The Effect of Moisture Content and Drying Temperature on the Colour of Two Poplars and Robinia Wood

Róbert Németh,[a,]* Ágota Ott,[b] Péter Takáts,[b] and Miklós Bak [a]

The colour change of wood has been the topic of numerous research activities worldwide. This study investigates the colour change of Robinia (*Robinia pseudoacacia* L.) and two hybrid poplars, namely Pannónia poplar (*Populus x euramericana* cv. Pannónia) and I-214 poplar (*Populus x euramericana* cv. I-214). The sapwood and heartwood were investigated separately for each of the poplars. The heartwood of Robinia was also investigated. The timbers were dried in a climate chamber at four different temperatures (20 °C, 40 °C, 60 °C, and 80 °C), as the relative humidity was reduced in 5 steps (95%, 80%, 65%, 40%, and 20%) at each temperature. The colour co-ordinates L^*, a^*, and b^* were measured according to the CIELab system. Differences in terms of colour change between wood species and sapwood versus heartwood are discussed in the paper. The effect of wood moisture content and heat on the colour co-ordinates is provided. The colour of Robinia is more sensitive to heat than poplar.

Keywords: Wood; Poplar; Robinia; Moisture; Colour; Drying

*Contact information: a: Institute of Wood Science, Faculty of Wood Sciences, University of West Hungary, 4 Bajcsy-Zsilinszky, H-9400 Sopron, Hungary; b: Institute of Wood and Paper Technology, Faculty of Wood Sciences, University of West Hungary, 4 Bajcsy-Zsilinszky, H-9400 Sopron, Hungary; * Corresponding author: nemethr@fmk.nyme.hu*

INTRODUCTION

Robinia is a dominant species in Hungarian plantation forestry and in the wood working industry (Molnár and Bariska 2002). The frequent use and importance of Robinia has spawned several studies performed around the world, dealing with the anatomical, physical, and chemical properties (Adamopoulos and Voulgaridis 2002; Adamopoulos *et al.* 2005; Oltean *et al.* 2008). Despite the usefulness of Robinia, its wood possesses an unattractive greenish-yellowish colour. However, the colour can be changed through steaming the wood (Varga and van der Zee 2008; Tolvaj *et al*. 2010). The effect of moisture content and drying temperature on the colour co-ordinates of Robinia wood had not yet been investigated. The utilisation of poplars is limited by the low natural durability and the moderate to low mechanical characteristics of the species. Recently, the wood of poplars has been widely used in the panel industry. It is also used in the furniture industry because of its light colour (Zhou 1989; Vassiliou 1996; De Boever *et al*. 2007; Alpár and Rácz 2009; Katona 2011).

The effect of elevated drying temperature on different physical properties of poplar has been published (Christiansen 1994), and a more recent published study has focused on the enhancement of colour and hydrophobicity of Pannónia poplar at high temperatures (Németh *et al*. 2009a). There is a lack of information in the literature that addresses the effect of lower temperatures and the moisture content on the colour of poplars.

Colour is an important property of wood and wood products, so it is necessary to know to what extent the color is influenced by the drying parameters. Discolouration of different wood species is diverse, but discolouration of hardwood species is considerable (Ward and Simpson 1997). Various conditions of exposure can affect discolouration of wood. Discolouration of the surface is often caused by hydrolysis and oxidation of wood components (Thompson *et al*. 2005). It is possible to limit oxidation with vacuum drying, but this technology has industrial limitations (*e.g*. dimension of the wood dried) (Sandoval-Torres *et al*. 2012). Discolouration in tannin-containing wood species (*e.g*. oak) can occur by metal-tannin reactions, which mainly causes darkening (Koch and Skarvelis 2002). According to a study (Stich and Ebermann 1987) involving oak heartwood, enzymatic activities of peroxydases and polyphenoloxydases could be responsible for discolouration under moist conditions. The colour is determined by the extractive content. The heartwood of the hardwoods generally shows higher discolouration compared with the sapwood. This property is attributed to the higher extractive content. Extractives are sensitive to heat and light; thus the colour change of heartwood is higher under drying conditions (Pandey 2005). An efficient method to decrease the colour difference between heartwood and sapwood involves steaming between 80 and 120 °C. Colour homogenization of hardwood species (*e.g*. red hearted beech, Robinia) is of great importance regarding their utilization (Tolvaj and Molnár 2006).

Colour change of wood during drying is dependent on the drying schedules and the climatic conditions (Tenorio *et al*. 2012), as well as on the provenance of wood (Luostarinen and Heikkonen 2010). The major colour changes during drying occur during the diffusive drying phase (between 20 and 30% moisture content). During the capillary drying phase (moisture content below 55 %), time is more important than temperature in terms of colour change (Stenudd 2004).

The main goal of this research was to investigate the effect of different drying temperatures and moisture content on the colour co-ordinates of Robinia heartwood (the sapwood of Robinia was very narrow and was thus neglected for this study) and Pannónia poplar and I-214 poplar sapwood and heartwood.

EXPERIMENTAL

Freshly cut Robinia and poplar logs were purchased at the Forestry District in Kapuvár (Hungary). Sampled tree age was 20 years for both poplars and Robinia. The logs were cut into boards, subsequently packed in foil and kept in a refrigerator to protect them against moisture loss and fungal attack. Five different types of wood material were tested: Robinia heartwood, Pannónia poplar sapwood and coloured heartwood, and I-214 poplar sapwood and coloured heartwood. Samples for colour and sorption (MC/EMC) measurements were prepared with different physical dimensions and amounts for each measurement. Six samples from each material type with dimensions of 5 mm thickness and a 45 mm x 120 mm planed surface served for colour measurements at all investigated temperatures (4 temperatures × 5 different wood material type × 6 pieces = 120 samples total). The equilibrium moisture content was determined with 20 samples of each material with dimensions of 20 mm x 20 mm x 5 mm. The colour co-ordinates of lightness (L^*), red hue (a^*), and yellow hue (b^*) were determined using a Konica Minolta 2600D device (D65 light source, 10° angle).

In order to avoid contamination of the poplars' wood surfaces by VOCs (Volatile Organic Compounds) evaporating from Robinia wood, the Robinia samples were treated (dried) separately, but in the same way. The test samples (poplar heartwood and sapwood, Robinia heartwood) with freshly cut moisture contents were put into a climate chamber (Binder KBF 115) where the temperature was kept constant (±1°C) and the relative humidity was reduced stepwise from 95% to 20% (±1.5%). Temperatures were: 20 °C, 40 °C, 60 °C, and 80 °C. Relative humidity steps were: 95%, 80%, 65%, 40%, and 20%. Drying schedules were the same at all temperatures. Colour measurements were performed at the beginning of the drying (in green condition) and at the end of every relative humidity content step (green condition, 95%, 80%, 65%, 40%, and 20% relative humidity). The colour of every sample was measured at six points, after which the colour data were averaged. Thus, the colour variation within a tree was taken into consideration, but the within-stand variation was not. After reaching equilibrium (72 h) at the last relative humidity step (20%), the samples were dried at 103±2 °C until mass was constant. According to our preliminary experiments, 72 h was enough to reach EMC for both the colour measurement and sorption samples. The treatments (drying schedules) are shown in Fig. 1.

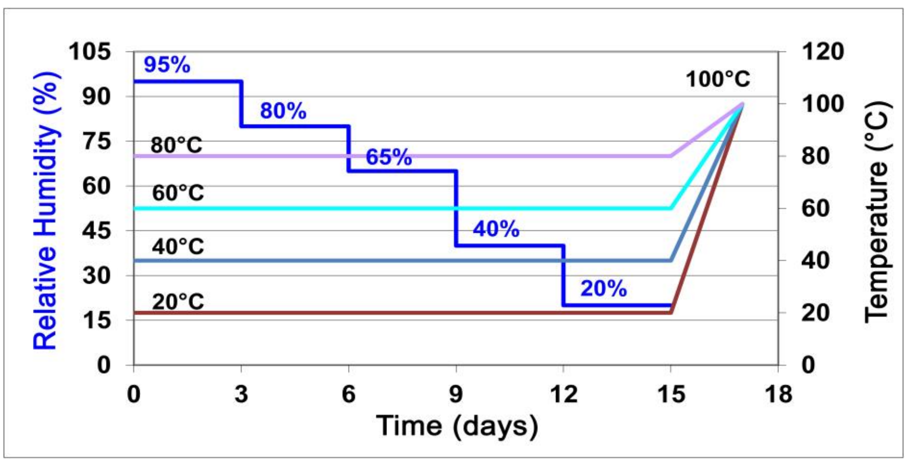

Fig. 1. Treatment / Drying schedules

RESULTS AND DISCUSSION

Colour Change of Robinia

The colour change of Robinia is shown in Figs. 2 to 4. The lightness values started at different levels, as there was natural colour variability within the tree. The moisture content of wood decreased gradually. Moisture change of Robinia was low compared to poplars, because green moisture content of Robinia is only about 30 to 40% (Simpson and Wolde 1999). The sections with an interrupted line at the right and left side of the curves represent the non-equilibrium moisture state of the wood. Sections with an interrupted line at the left side represent the phase from green state to first EMC state (at 95% RH by different temperatures). Sections with an interrupted line at the right side represent the phase from the last EMC state (at 20% RH by different temperatures) to absolute dry state of the wood. These are drying phases where the wood moisture is continuously changing and does not have the EMC belonging to the actual climatic conditions. Wood samples only had EMC at continuous lines in the curves. The decrease of lightness values was influenced by the moisture content at higher drying temperatures (60 °C and 80 °C) with lightness values of 7.45% and 20.65%, respectively. Lower temperatures caused only a slight lightness change. As a consequence, drying the samples in an oven at 103 °C decreased the lightness of the wood significantly.

Red hue and yellow hue values of Robinia heartwood responded differently. The red hue was influenced by the higher drying temperatures (60 °C and 80 °C) only. The red hue values increased by 18.22% and 128.57%, respectively. Also the values of the yellow hue changed at higher temperatures (60 °C and 80 °C) only. The yellow hue values decreased by 33.26% and 18.34%, respectively. If the temperature was kept below 40 °C, then the colour co-ordinates (L^*, a^*, b^*) were not influenced by moisture content below the fibre saturation point (FSP). Furthermore, the moisture loss from green state below the fibre saturation point resulted in increased lightness at 20 °C and 40 °C. Thus, if the temperature was kept below 40 °C, the lightness increased because of the evaporation of free water from the cell lumens and the change of the refraction coefficient (Németh 1998). The opposite tendency can be observed by the red hue values in the case of Robinia (Fig. 3), as the a^* values increased as the wood was dried from a fresh state to below the FSP. The yellow hue (Fig. 4) of Robinia wood changed with the initial moisture reduction at all investigated temperatures. The FSP for Robinia and poplar wood at different temperatures was reported earlier (Németh *et al*. 2009b).

Colour change of Robinia wood during steaming in the temperature range of 75 °C to 135 °C was investigated in an earlier study (Tolvaj et al. 2010). Comparing our findings with previous data, it can be concluded that a four day long steaming process at 80 °C caused the same lightness change ($\Delta L = 12$) as the drying process to 8% moisture content during six days. This six-day period consisted of two drying steps: three days at 95% relative humidity and an additional three days at 80% relative humidity. Larger samples (such as boards) would reach equilibrium moisture content slower in a drying chamber. Thus, the steaming period would last longer, presumably resulting in more pronounced colour change.

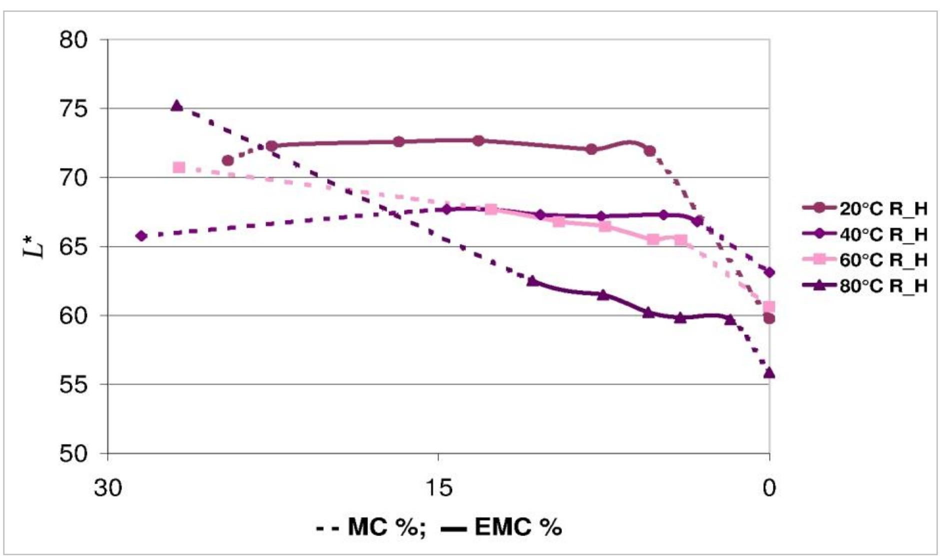

Fig. 2. Change of lightness values by Robinia heartwood (R_H) at different drying temperatures and moisture contents (not equilibrating moisture states are indicated with interrupted lines)

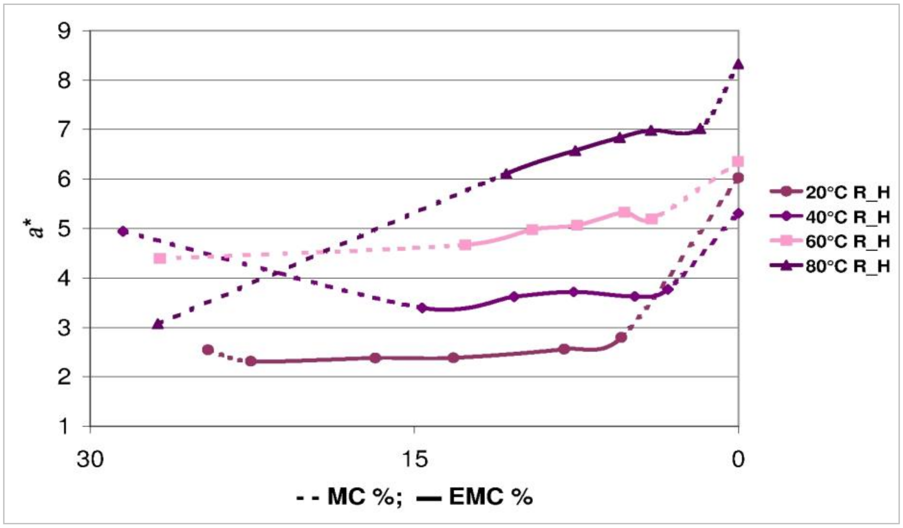

Fig. 3. Change of red hue values by Robinia heartwood (R_H) at different drying temperatures and moisture contents (not equilibrating moisture states are indicated with interrupted lines)

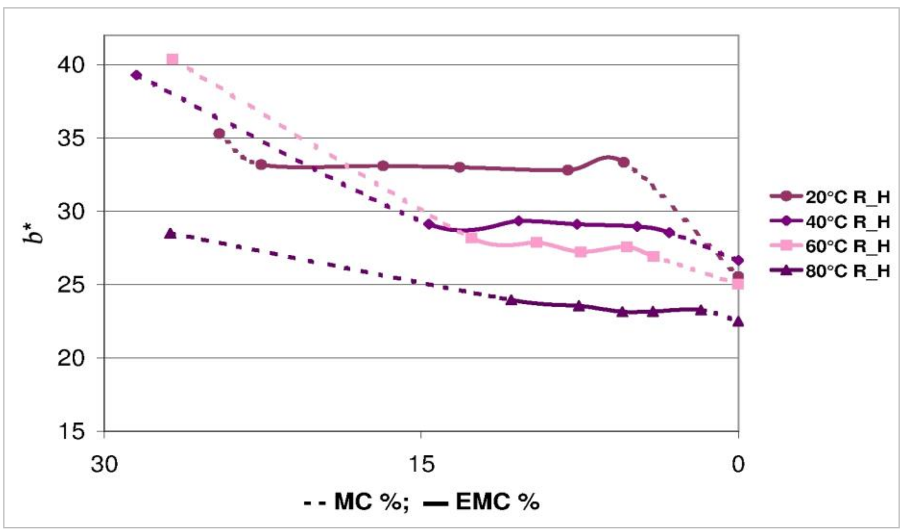

Fig. 4. Change of yellow hue values by Robinia heartwood (R_H) at different drying temperatures and moisture contents (not equilibrating moisture states are indicated with interrupted lines)

Colour Change of Poplars

The colour change of I-214 poplar sapwood and heartwood is shown in Figs. 5 to 7. The other investigated poplar (Pannónia Poplar) showed similar results, so only the I-214 results will be discussed. The initial moisture content of heartwood started from the range between 213 and 254% (dry mass based), while the sapwood started from between 88 and 100%.

The initial lightness values in green conditions started at different levels (Fig. 5), as there was natural colour variability observed within the tree. The moisture content of the wood decreased rapidly, as the samples reaching EMC values were lower than the FSP during the first 72 h of drying. The lightness values increased with decreasing moisture content from the fresh state to FSP at all temperatures for heartwood, while sapwood remained unchanged or there was only a very slight change. For example, at 40 °C the heartwood showed a 13% lightness increase, while the sapwood's L^* value remained unchanged (0.2% decrease). This discrepant behavior can be explained by the darker colour of the heartwood, which is caused by the higher extractive content. The heartwood of the hardwoods generally showed higher discolouration compared with the sapwood, because extractives are sensitive to heat and light (Pandey 2005). The temperature influences the lightness only at 80 °C, thus the lightness of poplar is more stable against heat compared to Robinia, where 60 °C resulted in significant decrease of lightness values. This is valid for the poplar's coloured heartwood as well; thus the chromophore groups of Robinia are more sensitive to heat (Tolvaj *et al.* 2012).

Figure 6 shows the red hue values for poplar sapwood and heartwood. The red colour co-ordinate of heartwood was higher compared to the a^* value of sapwood. During drying, the red hue values changed with decreasing moisture content. At the beginning there were significant differences between the samples' a^* values, but these differences decreased as moisture loss increased. At the end of the drying process, the differences between sapwood and heartwood decreased; thus, a board containing both sapwood and heartwood would appear more homogenous in terms of red hue. An important practical observation was made as the texture of the surface appeared more homogenous to the naked eye, as annual ring borders were difficult to detect on dry surfaces.

The yellow hue values are shown in Fig. 7. At 20 °C and 40 °C the b^* values decreased significantly during the whole drying process, while at 60 °C and 80 °C the yellow hue values decreased first and increased during the drying. The original (fresh conditions) yellow co-ordinate could not be regained by the investigated samples. This was similar to the red hue values, in that the differences present in fresh conditions between heartwood and sapwood decreased during the drying process.

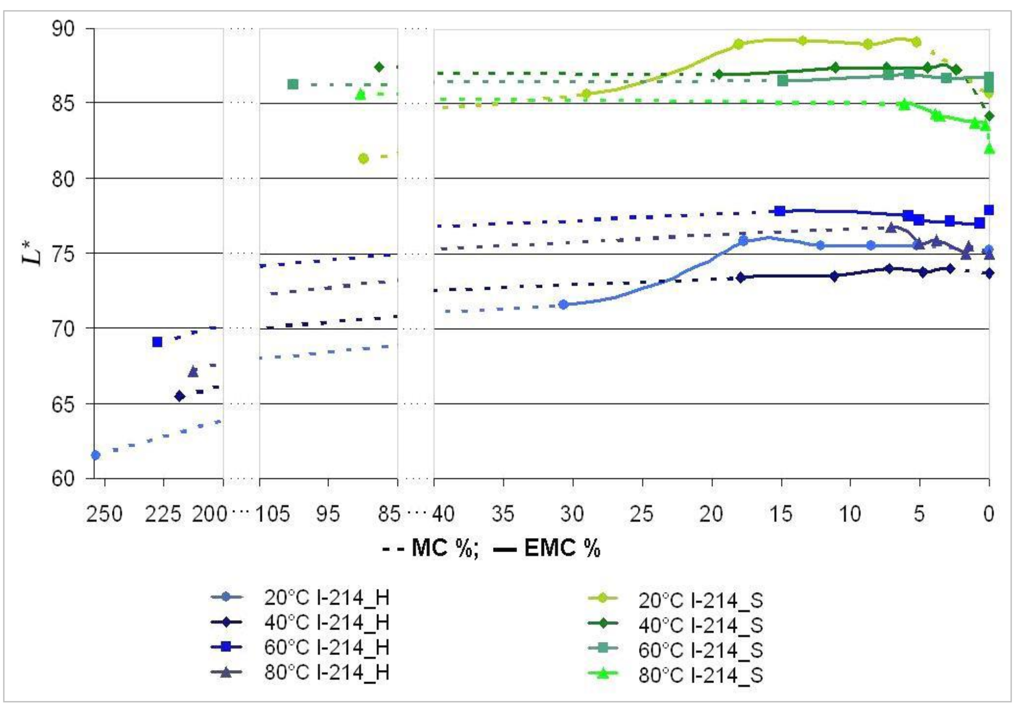

Fig. 5. Change of lightness values by I-214 poplar heartwood (H) and sapwood (S) at different drying temperatures and moisture contents (unequilibrated moisture states are indicated with interrupted lines)

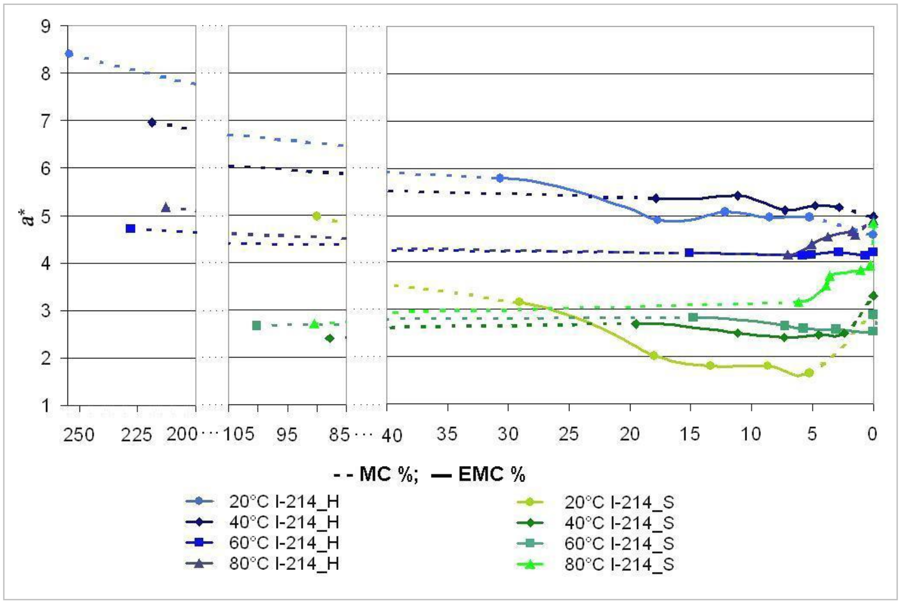

Fig. 6. Change of red hue values by I-214 poplar heartwood (H) and sapwood (S) at different drying temperatures and moisture contents (unequilibrated moisture states are indicated with interrupted lines)

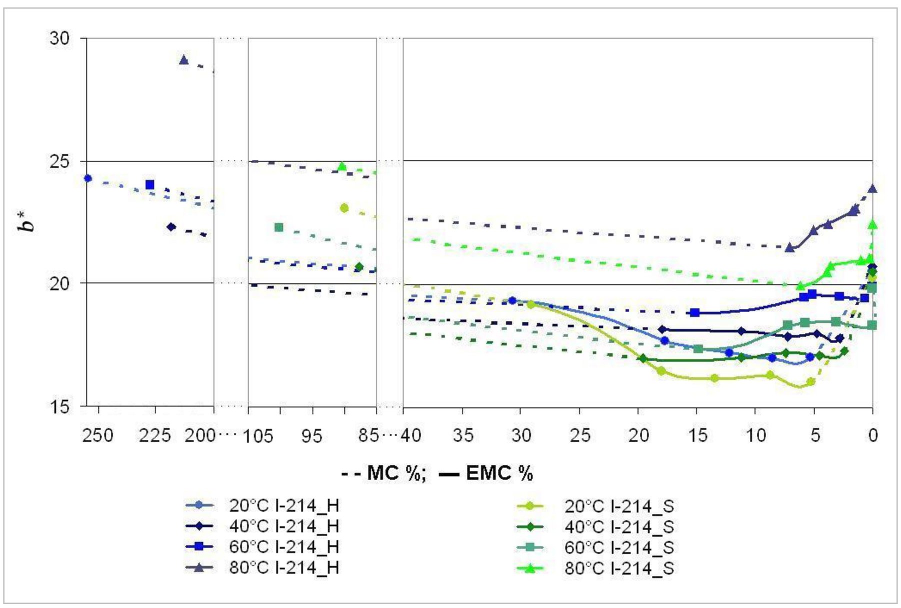

Fig. 7. Change of yellow hue values by I-214 poplar heartwood (H) and sapwood (S) at different drying temperatures and moisture contents (unequilibrated moisture states are indicated with interrupted lines)

Due to the laws of reflection, less light is reflected from a wet surface, because a part of the diffuse light is captured within the wet layer of the surface and is transformed into heat (Meichsner *et al*. 2011). Therefore, the surface should become brighter with the drying of wood. In spite of this, the surface of Robinia becomes darker with higher drying temperatures. This result shows the role of the drying temperature and wood species. By contrast, in the case of poplars the surface became brighter as a result of drying at all the investigated temperatures. The darkening effect is presumably due to the high extractive content of Robinia (Wagenführ 1996). Most of the extractives are sensitive to heat (Sundqvist and Morén 2002); the colour of the wood changes as a result of the decomposition of these extractives. The poplars, which have relatively low extractive content (Wagenführ 1996), became brighter during drying.

CONCLUSIONS

1. The colour of Robinia wood did not change significantly at 20 °C in the moisture range below FSP. Drying temperatures of over 40 °C resulted in the reduction of lightness, increased redness, and decreased yellowness.
2. The colour change of I-214 poplar was dominated by the loss of the free water over the FSP. The colour changed significantly only at 80 °C in the bound water range. The differences between heartwood and sapwood decreased as a consequence of moisture loss at all investigated temperatures, as the colour co-ordinates of heartwood shifted towards the co-ordinates of sapwood. The texture of poplar wood became more homogenous after drying, as the annual ring borders and streakiness were hard to detect. The last observation has practical importance in applications where poplar is used on "visible" places, *e.g.* furniture fronts.
3. Due to the laws of reflection, the surface should become brighter with the drying of wood. In spite of this, the surface of Robinia became darker with higher drying temperatures. By contrast, the surfaces of the wood of poplars became brighter as a result of drying at all the investigated temperatures.
4. Comparing the reaction to moisture loss and temperature on the part of poplar and Robinia woods, Robinia was more sensitive to heat. Considering that green moisture content is much lower in Robinia than poplar, the sensitivity was readily apparent, because of the equal or slightly greater colour change of Robinia.

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