The effect of dry heat treatment on physical properties of *Acacia mangium* and *Acacia auriculiformis* from Vietnam*

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ABSTRACT

Acacia mangium and *Acacia auriculiformis* are among the most important plantation trees in South-east Asia and particularly in Vietnam. Up till now their wood has been used mainly as pulpwood, but they are suitable for the purposes of timber and furniture industry as well. The aim of our research was to test the effect of dry thermal treatment on these woods to give a base to extend their industrial use. *Acacia mangium* and *Acacia auriculiformis* samples were transported to our laboratory from Hoa Binh province of Vietnam.

The treatment was performed with a schedule at 180° C degrees and 15 hours duration. After the treatment we measured the density, shrinkage, equilibrium moisture content, and compared to those of the samples of untreated wood. Also we measured the change of the colour properties. The colour changes were measured according to the CIELab measuring system by a Konica-Minolta CM-2600d spectrophotometer equipment.

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Changing of physical properties was as follows: Normal density decreased considerably in case of *Acacia mangium* and more significantly in case of *Acacia auriculiformis*. Swelling properties of both wood decreased significantly in all the three wood anatomical directions, therefore anti swelling efficiency increased significantly in case of both species. Equilibrium moisture content at normal climatic conditions (20°C, 65% RH) of both species decreased significantly.
As an effect of the thermal treatment, the Lightness (L*) values decreased in case of *Acacia mangium* and *Acacia auriculiformis* as well. The green-red (a*) component increased by significantly in case of both species (the colour turned to red direction). The blue-yellow (b*) component also increased in case of both species (the colour turned to yellowish direction).

INTRODUCTION

Forests of the Socialist Republic of Vietnam suffered serious damages during the second half of the twentieth century, as a consequence of the war with USA, overexploitation and other reasons. The government started huge afforestation program to establish forest plantations. *Acacia mangium* and *Acacia auriculiformis* are among the mostly planted species of the plantations. In 2009, more than 25% of the 2920 ha forest plantations in the country were *Acacias*. 91% of the logged wood is fuelwood, pulpwood and other industrial wood, only 9% is sawlog and veneer log (FAOSTAT). The wood processing and furniture industry at the same time has a tremendous demand of raw material. The wood of *Acacia* species in Australia and other countries is also used for furniture manufacturing. In the future more and more *Acacia* wood is expected to be used for furniture production purposes. Determining exact properties of Vietnamese *Acacia* wood and exploring its modification possibilities is an important issue. In the recent years several researches dealt with physical and mechanical properties, as well as workability of *Acacia* species, mostly in tropical countries. Thailandese researchers proved the suitability of local *A. mangium* for construction purposes. (Ouypornprasert et al. 2005) C. Tenorio et al. based and improved the industrial kiln drying of the wood of *A. mangium* plantations.
Our experiments aimed to test the main physical properties of *Acacia mangium* and *Acacia auriculiformis*. After finishing the tests with natural wood, we carried out a dry thermal treatment and measured the physical properties again. In the recent years a number of researches were carried out in the subject of thermal modification of wooden materials. It was proven, that equilibrium moisture content decreases, dimensional stability increases as an effect of thermal treatment in case of European hardwoods, like turkey

oak, beech and poplar. (Horváth N. 2008). Besides, colour of treated wood changes, lightness decreases, while red and yellowish components increases. As a comparison to the test results of *Acacias*, we used the respective figures of *Populus ×euramericana Pannonia* from the dissertation of Horváth N. (2008).

EXPERIMENTAL METHODS

Selection and preparation of samples

The wood samples were selected from 7-year-old trees of *A. mangium* and *A.auriculiformis* plantations from Hoa Binh province of Vietnam. The trees were cut to boards and kept together in Boules form and were transported to Hungary. Thus the original place of the boards was clearly seen. For the test of physical tests the samples were selected form the middle boards as it is shown in the Fig. 1.

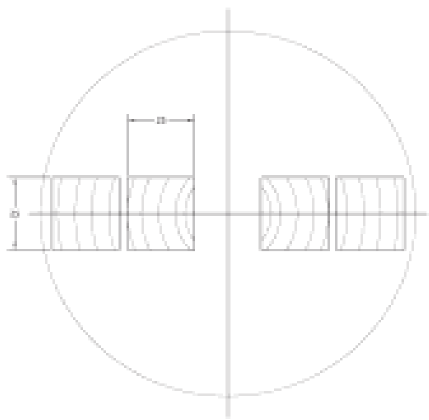

Figure 1: Selection of the samples from the tree

In case of all tests, the number of specimens were 25.

Schedule and heat treatment

Heat treatment was carried out in a 0,4 m^3 volume, insulated chamber, in atmospheric condition. Maximal temperature of treatment was 180°C for 15 hours duration. Initial moisture content of the samples was between 12%. ±2%.

Determination of equilibrium moisture content

The untreated and the treated samples were acclimatized under laboratory conditions in a Binder type equipment. Relative air humidity was 65% and temperature was 20°C (normal climate) The size of the samples were 20x20 mm in radial and tangential direction and 30 mm along grain according to MSZ 6786-2. Digital scales with 0,01 mm accuracy were applied for measuring. Equilibrium moisture content can be determined from the ovendry weight and the weight at the normal climate, which is measured after reaching the constant weight:

$$u = \frac{m_x - m_o}{m_o} \cdot 100 \quad (1)$$

where: u net moisture content, %
m_x wet weight, g
m_o ovendry weight, g

Determination of density

Samples for the determination of density were acclimatized at 65% relative air humidity and 20°C temperature: The sizes of the samples were 20x20 mm in radial and tangential direction and 30 mm in grain direction according to MSZ 6786-3. Sizes of the samples was measured by a slide calliper with 0,01 mm accuracy. Digital scales with 0,01 mm accuracy were applied for measuring the weight. Density of the samples was calculated with the formula as follows:

$$\rho = \frac{m}{l \cdot r \cdot t} \cdot 10^6 [\mathrm{kg/m^3}] \quad (2)$$

where: ρ density of the acclimatized sample
m weight of the acclimatized sample, g
l size of the sample in grain direction, mm
r size of the sample in radial direction, mm
t size of the sample in tangential direction, mm

Determination of dimensional stability

Terminology of the dimensional stability is in connection with the dimension change caused by the change of moisture content of the wood. Changing of water content bound in the wood structure results the swelling or shrinkage of wood. Changing of water content above saturation point doesn’t cause dimension change. The measurement of swelling is different in the three anatomical directions. It is the biggest in tangential direction, followed by radial and grain direction. Specimen blocks were placed in water till attaining full green volume. In this water saturated condition, the radial tangential and grain dimensions were marked and measured with a slide calliper with an accuracy of 0,01 mm . The blocks were then air dried for four days and oven dried at 105°C for further four days. The oven-dried blocks were then weighed and the dimensions were measured again along the points marked earlier using the same slide calliper. The ovendry to green swelling in radial and tangential directions of the same blocks was determined, expressed as a percentage of the saturated dimension to its ovendry dimension. The formulas used were

$$sw_{t,r,l} = \frac{x_{sat} - x_0}{x_0} \qquad sw_V = \frac{V_{sat} - V_0}{V_0} \qquad a_{sw} = \frac{sw_t}{sw_r} \qquad (3, 4, 5)$$

where: $sw_{t,r,l}$ linear swelling of the test specimen, % in t- tangential, r- radial, l- grain direction

sw_V volumetric swelling, %

x_{sat} dimension of the test block in the given anatomical direction, at/above saturation point, mm

x_o dimension of the test block in the given anatomical direction, at ovendry condition, mm

V_{sat} volume of test block at/above saturation point, mm3-ben

V_o ovendry volume of the test block, mm3
V=$x_r \times x_t * x_l$ in both cases

a_{sw} swelling anisotropy of wood

As the wood gets to ovendry condition during heat treatment, it was possible to measure the swelling caused by re-moisturizing and its corresponding parameters. Such parameters are swelling anisotropy (a_{sw}), which is determined as the quotient of maximal tangential swelling sw_t) and maximal radial swelling (sw_r).

Improvement of anti swelling efficiency (ASE_{sw}) is a result of decreased swelling and shrinkage as an effect of treatment. ASE anti-swelling efficiency is calculated by using the formula as follows, in all anatomical directions:

$$ASE_{sw} = \frac{sw_{control} - sw_{treated}}{sw_{control}} \qquad (6)$$

where: ASE_{sw} anti-swelling efficiency (+increase, -/decrease)
sw- in case of swelling
$sw_{control}$ swelling of untreated wood in the given anatomical direction, %
$sw_{treated}$ swelling of treated wood in the given anatomical direction, %

Colour measuring

Colour measuring was done by a KONICA-MINOLTA CM 2600d type colour spectrum measuring machine, with a 8 mm diameter opening. Measuring was controlled by a SpectraMagic NX computer software, using CIELab measuring system (Fig. 2.). In the CIELab system every colour is assigned to a point in a coordinate system.

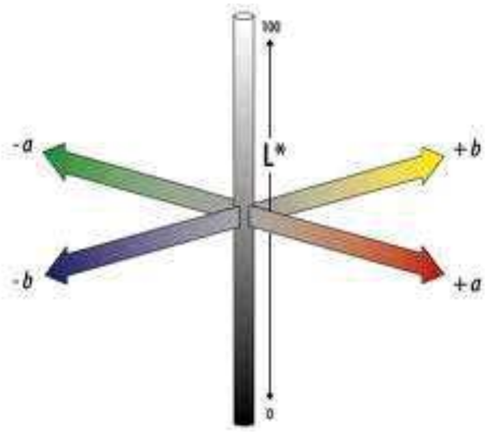

Figure 2. CIELab colour space system

Axes of the system are:
L*: positive direction is lightness, negative direction is darkness
a*: positive direction is red colour component, negative direction is green colour component
b*: positive direction is yellow colour component negative direction is blue colour component
Axes are perpendicular to each other.
Before the heat treatment sample blocks were acclimatized at normal air conditions (65% rel. h, 20°C temp.). Then they were marked and cut to two

pieces. One of the pieces was treated, the other one was the control block. This way the texture was the same in both pieces, the measured difference was clearly the effect of heat treatment.
Colour difference of the samples can be determined by counting the total colour difference parameter, which can be calculated from the colour coordinates using the formula below:

$$\sqrt{\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2}} \qquad (6)$$

Where : ΔE total colour difference of the samples
ΔL^* difference in lightness of treated and control samples ($L^*_{treated}$ - $L^*_{control}$)
Δa^* difference in red colour component of treated and control samples ($a^*_{treated}$ – $a^*_{control}$)
Δb^* difference in yellow colour component of treated and control samples ($b^*_{treated}$ - $b^*_{control}$)

When evaluating the total colour difference of samples the results are categorized into 5 groups. If ΔE is between 0-1, there is no difference
If ΔE is between 2-4, the difference is low
If ΔE is between 4-5, the difference is significant
If ΔE is above 5, the difference is very significant

RESULTS AND DISCUSSION

Change of equilibrium moisture content

After the treatment the equilibrium moisture content of the samples decreased significantly. The reason of the result can be explained by the decrease of the –OH groups in the wood and the spherical effect of the swelling. Diminishing of –OH groups in the wood components results the decreasing of the number of hydrogen-bridges of the water molecules, which determines the water bound in the cell walls.

Table 1: Change of equilibrium moisture content

U_{norm}	Untreated	Treated	Difference	Change [%]
Acacia mangium	12,26%	7,87%	-4,39%P	-35,81%
Acacia auriculiformis	12,17%	8,32%	-3,85%P	-31,64%
Populus eu. Pannónia	12,26%	9,59%	-2,67%P	-21,78%

Change of density

As an effect of thermal treatment chemical changes occur in the wood structure. Some components of the wood disappear as a result degradation. It causes the decreasing of the weight of the samples. At the same time, the matrix structure of the wood also changes. Both changes have an effect of the density. The two effects are opposite to each other.

Results of the tests were as follows:

Table 2: Change of density [kg/m^3]

Density	Untreated	Treated	Difference	Change [%]
Acacia mangium	496	473	-23	-4,64%
Acacia auriculiformis	569	465	-104	-18,28%
Populus eu. Pannónia	411	412	1	0,24%

Density of both *Acacia* species decreased. The degree of density change was -4,64% in case of the *A. mangium*, and -18,28% in case of *A. auriculiformis*.

As compared to the density change of the poplar, the rate of change of *Acacias* is much higher, as the respective data of the poplar is nearly 0.

Change of dimensional stability

Maximal swelling before and after heat treatment

The Table nr. 3. shows the values of maximal swelling in case of the untreated and the treated samples. The maximal swelling was measured as a quotient of the difference of the sizes of blocks above fibre-saturation point and sizes of ovendry blocks, divided by ovendry sizes. The value is given in percentage. We measured maximal swelling in case of all the three anatomical directions and calculated the volumetric swelling as well. Heat treatment decreased the values of swelling significantly in case of both species in all anatomical directions.

Table 3: Change of maximal swelling

Swelling	Species	Maximal swelling		Difference	Change [%]
		Untreated	**Treated**		
ST	*Acacia mangium*	7,47%	6,96%	-0,51%P	-6,83%
	Acacia auriculiformis	9,32%	6,38%	-2,94%P	-31,55%
	Populus eu. Pannónia	11,44%	7,93%	-3,51%P	-30,68%
SR	*Acacia mangium*	3,87%	3,25%	-0,62%P	-16,02%
	Acacia auriculiformis	3,28%	2,87%	-0,41%P	-12,50%
	Populus eu. Pannónia	4,60%	3,70%	-0,90%P	-19,57%
SL	*Acacia mangium*	0,95%	0,3%	-0,65%P	-68,42%
	Acacia auriculiformis	0,72%	0,32%	-0,40%P	-55,56%
	Populus eu. Pannónia	-.	-	-	-
SV	*Acacia mangium*	12,70%	10,80%	-1,90%P	-14,96%
	Acacia auriculiformis	13,72%	9,78%	-3,94%P	-28,72%
	Populus eu. Pannónia	-	-	-	-

Dimensional stability

The figure of dimensional stability shows the maximal difference of swelling of the treated material in the percentage of the same of the untreated material. Positive value means the increasing, negative value means the decreasing of dimensional stability.

Dimensional stability was calculated in all anatomical directions of both species. The values are summarized in the Table nr. 4. As a comparison, the relating figure of the poplar is shown. The values of dimensional stability show improvement in all anatomical directions in case of both species, similarly to the respective data of poplar.

Table 4: Dimensional stability

Characteristic	Species	Values
ASEt	*Acacia mangium*	3,76%
	Acacia auriculiformis	24,43%
	Populus eu. Pannónia	30,71%
ASE_r	*Acacia mangium*	14,30%
	Acacia auriculiformis	12,00%
	Populus eu. Pannónia	19,57%
ASE_l	*Acacia mangium*	64,14%
	Acacia auriculiformis	46,28%
	Populus eu. Pannónia	-
ASE_V	*Acacia mangium*	7,75%
	Acacia auriculiformis	22,51%
	Populus eu. Pannónia	-

Swelling anisotropy

Swelling anisotropy means the rate of maximal swelling in tangential and radial anatomical direction. Swelling anisotropy decreased significantly in case of *A. auriculiformis*, similarly to the respective data of poplar, however slightly increased in case of *A. mangium*.

Table 5: Change of swelling anisotropy

Species	Swelling anisotropy		Difference	Change [%]
	Untreated	Treated		
Acacia mangium	1,93	2,14	0,21	11%
Acacia auriculiformis	2,84	2,22	-0,62	-22%
Populus eu. Pannónia	2,54	1,98	-0,56	-22%

Change of colour

Lightness

All measurements were carried out on the heartwood of the samples. Original colour of *A. mangium* is rather light, L*value is cca 72, while *A. auriculiformis* is much darker, L* value is nearly 60. Lightness, the vertical coordinate of the CIELab colour space system decreased significantly in case of both tested material. The rate of decrease was very similar, 22,8% and 21,6% in case of *A. mangium* and *A. auriculiformis* respectively. These values were nearly the double of the relating value of the poplar.

Table 6: Change of lightness(L*)

Species	**L*(D65)**		**Difference**	**Change [%]**
	Original	**Treated**		
Acacia mangium	71,81	55,31	-16,50	-22,8%
Acacia auriculiformis	59,49	46,71	-12,78	-21,6%
Populus eu. Pannónia	84	76,24	-7,76	-9,2%

<u>Red colour component</u>

The values of red colour component (a*) were 6,42 and 7,66 of the untreated samples of *A. mangium* and *A. auriculiformis* respectively. As an effect of the thermal treatment, the values increased by 72,7% and 40,9%. Both materials turned to a reddish colour. As compared to the respective values of poplar, the direction of change is similar, however the rate of change is slightly smaller and considerably smaller in case of *A. mangium* and *A. auriculiformis*.

Table 7: Change of red colour component (a*)

Species	**a*(D65)**		**Difference**	**Change %**
	Original	**Treated**		
Acacia mangium	6,42	10,71	4,28	72,7%
Acacia auriculiformis	7,66	10,68	3,02	40,9%
Populus eu. Pannónia	3,63	6,51	2,88	79,3%

<u>Yellow colour component</u>

The value of red colour component (a*) were 22,49 and 24,47 of the untreated samples of *A. mangium* and *A. auriculiformis* respectively. As an effect of the thermal treatment, the values increased by 37,8% and 16,4%. Both materials turned to a yellowish colour. As compared to the respective values of poplar, the direction of change is similar. The percentage of change in case of poplar is between the two species of *Acacia*.

Table 8: Change of yellow colour component (b*)

Species	**B*(D65)**		**Difference**	**Change [%]**
	Original	**Treated**		
Acacia mangium	22,49	30,97	8,48	37,8%
Acacia auriculiformis	24,47	29,63	5,16	16,4%
Populus eu. Pannónia	18,42	21,83	3,41	18,5%

Total colour difference

The calculated total colour difference proves, that the colour change is very significant in case of both tested material. The total colour difference was higher in case of *A. mangium*, but the relating value of *A. auriculiformis* was also much higher, than that of the poplar.

Table 9: Total colour difference (b*)

Species	**Total colour difference ΔE**
Acacia mangium	19,03
Acacia auriculiformis	14,11
Populus eu. Pannónia	8,95

CONCLUSIONS

By completing the experiments of thermal treatment of *Acacia mangium* and *Acacia auriculiformis*, we proved that the change of physical properties of these tropical hardwoods is generally similar to the same of moderately hard European hardwoods. (The test results were compared to the same figures of *Populus* × *euramericana* Pannónia.)

Equilibrium moisture content decreased significantly in case of both species, especially in case of *A. auriculiformis*. Density decreased considerably, which shows, that degradation of the wood structure starts at the temperature of the applied thermal treatment (180°C). Anti swelling efficiency increased considerably as an effect of the heat treatment. This property is important when processing the wood.

Change of colour components was also similar to that of the European hardwoods and especially poplar: value of lightness decreased, while value of red and yellow components increased. This property can be well used in the industrial processing of *Acacias*, as favourable darker coloured wood can be gained by thermal treatment.

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