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The study of colour changes under artificial weathering of light red meranti and yellow balau wood from *Shorea* genus

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Abstract: *The study of colour changes under artificial weathering of light red meranti and yellow balau wood from Shorea genus.* This paper deals with the change in colour of selected tropical wood species from *Shorea* genus such as light red meranti and yellow balau. The artificial weathering method was used to determine the colour stability of wood surface. The used ageing method consisted of alternating soaking wood in water, drying at a temperature of 70°C and UV irradiation exposure. The colour changes were evaluated using CIE L^*C^*h system. Changes of particular colour parameters (lightness L^*, chroma C^*, hue h) were determine as well as the total colour change ΔE^*. The results showed that tested species of wood change their colour similarly under the influence of the artificial weathering (the changes in the tested wood appearance occurred in similar scope). Surfaces of tested wood species initially became darker and then lighter. The largest changes in intensity of the colour of wood took place at the beginning of artificial weathering process. The intensity of changes decreased with the progress of aging process.

Keywords: artificial aging, artificial weathering, light red meranti, yellow balau, tropical wood, colour stability.

INTRODUCTION

Tropical wood species are used for production of many products design for outdoor, such as garden furniture, fences, facades, terraces, etc. Popularity of wood from tropical and subtropical climate zone is an effect of the aesthetical and durability properties (Jankowska and Kozakiewicz 2016). The external factors (sunlight, snow, rain, extensive changes of humidity and temperature, photo-chemical and biological factors) cause weathering, what can be defined as irreversible changes in wood structure, its texture and colour (Feist 1990, Colom et al. 2003, Williams 1999, 2005). Among these factors, UV radiation (295–400 nm) is the most damaging element causing these changes at wood surfaces (Williams 2005). Degradation of material surface layers during weathering reasons of colour changes. The certain species of wood revealed colour changes within a few minutes of exposure (Williams 1999). The wood colour mainly depends on chemical components interacting with light such as extractives. The number of tests involving tropical wood species (present on European market) subjected to different weathering (aging) treatments has been already done (Pastore et al. 2004, Baar and Gryc 2012, Jankowska and Kozakiewicz 2016, Jankowska et al. 2017). But because of the number wood species on European market used for outdoors, the knowledge in this area is still incomplete.

Protective treatments have been used to improve the performance of woody materials for outdoor use since ancient times. In general, it is recommended to protect wood surface during outside exposition, especially in the context of making wood colour more stable and acting hydrophobically. However, one of the most important contributions to securing sustainable development is the use of renewable natural materials which is wood. To reduce the ecological problem, the surface of wooden structures could be left untreated with any painting and varnishing. In addition to the traditional interior design elements, the use of untreated wood is expanding even further into the exterior (Oberhofnerová et al. 2017). Presented research is part of extensive study dealing with changes taking place in tropical wood species during exterior exposition. In this paper, the colour changes under the influence of artificial weathering (assuming the absence of biotic interactions) were analysed. Wood species used in the research are from *Shorea* genus – the most popular wood genus in East-Southern Asia. *Shorea* is a genus of about 196 species of mainly rainforest trees in the family *Dipterocarpaceae*. Some of the species are imported to Europe such as meranti wood (white, dark red, yellow and the most popular - light red) and heavy balau wood derived from a number of species from *Shorea* genus (https://www.wood-database.com/). That wood is a material used for the production of elements used in external conditions (terrace boards, garden furniture, etc.). Therefore, acquiring knowledge in this area is justified. Considering that despite the number of publications on weathering processes, the use of different research methods and different aging processes results in the fact that comparison of results is inappropriate.

MATERIAL AND METHODS

Wood species used in this study are yellow balau and light red meranti, both from *Shorea* genus. In this paper, wood names presented in PN-EN 13556:2005 were used. Both kinds of wood are derived from a number species such as *Shorea acuminata* Dyer, *S. dasyphylla* Foxw., *S. johorensis* Foxw., *S. lepidota* (Korth.) Bl., S. *macroptera* Dyer, *S. parvifolia* Dyer in case of light red meranti; and *Shorea atrinervosa* Sym., *S. brunnescens* P.S. Asthon, *S. crassa* Ashton, *S. exelliptica* Meijer, *S. foxworthyi* Sym., *S. glauca* King, *S. havilandii* Brandis, *S. laevis* Ridl. in case of yellow balau (Richter and Dallwitz 2000). All test materials were heartwood, as it is more commercially usable than sapwood. Wood from each wood species was acquired from DLH Global, Warsaw, Poland. Identification was made in the laboratory based on macroscopic features. As a part of identification, wood density was identified based on PN-D-04101:1977.

Samples of each wood species were taken from one board to obtain "identical sample". The aim was to kept the wood structure so the appearing changes in the artificial weathering process were the main factor for the examined properties. 20 groups of 6 samples were taken from each species of wood. Dimensions of samples were 30×20×20 mm (L×T×R). Each group was intended for the research of different stages of weathering. Prior the experiment began, wood surfaces were sanded. Before the determination of colour parameters, each one group was conditioned in air at a temperature close to 20°C and relative humidity 65 ±5 %.

The examination of colour wood changes was made with use of a mathematical model of the CIE L^*C^*h drawn up by the International Commission of Illumination, based on the recommendations of PN-ISO 7724-3:2003. The spherical SP60 Spectrophotometer was used in this research. To determine differences in colour three parameters L^*, C^*, h (L^* - coordinate of brightness/lightness, C^* - chroma coordinate, h - hue coordinate) were used. L^* is the lightness from 100 (white) to 0 (black). The *LCh* system uses the four colours red, yellow, green, and blue (respectively h = 0, 90, 180, 270°). Regardless the angle h, C = 0 means the achromatic colours (the gray axis) (Zeiles et al. 2009).

The total colour difference ΔE between the two colours was calculated using the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta h)^2]^{1/2},$$

Where:

ΔL^*, ΔC^*, Δh represent the differences values between the original and the final coordinates, before and after ageing. A low value of ΔE^* means a low scope of colour changes.

To keep the natural colour, wood samples were isolated in dark until the first test was performed. The surface colour of samples was measured before the start of artificial weathering, and then during the process. Measurements were carried out on longitudinal sections (four measurements on each sample). The results obtained were averaged for each variant (artificial weathering step).

In this research, the artificial weathering method was based on literature (Matejak et al. 1983, Follrich 2011, Jankowska et al. 2017) and was divided on cycles. 60 cycles were carried out. One artificial weathering cycle took 30 hours and was separated into three steps. The first step was soaking in water at 20°C (16 hours). The conditions of second step (8 hours) were 70°C and 5-10% rH and the third step was performed at 30°C and 20-25 rH (6 hours) with irradiation with UV rays. Four fluorescent lamps100R's Lightech of 100 W each, and the spectrum 300 - 400 nm (90% of the radiation spectrum is a wavelength of 340 -360 nm) were used for irradiating.

RESULTS

Initial characteristics of wood samples before weathering are shown in Table 1. Prior the tests, both light red meranti and yellow balau were characterized similar colour, however yellow balau wood was darker and more brown.

Table 1. The mean values of density, colour parameters *L**, *C** and *h* at the beginning of the weathering test

Wood species	Colour parameters			Density [kg/m^3]
	*L**	*C**	*h* [°]	
light red meranti	67.68 (2.74)	21.48 (0.58)	73.58 (1.05)	514 (16)
yellow balau	61.01 (3.15)	29.06 (1.91)	76.33 (0.50)	975 (39)

Note: Mean values and standard deviations in parenthesis

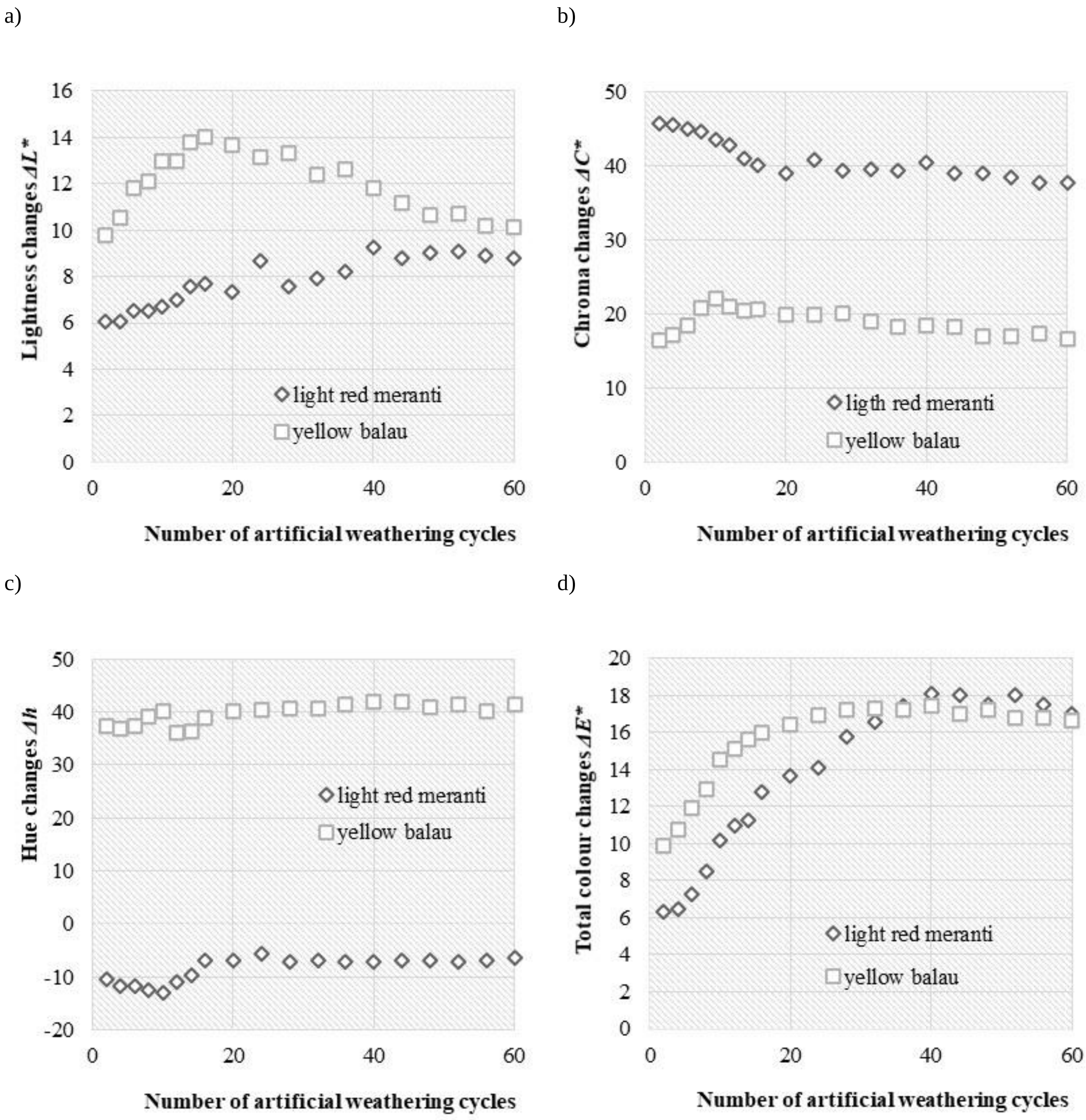

Figure 1. Summary of results testing changes of colour parameters: a – lightness, b – chroma, c – hue, d - total colour change

The results showed that colour of surface tested wood species changed under the influence of the artificial weathering. The largest colour changes were observed at the beginning of the aging process - samples became darker (Fig. 1a). Probably it was the result of dissolving dye substances in deeper layers, and then depositing them on the surface of wood during drying. Next cycles of artificial weathering caused a gradual leaching of dye substances, causing brightening the colour of wood – increasing value of lightness parameter (L^*).

The quick change of wood surface colour at the beginning of artificial weathering process as results of the reaction of extractives contained in wood was explained by Pandey (2005) who compared the behaviour of unextracted and extractive free wood of *Acacia auriculaeformis*. The unextracted wood surface showed a rapid colour change at the initial period of exposure to UV irradiation which decreased upon prolonged exposure. Tests on wood (coniferous, deciduous) from moderate climates during weathering in natural external conditions did not show a wide range of changes, which can be explained by the relatively low content of extractives.

The highest intensity of the colour changes during the progressive weathering process of the initial phases showed also research of Tolvaj and Mitsui (2005). Filson et al. (2009). Jankowska (2013), Jankowska and Kozakiewicz (2014), Jankowska et al. (2017). The total colour difference (ΔE^*) showed a systematic trend to increase values with longer duration of artificial weathering. In the first 20 cycles of artificial weathering increase in the parameter ΔE^* was observed. After an initial increase in ΔE^*, the total colour changes of tested wood species was at the same level to the end of ageing treatment. The greatest value of the total colour change (ΔE^*) was found at similar level for both tested wood species (the maximum value of ΔE^* was 18.06 for light red meranti and 17.40 for yellow balau wood). Hon et al. (1985) and Tolvaj and Papp (1999) mentioned that colour reflects the basic chemical composition of wood. If the wood contains a high amount of extractives, the chemical processes of the colour changes quickly take place (Pandey 2005).

As UV light causes decomposition of lignin especially in the surface layer, the yellowing or browning of wood can be observed (Williams 1999). Washing out the degraded lignin from wood surface layers contributed to brightening samples as well. Irrespective of the tested wood species. the direction of change changed from 20 to 40 cycle of artificial aging - wood colour became lighter (brightening followed until the end of the process of artificial weathering). Similar results were obtained in previous research (Jankowska 2013, 2015, Jankowska et al. 2017) during weathering two species from South America and Africa. But the scope of changes was different.

Initially the weathering process, the colour of wood surfaces became more intense. With the increasing number of artificial weathering cycles, contained in the wood dyes washed out to an increasing extent and finally top layers of wood in the amount of dye has become very limited and wood became a little paler (decrease parameter C^*) - Fig. 1b. During weathering. yellowing of tested wood was observed - the surface colour hue of tested samples of wood was more yellow. The increase in the value of a parameter h to values describing the colour tones of yellow (90°). The biggest scope of changes colour hue occurred in case of yellow balau wood (Fig. 1c). Both ΔC^* and Δh are determined mainly by the changes of the chromophore groups in extractives and change by the lignin degradation and later leaching (Pandey 2005).

Regardless of the colour changes, the tested wood cracked during aging. These were surface cracks. A larger number of cracks and larger cracks were observed in case of yellow balau wood. Cracks during the aging process are the result of sorption stress. The density of yellow balau wood was almost twice higher than density of light red meranti wood. Thus it can be concluded that in wood of higher density, desorption stresses are higher, hence those observations.

CONCLUSIONS

The results of this experiment describe surface colour changes of two wood species from *Shorea* genus. The artificial weathering consisted of wood wetting, drying and UV irradiation caused changes in the parameters describing the wood surfaces colour: lightness, saturation and hue. With the progressive artificial weathering process colour of wood changed gradually. Tested wood species initially became darker and then lighter. During weathering, yellowing of tested wood was observed as a result of UV irradiation. These processes were similar for both tested wood species. The largest changes in intensity of the colour of wood took place at the beginning of artificial weathering process. The intensity of changes decreased during the aging process.

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Streszczenie: *Badanie zmian barwy drewna meranti różowego i balau jasnego z rodzaju Shorea.* Niniejszy artykuł dotyczy zmiany barwy dwóch gatunków drewna tropikalnego z rodzaju *Shorea*, takich jak meranti różowego i balau jasnego. Do określenia stabilności barwy powierzchni drewna zastosowano metodę sztucznego starzenia, która polegała na naprzemiennym moczeniu drewna w wodzie, suszeniu w temperaturze 70°C i ekspozycji na promieniowanie UV. Przeprowadzono 60 cykli sztucznego starzenia. Zmiany barwy oceniono za pomocą systemu CIE L^*C^*h. Określono zmiany poszczególnych parametrów barwy (jasność L^*, barwa C^*, odcień h), a także całkowitą zmianę barwy ΔE^*. Wyniki przeprowadzonych badań pozwalają na stwierdzenie, że barwa badanego drewna zmienia się podobnie (zmiany występowały w podobnym zakresie). Powierzchnie badanych gatunków drewna początkowo stały się ciemniejsze, a następnie jaśniejsze. Największe zmiany w intensywności barwy drewna miały miejsce na początku procesu sztucznego starzenia. W trakcie jego trwania intensywność zmian malała.

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