Quality control by colour measurements after different drying schedules of solid plantation teakwood (*Tectona grandis* L.f.)

H.L. Pleschberger[1], A. Teischinger[2], U. Müller[3] & C. Hansmann[4]

Abstract

The colouration of wood surfaces gets more and more to a determining quality criterion in industrial hardwood drying. The task of kiln drying particularly in hardwood processing is not merely the remove of water, but rather the colour scheme of hardwood surfaces. In the present study planed heartwood surfaces of fast grown plantation teakwood (*Tectona grandis* L.f.) from Costa Rica were investigated after different convection drying procedures. For each of the three applied drying schedules all relevant drying parameters were changed in order to analyse the influence on wood colouration. Adjoining boards dedicated exactly to their origin logs were dried under different drying conditions to final moisture content of 8.5 %. The facing board surfaces of each kiln drying were analysed, using the CIE-L*a*b* colour measuring system. Colour difference was calculated according to ΔL*, Δa*, Δb* and results in ΔE* respectively ΔC* and Δh* values, which contain information of overall changes in colour, saturation and hue. Imperceptible discolouration with no significant influence on discolouration of the wood surface was observed after investigated and compared kiln operations. It could be noticed that increasing drying temperature and lower equilibrium moisture content causes a darker, more greenish and bluish wood surface after drying regarding to plantation teakwood. Present research work provides a correlation between different kiln operations and their influence on the colouring of plantation teakwood.

1 Introduction

Purchase decision has become critical for the wood working industry and is influenced to some extent by consumers' selective perception. Subjective colour perception has established definitely to a constitutive characteristic of wood products appearance. Conventional requirements such as manageability to take a single example are provided as granted by now.

---

[1] Junior Researcher and Ph.D.-Student, h.pleschberger@kplus-wood.at
[3] Area Manager, ulrich.mueller@kplus-wood.at
[4] Key Researcher, c.hansmann@kplus-wood.at
Wood K plus – Competence Centre of Wood Composites and Wood Chemistry, Linz, AT
[2] Head of the Institute and Scientific Director, alfred.teischinger@boku.ac.at
Institute of Wood Science and Technology, Department of Material Sciences and Process Engineering , University of Natural Resources and Applied Life Science, Vienna, AT
Wood K plus - Competence Centre of Wood Composites and Wood Chemistry, Linz, AT

Wood is competing with other materials such as steel, stone, glass, several plastics and decorative papers and is often favoured because of its aesthetic properties, particularly colour. A survey of wood-using professionals showed that lightness is the most important colour criterion, followed by its hue and saturation (Klumpers *et al*. 1993). The natural colour of wood can vary greatly concerning wood anatomy and genetic factors within one species, one tree or due to their provenance to name just a few examples (Oltean *et al*. 2008, Liu *et al*. 2005). It is possible to deliberately and significantly change the wood colour in an artificial way. Modification of wood extractives and cell wall components provide an enabled opportunity to change colour of the wood tissue. Another effect-relating possibility offers the incorporation respectively accretion of impurities inserted as liquids or solids to the cell wall and lumen. These mechanisms of action are based on biological and biochemical (enzyme, micro organisms), chemical (acids and bases – fuming, staining, bleaching) and physical (temperature, ultraviolet radiation, dye impregnation and saturation) procedures (Weigl *et al*. 2009, Pöckl 2007).

Wood processing and machining, especially hardwood kiln drying may cause physical discolorations which become visible in end uses as panelling or furniture. Technical wood drying constitutes a primary wood processing that exerts determining influence on sawn hardwood quality. The most influential factors on discolouration during kiln drying represent the initial moisture content (MC) of the drying material, drying condition affected by kilning temperature (T) and equilibrium moisture content (EMC), as well as the duration of the drying time. Changes, particularly colour perception, compared before and after seasoning seizes a distinction. Bekhta and Niemz (2003) found that treatment time and temperature were more important than relative humidity regarding colour response. Furthermore colour parameters can be estimated quantitatively and used as a prediction of spruce wood strength. According to Luostarinen and Luostarinen (2001) temperature, in particular, seemed to be important for final discolouration during conventional drying of birch parquet boards.

Wood colour evolution during convection drying of tropical hardwood, in particular of plantation teakwood (*Tectona grandis L.f.*), is not well known. Wagenführ and Scheiber (1985) specify natural grown teakwood as a slow but pretty uncomplicated species to dry, with no meaning to check or warp and a good ability to stay. Simatupang and Yamamoto (2000) rated natural grown teak sapwood as white to yellowish respectively greyish. Freshly cut teak heartwood as dull pale yellow, which turns to gold-yellowish and gold-brown after being exposed to sunlight. The colour and pattern of various teak specimens can show much variation depending on their species ranges. In Indonesia it was observed that teak heartwood from regions with a more wet climate have a lighter colour for instance. Apart from the colour variations and differences, the discoloration of teakwood due to drying is a serious problem as well. According to Dahms (1989), untreated teakwood starts greying in outdoor exposure whereas indoor sunlight exposure causes a decrease of lightness but an increase of saturation. Jachs (2007) observed not verified minor

discolorations after convection drying of plantation teakwood from Costa Rica. Wagenführ and Scholz (2005) explained the time-consuming kiln drying process on limited diffusion due to its ingredients, such as caoutchouc, and attributed high temperature during the drying process as the reason for undesirable discolouration. Simpson (2001 b) found that the higher the temperature the more intense the discoloration. As much as high temperature the chemical nature of extractives of teakwood influences the intensity of discolouration. Beside uniform discolouration, also non-uniform darkening, such as coffee-coloured or oily-looking blotches occurs during kiln drying of teakwood. These spots develop just under the surface of the board and are chemically identical to the extractives that contribute to the normal, brown colour of teak heartwood. It is possible to lighten these blotches by exposing the dried wood to sunlight. However, the reason for this is unknown. Basri *et al*. (2003) assigned dark-brown streaks a reason for drying conditions and extractives which can not be removed by planning. It is recommended to adjust low drying temperature above fibre saturation point and using a higher temperature thereafter to diminish discoloration. During the drying process, extractives diffuse from the inside of the wood material to the wood surface. These greenish extractives oxidize as a result of the heat influence and their colour became dark brown to black which are seen as dark brown to black marks/stains on the surface and also in the inside of the wood. Jachs (2009) investigated colour evolution after processing of plantation teakwood from Costa Rica. Subjective qualification showed a colour change to greenish orange which was most visible within two weeks after planning. Discolouration after indoor sunlight exposure was 60% higher than after storage without irradiation.

In this paper experiments were conducted to study colour transforming of plantation teakwood from Cost Rica under different industrial drying schedules.

2 Material and Methods

2.1 Wood species

Plantation teakwood (*Tectona grandis* L.f.) from a mountained region of the provincial site of Puntarenas near Parrita on the pacific coast of Costa Rica were used and analysed in this study. Logs with an age of eighteen years were harvested, measured, containerized in green conditions, shipped to Europe and finally carried to an Upper Austrian sawmill in February 2009. Five stems with diameters from 21.0 cm to 27.5 cm and with log lengths from 5.66 m to 5.77 m were cut into boards on a log band sawing machine to a thickness of 27.0 mm. Estimated initial moisture content (MC) of the heartwood varied from 88.06% to 112.59%, density values from 0.59 g/cm³ to 0.63 g/cm³ through measuring. Boards were bucked to 1.5 m long sections, wrapped separately into flexible PVC films and stored at about -10°C to keep moisture as high as possible before drying.

2.2 Drying experiments

Adjoining boards dedicated exactly to their origin logs were dried under different drying conditions to the same finial moisture content. Before seasoning and

after gentle overnight defrosting at about +4°C of the selected boards cross sectional areas were sealed with an adhesive end coating to avoid accelerated drying from the boards end. For the experiments a convectional laboratory kiln drier (Mühlböck, Eberschwang, Austria) with a computer-aided process control according the industrial standard was used. Drying was carried out using three different procedures in which values of temperature, humidity and air velocity were regulated over a wide range. The boards were dried from green to target MC of 8.5% in all experiments. During the drying experiments, climates were provided within the chamber visible in Figure 1-3.

In all applied drying schedules the two median values out of ten gauges were regulating the process. The following instantaneous values for temperature, EMC and drying gradient for each kiln drying are related to the drying step. Heat up respectively through, conditioning and cooling were excluded in order to focus on ranges in the most influential step during the run. However Figure 1-3 show all steps from the beginning till the end of each drying schedule.

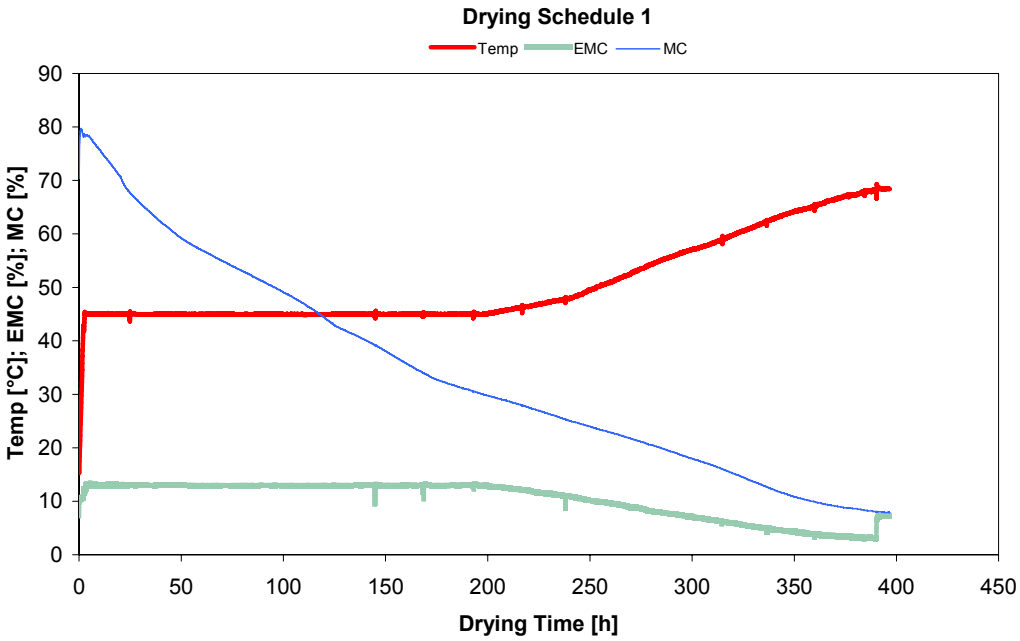

Figure 1: Temperature (Temp), Equilibrium moisture content (EMC) and Wood moisture content (MC) of drying schedule 1 against the drying time.

In the first drying schedule (Figure 1) drying temperature started at 43.6°C up to the maximum of 68.3°C was reached. EMC was down-regulated from 13.4% at the beginning to 2.8% at the end of drying. A drying gradient of 3.2% was not exceeded. In the second kiln schedule (Figure 2) drying temperature was in the range of 54.7°C to 78.3°C. EMC was in the range of 12.7% to 2.9% and drying gradient peaked at 2.9%.

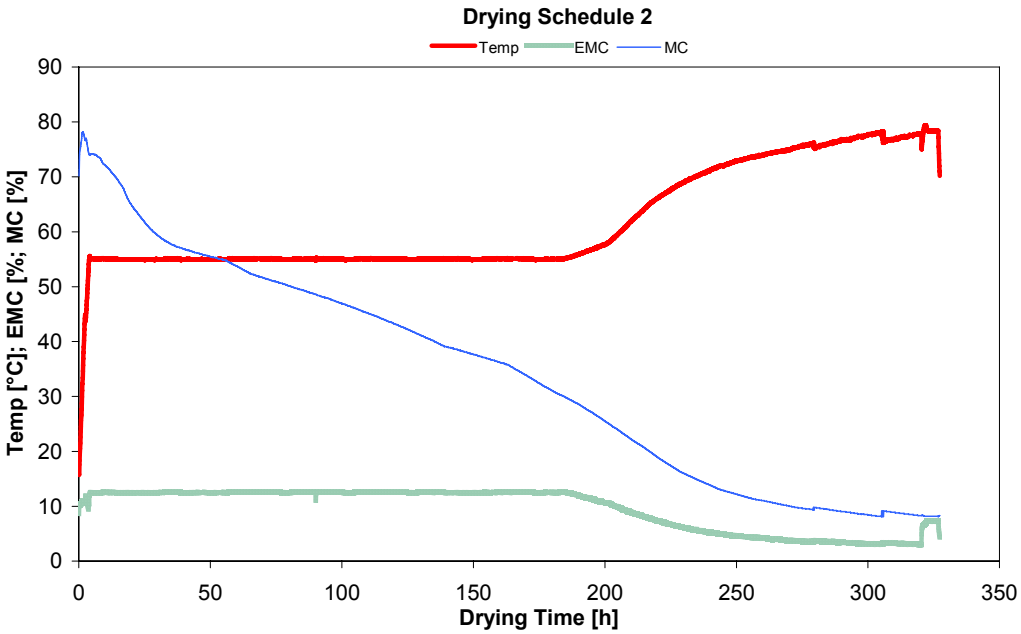

Figure 2: Temperature (Temp), Equilibrium moisture content (EMC) and Wood moisture content (MC) of drying schedule 2 against the drying time.

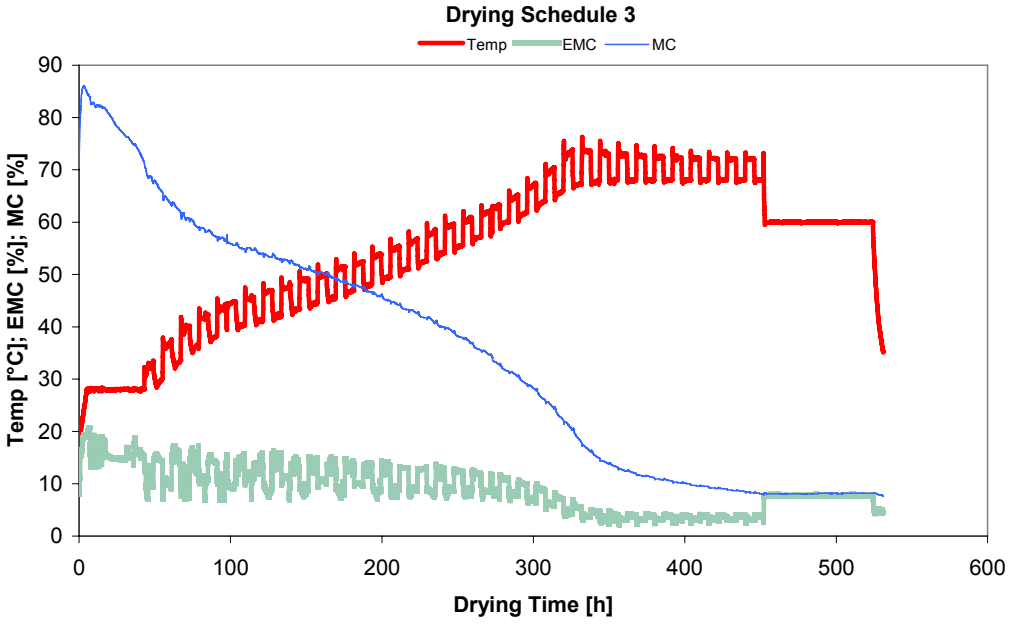

Figure 3: Temperature (Temp), Equilibrium moisture content (EMC) and Wood moisture content (MC) of drying schedule 3 against the drying time.

The third drying experiment (Figure 3) had a time-controlled drying temperature and EMC as its specific characteristic. With an interval of six hours, the kiln

schedule was switched between a gentler program and a more severe one, which is clearly recognizable in the temperature and EMC curve in Figure 3. Dual drying procedure started with 5°C alternating difference in the temperature, where EMC alternated initially 5.0% and in the end only 0.5%. 76.3°C was the peak value in temperature and EMC decreased from 17.3% at the beginning to 2.0% in the end with a maximal drying gradient of 6.4%.

2.3 Colour measurements

The facing board surfaces of each kiln drying were compared and analysed, using the CIE-L*a*b* colour measuring system according to the ISO 7724-3 (1984) standard. The CIE-L*a*b* colour space is characterized by three parameters, L* for lightness and a* and b* for colour opponent dimensions. L* values vary from +100 (+L*) for white to zero (-L*) for black and the chromaticity coordinates range from +128 (+a*) for red to -127 (-a*) for green and from +128 (+b*) for yellow to -127 (–b*) for blue. Colorimeter device a Chroma Meter CR-410 (Konica Minolta, Tokyo, Japan) equipped with a measuring orifice of 50 mm was used. D65 light source (daylight) and an observation angle of 2° were adjusted. Colour difference was calculated according to ΔL*, Δa*, Δb* and results in ΔE* (distance in L*a*b* colour space), Δa* and Δb* in ΔC* (saturation) and a* and b* in h* (hue) values, which contain information of overall changes in colour using equations 1-6.

$$\Delta L^* = L_x^* - L_y^* \qquad \text{Equation 1}$$

$$\Delta a^* = a_x^* - a_y^* \qquad \text{Equation 2}$$

$$\Delta b^* = b_x^* - b_y^* \qquad \text{Equation 3}$$

$$h^* = Arctg\left(\frac{b^*}{a^*}\right) \qquad \text{Equation 4}$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{Equation 5}$$

$$\Delta C^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{Equation 6}$$

ΔL*, Δa* and Δb* are the changes between coupled facing measuring points (initials x and y) of different drying experiments. A low value of ΔE* respectively ΔC* corresponds to a marginal change in colour respectively in saturation. The calculated hue angle h*, which ranges from 0° to 90°, suggests little or no effect on discolouration concerning redness (close to 0°) or yellowness (close to 90°) Charrier *et al*. (2002).

After all drying experiments were finished the adjoining heartwood board surfaces were planed and stored over three month at constant climate (20°C/65% relative humidity) without exposure to light. Measuring points positioned face to face of clear heartwood sections of comparable boards of the same origin log with a measuring orifice of 50 mm were performed. The

analysis was carried out on 184 single measurements (92 coupled comparable measuring points) on six paired boards out of five different teakwood logs. Obvious discolouration caused by the planing process was excluded of this analysis in order to focus only on drying induced colour changes. One-way ANOVA was used to compare and determine any significant difference of colour change on clear heartwood surface sections after different drying schedules.

3 Results

CIE-L*a*b* parameters in Figure 4 represent the influence of each investigated drying procedure (Drying_1, Drying_2 and Drying_3) on surface colouring. Statistical analysis was performed (one-way ANOVA) and a significant discoloration according to all colour components (at a 5% significance level) could not be observed.

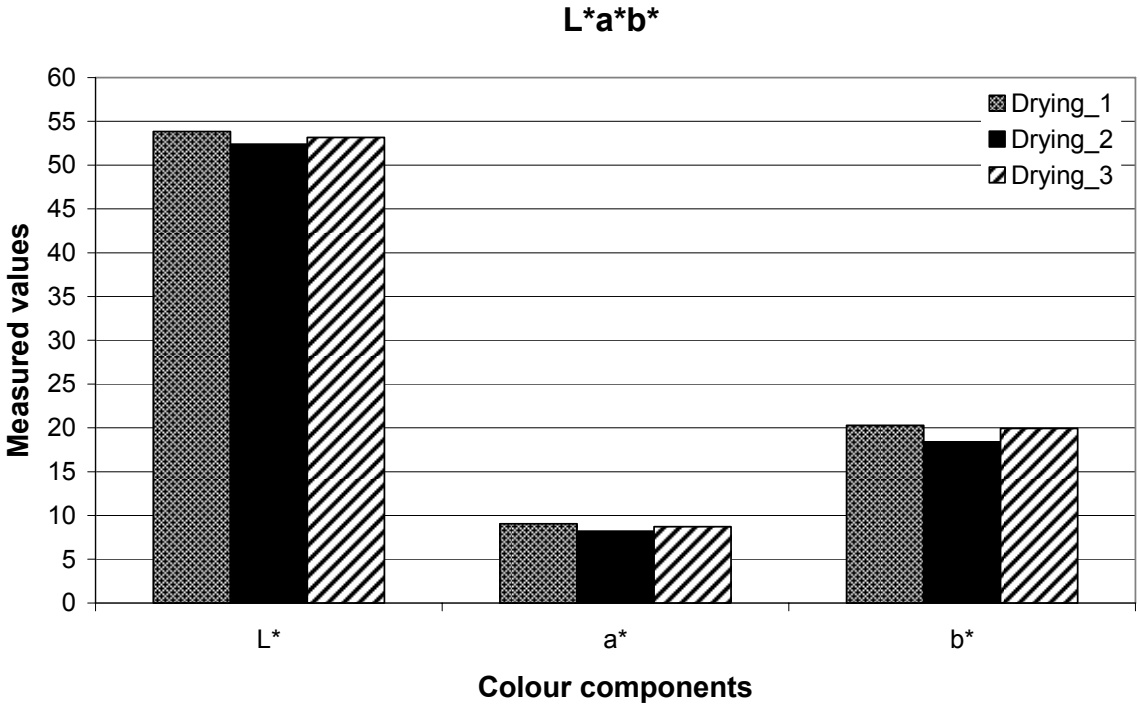

Figure 4: Comparison of absolute L*a*b*-values of three different plantation teakwood dryings.

Average lightness (L*) of the first drying constituted at an absolute value of 53.86 and decreased slightly in the second drying to 52.40 to show in the third drying a slow rise up to 53.18. Expressed in colour perception the lowering of L* stands for a slight darkening effect. Chromaticity values a* and b* follow the same trend as lightness. In case of absolute a* value, 9.03 was measured in average in the first drying, 8.21 in the second and 8.71 in the third. A drift on the red-green axis (a*) yields to a more greenish appearance of the wooden surface. Further b* values in the first drying reached 20.28 in mean, in the second 18.41 and in the third 19.94. A gradual reduction of the values on the yellow-blue axis (b*) fortifies the shade of blue.

Out of the effectively measured L*a*b*-values of each investigated drying, colour change (ΔE*), the change in saturation (ΔC*) and the displacement on the hue circle (Δh*) were computed for adjoining and comparable boards and are shown in Figure 5.

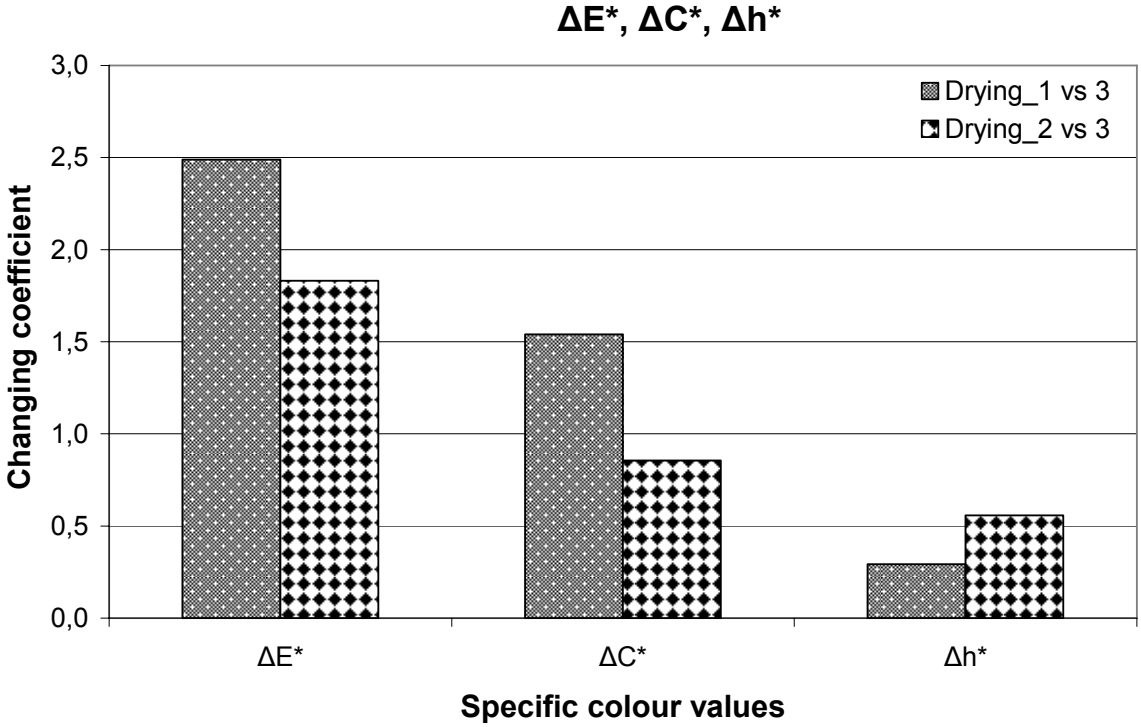

Figure 5: ΔE (over all changes in colour), ΔC (colour saturation) and Δh (hue) of different dryings of plantation teakwood.

Macroscopically discolouration become visible if ΔE* values exceeds changing a coefficient above 3. Colour change of drying one (Drying_1) compared to drying three (Drying_3) results in an average changing index of 2.49. However the outcome of drying two (Drying_2) compared to drying three (Drying_3) is 1.83 in mean. The change in saturation follows the trend of the discolouration. The first comparison (Drying_1 vs 3) determines an average value of 1.59 whereas in the second (Drying_2 vs 3) merely 0.85 can be calculated. Basic changes of the second polar coordinates h*, beside C*, could not be observed. Narrow differences of 0.29 in average between drying one (Drying_1) and three (Drying_3) and 0.59 between drying two (Drying_2) and three (Drying_3) are identified.

4 Conclusion

An imperceptible trend of discolouration during kiln drying on industrial standard at different ranges of temperature and equilibrium moisture content of solid plantation teakwood was observed. Cartesian colour coordinates (L*a*b*) calculated in colour change (ΔE*) as well as polar coordinates saturation (C*) and hue (h*) show a slight but a non-significant effect on discolouration of planed wood surfaces of adjoining boards. Changes could only be noticed in computed results, a macroscopically determination of discolouration four human

eyes is not visible. In general, if process-related discolouration during drying is neglected, increasing drying temperature and lower equilibrium moisture content cause a darker, more greenish and bluish teakwood surface. However, for a detailed research of discolouration during kiln drying, we have to leave industrial kiln drying standard and compare gentler to more severe drying procedures. In case of plantation teakwood, colour measurements after industrial convection drying could be applied as a quality control in the investigated range of drying parameters used in this study. Almost unnoticeable discolouration after different drying schedules indicates a constant surface performance regarding colour and optical requirements.

Acknowledgement

Financial support by Teak Holz Handels- Verarbeitungs GmbH is gratefully acknowledged.

References

Basri, E. Rohadi, D. & Priadi, T. (2003). "The Alleviation of Discoloration in Teak (Tectona grandis) Wood through Drying and Chemical Treatment". 8th International IUFRO Wood Drying Conference, pp 319-323.

Bekhta, P. & Niemz, P. (2003). "Effect of High Temperature on the Change in Color, Dimension Stability and Mechanical Properties of Spruce Wood". Holzforschung, Vol. 57, pp 539-547.

Brischke, C. Welzbacher, R.C. Brandt, K. & Rapp, O.A. (2007). "Quality control of thermally modified wood: Interrelationship between heat treatment and intensities and CIE L* a* b* colour data on homogenized wood samples". Holzforschung Vol. 61, pp 19-22.

Charrier, B. Charrier, F. Janin, G. Kamdem, P.D. Irmouli, M. & Goncalez, J. (2002). "Study of industrial boiling process on walnut colour: Experimental study under industrial conditions". Holz als Roh- und Werkstoff, Vol. 60, pp 259-264.

Dahms, K.-G. (1989). "Das Holzportrait Teak". Holz als Roh- und Werkstoff, Vol. 47, pp 81-85.

Jachs, M. (2007). "Utilization of plantation teakwood (*Tectona grandes L.f.*) as solid wood". Part I: Chemical an mechanical characteristics of Costa Rica plantation teak. Bachelor Thesis. Department of Material Science and Process Engineering, Institute of Wood Science and Technology, University of Natural Resources and Applied Life Science, Vienna.

Jachs, M. (2009). "Zerspanungseigenschaften von Teak (*Tectona grandis L.f.*) am Beispiel Hobeln sowie die Beobachtung der Farbveränderung nach dem Bearbeitungsschritt". Master Thesis. Department of Material Science and Process Engineering, Institute of Wood Science and Technology, University of Natural Resources and Applied Life Science, Vienna.

Liu, S. Loup, C. Gril, J. Dumonceaud, O. Thibaut A. & Thibaut B. (2005). "Studies on European beech (*Fagus sylvatica L.*). Part 1: Variations of wood colour parameters". Annals of Forest Science, 62, pp 625-632.

Luostarinen, K. & Luostarinen, J. (2001). "Discolouration and Deformation of birch parquet boards during conventional drying". Wood Science and Technology 35, pp 517-528.

Klumpers, J. Janin, G. Becker, M. & Lévy, G. (1993). "The influence of age, extractive content and soil water on wood color in oak: the possible genetic determination of wood color". Annals of Forest Science, 50, pp 403s-409s.

Oltean, L. Teischinger, A. & Hansmann, C. (2008) "Wood surface discolouration due to simulated indoor sunlight exposure". Holz als Roh- und Werkstoff, Vol. 66, pp 51-66.

Pöckl, M.J. (2007) "Neue Methoden der Laubholzvergütung". Dissertation. Department of Material Science and Process Engineering, Institute of Wood Science and Technology, University of Natural Resources and Applied Life Science, Vienna.

Simatupang, H.M. & Yamamoto, K. (2000). "Properties of teakwood (*Tectona grandis L.f.*) and mahogani (*Swietenia Macrophylla King*) from manmade forest and influence on utilization". In: Hing Hon , C. & Matsumoto, K. (Eds.), Proceedings of the Seminar on High Value Timber of Plantation Establishment, Conferérence Tawan, Sabah, Japan. JIRCAS. Working Report No.16, pp 103-114.

Simpson, T. (2001) b. "Drying Defects". Chapter 8, http://www.fpl.fs.fed.us/documnts/usda/ah188/chapter08.pdf [Accessed 9 March 2010].

Wagenführ, R. & Scheiber, C. (1985). "Holzatlas". 2. Auflage, Fachbuchverlag, Leipzig, Carl Hanser Verlag, pp 626-628.

Wagenführ, R. & Scholz, F. (2005). "Taschenbuch der Holztechnik". Carl Hanser Verlag, München.

Weigl, M. Kandlbauer, A. Hansmann, C. Pöckl, J. Müller, U. & Grabner M. (2009). "Application of natural dyes in the colouration of wood". In: Bechthold, T. & Mussak, R. (Eds.), Handbook of natural colourants, John Wiley and Sons, Inc.