ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 11 N° 4 2015
pp. 360-365

CORRELATION BETWEEN THE CHANGES OF COLOUR AND MECHANICAL PROPERTIES OF THERMALLY-MODIFIED SCOTS PINE (*PINUS SYLVESTRIS* L.) WOOD

Vasiliki KAMPERIDOU
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment
Laboratory of Wood Products and Furniture Technology
54124 Thessaloniki, Greece, E-mail: vkamperi@for.auth.gr

Panagiotis BARMPOUTIS
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment
Laboratory of Forestry Informatics,
54124, Thessaloniki, Greece, E-mail: panbar@auth.gr

Abstract

In this study, Scots pine wood (Pinus sylvestris L.) was thermally treated at 200°C, for three different time periods of 4, 6 and 8 hours. The Bending strength (MOR) and Impact Bending strength of treated and untreated pine wood specimens were determined and measurements of wood colour were implemented before and after each thermal treatment, in order to evaluate the colour changes coming from the treatment processes. An attempt was made to correlate this colour change with the change of the mechanical properties of treated wood. The results indicated that MOR decreased as the intensity of the treatment increased, recording decrease percentages of between 0.34-25.9%, compared to untreated wood, while the impact bending strength values of treated specimens marked 0.69-22.34% lower strength. The noteworthy is that a strong and significant relationship was recorded between the colour change and the mechanical properties change. Based on the results of this study, it could be claimed that the mechanical strength values of treated pinewood could be sufficiently estimated by the corresponding colour change values that have been measured. Therefore, the measurement of colour coordinates and the calculation of the total colour change (ΔE) values offer the opportunity to estimate automatically, quite precisely and through a non-destructive way the mechanical properties of wood.

Key words: *correlation; colour; mechanical properties; Scots pine; thermal treatment.*

INTRODUCTION

Modification of wood using high temperature offers superior qualities in wood, without carrying the environmental impact of preservatives. Thermal modification seems to be one of the oldest and simplest method of wood modification and improve dimensional stability and biological durability of wood, even though some mechanical properties appear to deteriorate increasing the treatment intensity. The change of the physical, chemical and mechanical properties of wood after its thermal treatment depends on the wood species and consequently, the initial density, colour, strength and durability of wood. The variability in modification degree and the thermal treatment conditions ensures a huge range of treated wood products with totally different properties.

The colour of wood tends to get darker tones after treatment, due to the alteration of the extractives and the change of the basic wood components. Depending on the temperature and duration of the treatment, the color of wood changes towards darker shades and the color become even darker when the modification is conducted in the presence of air. The color darkens throughout the mass of wood, because of the increase of lignin content in the cell walls but also the depolymerisation of the hemicelluloses and the increase of low molecular weight sugars produced there from (Ates et al. 2010, Gunduz et al. 2009).

The color has also been suggested to be an indicator of chemical and therefore, physical and mechanical properties changes and presents the potential of predicting the quality of heat treatment by predicting various property changes such as chemical changes (Bourgois, Janin and Guyonnet 1991), strength loss (Bekhta and Niemz 2003) and mass loss due to thermal degradation (Patzelt, Emsenhuber and Stingl 2003). Another researcher, Johansson (2005) also tried to connect colour of Birch wood with the static bending and impact bending strength reduction caused by the heat treatment at 175°C and 200°C for 0, 1, 3 and 10h., and concluded that colour measurements are not the most appropriate way of predicting strength loss on an industrial scale, but on an experimental level it is an effective way to study the changes that occur in wood during treatment, a fact mainly attributed by the researcher to the colour inhomogeneity of thermally treated Birch wood.

ONLINE ISSN 2069-7430 ISSN-L 1841-4737 PRO LIGNO www.proligno.ro Vol. 11 N° 4 2015 pp. 360-365

OBJECTIVE

Therefore, due to the lack of clear evidence, the objective of the current study is to detect the relationships between the colour change of thermally treated pine wood in the presence of oxygen and the change in the mechanical properties of this species after treatment, such as Bending strength and Impact Bending strength, in order to investigate and provide information about the potential of using the colour as an indicator of treated pine wood strength.

Part of the results concerning the mechanical properties of Scots pine wood were recently presented in Wood research journal publication (Kamperidou et al. 2014), while the physical properties and specifically the colour parameters values were presented separately in Journal of Forestry research publication (Kamperidou et al. 2013).

MATERIALS AND METHODS

Scots pine wood (Pinus sylvestris L.) specimens used in this research work was of Greek origin, obtained from a local wood industry (North Greece) and it has been naturally desiccated for 8 months. The boards were cut parallel to grain and the dimensions of the boards, intended for thermal treatment, were 35mm thickness x 70mm width x 400mm length. Prior treatment, the boards were placed into a conditioned room at 20 ± 2^{o}C temperature and 60 ± 5% relative humidity and were allowed there to attain a nominal equilibrium moisture content (EMC) of 11.63%. The mean density (oven-dry mass/volume, measured at 11.63% moisture content) of wood before treatment was 0.505g/cm^3.

For the thermal treatment of the boards, a laboratory heating unit (80cm x 50cm x 60cm) was used, capable of controlling the temperature within a range of ±1^{o}C. The temperature applied during the thermal treatment was constantly 200^{o}C, while the treatment was implemented under atmospheric pressure environment, in the presence of air. The boards placed in the kiln, were of 11.63% moisture content, as mentioned before, and the interior of the kiln had already reached the temperature of 200^{o}C. The time periods of thermal treatment of the boards were of 4, 6 and 8 hours and for each treatment 8 boards were used.

At the end of each treatment, samples were cooled down and stored in climate control room. After a conditioning period of two months, at 20 ± 2^{o}C temperature and relative humidity of 60 ± 5%, the boards that were free of defects were selected and cut in final cross section dimensions for the measurement of mechanical properties, according to the respective standards (Bending strength test: ISO 3133:1975, impact bending strength test: ISO 3348:1975). For each property test 10 specimens were prepared. Therefore, a total of 120 specimens were prepared in this experiment.

Bending tests were carried out on a Universal Testing Machine (SHIMADZU UH- 300kNA), and the rate of crosshead-movement was adjusted at 5mm/min, so that the maximum load was reached within 1.5 ± 0.5min throughout the test. The impact bending strength tests were carried out on an Amsler Universal Wood Testing machine at 24-cm span with center loading. For each specimen, the impact by the falling pendulum occurred in the respected plane of static bending test.

Colour of the specimens was measured using a Minolta Colourimeter (ASTM D 1536-58 T 1964), in order to evaluate the colour change owing to heat modification. The Colourimeter specifies the colour as 3 coordinates in 3-dimensional colour space. This system is called CIE *L*a*b**, works according to the CIE standard and provides a standard scale for comparison of colour values. *L** coordinate describes the lightness and ranges between 100 which represents a perfect reflecting diffuser and 0 which represents black colour, and *a** and *b** describe the chromatic coordinates on the green–red and blue–yellow axes, respectively, without specific numerical limits. The 3 colour coordinates, *L**, *a**, and *b**, were recorded before and after each thermal treatment and the relation between *L** values of treated or untreated wood and the mechanical properties of wood was examined.

The color values that were correlated to mechanical properties values of thermal treated wood were the mean values coming from the three surfaces wood colour values (tangentially, radially and transversely), in order to have the most representative values of wood surface colour of specimens. For the generation and the processing of the relationship equations between the color coordinates and mechanical properties values and also for the creation of diagrams MATLAB program was used, which constitutes a software program environment of numerical methods, simulation and graphical visualization. Comparison was implemented among several different equations, while linear and second degree polynomial equations were chosen, because linear regression is the simplest one (first degree) and second degree polynomial regression was chosen, because it presented the highest coefficient of determination (r^2) values.

RESULTS AND DISCUSSION

Mean value of MOR of 4 hours treated specimens was found to be 0.34% lower than the corresponding value of untreated wood specimens, while the 6 hours and 8 hours treated specimens recorded 14.6% and 25.90% lower MOR values, respectively. The decrease of bending strength values for a treatment duration of 6 hours was proved to be quite intensive, whereas as the treatment duration reaches the 8 hours, the impact bending strength values marked a milder decrease.

The impact bending strength values of treated specimens generally recorded a decrease compared to values of untreated specimens. The impact bending strength values of specimens treated for 4 hours marked 0.69% lower strength compared to the strength level of untreated specimens, while the values of 6 and 8 hours treated specimens decreased 17.09% and 22.34%, respectively, compared to the control specimens. Noticeable is the fact that, the decrease of impact bending strength for a treatment duration of 6 hours was intensive, whereas as the treatment duration increases to 8 hours, the impact bending strength values tend to decrease in less extent, which was less intensive than the corresponding decrease of bending strength values referring to the same duration. Generally, the results showed that treatment conditions of 200^{o}C for 8 h resulted in the greatest decrease in mechanical properties, referring to MOR and impact bending strength.

Table 1
Mean values of Modulus of Rupture, Impact Bending strength and the Lightness (L*) of the pine wood specimens

Treat.	MOR N/mm^2	Imp. Bend. Str. J/cm^2	Mean (*L**)	*L** in tang. surf.	*L** in rad. surf.	*L** in long. surf.
Control	81.39 (9.22)	2.75 (0.99)	79.3 (5.29)	82.83 (1.40)	82.69 (1.30)	72.38 (2.54)
4h	81.11 (6.10)	2.73 (0.95)	60.76 (6.56)	62.71 (4.79)	65.28 (2.78)	54.3 (5.96)
6h	69.51 (5.87)	2.28 (0.74)	51.76 (5.21)	46.13 (2.19)	48.69 (3.32)	39.64 (4.90)
8h	60.31 (10.01)	2.14 (0.99)	44.82 (5.73)	53.8 (4.11)	53.05 (5.80)	48.43 (6.10)

Numbers in parentheses represent the standard deviation of ten replicates
Mean Lightness (L*) value of the three wood surfaces (tangential, radial, transversal)

Contrary to mechanical properties tendency that was previously analyzed, the most intensive decrease of *L** parameter and therefore, colour change was caused and recorded at the duration of 4 hours. *L** parameter tends to decrease as well as mechanical strength, with the increasing of treatment time period. This fact indicates that many components absorbing visible light are formed during heat treatment. These colour parameter values of thermal treated pinewood were correlated with the values of mechanical properties using first and second degree relations, presenting the following equations (Table 2).

According to the correlation results and generated equations, a strong correlation between the mean *L** values, of the three wood surfaces (tangential, radial and transversal) and the mechanical strength of treated pine wood, referring to mean static bending and impact bending strength values of wood was found. The accuracy of the estimation of bending strength using colour (mean *L**) as an index appeared to be quite high, since the coefficient of determination (r^2) ranged from 0.73 for the linear regression up to 0.99 for the second degree polynomial regression. Indicatively, according to the linear equation (y=38.59+0.58*x), if *L** marks a decrease of 20 units, the MOR strength values would have marked a decrease of 11.6 units, while according to polynomial equation this decrese would be 2.4 units, respectively, which was much closer to real values that were found.

Table 2

Equations of covariance between mean values of Lightness (L*) and the Mechanical properties of Scots pine wood

Correlations	Type of regression	Equation	Coefficient of determination (r^2)
***L** parameter – Bend. Strength**	Linear regression	y=38.59+0.58*x	0.73
	Second degree polynomial regression	y= -0.03539*x^2+5.026*x-94.45	0.99
***L** parameter – Impact. Bend. Strength**	Linear regression	y=1.40+0.02*x	0.76
	Second degree polynomial regression	y= -0.0008726*x^2+ 0.1278*x-1.884	0.93

The calculated equations connecting colour with bending strength give the opportunity to estimate quite accurately the bending strength of wood specimens of each thermal treatment, from the respective *L** value of the corresponding wood piece and vice versa, as it is easily comprehended (Table 3). Similarly to bending strength, the equations of covariance between the impact bending strength values of treated wood and the respective values of *L** also, tend to present a quite strong relation. Specifically, coefficient of determination (r^2) obtained by the linear regression was measured to be 0.76, while the second degree polynomial model relation showed a very high coefficient of determination of 0.93.

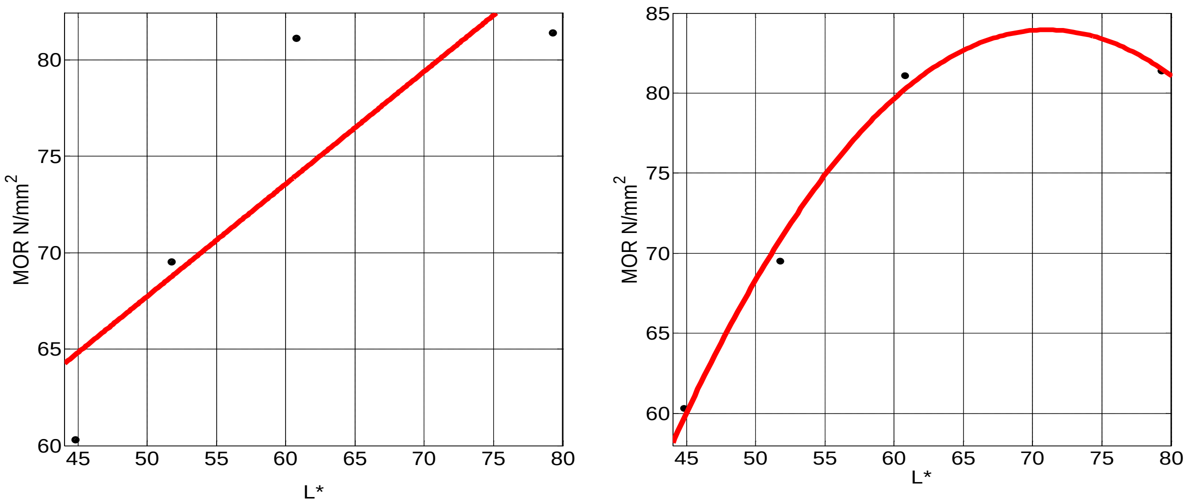


Fig. 1.
Linear (left) and Second degree polynomial (right) regression between the L* parameter and the bending strength (MOR) of Scots pine wood

According to the results, the variable *L** seems to be severely influenced by the duration period of the thermal treatment, except for the temperature and initial moisture content of wood that previous researches have showed (Akgul and Korkut 2012). The changes in the brightness (*L**) are more pronounced in the initial stages of the thermal treatment (mostly within the first hours of treatment) and seem to be less severe in the subsequent hours of the process. Obviously, a rapid decrease in *L** parameter occurs early in the heat-treatment process, where the largest change can be found between 0 and 4 hours treatment, indicating that a short period of time is quite enough for the altering of the wood surface colour by heat. This kind of behavior also explains why the second degree relation and the polynomial model presented higher coefficient of determination (r^2) values in both of the cases of bending and impact bending strength, compared to linear model equations (Fig. 1, 2).

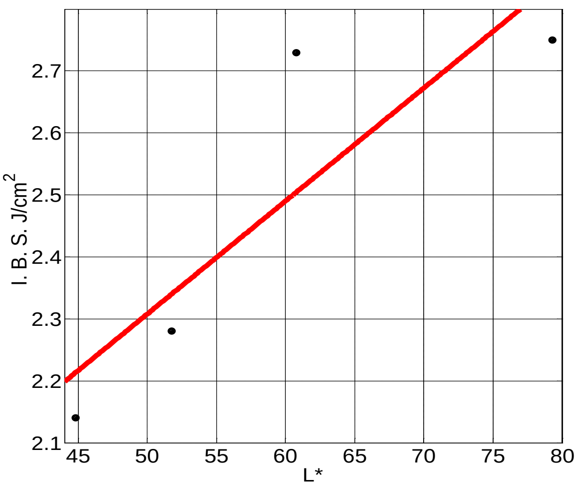
ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 11 N° 4 2015
pp. 360-365

Table 3

Comparison between the measured bending and impact bending strength values of Scots pine coming from this research and the respective values estimated by the colour values of wood using the linear and second degree regression

Time Treat.	MOR (N/mm^2)			I. B. S. (J/cm^2)		
	Measured values	Estimated by linear regression	Estimated by second degree regression	Measured values	Estimated by linear regression	Estimated by second degree regression
4h	81.11	73.83	80.27	2.73	2.61	2.66
6h	69.51	68.61	70.88	2.28	2.43	2.39
8h	60.31	64.58	59.72	2.14	2.29	2.09

The findings could be of great significance for the estimation of mechanical strength of heat treated wood, measuring only the colour of the specimens, without having to test and destroy large quantity of wood or following the time consuming method of strength investigation. As the strength of thermal treated wood appears to be often quite a complicated matter, further research should be conducted, including mechanical properties in combination with chemical composition tests, as well, and correlating the values of one factor to another.



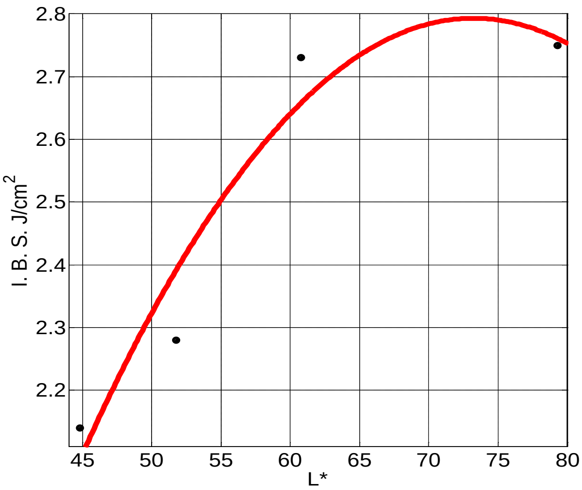


Fig. 2.
Linear (left) and Second degree polynomial (right) regression between L* parameter and Impact Bending strength values of Scots pine wood

CONCLUSIONS

Based on the results of this current project, it is concluded that as the intensity of the treatment increases (duration in this research), bending and impact bending strength values tend to decrease. Referring to bending and impact bending strength values of treated specimens, the decrease they recorded was initially negligible for the treatment duration of 4 hours, while as the treatment duration increases, the bending and impact bending strength values decreased abruptly and significantly. Generally, the results showed that treatment conditions of 200°C for 8 h resulted in the greatest decrease in mechanical properties, referring to MOR and impact bending strength. On the contrary, the changes in *L** are more pronounced in the initial stages of the thermal treatment (mostly within the first hours of treatment), while the change of *L** seem to be less severe in the subsequent hours of the process.

The results showed also a quite strong relationship, especially using a second degree polynomial regression, between lightness (*L**) parameter values and bending or impact bending strength of thermally treated pine wood. Therefore, mechanical strength of thermally treated under the specific conditions (in the presence of oxygen) Scots pine could be sufficiently estimated by measuring only the colour brightness of wood surface, following a less time labor and mainly a non material consuming method. The accuracy of this estimation method could be undoubtedly increased by expanding the reserach using higher range of treatment conditions, such as temperature level, time, boards dimensions etc. Additionally, it would be very interesting and helpful, mainly for manufacturers, to expand and deepen the research on the strength properties correlation of this and several other thermally treated wood species, using treatments under different conditions and following different methods, so that they would be able to comprehend and calculate accurately the strength and behavior of modified wood, by measuring only the colour parameters.

REFERENCES

Akgul M, Korkut S (2012) The effect of heat treatment on some chemical properties and colour in Scots pine and Uludağ fir wood. International Journal of Physical Sciences, 7(21):2854-2859, 30 May, 2012.

Ates S, Akyildiz MH, Özdemir H, Gumuskaya E (2010) Technological and chemical properties of chestnut (Castanea sativa Mill.) wood after heat treatment. Romanian Biotechnological Letters, 15(1).

Bekhta P, Niemz P (2003) Effect of high temperature on the change in colour, dimensional stability and mechanical properties of spruce wood. Holzforschung 57:539–546.

Bourgois PJ, Janin G, Guyonnet R (1991) The color measurement: A fast method to study and to optimize the chemical transformations undergone in the thermically treated wood. Holzforschung 45(5):377–382.

Gunduz G, Aydemir D, Karakas G (2009) The effects of thermal treatment on the mechanical properties of wild Pear (Pyrus elaeagnifolia Pall.) wood and changes in physical properties Materials and Design 30:4391–4395.

Johansson D (2005) Strenght and Colour Response of Solid Wood to Heat Treatment. Licentiate thesis. Luleå University of Technology, 2005:93.

Kamperidou V, Barboutis I, Vassiliou V (2014).Influence of Thermal Treatment on Mechanical strength of Scots Pine (Pinus sylvestris L.) wood. Wood Research 59(2):373-378.

Kamperidou V, Barboutis I, Vasileiou V (2013) Response of Colour and Hygroscopic properties of Scots Pine wood to thermal modification. Journal of Forestry Research, 24(3):571-575.

Patzelt M, Emsenhuber G, Stingl R (2003) Colour Measurement as means of Quality Control of Thermally Treated Wood. Proceedings of the first European conference on wood modification, Ghent, Belgium. April 3–4 2003.