Research Journal of Forestry

ISSN 1819-3439

Academic Journals Inc.

www.academicjournals.com

Research Journal of Forestry 5 (4): 162-168, 2011
ISSN 1819-3439 / DOI: 10.3923/rjf.2011.162.168
© 2011 Academic Journals Inc.

A Screening Study of Natural Colour of Wood from Different Geographical Regions

[1]I. El Bakali, [2]S. Yagi, [3]A. Merlin and [3]X. Deglise

[1]Laboratoire d'Analyse Physico-Chimique et Materiaux Catalytiques (LAPCMC), Faculté des Sciences Dhar El Mahraz, USMBA, Fez, Morocco

[2]Department of Botany, Faculty of Science, University of Khartoum, Khartoum, Sudan

[3]LERMAB UMR INRA/ENGREF/UHP 1093, Universite Henri Poincare, Nancy 1, France

Corresponding Author: I. El Bakali, Laboratoire d'Analyse Physico-Chimique et Matériaux Catalytiques (LAPCMC), Faculté des Sciences Dhar El Mahraz, USMBA, Fez, Morocco

ABSTRACT

The present study was a first step of a systematic comparative study on the surface colour of 83 wood species from different geographical regions. The colour measurements were monitored by CIE L*a*b* and CIE L*h*c* colour coordinated systems. Moreover, the exposure to light of a solar type in the conditions of accelerated ageing of 24 selected wood species made it possible to evaluate the stability of their natural colour. Generally the colour of wood from Europe and North America was lighter than the colour of the tropical wood form Africa and South America. The European woods showed wide variations in the stability of their natural colour while the African and darkest South American woods had highest stability. It was suggested that colour stability of wood was mainly attributable to the diverse chemical nature specific for each species.

Key words: Wood, different geographical regions, natural colour stability, colour measurements, accelerated aging effect

INTRODUCTION

The colour of wood is very important for its identification, aesthetic and commercial values. The variation of environmental factors such as solar radiation, humidity, pollution gases, temperature etc., affects the wood surface and its colour; its protection is of constant concern (Janin *et al*., 2001). The UV region of solar radiation causes the most damage to the wood surface, which is an excellent absorbing material (Hon and Feist, 1992). The photochemistry of this process is very complex and it is determined by the chemical composition of wood (Janin, 1987). Among the principal macromolecular components of wood (lignin, cellulose and hemicelluloses) it was found that, only the lignin has chromophores that absorb light energy and thus contributes 80-95% in the colour change by complex reactions forming free radicals species (Merlin and Deglise, 2001; Moore and Owen, 2000; Pastore *et al*., 2004). However, the phenolic extractives in general affect the wood colour and colour change to the greatest extent (Nzokou and Kamdem, 2006).

If natural wood is exposed to solar radiation, the exposure leads initially to a fast colour change due to absorption of all wavelengths of electromagnetic radiation and in the further stages to large chemical changes and breakdown of the surface layer (Ayadi *et al*., 2003; Deka and Petric, 2008).

On exposure to light, some woods become bleached or grey, others turn yellow, red-orange, or brown colour, depending on the effect of their extractives composition (Hon, 2001; Kamdem and Grelier, 2002).

There is a large body of literature concerning the colour of wood. The work on fir tree (*Abies grandis*) is significant because this wood is lacking coloured extractives and can be considered as a reference for the lightest-coloured wood in colour studies (Dirckx, 1988; Dirckx *et al*., 1992; Merlin and Deglise, 2001). European oak is another extreme frequently studied tree because of its slow but distinct colour change due to its high extractives content (Mazet *et al*., 1993; Merlin and Deglise, 2001). The comparison of the photo degradation of the heartwood and sapwood of oak has made it possible to understand the role of extractives in the process of colour change (Scalbert and Monties, 1987).

Although, the literature concerning the wood colour is immense it is difficult to find comparable data obtained with the same method for species from different geographical areas. The objectives of the present work were to produce colour data for 83 wood species from different geographical regions by the same method and to add it to the available data in this respect. Furthermore, from these wood species 24 species were selected to observe the wood colour change as function of their extractives content at artificial ageing conditions of irradiation with UV light of 365 nm for 800 h.

MATERIALS AND METHODS

Wood extraction: Extraction of wood samples was carried out with the accelerated extracting system ASE 200 of Dionex Co. After defatting with petroleum ether for 24 h, each wood sample was extracted with a solution of ethanol-water (70/30 v/v) at 100°C and 100 bars in two 5 min stages. Extracts were dried with a vacuum rotary evaporator at 40°C and the yield was determined.

Colour measurement and ageing system: The colour measurements (Bourgois *et al*., 1991) were carried out in the CIE- L*a*b* colour space using a spectrophotometer (Spectro-penlange) with a standard illuminant D65 and 10° circular illumination. The colour coordinates are calculated from the reflection data on the sample surface. In this colour range, a colour is defined by its Cartesian chromatic coordinates: lightness L* which varies from 0 (black) to 100 (white) and a* and b* coordinates which define the chromatic plane; negative values of a* indicate green while positive values indicate red, while the negative values of b* indicate blue and positive values indicate yellow. The difference in chromaticity is defined as $\Delta C = [(\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. The CIE L*a*b* system produces a fair correlation with the visual perceptions (Chrisment, 2000). Concerning the colour development during irradiation, it is useful to present the data in the CIE L*C*h* system which is more uniform (closer to the psycho-sensory assessment). The colour development can be derived simply from the CIE L*a*b* system by changing the Cartesian coordinates to cylindrical ones in the chromatic plane [a*, b*]. The chroma (concentration or degree of colour saturation) is defined then by $C^* = (a^{*2} + b^{*2})^{1/2}$ and the hue (saturation angle) h = arctan (b*/a*). The mean values of chromatic coordinates were calculated from ten measurements at different points on the radial surface of the sample (30×30 ×10 mm, L×T×R).

Accelerated ageing of the wood was carried out in a SEPAP chamber (MPC, France) equipped with standard pressure mercury vapour lamps with a light flow of 5 mW cm^{-2} at 365 nm. Samples,

rotating at constant speed and distance from the sources, were exposed during 800 h at 50°C. The variation of chromatic coordinates during irradiation was determined as:

$$\Delta\alpha^*(t) = \alpha^* \text{after irradiation at time t} - \alpha^* \text{ before irradiation}$$

Where:

$$\alpha^* = L^*; a^*; b^*; c^* \text{ or } h$$

The total colour change ΔE^* in the CIE L*a*b* system:

$$\Delta E^* = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$$

where, ΔL^*, Δa^* and Δb^* are changes between the initial and final value of L*; a* and b* values, respectively (Brock *et al.*, 2000).

RESULTS AND DISCUSSION

Natural colour diversity of wood species: The colour measurements carried out according to the CIE L*a*b* and the CIE L*C*h* systems of different wood species from different geographical origin are given in Table 1. Comparison between species of different geographical regions in their range of lightness indicated the following order in decrease of lightness from the European (51.1-84.5), North American (59.9-79.5), Asian (48.1-55.1), South American (36.3-81.2) to African (30.5-72.3) species. As expected the temperate woods from Europe and North America were lighter (i.e., they had higher L* values) than most of the species from Africa, South America and Asia, which are tropical woods richer in extractives (Khristova, 1996). An important correlation between the values of lightness L and the hue angle h was observed (Tolvaj and Nemeth, 2008). The more light-coloured (high L values) were the wood species the more yellow they were (h around 90°). However, *Peltogyne* wood (North America) had a peculiar behaviour in revealing a dark violet colour characterised by low L* value (36.3) and a very narrow colour angle (low value of b*-3.4 and high value of a*-11.3) at corresponding lowest hue angle of 16.5°.

Photo degradation under solar light: The total change in the wood colour (ΔE^*_{800}) for the 24 species selected from the species studied after 800 h of UVA irradiation at 365 nm is presented in Table 2. All species had their lightness after radiation decreased to a different degree depending on their original lightness. Generally it was observed that the change of colour during photo ageing was more pronounced in wood species of lighter colour i.e. with originally high L* values of above 55. The low and the negative values of ΔL^* indicated loss of lightness, which resulted in darkening of the wood. European species studied revealed a greater decrease in colour and photo stability, in addition to the known colour changes from season to season (perenniality). The dark African and darkest Southern American woods changed colourless under irradiation. The most intensive degree of discolouration observed was 23.9 and the lowest was 0.96 (Table 2), which is below the limiting value of discolouration that can be distinguished by naked eye of $\Delta E = 3$ (Pastore *et al.*, 2004). A peculiar behaviour of *Pterocarpus soyauxii* wood was that despite its dark colour ($L^* = 43.8$, Table 1) it underwent the most intensive total colour modifications ($\Delta E^*_{800} = 23.9$, L^*_{800} 13.6, a^*_{800}-19.6, b^*_{800} -0.73, Table 2). This could be due to the considerable presence of extractives (R = 13.0%)

Table 1: Colour characteristics of wood species from different geographical regions

Origin	Latin name	Common name	L*	a*	b*	C*	h°
Africa	*Khaya ivorensis*	Acajou	59.46	12.85	22.20	25.65	59.94
	Pericopsis elata	Golden teak	48.71	10.65	21.06	23.60	63.17
	Lophira alata	Ekki	36.95	10.16	11.04	15.00	47.38
	Nauclea diderrichii	Bilinga	48.47	16.93	29.17	33.73	59.87
	Guarera cedrata	scented guarea	60.12	12.31	19.35	22.93	57.54
	Guibourtia demeusei	Bubinga	43.49	16.70	15.28	22.64	42.46
	Piptadeniastrum africanum	Dahoma	54.29	9.790	23.29	25.26	27.20
	Copaifera salikounda	Etimoe	47.99	13.84	19.14	23.62	54.13
	Terminalia ivorensis	Idigbo	67.63	6.100	30.34	30.95	78.63
	Chlorophora excelsa	Iriko	63.56	8.530	31.42	32.56	74.81
	Nesogordonia papaverifera	Kotibé	41.16	16.08	17.65	23.88	47.66
	Terminalia superba	Frake	72.66	4.820	27.13	27.55	79.93
	Dumoria spp.	Douka	44.05	13.51	18.46	22.88	53.80
	Detarium macrocarpum	Mambode	37.86	11.42	15.13	18.96	52.95
	Baillonella toxisperma	pearwood	46.36	12.05	15.52	19.65	52.17
	Distemonanthus benthamianus	Ayan	70.69	5.620	37.51	37.93	81.48
	Tarrietia utilis	Niangon	47.16	14.77	22.57	26.97	56.80
	Triplochiton scleroxylon	Obeche (ayous)	78.52	5.670	25.14	25.77	77.29
	Pterocarpus soyauxii	Padauk	43.82	27.86	23.58	36.50	40.24
	Entandrophragma cylindricum	Sapele	51.73	13.57	21.40	25.34	57.62
	Entandrophragma utile	Utile	57.19	14.21	20.86	25.24	55.74
	Gossweilerodendron balsamiferum	Agba	60.10	9.700	23.70	25.60	59.90
	Millettia laurentii	Wenge	30.45	5.060	6.590	8.310	52.48
	Quercus suber	Oak cork	54.46	6.960	18.32	19.60	69.20
	Quercus rotundifolia	Holm oak	51,16	8.300	16.98	18.90	63.95
	Cedrus atlantica	Cedar	73.03	7.480	24.52	25.64	73.04
	Eucalyptus camaldulensis	Eucalypt	64.45	10.83	19.27	22.10	60.66
	Tetraclinis articulata	Thuja	47.43	8.580	14.06	16.47	58.61
North America	*Quercus alba*	White oak	63.55	8.690	23.02	24.61	69.32
	Quercus rubra	Red oak	66.80	10.67	24.46	26.69	66.43
	Acer saccharum	Maple	79.53	5.350	19.00	19.74	74.27
	Tsuga heterophylla	Hemlok	68.39	9.920	23.17	25.20	66.82
	Prunus serotina	Merisier	68.35	7.200	18.60	19.94	68.84
	Pinus edulis	Caroline pine	71.03	9.200	32.85	34.11	74.35
	Pinus rigida	Pitchpine	59.86	13.20	27.78	30.76	64.58
	Juniperus virginiana	Red cedar	67.38	10.60	22.45	24.83	64.73
South America	Peltogyne spp.	Amaranth	36.32	11.33	3.350	11.81	16.47
	Aspidosperma spp.	Araracanga	57.77	16.49	34.80	38.51	64.65
	Dycorynia paraensis	Opepe	43.17	12.22	19.11	22.68	57.40
	Cedrela spp.	Cedar	56.93	14.63	25.11	29.06	59.77
	Micropholis spp.	Curupixa	67.35	10.98	23.16	25.63	64.63
	Eucalyptus robusta	Eucalyptus	67.88	7.090	17.14	18.55	67.53
	Roupala sessilifolia	Faeira	47.65	13.16	17.52	21.91	53.09
	Tabebuia spp.	Ipe	45.09	11.23	21.47	24.23	62.39
	Hymenaea courbaril	Locnst	49.60	16.34	22.34	27.68	53.82
	Roupala brasiliensis	Lauro Faia	55.05	13.43	21.69	25.51	58.23
	Ocotea rubra	Determa	53.70	14.12	21.80	25.97	57.07
	Manilkara bidentata	Bulletwood	38.49	10.66	11.58	15.74	47.37

Table 1: Continued

Origin	Latin name	Common name	L*	a*	b*	C*	h°
	Pinus radiata	Pine radiata	81.85	4.71	23.51	23.98	78.67
	Diplotropis purpurea	Sucupira	43.33	8.00	15.23	17.20	62.29
	Bagassa guianensis	Tatajuba	50.04	12.24	25.74	28.50	64.57
	Couratari spp.	Tauari	62.32	5.810	19.78	20.62	73.63
	Gossipiospermum praecox	Zapatero	73.32	3.420	36.41	36.57	84.63
Asia	*Heritiera javanica*	Mengkulang	53.53	12.28	18.94	22.57	57.04
	Shoria curtusii	Méranti	55.10	9.290	18.42	20.63	63.24
	Intsia bakerie	Merbau	48.14	16.70	24.02	29.25	55.19
	Tectona grandis	Teak	49.90	10.27	25.41	27.41	67.99
Europe	*Alnus glutinosa*	Alder	75.25	8.740	23.06	24.66	69.24
	Betula spp	Birch	81.96	4.820	23.57	24.06	78.44
	Cedrus libani	Cedar	70.02	9.120	27.27	28.75	71.51
	Carpinus betulus	Charme	76.26	4.400	20.30	20.77	77.77
	Castanea sativa	Chesnut	66.37	8.100	22.49	23.90	70.19
	Quercus pedunculata	Oak	63.44	7.540	22.56	23.79	71.52
	Quercus ilex	Holm oak	51.06	7.810	15.72	17.55	63.58
	Cupressus macracarpa	Zipresse	74.51	6.500	27.57	28.42	75.95
	Picea abies	Spruce	84.22	3.700	23.77	24.06	81.15
	Acer pseudoplatanus	Maple	85.70	2.130	23.98	24.07	84.92
	Gleditzia tricanthos	Fevier	72.36	10.08	24.40	26.40	67.55
	Fraximus excelsior	Ash	76.33	6.450	22.86	23.75	74.24
	Fagus sylvatica	Beech	69.53	8.540	18.51	20.39	65.23
	Larix decidua	Larch	67.12	10.94	26.54	28.71	67.60
	Prunus avium	Merisier	70.24	7.660	19.46	20.91	68.51
	Juglans regia	Noyer	64.00	6.950	17.85	19.16	68.73
	Ulmus spp.	Elm	59.30	9.140	20.60	22.54	66.07
	Populus alba	Poplar	84.46	1.850	19.49	19.58	84.58
	Pinus pinaster	Pine	76.93	6.470	23.99	24.85	74.91
	Pinus sylvestris	Pine	74.70	9.940	29.29	30.93	71.25
	Platanus acerifolia	Plane	76.45	4.250	16.81	17.34	75.81
	Robinia pseudoacacia	Robinier	60.00	8.740	27.20	28.57	72.19
	Abies grandis	Vancouver fir	80.15	4.150	19.95	20.38	78.25
	Salix spp	Saule	70.55	11.21	21.61	24.34	62.58
	Tilia vulgaris	Tilleul	72.35	6.950	22.48	23.53	72.82
	Liriodendron tulipifera	Yellow poplar	72.94	1.010	23.22	23.24	87.51

L*, brightness a*, b* colour coordinates C, chroma h, hue angle

of low photochemical stability. Furthermore it was observed that the wood species with the exception of African *Pterocarpus soyauxii* (ΔE^*_{800} = 23.9, R = 13.0%) and *Millettia laurentii* (ΔE^*_{800} = 14.1, R = 14.4%) species, most affected by solar radiation contained less extractives (R). The opposite was true for the species with low extractives content that had low ΔE^*_{800} and were less affected by irradiation, except for African *Lophira alata* (R = 3.4%) and Asian *Shoria curtusii* (R = 4.6%) and *Intsia bakerie* (R = 4.0%) species (Table 2). It is well known that different wood from different species contain extractives of diverse chemical nature and quantity (Fengel and Wegner, 1984). Thus it is not surprising that the irradiation with UVA at 365 nm during 800 h had affected in a different way the wood colour of the different species studied.

Table 2: Extractives content and colour variation after artificial ageing of selected wood species from different geographical origin

Latin name	Origin	L*	L^*_{800}	a*	a^*_{800}	b*	b^*_{800}	h°	DE^*_{800}	R,%
Copaifera salikounda	Africa	47.99	3.97	13.84	-3.11	19.14	1.45	54.13	5.25	9.2
Distemonanthus benthamianus	Africa	70.69	-9.28	5.62	6.53	37.51	-2.32	81.48	11.58	7.4
Guibourtia demeusei	Africa	43.49	0.30	16.70	-5.53	15.28	2.66	42.46	5.96	9.0
Lophira alata	Africa	36.95	3.97	10.16	-3.11	11.04	1.45	47.38	3.64	3.4
Millettia laurentii	Africa	30.45	13.30	5.06	-1.76	6.59	4.19	52.48	14.10	14.4
Nauclea diderrichii	Africa	48.47	-2.13	16.93	-3.93	29.17	-5.25	59.87	6.89	10.2
Nesigordonia papaverifera	Africa	41.16	0.61	16.08	-7.38	17.65	-4.10	47.66	8.46	5.7
Pterocarpus soyauxii	Africa	43.82	13.60	27.86	-19.60	23.58	-0.73	40.24	23.88	13.0
Tetraclinis articulata	Africa	47.43	0.12	8.58	0.25	14.06	4.36	58.61	4.38	10.2
Shoria curtusii	Asia	55.10	-0.44	9.29	-0.55	18.42	-3.62	63.24	3.69	4.6
Heritiera javanica	Asia	53.53	3.00	12.28	3.14	18.94	4.47	57.04	6.23	2.0
Intsia bakerie	Asia	48.14	0.78	16.70	-4.27	24.02	-2.45	55.19	4.98	4.0
Tectonia grandis	Asia	49.90	1.33	10.27	0.00	25.41	-1.75	67.99	2.20	10.6
Quercus ilex	Europe	51.06	-4.48	7.81	2.40	15.72	1.46	63.58	5.25	11.7
Populus alba	Europe	84.46	-11.50	1.85	8.03	19.49	12.30	84.58	18.67	2.9
Gleditzia tricanthos	Europe	72.36	-13.10	10.08	2.60	24.40	1.08	67.55	13.44	7.8
Juglans regia	Europe	64.00	-0.06	6.95	2.38	17.85	7.62	68.73	7.98	8.4
Prunus serotina	North America	68.35	-3.71	7.20	-1.63	18.60	-3.62	68.84	5.42	7.9
Couratari spp	South America	62.32	-4.46	5.61	3.70	19.78	7.06	73.63	9.12	6.1
Eucalyptus robusta	South America	67.88	-2.40	7.09	-3.71	17.14	3.74	67.53	5.78	5.2
Pinus radiata	South America	81.85	-16.10	4.71	7.40	23.51	8.70	78.67	19.31	1.4
Tabebuia spp.	South America	45.09	5.45	11.23	0.11	21.47	4.21	62.39	6.89	14.0
Diplotropis purpurea	South America	43.33	0.60	8.00	-0.30	15.23	0.70	62.29	0.96	13.8
Micropholis spp.	South America	67.35	-1.13	10.98	-1.76	23.16	6.04	64.63	6.39	5.8

L^* , L^*_{800} brightness in CIE L*, a*, b* system for untreated and aged species*, b* and a*800, b*800 colour coordinates in CIE L*, a*, b* system for untreated and aged species h hue angle in CIE L*, a*, b* system DE^*_{800} total change in colour after ageing R extractives content

CONCLUSIONS

European wood species with light colour showed a wide variation both in colour and photo stability. African and darkest South American woods, which were dark from the very beginning, did change colour less upon irradiation. The observed differences in the photo stability of the different wood species seems dependent not on the extractives quantity but on their diverse chemical nature. The effect of extractives nature on colour stability should be studied for each species individually.

REFERENCES

Ayadi, N., F. Lejeune, F. Charrier, B. Charrier and A. Merlin, 2003. Colour stability of heat-treated wood during artificial weathering. Eur. J. Wood Wood Prod., 61: 221-226.

Bourgois, P.J., G. Janin and R. Guyonnet, 1991. The colour measurement: A fast method to study and to optimize chemical transformations undergone in the thermally treated wood. Holzforschung, 45: 377-382.

Brock, T., M. Groteklaes and P. Mischke, 2000. European Coating Handbook. Vincentz Verlag, Hannover, Germany, pp: 370-373.

Chrisment, A., 2000. Color by the numbers. CD ROM Datacolor International, 3C-Conseil.

Deka, M. and M. Petric, 2008. Photo-degradation of water borne acrylic coated modified and non-modified wood during artificial light exposure. Bio Resour., 3: 346-362.

Dirckx, O., 1988. Etude du comportement photochimique de *l'Abies grandis* sous irradiation solaire. Ph.D. Thesis, University H. Poincare, Nancy, France.

Dirckx, O., M.C. Triboulot, A. Merlin and X. Deglise, 1992. Modifications de la couleur du bois *d'Abies grandis* expose a la lumiere solaire. Ann. Sci. For., 49: 425-477.

Fengel, D. and G. Wegner, 1984. Wood: Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin, ISBN: 9783110084818, Pages: 613.

Hon, D.N.S. and W.C. Feist, 1992. Hydroperoxidation in photoirradiated wood surfaces. Wood Fiber Sci., 24: 448-455.

Hon, D.N.S., 2001. Weathering and Photochemistry of Wood. In: Wood and Cellulosic Chemistry, Hon, D.H.S. and N. Shiraishi, (Eds.). Marcel Dekker, New York, pp: 512-546.

Janin, G., 1987. Mesure de la couleur: Interet forestier et industriel. Ann. Sci. For., 44: 455-472.

Janin, G., J. Goncalez, R. Ananias, B. Charrier, A. Dilem, F. da Silva and A. Dilem, 2001. Aesthetics appreciation of wood colour and patterns by colorimetry: Part 1. Colorimetry theory for the cielab system. Madears Ceincia Technol., 1: 3-11.

Kamdem, D.P. and S. Grelier, 2002. Surface roughness and colour change of copper amine and UV absorber-treated red maple (*Acer rubrum*) exposed to artificial ultraviolet light. Holzforschung, 56: 473-478.

Khristova, P., 1996. Tropical Wood Chemistry. Khartoum University Press, Khartoum.

Mazet, J.F., M.C. Triboulot, G. Janin, A. Merlin and X. Deglise, 1993. Modifications de la couleur du bois de chenes europeens expose a la lumiere solaire. Ann. Sci. For., 50: 119-146.

Merlin, A. and X. Deglise, 2001. Comportement photochimique du bois non traite. In: Durabilite des Bois et Problemes Couples. Hermes Sciences Publications, pp: 229-276.

Moore, A.K. and N.L. Owen, 2000. Infrared spectroscopic studies of solid wood. Applied Spectrosc. Rev., 36: 65-86.

Nzokou, P. and D.P. Kamdem, 2006. Influence of wood extractives on photo-discolouration of wood surfaces exposed to artificial weathering. Color Resh. Applied, 31: 524-543.

Pastore, T.C.M., K.O. Santos and J.C. Rubin 2004. A spectrocolorimetric study on the effect of ultraviolet irradiation of four tropical hardwoods. Bioresource Technol., 93: 37-42.

Scalbert, A. and B. Monties, 1987. Comparison of the lignin and phenolic contents in the heartwood and sapwood of oaks. INRA Report, INA Grignon., France.

Tolvaj, L. and K. Nemeth, 2008. Correlation between hue-angle and colour lightness of steamed black locust wood. Acta Silv. Lign. Hung., 4: 55-59.