consideration. In the previous research work, half of the sample areas were covered with aluminium foil and colour measurements were performed on both wood surface areas. The differences in colour coordinates were calculated as the differences between the exposed and non-exposed (covered) areas of the samples. Another explanation might be the differences between and within the wood species investigated.

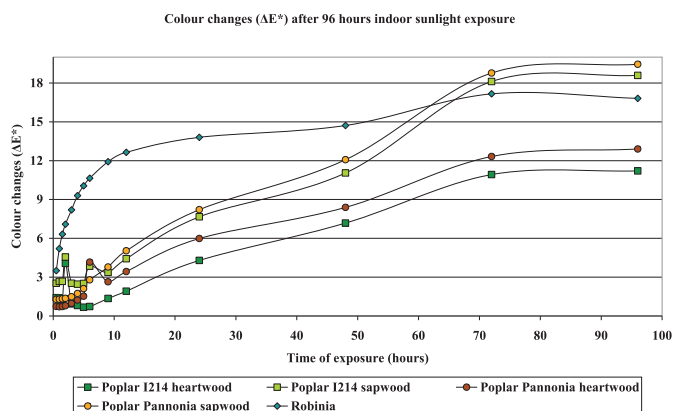


Fig. 1: Colour changes ( $\Delta E^*$ ) of Hungarian hardwood species due to simulated indoor sunlight exposure for 96 hours, mean values of 5 measurements

After 12 hours of irradiation, the limits of overall discolouration were recorded for the heartwood of poplar I 214 ( $\Delta E^* = 1.92$ ) as a minimum value and for Robinia ( $\Delta E^* = 12.64$ ) as a maximum value, respectively. However, after a further exposure up to 96 hours of simulated indoor sunlight exposure, the limits of total colour changes were recorded in the range of minimum of  $\Delta E^* = 11.21$  for the heartwood of poplar I 214 and maximum of  $\Delta E^* = 19.44$  for the sapwood of poplar Pannonia (Fig. 2). After 96 hours of exposure, the highest discolouration values were recorded for the sapwood of both poplar species, followed by Robinia wood species with an overall colour change of  $\Delta E^* = 16.81$ .

When comparing the intermediary steps of 12 hours of simulated indoor sunlight irradiation with the final step of exposure of 96 hours, a substantial increase in the overall discolouration was recorded for all wood species investigated. The highest values were recorded for the sapwood of both poplar hybrid species (for poplar I 214  $\Delta E^*_{96h} - \Delta E^*_{12h} = 14.17$  and poplar Pannonia  $\Delta E^*_{96h} - \Delta E^*_{12h} = 14.40$ ) followed by their heartwood parts (for poplar I 214  $\Delta E^*_{96h} - \Delta E^*_{12h} = 9.29$  and poplar Pannonia  $\Delta E^*_{96h} - \Delta E^*_{12h} = 9.47$ ), while the minimum value was recorded for Robinia wood species of approximately  $\Delta E^*_{96h} - \Delta E^*_{12h} = 4.17$ .

Due to the fact that the total colour changes recorded were higher than  $\Delta E^* = 3$ , which is considered as the limit of colour changes detectable by the human eye (Hon and Shiraishi 2001), as for the 12 hours step exposure as well as for the final step of 96 hours exposure, it can be stated that consistent and visible with the naked eye discolouration occurred for all wood species investigated.

According to  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  values (Fig. 2 and Fig. 3), after 96 hours of simulated indoor sunlight exposure, all wood species showed darkening (negative  $\Delta L^*$  values), a reddish behaviour (positive  $\Delta a^*$  values), and a yellowing behaviour (positive  $\Delta b^*$  values). The limits of the colour coordinates differences  $\Delta L^*$  after 96 hours of irradiation, were recorded for the heartwood of poplar Pannonia ( $\Delta L^*=-4.32$  as a minimum value) and for Robinia ( $\Delta L^*=-15.38$  as a maximum value, respectively).

In the case of  $\Delta a^*$  and  $\Delta b^*$  values, the minimum and maximum limits were recorded for the heartwood of poplar Pannonia ( $\Delta a^*=2.53$ ) and Robinia ( $\Delta a^*=6.58$ ) for the reddish behaviour of discolouration, while for the yellowish behaviour, Robinia ( $\Delta b^*=1.03$ ) and the sapwood of poplar Pannonia ( $\Delta b^*=15.50$ ) were recorded, respectively.

During the 96 hours of exposure, some of the wood species investigated changed their behaviour regarding  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  values. According to  $\Delta L^*$  values, a slight darkening was observed after 12 hours of irradiation for the heartwood samples of both poplar hybrids, poplar I 214 and poplar Pannonia, after which all wood species showed a darkening behaviour up to almost plateau reached after 96 hours of irradiation. In the case of  $\Delta a^*$  values, the poplar hybrids (sapwood and heartwood samples) showed a slight initial greenish behaviour in the first hours of irradiation, after which they showed a reddish behaviour. After 12 hours of simulated indoor sunlight exposure, only the heartwoods of both poplar hybrids were still presenting an almost undetectable greenish behaviour. The exception was recorded for Robinia which showed a reddish behaviour during the whole period of irradiation. According to  $\Delta b^*$  values, a slightly bluish behaviour was recorded for all wood species in the first hours of irradiation, while after 9 hours of simulated indoor sunlight exposure all wood species investigated presented a yellowish behaviour.

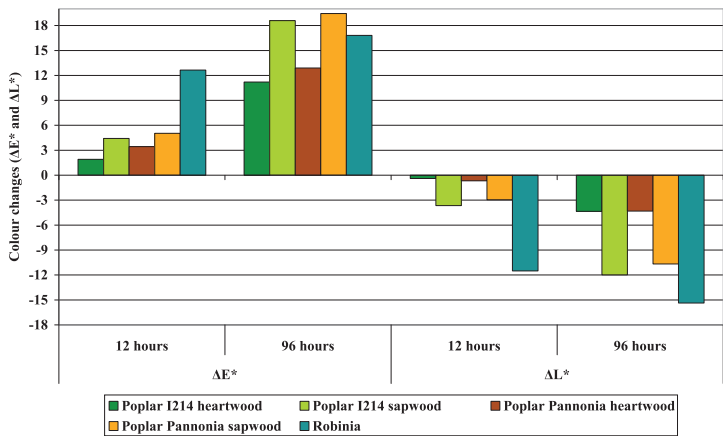


Fig. 2:  $\Delta E^*$  and  $\Delta L^*$  values after 12 hours and 96 hours of simulated indoor sunlight exposure

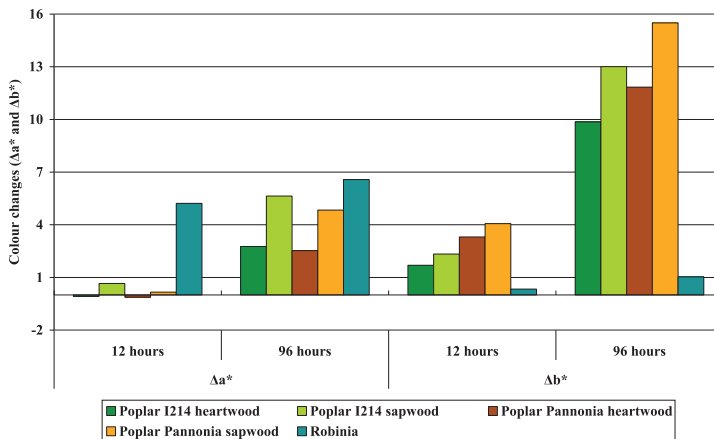


Fig. 3:  $\Delta a^*$  and  $\Delta b^*$  values after 12 hours and 96 hours of simulated indoor sunlight exposure

## CONCLUSIONS

For wood used in indoor applications, one of the most important criteria of wood utilization is its visual appearance. Colour and colour stability are the main features of this appearance. In this study, a trend of discolouration could be observed for some of the most used hardwood species in Hungary, tested according to the overall changes in colour ( $\Delta E^*$ ), after 96 hours of simulated indoor sunlight exposure.

Similar trends in overall colour changes ( $\Delta E^*$ ) could be observed for the hardwood species investigated due to simulated indoor sunlight exposure for a maximum period of exposure of 96 hours of exposure, with a fast initial discolouration recorded in the first 12 hours of exposure, continuing to increase with time, reaching almost plateau after 96 hours of exposure. However, the sapwood samples of both poplar hybrids (poplar I 214 and poplar Pannonia) showed higher overall discolouration values ( $\Delta E^*$ ) as well as higher values of colour coordinates differences values ( $\Delta L^*$ ,  $\Delta a^*$ ,  $\Delta b^*$ ) when compared to the heartwood samples.

After 96 hours of simulated indoor sunlight exposure, the smallest and greatest values of discolouration were recorded for the heartwood of poplar I 214 and for the sapwood of poplar Pannonia.

When comparing the intermediary steps of 12 hours of simulated indoor sunlight irradiation with the final step of exposure of 96 hours, a substantial increase in the overall discolouration ( $\Delta E^*$ ) was recorded for all wood species investigated. During the 96 hours of exposure, some of the wood species investigated changed their behaviour regarding  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  values.

The results of this research work could provide a first general idea of how the Hungarian wood species investigated behave regarding the wood surface discolouration due to their exposure to simulated indoor sunlight. Longer exposure duration times or a greater amount of samples might provide more detailed information. However, in this study, an overview is presented of how the most important wood species in Hungary exposed at one time to simulated indoor sunlight irradiation, discolours in time. The trend of overall discolouration and the different behaviour of these species after 12 hours and 96 hours of exposure time, according to CIE- $L^*a^*b^*$  colour system was given.

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