# On the Modelling of Colour Changes of Thermally Treated Hardwoods during Artificial Weathering

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## ABSTRACT

Wood is a well accepted material for visible structures and products in building construction. The influences on the properties of exterior wood surfaces are very complex. General, artificial weathering tests are used to screen the material degradation and to evaluate the product life span behaviour. For any predictions it is necessary to apply adequate analysis methods on the modelling and on the comparison of the material changes during ageing. Different parametric regression analysis methods were compared with a new mathematical model for the estimation of the degradation process of wood surfaces, in particular relating to the colour changes. The surface colour for thermally modified ash and beech samples with various heat treatment conditions was determined according to the CIE L*a*b* system during artificial weathering over 1661 hours. The collected data was investigated using various polynomial functions and a local regression method. The corresponding parameters of the local regression methods were applied to generate the confidence intervals around the smoothed curve. These results indicate that all three colour parameters show varying differences during the exposed time. The locally weighted regression seems to be an appropriate method for modelling weathering effects (changing material properties).

## INTRODUCTION

Artificial weathering is an important test for estimating material properties (*e.g.* aesthetic aspects) during the product life span. Ayadi *et al*. (2003) mentioned the good colour stability of heat-treated wood during artificial weathering over 835 hours. The reproducibility and comparison of weathering conditions can not always be guaranteed. Accordingly, methods for the comparability of different weathering tests and their visualization are important. Wypych (2003) provides an introduction to the general laws of the photo-degradation of polymers and their potential for the modelling of the changes. The most appropriate smoothing method always depends on the data and the research question formulated, and there is a risk of using a smoothing function that misrepresents the structure within the data.

## MATERIAL AND METHODS

### *Material*

In this study, two boards of ash (*Fraxinus excelsior* [L.]) and beech (*Fagus sylvatica* [L.]) were selected. Two different types of heat treatment were used for the ash samples. Three different types of heat treatment were used for the wood modification for the beech samples. With regard to the various thermally modified processes, the samples were divided into three heat intensities (low, medium and strong).

***Colour measurement***

Wood colour was measured with a Mercury 2000 spectrophotometer (Datacolor) and the selected diameters for measurement were 11 mm. Colour is expressed according to the Commission International de l'Eclairage (CIE) L*a*b* colour space with a standard illuminat $D_{65}$ and a 10° standard observer. Nine points per sample were measured on the surface.

***Artificial weathering***

The artificial weathering procedure was performed according to the DIN EN 929-6, with an exposure period of over 1661 hours.

***Analysis of data***

The Mathcad® 14 und SPSS® 16.0 software packages were used for the analysis of data. The collected data was smoothed over the time axis by various regression analysis methods. Firstly, a cubic polynomial function was used. Secondly, a LOESS (locally weighted regression) with a smoothing factor value of 0.3 was applied according to Schnabel et al. (2009). The smoothing factor value defines the proportion of the neighbourhood used in the local regression. A good approximation of the various methods was chosen by visual assessment of the smoothing quality according to Guseva and Lichtblau (2005). The 99% confidence intervals of the estimated smoothing functions were calculated for every time step.

## RESULTS AND DISCUSSIONS

To give a qualitative impression of the variation of measured colour parameters (*e.g*. the a* values of unmodified beech) and the adaption of the smoothing curves, the modelling results are shown in Figure 1. The parametric regression function indicated great differences between the experimental data and the 3rd order polynomial. In this case, the model did not fulfil the robust estimation and the modelling of the a* values during the exposure time. In contrast to the polynomial used the model with the smoothed curve of the LOESS function approximated precisely the data. The tendency of the differences between the 3rd order polynomial function and the LOESS method were similar for the other wood samples and colour parameters.

To analyse the relevant model, the differences between the measured and the smoothing data were calculated. If the residues were distributed almost around zero then a robust approximation procedure was applied. Moreover, the sum of squares residuals (SQR) were analysed for every model. These findings show a robust estimation of the discolouration process with the LOESS function.

On visual inspection, it was obvious that the wood colour had changed during the weathering test. To give an impression of the colour values in the course of time, the effect of the weathering simulation on the CIE L*a*b* colour parameters is shown in Figure 2 for ash and in Figure 3 for beech. The bands are the 99% confidence intervals, which were calculated around the smoothing curve.

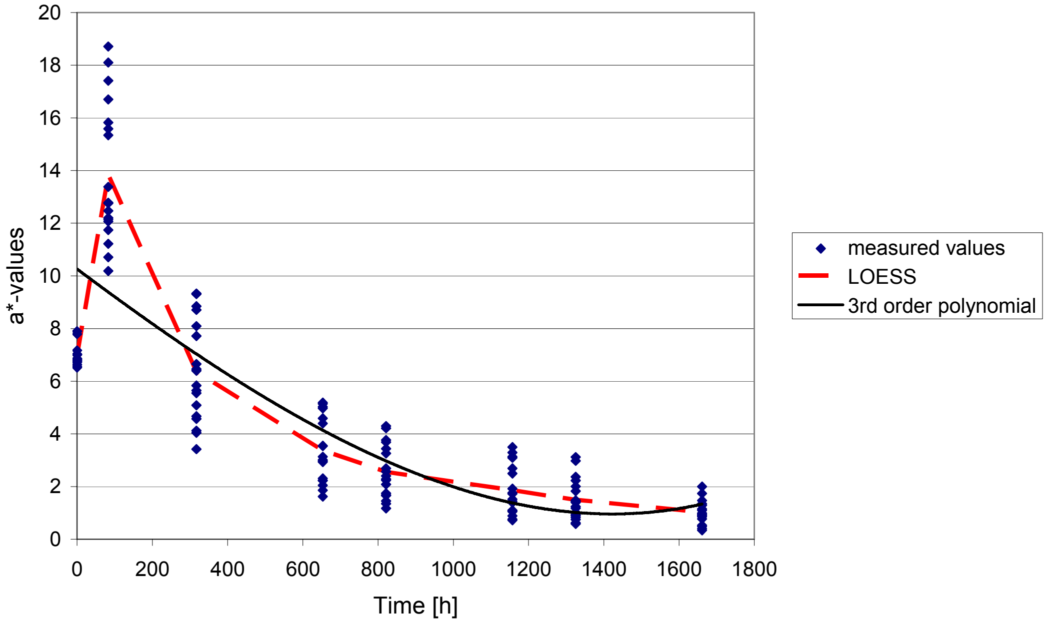


*Figure 1: Measurements of a* colour parameter of unmodified beech together with the LOESS smoothing curve and the 3rd order polynomial*

The L*values of the ash samples decrease for the first 83 hours (Figure 2). Then the L* values increase during the exposure period. An increase in the L* values led to a brighter colour impression. The a* and b* values of the modified wood decrease considerably for the first 821 hours. After this time, the changes were not significant. Considering the a* and b* values for the unmodified samples, the weathering effects during the first 83 hours were more pronounced, and the colour of the samples shifted to reddish and yellow. Then the values decreased considerably, as the intensity of the colour faded.

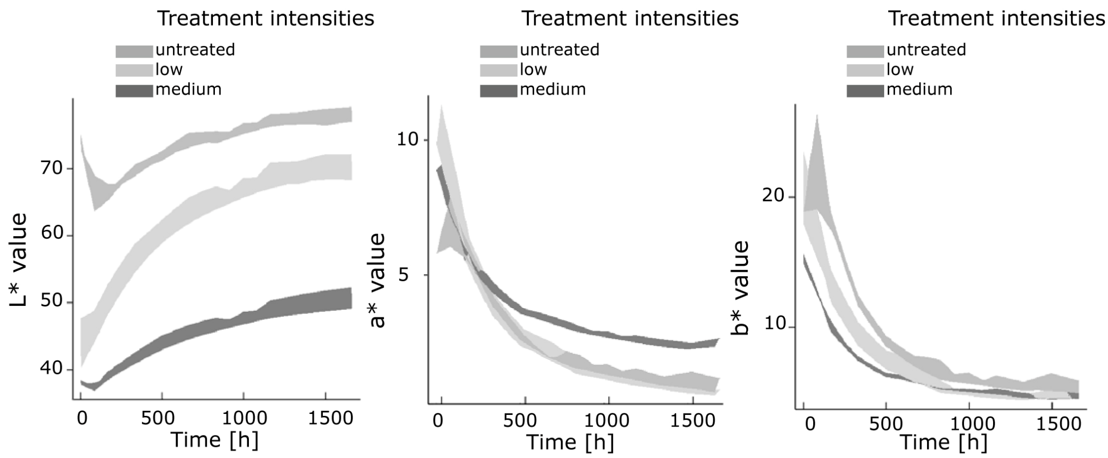


*Figure 2: The 99% confidence intervals for the values of L*, a*, and b* from various treatment intensities of ash samples*

The L*values of beech samples decreased for the first 83 hours (Figure 3). Then the L* values increased during the exposure period. The a* and b* values of the modified wood decreased considerably for the first 821 hours. After the exposed time of 821 hours the a* and b* values were steady. Considering the a* and b* values for the unmodified samples, the weathering effects during the fist 83 hours led to a rise, followed by a decrease in the a* and b* values.

The tendency of the changes in ash and beech were similar, and the weathered samples became grey. These findings show that thermally treated ash and beech samples do not attain colour stability. However, samples with higher treatment intensities show fewer changes in the wood colour during the artificial weathering test.

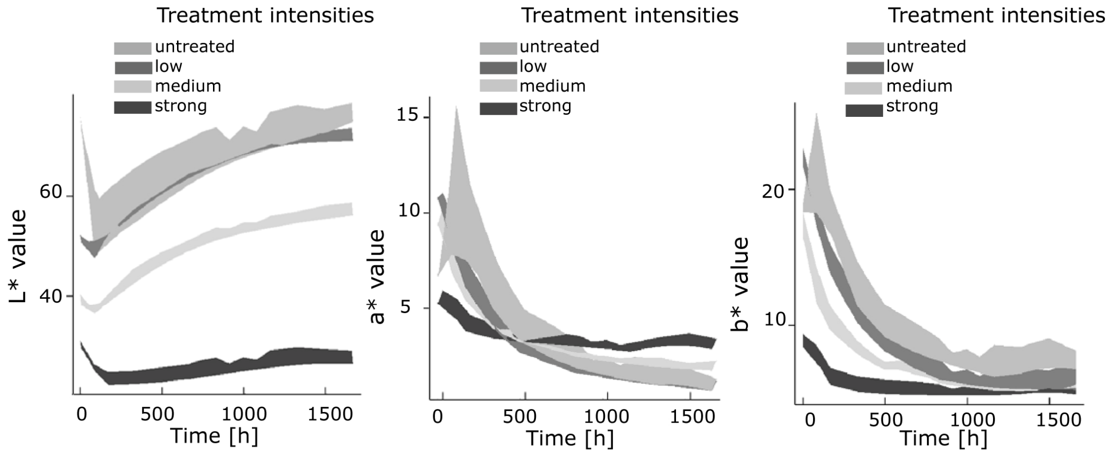


***Figure 2:  The 99% confidence intervals for the values of L*, a*, and b* from various treatment intensities of beech samples***

## CONCLUSIONS

Results of this investigation indicate that the method of locally weighted regression was applied successfully and the effects of the artificial weathering on thermally treated wood could be compared by means of statistical analysis. The quantitative analysis shows a significantly different behaviour for various treatments. These findings provide a helpful basis for further investigation about the description of the weathering process.

## ACKNOWLEDGEMENT

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