Leaflet No.

The Republic of the Union of Myanmar
Ministry of Natural Resources and Environmental Conservation

The 36th Research Congress on Forestry, Mining and Environment

Water-related Properties of Two Myanmar Timber Species Modified with Melamine Resin

Dr. Khin Maung Sint, Rector
University of Forestry and Environmental Science

February, 2025

Contents

List of Tables

Lists of Figures

Water-related Properties of Two Myanmar Timber Species Modified with Melamine Resin

Dr. Khin Maung Sint, Rector

University of Forestry and Environmental Science

Abstract

Water-related properties of melamine-treated and untreated *B. ceiba* and *B. insigne* heartwood were investigated and the efficacy of melamine treatment to a varying degree of resin load on these properties discussed. The tests performed were anti-swelling efficiency, sorption and capillary water uptake. The main properties measured were anti-swelling efficiency (ASE), radial, tangential and volumetric swelling, swelling anisotropy, coefficient of swelling, differential swelling coefficient, two types of equilibrium moisture content (EMC), fiber saturation point (FSP), water uptake and water diffusion coefficient. Solution uptake, weight percent gain and solid resin retention were calculated and presented as important indices to treatability. Treatment with melamine caused a reduction in radial, tangential and volumetric swelling, and resulted in ASE of up to 61% at about 35% WPG. The amount of water adsorbed by the treated and control specimens were the same at RH ≤90%, the reduction in EMC on the basis of oven-dry weight after treatment being due to the mere mass of impregnated melamine resin. Fiber saturation point and EMC at 95% RH were, however, greatly reduced. Similarly, the water uptake was significantly retarded by melamine treatment and subsequently higher WREs were achieved in both species.

Keywords: Anti-swelling efficiency, weight percent gain, equilibrium moisture content, fiber saturation point, water uptake

မယ်လမင်းအစေးသွင်းထားသော မြန်မာ့သစ်နှစ်မျိုး၏ ရေနှင့်ဆက်စပ်နေသော ဂုဏ်သတ္တိများ

ဒေါက်တာခင်မောင်ဆင့်၊ ပါမောက္ခချုပ်
သစ်တောနှင့်ပတ်ဝန်းကျင်ဆိုင်ရာတက္ကသိုလ်

စာတမ်းအကျဉ်း

မယ်လမင်းအစေးသွင်းထားသည့် လက်ပံနှင့် ဒီဒူးအနှစ်သားတို့၏ ရေနှင့်ဆက်စပ်နေသော ဂုဏ်သတ္တိများကို စမ်းသပ်ထားပြီး အဆိုပါဂုဏ်သတ္တိများအပေါ် (သစ်သားအတွင်း) မယ်လမင်း ပမာဏအမျိုးမျိုး ဝင်ရောက်မှု၏ သက်ရောက်မှုများ၊ အကျိုးရှိမှုများကို ဆွေးနွေးထားပါသည်။ စမ်းသပ်ထားသော ဂုဏ်သတ္တိများတွင် ကြွခြင်းလျော့နည်းသွားမှု၊ နှစ်ကွင်းထောင့်မှန်ကျကြွမှု၊ နှစ်ကွင်းအပြိုင်ကြွမှု နှင့်ထုထည်လိုက်ကြွမှု၊ကြွခြင်းမညီမျှမှု(T/R)၊ စိုထိုင်းဆ အပြောင်းအလဲကြောင့် ကြွမှုပြကိန်း၊ အစိုဓာတ် ပါဝင်ပြောင်းလဲမှုကြောင့် ကြွမှုပြကိန်း၊ မျှခြေအစိုဓာတ်ပါဝင်မှုများ၊ ဖိုင်ဘာမျှင်များ ရေပြည့်ဝအမှတ်၊ ရေစုပ်ယူမှုနှင့် ရေပုံ့နှံ့မှုပြကိန်းများကို စမ်းသပ်တွက် ချက်တင်ပြထားပါသည်။ မယ်လမင်းဖျော်ရည် ဝင်ရောက်မှု၊ အလေးချိန်တိုးမှုရာခိုင်နှုန်း၊ သစ်သားအတွင်း မယ်လမင်းအစေး ဝင်ရောက်မှုပမာဏတို့ကို တွက်ချက်ထားပြီး အဆိုပါသစ်များ၏ ဆေးသွင်းရန် လွယ်ကူမှုပြညွှန်းကိန်းများအဖြစ် တင်ပြထားပါသည်။ မယ်လမင်းအစေးသွင်း လိုက်သည့်အတွက် ကြွမှုအားလုံး (နှစ်ကွင်းထောင့်မှန်ကျ၊ အပြိုင် နှင့် ထုထည်လိုက်ကြွမှု) လျော့ကျသွားပြီး အလေးချိန်တိုးမှု ၃၅ ရာခိုင်နှုန်းခန့်တွင် ကြွမှုသည် ၆၁ ရာခိုင်နှုန်းအထိ လျော့ကျသွားပါသည်။ မယ်လမင်း သွင်းထားသော နမူနာတုံးငယ်များနှင့် မသွင်းသော နမူနာတုံးငယ်များသည် စိုထိုင်းဆ ၉၀ ရာခိုင်နှုန်းအောက်တွင် ရေစုပ်ယူမှုမှာအတူတူပင်ဖြစ်ပါသည်။ အနည်းငယ်လျော့နည်းသွားသည်မှာ မယ်လမင်း အစေးဝင်ရောက်သည့် ပမာဏသာလျှင်ဖြစ်ပါသည်။ သို့ရာတွင် စိုထိုင်းဆ ၉၅ ရာခိုင်နှုန်းတွင် ဖိုင်ဘာမျှင်များရေပြည့်ဝမှတ်နှင့် မျှခြေအစိုဓာတ်ပါဝင်မှုတို့မှာ သိသိသာသာ လျော့ကျသွားပါသည်။ ထို့အတူ မယ်လမင်းအစေးသွင်းခြင်းကြောင့် ရေစုပ်ယူမှုမှာလည်း သိသာစွာလျော့ကျသွားပြီး ရေပယ်နိုင်မှုစွမ်းရည်မှာလည်း သစ်မျိုးနှစ်မျိုးလုံးတွင် ကောင်းမွန်ကြောင်း တွေ့ရှိရပါသည်။

Water-related Properties of Two Myanmar Timber Species Modified with Melamine Resin

1. Introduction

Wood is a hygroscopic material and possesses sorptive nature. When placed in a new environment, it undergoes the exchange of water vapor with the surrounding air until moisture equilibrium is established with the air. This exchange of water vapor below fiber saturation point affects physical, mechanical, elastic and thermal properties, and resistance to biological deterioration (Bowyer et al. 2007; Rowell 2005). When wood gains moisture, mechanical strength decreases, thermal and electrical conductivity increases, and the rate of bond water diffusion increases (Siau 1984). Weathering of wood is also affected by changes in moisture content (Forest Products Laboratory 1999), although principally initiated by the UV light from solar energy.

Gain or loss of moisture below fiber saturation point changes dimensions of wood. As it gains moisture in its cell walls, it swells and when it loses moisture from its cell walls, it shrinks. This swelling and shrinking can result in warping, checking, splitting, loosening tool handles, gaps in strip flooring, etc. (Forest Products Laboratory 1999). In fact, movement (shrinkage or swelling) of wood is the result of water adsorption or desorption by the hydroxyl groups present in the wood matrix constituents. Thus, many attempts have been made to reduce the hygroscopicity of timber and hence to stabilize it by eliminating these groups or reducing their accessibility to water. This can be accomplished by chemical changes or by introducing physical bulking agents (Dinwoodie, 2000).

Acetylation is one of the most effective systems that reduce the hygroscopicity and improve wood stability. Goldstein et al. (1961) acetylated 12 timber species and found enhanced dimensional stability and reduced equilibrium moisture content. These results were in agreement with the current research findings (Thygesen et al. 2010; Rowell et al. 2009; Rowell 2006; Minato et al. 2003; Ramsden et al. 1997). The reduction in hygroscopicity and enhancement in dimensional stability of acetylated wood is attributable to the replacement of hydroxyl groups on the cell wall polymers with bonded acetyl groups and the bulking of bonded acetyl groups (Rowell et al. 2009; Rowell 2006;). However, this system also led to reduction in mechanical properties of solid wood although it is not significant in most cases (Papadopolous 2008; Jorissen et al. 2005; Ramsden et al. 1997; Larsson and Simonson 1994; Dreher et al. 1964; Narayanamurti and Handa 1953). There are still some reports on the improvement of these properties, especially fiber stress at proportion limit and modulus of rupture in static bending, compressive strength perpendicular to the grain and hardness (Dreher et al. 1964; Goldstein et al. 1961). Impact bending was not significantly unchanged by acetylation (Dreher et al. 1964; Goldstein et al. 1961).

Thermal modification also reduced moisture uptake and differential swelling, thus leading to enhancement of dimensional stability while mechanical properties were greatly diminished, especially impact bending (Johansson and Moren 2006; Chikova et al. 2005; Christmas et al. 2005; Esteves et al. 2005; Metsa-Kortelainen 2005; Scheiding et al. 2005; Tremblay and Lihra 2005; Yildiz et al. 2005).

Other systems such as application of oil-based or alkyl-based finishes, and reaction of wood with formaldehyde under acidic condition, polyethylene glycol (PEG), phenol formaldehyde, various epoxides, anhydrides and isocyanates have shown to reduce hygroscopicity and to improve dimensional stability (Dinwoodie 2000).

Melamine formaldehyde and melamine urea formaldehyde resins are thermosetting resins primarily used for exterior and semi-exterior plywood and particleboards, finger-joints and for overlays (Frihart 2006; Pizzi 2003). Due to the improved moisture resistance and enhanced durability of the products treated with these resins, the technology has been transferred to improving multiple properties of solid wood. Different formulations of melamine resin have demonstrated to enhance dimensional stability (Deka et al. 2007; Lukowsky 2002; Deka and Saikia 2000; Miroy et al. 1995; Rapp and Peek 1995; Pittman et al. 1994) and hydrophobicity (Epmeier et al. 2004; Deka and Saikia 2000; Pittman et al. 1994) depending on the degree of resin load. Moreover, several authors described improved weathering resistance (Hansmann et al. 2006), reduced discoloration (Müller and Steiner 2009), and enhanced biological resistance (Westin et al. 2006; Krause et al. 2004; Rapp and Peek 1996) by modification with melamine resins. The water resistance of melamine-treated products is due to the condensation reaction to form oligomers and polymers, which is not reversible (Frihart 2005). Moreover, melamine resin acts as a photometrically inert matrix and absorbs no light wavelengths longer than 280 nm, thus improving weathering resistance (Müller and Steiner 2009).

Treatment with melamine resin also improved hardness (Epmeier et al. 2004; Gindl and Gupta 2002; Miroy et al. 1995), and elastic properties (Epmeier et al. 2004; Gindl and Gupta 2002; Deka and Saikia 2000) and mechanical strengths (Epmeier et al. 2007). Transverse compression strength is far from satisfaction in wood utilization, which is positively influenced stronger than other mechanical properties by melamine treatment (Gindl et al. 2003). The enhancement of these mechanical strengths can be seen as advantages over acetylation and heat treatment.

Thus, this paper was designed to assess the effect of modification with melamine resin on dimensional stability and hydrophobicity of two light tropical timber species. Water-related properties such as anti-swelling efficiency, differential swelling, water diffusion coefficients, and equilibrium moisture contents at different relative humidity environments were investigated for melamine-treated wood and the effect of resin loads on them discussed.

2. Materials and methods

2.1. Materials

The timber species investigated were *Bombax ceiba* and *B. insigne* harvested from deciduous forests of Myanmar. Myanma Timber Enterprise provided with two five-meter long logs per species, each with an average mid diameter of 70 cm. After conversion into lumbers 50 mm (R) x 125 mm (T) x 5 m (L), they were dried in a kiln regulated at a temperature of 50-55ºC to around 12% moisture content. Then, the lumbers were stacked in an open shed with roof, from which wood specimens were prepared for this research.

2.2. Sample preparation

Wood specimens were prepared from the randomly selected kiln-dried lumber heartwood and oven-dried at 103±2ºC for 48 hours. After cooling down, their dimensions (L_1) and weight (W_1) were measured and conditioned at 65% relative humidity and 20ºC until they were impregnated with melamine solutions. Just before impregnation, wood specimens were weighed (W_2) and measured (L_2) again. The sizes of specimens were 30 mm (radial) x 30 mm (tangential) x 10 mm (longitudinal) for dimensional stability, 20 mm (radial) x 20 (tangential) x 10 mm (longitudinal) for sorption, and 40 mm (radial) x 40 mm (tangential) x 40 (longitudinal) mm for capillary water uptake.

2.3. Preparation of melamine solutions

Solutions with 5%, 10%, 20% and 40% melamine resin concentration were applied to different combinations of wood specimens of both timber species, to analyze effects of resin loads on water-related properties. N-methylol melamine resin (MW 840) was provided by INEOS Melamine (GmbH) with a 75% content of solids. To analyze the effect of melamine concentration (ML) on the treatability of samples, solutions with stated melamine concentrations were prepared. Melamine resin was diluted with tap water of round pH 7 in gram ratios 66:934 (ML 5%), 132:868 (ML 10%), 264:736 (ML 20%) and 528:472 (ML 40%). After adding water to the N-methylol melamine resin, the mixture was well stirred in an electric shaker until no suspension was observed and the pH value of the solution was recorded. Then, 1% of ethanolamine was supplemented, and the pH of the solution was measured. Finally, sodium hydroxide was buffered until the solution attained a pH of around 10.

2.4. Impregnation and curing

The conditioned wood samples were impregnated in a stainless steel plant using a full cell process which included an initial vacuum phase of 50 mbars for 45 minutes and a pressure phase of 12 bars for two hours. After impregnation, the excess solution from the surface of the samples was removed with paper and the samples were weighed (W_3). Half of the samples (per species and size) were cured at 90ºC and the others were cured at 120ºC for 72 hours in an oven. After curing, the samples were cooled down in desiccators and weighed (W_3).

2.5. Testing procedure

Dimensional stability: Specimens were first subjected to leaching according to EN 84. Anti-swelling efficiency (ASE) was determined from the oven-dry and saturated dimensions as an index to dimensional stability in accordance with the method described by Hill et al. (2004). The maximum swelling and ASE were given by the relationships:

$$S = \frac{(A_s - A_o)}{A_o} \, x\, 100\ (\%) \quad (1)$$

$$ASE = \frac{S_u - S_t}{S_u} \, x\, 100\ (\%) \quad (2)$$

where S stands for maximum swelling, A_s and A_o for saturated and oven-dry cross-sectional area (obtained by multiplication of radial and tangential dimensions), ASE for anti-swelling efficiency, and S_u and S_t swelling of untreated and treated specimens.

To investigate the stability of melamine resin in the treated wood, all specimens were subjected to 10 cycles of water saturation and oven-drying, and ASE determined at each cycle.

Radial, tangential and volumetric swelling and swelling anisotropy were also determined for treated and untreated specimens according to DIN 52184 as follows:

$$S_R = \frac{L_s - L_o}{L_0} \, x\, 100 \quad (\%) \quad (3)$$

$$S_T = \frac{L_s - L_o}{L_0} \, x\, 100 \quad (\%) \quad (4)$$

$$S_V = \frac{V_s - V_o}{V_0} \, x\, 100 \quad (\%) \quad (5)$$

$$Swelling\ Anisotropy = \frac{S_T}{S_R} \quad (6)$$

where S_R, S_T and S_V are radial, tangential and volumetric swelling of a specimen, respectively. L_s and L_o represent radial or tangential dimensions of the specimen in saturated and oven-dry conditions, and V_s and V_o volume of the specimen in saturated and oven-dry conditions.

Equilibrium moisture content: Leaching test was, in accordance with EN 84, performed on all specimens prior to sorption test. Then, they were conditioned consecutively in an ascending order of relative humidity at 30% RH, 50% RH, 65% RH, 80% RH and 95% RH. At each relative humidity, the specimens were stored in a climatic chamber for two weeks and measurements on dimensions and weight were taken. The temperature was kept constant at 20ºC throughout the test. At the end of conditioning at 95% RH, the specimens were vacuum-impregnated with tap water and submerged in water for two days prior to final measurement of their dimensions. Two kinds of equilibrium moisture content were determined based on oven-dry weight before and after modification by the relationships:

$$EMC^1 = \frac{W_3 - W_{RH}}{W_3} \, x \, 100 \ (\%) \qquad (7)$$

(based on oven-dry weight after modification)

$$EMC^2 = \frac{W_3 - W_{RH}}{W_1} \, x \, 100 \ (\%) \qquad (8)$$

(based on oven-dry weight before modification)

where EMC is equilibrium moisture content of a specimen, W_1 and W_3 oven-dry weight of the specimen before and after impregnation with melamine, and W_{RH} weight of the specimen measured at a specific relative humidity.

The moisture excluding efficiency ***(MEE)*** was calculated from the EMC^1 as follows:

$$MEE = \frac{EMC_{control} - EMC_{treated}}{EMC_{control}} \, x \, 100 \ \% \qquad (9)$$

where $EMC_{control}$ and $EMC_{treated}$ are equilibrium moisture contents of control and treated specimens established under a given relative humidity. The higher the MEE, the higher is the reduction in EMC of treated wood due to melamine treatment.

Fiber saturation point was estimated by the common relationship as follows:

$$FSP = \frac{V_{Sat} - V_{dry}}{W_{dry}} \, x \, 100 (\%) \qquad (10)$$

where FSP is fiber saturation point (%) of a specimen, V_{sat} and V_{dry} volume of the specimen at fully swollen and oven-dry conditions (cm^3), and W_{dry} oven-dry weight of the same specimen measured in gram (g). Two assumptions must be met in regard to estimating the fiber saturation point from the relationship 10. After saturation, the specimens must be in a fully swollen state so that the cell wall cannot swell any more. The volume of cell lumina of the specimens must remain constant at both fully swollen saturated and completely oven-dried states.

The coefficient of swelling and differential swelling coefficient were determined according to DIN 52184, as follows:

$$C = \frac{L_{80} - L_{30}}{RH_{80} - RH_{30}} \, x \, 100 \ (\%/\%) \qquad (11)$$

$$D = \frac{L_{80} - L_{30}}{u_{80} - u_{30}} \, x \, 100 \ (\%/\%) \qquad (12)$$

where ***C*** is coefficient of swelling of a specimen, L_{80} and L_{30} radial or tangential dimension of the specimen at ***80%*** and ***30%*** relative humidity, RH_{80} and RH_{30} ***80%*** and ***30%*** relative humidity, and u_{80} and u_{30} moisture contents of the specimen at ***30%*** and ***80%*** relative humidity.

Capillary water uptake: The cured specimens were conditioned at 65% relative humidity and 20ºC for two weeks. Then they were sealed with the epoxy (water resistant type) on radial surfaces of radial water uptake test specimens and on tangential surfaces of tangential water uptake test specimens. Prior to exposure to water, the sealed specimens were again conditioned at the previous condition. Just before exposure to water, they were weighed again as initial weight, and placed vertically on the saturated sponges that were laid on the test vessels horizontally and covered by water to 2 mm. The weights of the specimens were measured at 1, 2, 3, 4, 8, 12, 24, 36, 48, 60, 72, 96, 120 hours, etc. after exposure to water. The test was conducted according to DIN 52617 up to four weeks, with measurement of weight at every hour at the start to every two to four days at the later stages.

Water uptake, water diffusion coefficient and water repellency efficiency were determined as follows:

$$US = \frac{W_{end} - W_{start}}{A} \; (kg/m^2) \tag{13}$$

$$D_w = \frac{US}{\sqrt{T}} \; (kg/m^2/h^{1/2}) \tag{14}$$

$$WRE = \frac{D_w\,(untreated) - D_w\,(treated)}{D_w(untreated)} \; x\ 100\% \tag{15}$$

where ***US*** is water uptake by a specimen, W_{start} and W_{end} weights of the specimen at the start and after a specific time (after 1, 2, 3, 4 hour, etc.), ***A*** area of the specimen through which water diffuses, D_w water diffusion coefficient of the specimen, ***T*** time of exposure, WRE water repellency efficiency, D_w ***(untreated)*** water diffusion coefficient of untreated specimens, and D_w ***(treated)*** water diffusion coefficient of treated specimens.

2.6 Data analysis

Three factors, i.e. species (2 levels: *B. ceiba* and *B. insigne*), melamine concentration (4 levels: 5%, 10%, 20% and 40%) and curing temperature (2 levels: 90ºC and 120ºC) were considered as sources of variation. Thus, the statistical model was a completely randomized three-factorial one with 10 replications. The exception to this model is the capillary water uptake test, in which two melamine concentrations (10% and 20%) were applied to *B. ceiba* specimens, and all wood specimens were cured only at one curing temperature (120ºC). However, different anatomical directions were considered as an alternative source of variation. Thus, the statistical model for this test was a completely randomized three-factorial one with five replications. With the help of STATISTICA software (version 7.0), the data were subjected to Analysis of Variance (ANOVA) to investigate their influence on the dimensional stability, equilibrium moisture content and water uptake. The ANOVA tables were presented in Appendix II.

3. Results and discussion

3.1. Wood treatability

Solution uptake, WPG and SRR, which demonstrated the treatability of wood, were presented in Table 1 for *B. ceiba* and in Table 2 for *B. insigne*. All of them increased with the amount of melamine concentration in the treating solution. Wood structure, solubility of resin in water, molecular size or molecular weight, viscosity of resin solution, and the solid content of the resin solution affects the treatability of wood (Pittman et al. 1994). Melamine resin used in this research is readily soluble in water, giving low viscosity. With increasing solid content of resin, the treatability generally decreases. Pittman et al. (1994) found increasing solid content of melamine/amine/formaldehyde to give lower solution uptake, WPG and SRR. However, all these parameters increased with increasing solid content in this research, which might be attributable to wood structure of *B. ceiba* and *B. insigne*. Both timber species have large vessels with numerous slit-like intervessel pits and the profound quantity of large axial parenchyma (Pearson and Brown 1932), which facilitated the infiltration of melamine resin, thus giving higher values with higher concentration.

3.2 Dimensional stability

Dimensional stability of wood specimens was generally evaluated by measuring ASE in most research papers. The higher the ASE values, the more dimensionally stabilized the treated specimens become compared to untreated control specimens. In this research, it was also assessed in normal way by measuring radial, tangential and volumetric swelling of treated and untreated specimens.

Radial, tangential and volumetric swelling, ASE and swelling isotropy were presented in Table 1 for *B. ceiba* and in Table 2 for *B. insigne*. With increasing WPG of melamine resin, the swelling of treated specimens decreased in both species up to about 35-37% WPG, and then increased or remained the same. Thus, the weight percent gain should not be over 40% in treatment of these species with methylol melamine resin to enhance dimensional stability as over this value the ASE did not increase.

Table 1: Solution uptake, weight percent gain, solid resin retention, radial, tangential and volumetric shrinkage, anti-swelling efficiency and swelling anisotropy of Bombax ceiba treated and untreated with N-methylol melamine resin (Standard deviations are in parentheses.)

Properties	Curing temperature 90°C				Control
	ML5%	ML10%	ML20%	ML40%	
Solution uptake –kg/m^3	871(9)	883 (9)	902 (9)	965 (9)	-
WPG - %	17(0.5)	35 (1.4)	55 (3.6)	138 (5)	-
SRR – kg/m^3	42 (0.6)	83 (0.7)	131(7.7)	327 (2)	-
R[1] - %	2.1(0.3)	2.1(0.4)	2.2(0.2)	2.4(0.2)	3.2(0.3)
T[1] - %	5.3(0.7)	5.3(0.7)	5.5(0.7)	5.4(0.7)	6.0(0.7)
V[1] - %	7.3(1.0)	7.2(0.7)	7.6(0.9)	7.6(1.0)	9.3(0.4)
ASE[1] - %	42.1	43.5	37.7	33.7	-
Swelling anisotropy[1]	2.5	2.6	2.4	2.3	1.9
Solution uptake–g/m^3	876 (10)	884 (8)	895 (17)	961 (13)	-
WPG - %	15 (0.6)	32 (0.8)	49 (0.3)	125 (5)	-
SRR – kg/m^3	38 (0.7)	78 (0.6)	122 (6)	310 (4)	-
R[1] - %	1.9 (0.2)	1.7 (0.1)	2.1 (0.2)	2.4 (0.1)	3.2 (0.3)
T[1] - %	5.1 (0.6)	4.4 (0.4)	4.5 (0.2)	4.1 (0.1)	6.0 (0.7)
V[1] - %	7.1 (0.7)	6.2 (0.5)	6.8 (0.3)	6.7 (0.3)	9.3 (0.4)
ASE[1] - %	50.3	61.7	51.5	49.6	-
Swelling anisotropy[1]	2.6	2.6	2.1	1.7	1.9

[1]data from the first saturation and oven-drying cycle; Replication = 10 per combination (treated) and 20 (control); ML = melamine resin concentration, WPG = weight percent gain; SRR = solid resin retention; R, T, V = radial, tangential and volumetric swelling from oven-dry to fully swollen state; ASE = anti-swelling efficiency.

Table 2: Solution uptake, weight percent gain, solid resin retention, radial, tangential and volumetric shrinkage, anti-swelling efficiency and swelling anisotropy of *Bombax insigne* treated and untreated with N-methylol melamine resin (Standard deviations are in parentheses.)

Properties	**Curing temperature 90°C**				**Control[3]**
	ML5%	**ML10%**	**ML20%**	**ML40%**	
Solution uptake -kg/m^3	752 (15)	758 (21)	787 (10)	836 (12)	-
WPG - %	11 (0.5)	22 (0.9)	37 (1.7)	85 (2)	-
SRR – kg/m^3	39 (1.1)	77 (2.3)	124 (6.6)	298 (6)	-
R[1] -%	3.7 (0.4)	3.4 (0.2)	3.3 (0.2)	3.3 (0.3)	4.2 (0.4)
T[1] - %	6.2 (0.6)	5.8 (0.2)	5.6 (0.2)	6.4 (0.6)	7.1 (0.5)
V[1] - %	10.2(1.0)	9.5 (0.4)	9.1 (0.4)	9.9 (0.9)	11.8 (0.8)
ASE[1] - %	21.4	31.4	34.8	26.6	-
Swelling anisotropy[1]	1.7	1.7	1.7	1.9	1.7
Solution uptake –g/m^3	836(12)	750(18)	747(17)	833(20)	-
WPG - %	10(0.6)	19(0.6)	34(2.6)	79 (2)	-
SRR – kg/m^3	34(1.4)	67(1.4)	116(6.8)	281 (5)	-
R[1] -%	3.1(0.2)	2.6(0.1)	2.5 (0.1)	2.8(0.1)	4.2 (0.4)
T[1] - %	5.3(0.3)	4.3(0.2)	4.2 (0.3)	3.9(0.1)	7.1 (0.5)
V[1] - %	8.8(0.5)	7.1(0.2)	6.8 (0.4)	6.9(0.3)	11.8(0.8)
ASE[1] - %	40.7	59.4	61.4	59.2	-
Swelling anisotropy[1]	1.7	1.7	1.7	1.4	1.7

[1]data from the first saturation and oven-drying cycle; Replication = 10 per combination (treated) and 20 (control); ML = melamine resin concentration, WPG = weight percent gain; SRR = solid resin retention; R, T, V = radial, tangential and volumetric swelling from oven-dry to fully swollen state; ASE = anti-swelling efficiency.

These findings were comparable with the results of the test conducted by Miroy et al. (1995) who pointed out that the dimensional stability appeared to be relatively independent on the WPG in the range of 40-80%. The dimensional stability of southern yellow pine specimens treated with melamine formaldehyde and melamine amine formaldehyde did not correspond with WPG values (Pittman et al. 1994). Deka and Saikia (2000) treated *Anthocepalus cadaba* Miq with 30% melamine formaldehyde and 68% ASE was achieved at 33-35% WPG. All the literature data are comparable to the findings of this research. Norway spruce treated with melamine formaldehyde improved the dimensional stability by 17.5% at 22.9% WPG (Deka et al. 2007), which seemed to be less than the ASE achieved in this research. The low ASE achieved in Norway spruce could be attributed to less infiltration of melamine resin into the cell wall due to difficulty in its treatability. Deka et al. (2007) calculated the amount of resin penetrated into the cell wall by ultraviolet microspectrophotometry (UMSP) to be 0.1% (v/v), most resin being deposited in the cell lumina.

Higher curing temperature resulted in higher dimensional stability with the highest ASE of 61-62% at WPG of 32-35%. It should be noteworthy that even at a low weight percent gain of 15-20%, both species achieved 50-60% ASE (which was not much lower than ASE values at 32-35 WPG) at 120ºC curing temperature. As 90ºC curing temperature was too low for melamine resin to cure and cross-link with wood components, the ASE values were correspondingly lower at that curing temperature.

In *B. insigne*, the swelling anisotropy remained the same at 1.7 before and after treatment with melamine resin, indicating the reduction in radial and tangential swelling took place in a specific ratio. In *B. ceiba*, the swelling anisotropy varied from 1.7 to 2.6.

Melamine treated specimens underwent steady loss of ASE due to water saturation and oven-drying over 10 cycles as depicted in Fig. 1 and 2, raising question in the long-term dimensional stability of melamine treated specimens. Deka and Saikia (2000), however, reported the stability of ASE values over repeated wetting and drying cycles.

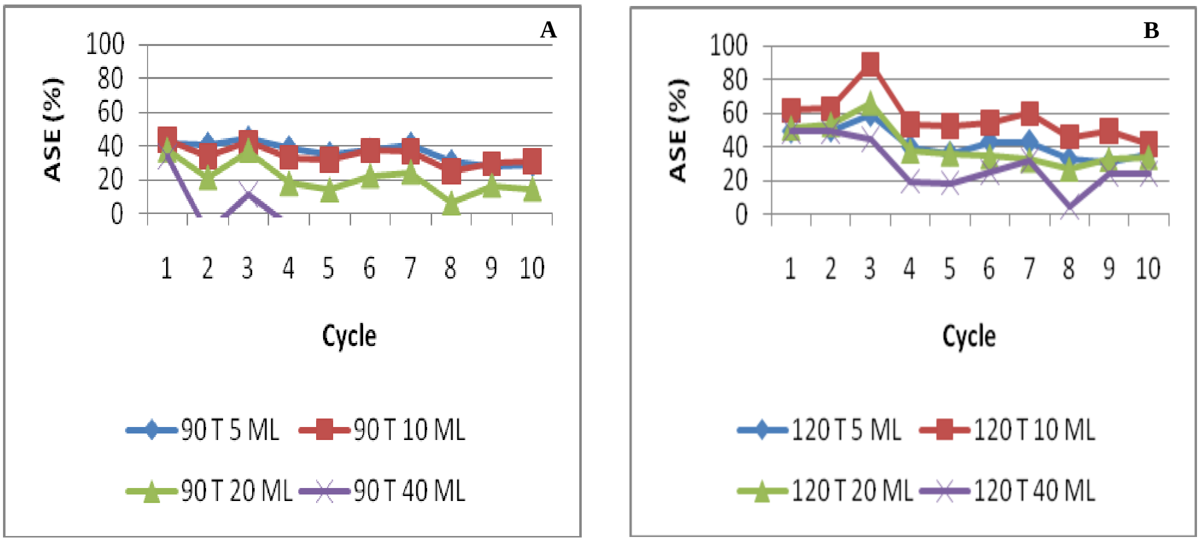


Figure 1: Stability of ASE of *B. ceiba* heartwood treated with N-methylol melamine resin in 10 leaching cycles: (A) specimens cured at 90ºC and (B) specimens cured at 120ºC (ML = melamine concentration %)

Incomplete curing of melamine resin at 90ºC was demonstrated by higher mass loss due to leaching test conducted in accordance with EN 84 (Figure 3), which amounted as high as to 19% in specimens treated with 40% melamine concentration. The mass loss encountered by specimens cured at 120ºC was kept as low as 2% due to complete curing of melamine resin. Holmberg (1984) described the need for melamine resins for high curing temperatures, and even with a very high amount of catalyst up to 25% of melamine resin, the curing temperature about 100ºC was necessary.

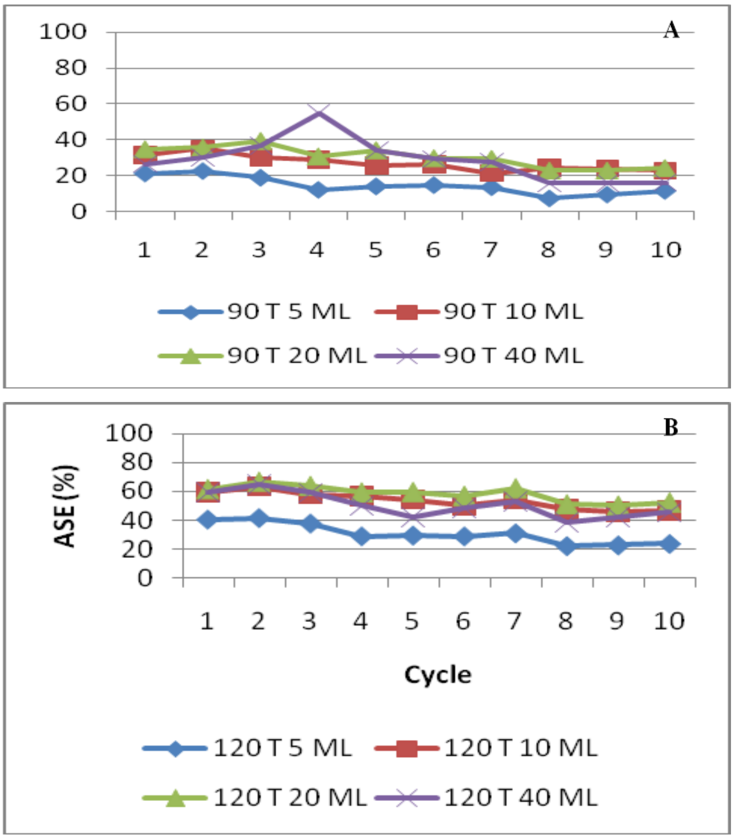


Figure 2: Stability of ASE of *B. insigne* heartwood treated with N-methylol melamine resin in 10 leaching cycles of water saturation and oven-drying: (A) specimens cured at 90ºC and (B) specimens cured at 120ºC (ML = melamine concentration %)

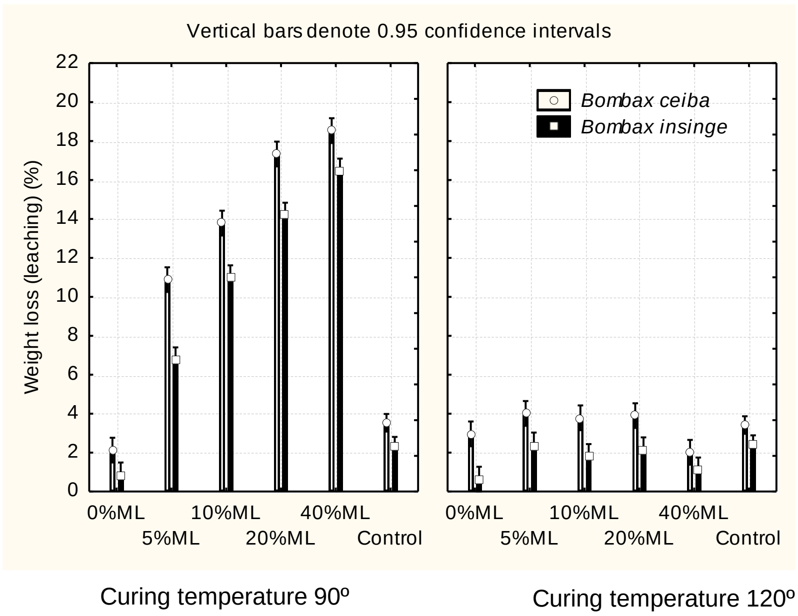


Figure 3: Mass loss of melamine-treated and control specimens of *B. ceiba* and *B. insigne* heartwood in EN 84 leaching test

3.3 Equilibrium moisture content

The equilibrium moisture content established by treated and untreated heartwood specimens with varying environments were presented in Tables 3 and 4 for *B. ceiba* and in Tables 5 and 6 for *B. insigne*.

As expected, the equilibrium moisture contents of all treated and control specimens increased with increasing relative humidity. The EMCs of control specimens from 30% RH to 95% RH increased from 4.7% to 22.6% for *B. ceiba* and from 5.2% to 22.9% for *B. insigne*. Higher EMCs in *B. insigne* were attributable to its higher density.

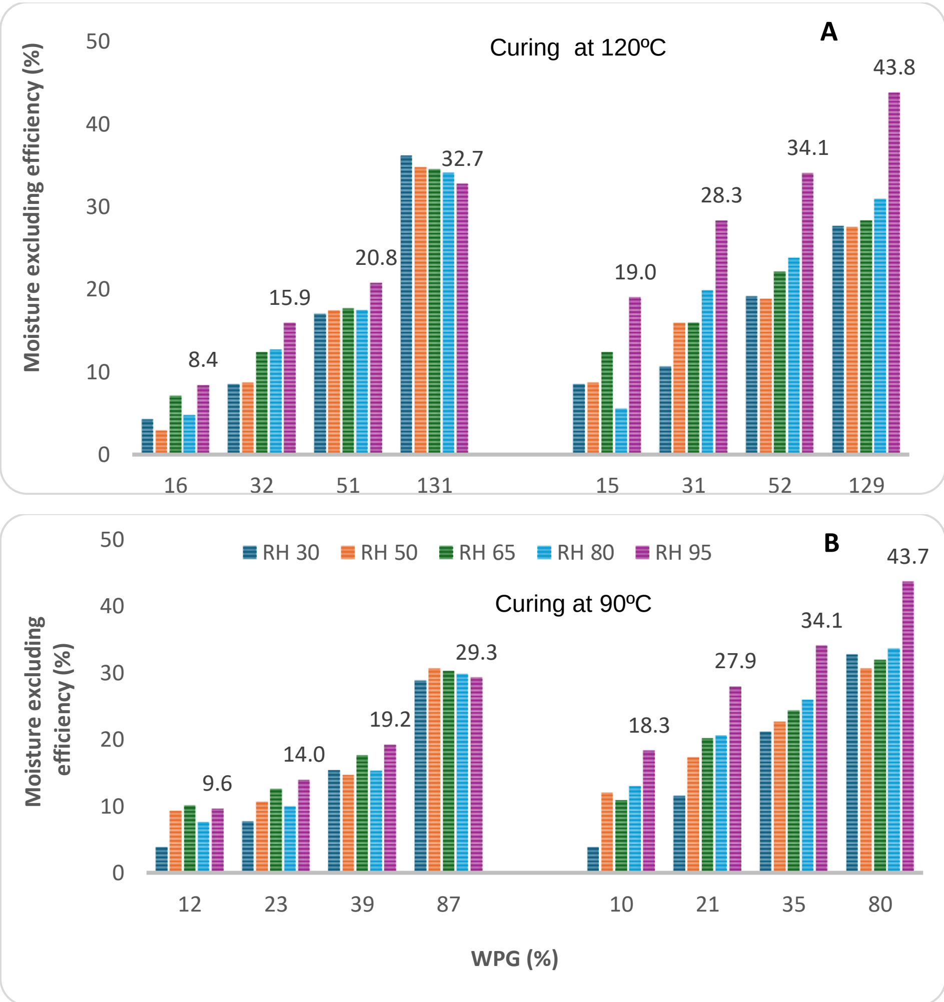


Figure 4: Moisture excluding efficiency (MEE) of *B. ceiba* (A) and *B. insigne* (B) heartwood treated and untreated with N-methylol melamine resin under varying relative humidity

Treatment with melamine caused a reduction in EMC (EMC[1] in Tables 3 to .6) based on the oven-dry weight after treatment, decreasing with increasing WPG. The reduction in EMC, measured by the moisture excluding efficiency (MEE) remained almost the same under varying environments for the lower temperature curing specimens; even at higher curing temperature, the MEEs were similar to lower curing temperature at relative humidity $\leq 90\%$ (Fig. 4). At 95% RH, the MEE became significantly pronounced, indicating the effectiveness of melamine treatment in reduction of EMC in very humid environments.

Table 3: Fiber saturation point, equilibrium moisture content, coefficient of swelling and differential swelling coefficient of *B. ceiba* heartwood treated with N-methylol melamine resin and cured at 90ºC (Standard deviations are in parentheses.)

Properties	Curing temperature 90ºC/WPG%				Control
	16 (1.4)	32 (2.1)	51 (3.3)	131 (7.3)	
FSP[1] - %	21.9(2.5)	18.6(2.7)	17.4(1.9)	13.1(1.9)	28.3 (2.8)
FSP[2] - %	22.9(2.8)	21.4(3.6)	22.8(4.6)	25.0(5.0)	28.3(2.8)
EMC[1] - %					
30%RH	4.5 (0.1)	4.3 (0.2)	3.9 (0.1)	3.0 (0.1)	4.7 (0.4)
50%RH	6.7 (0.1)	6.3 (0.2)	5.7 (0.1)	4.5 (0.2)	6.9 (0.3)
65% RH	10.5(0.2)	9.9 (0.2)	9.3 (0.1)	7.4 (0.2)	11.3(0.4)
80% RH	12.0(0.1)	11.0(0.3)	10.4(0.2)	8.3 (0.2)	12.6(0.5)
95% RH	20.7(0.4)	19.0(0.3)	17.9(0.1)	15.2(0.2)	22.6(0.7)
EMC[2] - %					
30%RH	4.7 (0.1)	4.9 (0.3)	4.9 (0.2)	5.6 (0.2)	4.7 (0.4)
50% RH	7.0 (0.2)	7.2 (0.3)	7.1 (0.2)	8.5 (0.2)	6.9 (0.3)
65% RH	11.0(0.3)	11.4(0.4)	11.5(0.3)	14.0(0.5)	11.3 (0.4)
80% RH	12.5(0.2)	12.7(0.5)	12.9(0.4)	15.8(0.5)	12.6 (0.5)
95% RH	21.6(0.6)	21.8(0.9)	22.4(0.8)	28.8 (1)	22.6 (0.7)
C_R	0.013 (0.003)	0.011 (0.003)	0.014 (0.004)	0.020 (0.004)	0.012 (0.003)
C_T	0.033 (0.003)	0.030 (0.003)	0.029 (0.005)	0.032 (0.004)	0.031 (0.003)
D_R	0.090 (0.020)	0.081 (0.022)	0.108 (0.029)	0.187 (0.036)	0.081 (0.020)
D_T	0.224 (0.022)	0.218 (0.019)	0.227 (0.035)	0.303 (0.042)	0.195 (0.020)

[1]calculated on the basis of oven-dry weight of specimens after impregnation
[2]calculated on the basis of oven-dry weight of specimens before impregnation
FSP= fiber saturation point estimated by equation (10); EMC= equilibrium moisture content measured from the test; R= radial; T= tangential; C= coefficient of swelling; D= differential swelling coefficient

Table 4: Fiber saturation point, equilibrium moisture content, coefficient of swelling and differential swelling coefficient of *B. ceiba* heartwood treated with N-methylol melamine resin and cured at 120ºC (Standard deviations are in parentheses.)

Properties	Curing temperature 120ºC/WPG%				Control
	15(2.3)	31(1.5)	52(7.5)	129(12.4)	
FSP[1] - %	19.2(2.1)	15.7(1.3)	14.8(1.4)	11.3 (0.7)	28.3(2.8)
FSP[2] - %	21.0(2.4)	19.9(1.8)	20.0(5.8)	24.9 (5.7)	28.3(2.8)
EMC[1] - %					
30%RH	4.3 (0.2)	4.2 (0.3)	3.8 (0.2)	3.4 (0.1)	4.7 (0.4)

Properties	Curing temperature 120°C/WPG%				Control
	15(2.3)	31(1.5)	52(7.5)	129(12.4)	
50%RH	6.3 (0.2)	5.8 (0.3)	5.6 (0.2)	5.0 (0.1)	6.9 (0.3)
65% RH	9.9 (0.2)	9.5 (0.4)	8.8 (0.3)	8.1 (0.2)	11.3(0.4)
80% RH	11.9(0.3)	10.1(0.3)	9.6 (0.3)	8.7 (0.2)	12.6(0.5)
95% RH	18.3(0.6)	16.2(0.4)	14.9(0.4)	12.7 (0.2)	22.6(0.7)
EMC[2] - %					
30%RH	4.7 (0.3)	5.3 (0.4)	5.5 (0.2)	7.5 (0.5)	4.7 (0.4)
50% RH	6.9 (0.4)	7.4 (0.4)	8.2 (0.4)	11.2 (0.6)	6.9 (0.3)
65% RH	10.9(0.4)	12.1(0.6)	12.9(0.5)	18.2 (0.8)	11.3(0.4)
80% RH	11.9(0.6)	12.8(0.5)	14.0(0.6)	19.4 (0.9)	12.6(0.5)
95% RH	20.1(1.0)	20.5(0.6)	21.8(0.9)	28.5 (1.4)	22.6(0.7)
C_R	0.009 (0.005)	0.011 (0.002)	0.014 (0.003)	0.022 (0.003)	0.012 (0.003)
C_T	0.028 (0.004)	0.027 (0.002)	0.028 (0.002)	0.035 (0.004)	0.031 (0.003)
D_R	0.071 (0.037)	0.096 (0.016)	0.122 (0.023)	0.207 (0.030)	0.081 (0.020)
D_T	0.208 (0.027)	0.225 (0.020)	0.241 (0.013)	0.327 (0.029)	0.195 (0.020)

[1]calculated on the basis of oven-dry weight of specimens after impregnation
[2]calculated on the basis of oven-dry weight of specimens before impregnation

FSP = fiber saturation point estimated by equation (10); EMC = equilibrium moisture content measured from the test; R= radial; T = tangential; C= coefficient of swelling; D= differential swelling coefficient

Many papers reported on treatment with different formulation of melamine resin to cause a minor reduction in EMC at relative humidity below 90% (Epmeier et al. 2007; Epmeier et al. 2004; Krause et al. 2004), which agreed with the findings of this research. In fact, this minor reduction in EMC accounted for the mere mass of melamine impregnated into wood specimens. When EMC was measured based on the oven-dry weight of wood specimens before impregnation with melamine, the EMC of melamine-treated specimens was almost the same as that of untreated specimens established at varying relative humidity (EMC[2] in Tables 3 to 6). At a higher WPG of about 130% in *B. ceiba*, the EMC of treated specimens was even higher than that of control specimens in every relative humidity environment. At 95% RH, the EMC obtained by those specimens was as high as up to 28.8%, which was even higher than the calculated FSP of the same specimens. Epmeier et al. (2007) found the increasing EMC with increasing methylated melamine formaldehyde concentration. It might be explained by the absorption of moisture by melamine deposited in the cell lumina. The deposition of melamine resins was demonstrated by the UV-microspectrophotometry.

Table 5: Fiber saturation point, equilibrium moisture content, coefficient of swelling and differential swelling coefficient of *B. insigne* heartwood treated with N-methylol melamine resin and cured at 90°C (Standard deviations are in parentheses.)

Properties	Curing temperature 90°C/WPG				Control
	12 (0.8)	23 (1.1)	39 (2.3)	87 (3.7)	
FSP[1] - %	23.6(1.1)	20.7(2.0)	18.6(1.5)	14.1(0.8)	29.2(2.5)
FSP[2] - %	24.3(1.2)	22.2(2.2)	21.3(1.6)	20.7(1.0)	29.2(2.5)
EMC[1] - %					

Properties	Curing temperature 90ºC/WPG				Control
	12 (0.8)	23 (1.1)	39 (2.3)	87 (3.7)	
30%RH	5.0 (0.2)	4.8 (0.2)	4.4 (0.2)	3.7 (0.1)	5.2 (0.2)
50% RH	6.8 (0.2)	6.7 (0.2)	6.4 (0.2)	5.2 (0.1)	7.5 (0.2)
65% RH	10.7(0.3)	10.4(0.3)	9.8 (0.2)	8.3 (0.2)	11.9(0.2)
80% RH	12.1(0.3)	11.8(0.4)	11.1(0.3)	9.2 (0.2)	13.1(0.2)
95% RH	20.7(0.4)	19.7(0.4)	18.5(0.3)	16.2(0.3)	22.9(0.3)
EMC[2] - %					
30%RH	5.0 (0.2)	5.4 (0.2)	5.0 (0.2)	5.4 (0.1)	5.2 (0.2)
50% RH	7.0 (0.3)	7.2 (0.2)	7.3 (0.2)	7.6 (0.2)	7.5 (0.2)
65% RH	11.0(0.3)	11.1(0.3)	11.2(0.2)	12.1(0.2)	11.9(0.2)
80% RH	12.4(0.5)	12.7(0.4)	12.7(0.3)	13.5(0.2)	13.1(0.2)
95% RH	21.4(0.4)	21.2(0.4)	21.2(0.3)	23.7(0.4)	22.9(0.3)
C_R	0.021 (0.003)	0.022 (0.002)	0.021 (0.003)	0.023 (0.003)	0.023 (0.003)
C_T	0.037 (0.006)	0.036 (0.005)	0.036 (0.004)	0.032 (0.004)	0.037 (0.003)
D_R	0.144 (0.017)	0.162 (0.016)	0.154 (0.025)	0.205 (0.028)	0.145 (0.015)
D_T	0.253 (0.036)	0.263 (0.036)	0.265 (0.026)	0.291 (0.036)	0.234 (0.020)

[1]calculated on the basis of oven-dry weight of specimens after impregnation
[2]calculated on the basis of oven-dry weight of specimens before impregnation
FSP = fiber saturation point estimated by equation (10); EMC = equilibrium moisture content measured from the test; R = radial; T= tangential; C= coefficient of swelling; D= differential swelling coefficient

Table 6: Fiber saturation point, equilibrium moisture content, coefficient of swelling and differential swelling coefficient of *B. insigne* heartwood treated with N-methylol melamine resin and cured at 120ºC (Standard deviations are in parentheses.)

Properties	Curing temperature 120ºC/WPG				Control
	10(0.8)	21(0.9)	35(2.8)	80 (2.5)	
FSP[1] - %	20.2(1.8)	15.1(0.7)	13.9(0.6)	10.1(0.7)	29.2(2.5)
FSP[2] - %	21.7(2.0)	17.7(0.9)	18.2(0.7)	17.9(1.3)	29.2(2.5)
EMC[1]					
30%RH	5.0 (0.2)	4.6 (0.1)	4.1 (0.2)	3.5 (0.1)	5.2 (0.2)
50% RH	6.6 (0.2)	6.2 (0.2)	5.8 (0.2)	5.2 (0.1)	7.5 (0.2)
65% RH	10.6(0.2)	9.5 (0.2)	9.0 (0.1)	8.1 (0.1)	11.9(0.2)
80% RH	11.4(0.2)	10.4(0.3)	9.7 (0.2)	8.7 (0.1)	13.1(0.2)
95% RH	18.7(0.2)	16.5(0.3)	15.1(0.2)	12.9(0.1)	22.9 0.3)
EMC[2]					
30%RH	5.4 (0.2)	5.4 (0.2)	5.4 (0.3)	6.2 (0.1)	5.2 (0.2)
50% RH	7.1 (0.2)	7.3 (0.2)	7.6 (0.3)	9.1 (0.1)	7.5 (0.2)
65% RH	11.4(0.2)	11.1(0.2)	11.9(0.3)	14.3(0.3)	11.9(0.2)
80% RH	12.3(0.2)	12.3(0.3)	12.8(0.4)	15.3(0.3)	13.1(0.2)
95% RH	20.1(0.3)	19.3(0.3)	19.8(0.4)	22.7(0.4)	22.9(0.3)
C_R	0.019 (0.003)	0.019 (0.002)	0.019 (0.002)	0.022 (0.007)	0.023 (0.003)

Properties	Curing temperature 120°C/WPG				Control
	10(0.8)	21(0.9)	35(2.8)	80 (2.5)	
C_T	0.031 (0.004)	0.030 (0.003)	0.031 (0.003)	0.033 (0.003)	0.037 (0.003)
D_R	0.145 (0.026)	0.159 (0.017)	0.171 (0.021)	0.217 (0.070)	0.145 (0.015)
D_T	0.239 (0.027)	0.258 (0.034)	0.278 (0.027)	0.325 (0.033)	0.234 (0.020)

[1]calculated on the basis of oven-dry weight of specimens after impregnation
[2]calculated on the basis of oven-dry weight of specimens before impregnation
FSP = fiber saturation point estimated by equation (10); EMC = equilibrium moisture content measured from the test; R = radial; T = tangential; C = coefficient of swelling; D = differential swelling coefficient

3.4. Fiber saturation point

Two kinds of fiber saturation point of treated and untreated specimens, calculated on the basis of oven-dry weight before and after impregnation with melamine resin, were presented in Tables 3 to 6. No matter by what method it has been calculated, melamine treatment led to reduction in fiber saturation point, in contrast to EMCs at RH ≤ 90%, confirming the high resistance of melamine treated wood at moist environments (Conner 2001). Krause et al. (2004) found a significant decrease in moisture content above 90% RH and close to 100% RH.

3.5. Coefficients of swelling and differential swelling coefficients

The coefficient of swelling is the amount of swelling taking place in a wood specimen by 1% RH change in the RH range from 30% to 85% whereas the differential swelling coefficient is the amount of swelling due to 1% MC change in the same range of relative humidity. In the research these coefficients were measured for the RH range from 30% to 80%, which were described in Tables 3 to 6, together with standard deviations in brackets. The coefficients of treated and untreated specimens were almost the same, which could be linked to the same moisture adsorption by both types of specimens in this range of relative humidity.

Table 7: Water diffusion coefficients and water repellence efficiency of *B. ceiba* wood treated with melamine resin

properties	Radial at WPG%			Tangential at WPG%		
	30.3 (1.9)	**69.4 (4.8)**	**Control**	**27.0 (5.3)**	**68.2 (2.0)**	**Control**
Water diffusion coefficients (kg/m²/h^0.5)						
1 hour	16.25	2.96	25.50	1.97	0.13	22.3
8 hours	7.60	5.25	9.16	5.75	1.05	8.7
12hours	6.32	4.76	7.51	5.15	1.78	7.16
1 day	4.66	3.89	5.35	4.05	1.28	5.13
2 days	3.53	3.18	3.93	3.16	1.57	3.73
1week	1.86	1.80	2.23	1.87	1.92	2.15
2 Weeks	1.31	1.18	1.65	1.31	1.36	1.60
3 weeks	1.11	0.96	1.40	1.10	1.10	1.32
4 weeks	1.00	0.86	1.24	0.98	0.96	1.18
Average	**4.8**	**2.8**	**6.4**	**2.8**	**1.24**	**5.9**
Water repellence efficiency (%)						

properties	Radial at WPG%			Tangential at WPG%		
	30.3 (1.9)	**69.4 (4.8)**	**Control**	**27.0 (5.3)**	**68.2 (2.0)**	**Control**
1 hour	36.3	88.4	-	91.2	99.4	-
1 day	12.9	27.4	-	21.1	75.0	-
1 week	16.7	19.3	-	13.0	10.7	-
2 weeks	20.5	28.6	-	18.1	14.8	-
3 weeks	20.9	31.1	-	17.3	17.2	-
4 weeks	19.7	30.6	-	17.3	18.9	-
Average	**21.2**	**37.6**		**29.7**	**39.3**	

Control = untreated specimens

Table 8: Water diffusion coefficients and water repellence efficiency of *B. insigne* wood treated with melamine resin (Radial)

properties	Radial at WPG%				
	9.4 (1.3)	**14.7 (1.8)**	**36.7 (1.1)**	**74.7 (7.4)**	**Control**
Water diffusion coefficient ($kg/m^2/h^{0.5}$)					
1 hour	0.144	0.098	0.075	0.079	0.302
8 hours	0.212	0.126	0.100	0.080	0.294
12 hours	0.209	0.129	0.106	0.080	0.315
1 day	0.209	0.133	0.115	0.085	0.342
2 days	0.217	0.146	0.122	0.085	0.379
1 week	0.242	0.187	0.134	0.094	0.432
2 weeks	0.265	0.214	0.131	0.091	0.364
3 weeks	0.265	0.227	0.142	0.100	0.320
4 weeks	0.226	0.203	0.133	0.096	0.272
Average	**0.221**	**0.163**	**0.118**	**0.088**	**0.336**
Water repellence efficiency (%)					
1 hour	52.3	67.5	75.2	73.8	
1 day	38.9	61.1	66.4	75.1	-
1 week	44.0	56.7	69.0	78.2	-
2 weeks	27.2	41.2	64.0	75.0	-
3 weeks	17,2	29.1	55.6	68.8	-
4 weeks	16.9	25.4	51.1	64.7	-
Average	**35.9**	**46.8**	**63.6**	**72.6**	**-**

Control = untreated specimens

3.6 Capillary water uptake

The water diffusion coefficients (D_w) and water repellency efficiency (WRE) of treated and untreated specimens were described in Table 7 for *B. ceiba* and in Tables 8 and 9 for *B. insigne*. In both species, water uptake by both control and treated specimens took place faster in radial direction than in tangential direction due to rays with large lumina and thin cell wall running along radial direction, which facilitated the diffusion of water.

Treatment with N-methylol melamine resin reduced the water diffusion coefficient in both radial and tangential directions. With increasing WPG, the water uptake was reduced and thus, the water repellency efficiency increased correspondingly. Water repellency efficiency values as high as up to 88% in radial direction and up to 99% in tangential direction were achieved in *B. ceiba* at WPG of 69%. Similarly, treated *B. insigne* specimens presented WRE of 78% in radial direction and of 82% in tangential direction at WPG of 70-74%.

Generally, the water uptake decreased with time in both treated and untreated specimens, thus the WRE also decreased accordingly. However, the control specimens reached the maximum uptake first as shown in Fig. 5 and 6. *B. ceiba* control specimens absorbed water so fast that they attained more than half of their maximum water uptake (kg/m^2) within one hour.

Table 9: Water diffusion coefficients and water repellence efficiency of *B. insigne* wood treated with melamine resin (Tangential)

properties	Tangential at WPG%				
	10.7 (1.5)	**17.1 (0.7)**	**36.4 (0.8)**	**70.0 (12.1)**	**Control**
Water diffusion coefficient (kg/m^2/h$^{0.5}$)					
1 hour	0.126	0.075	0.071	0.091	0.206
8 hours	0.121	0.099	0.057	0.065	0.201
12 hours	0.126	0.100	0.058	0.059	0.215
1 day	0.128	0.104	0.066	0.054	0.238
2 days	0.151	0.123	0.068	0.056	0.280
1 week	0.178	0.166	0.087	0.059	0.340
2 weeks	0.216	0.196	0.109	0.084	0.325
3 weeks	0.205	0.201	0.122	0.088	0.280
4 weeks	0.196	0.185	0.098	0.083	0.227
Average	**0.161**	**0.139**	**0.082**	**0.071**	**0.257**
Water repellence efficiency (%)					
1 hour	38.8	63.6	65.5	55.8	-
1 day	46.2	56.3	72.3	77.3	-
1 week	47.6	51.2	74.4	82.6	-
2 weeks	33.5	39.7	66.5	74.1	-
3 weeks	26.8	28.2	56.4	68.6	-
4 weeks	13.7	18.5	56.8	63.4	-
Average	**34.4**	**42.9**	**65.3**	**70.3**	**-**

Control = untreated specimens

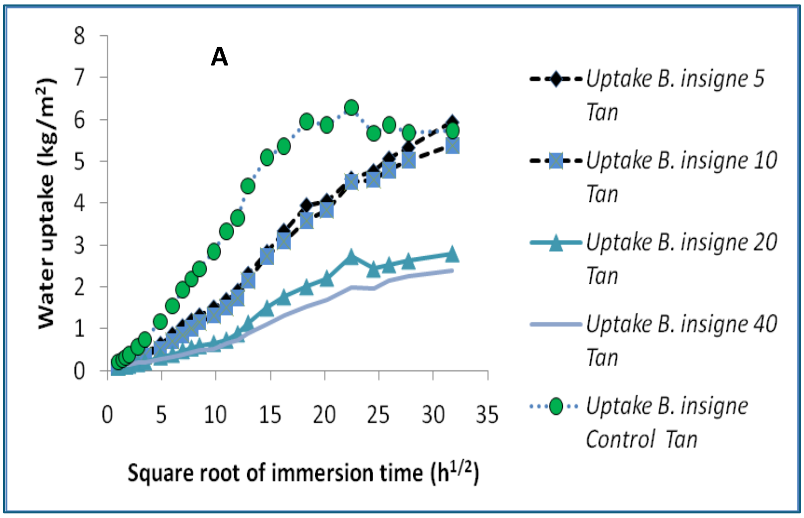
Treatment with melamine reduced the maximum tangential water uptake from 31.9 kg/m^2 to 26.8 kg/m^2 at WPG of 68% but prolonged the time to reach half the maximum water uptake (13.4 kg/m^2) from less than 1 hour to about 64 hours in *B. ceiba* (Fig. 6). The treatment was more effective in *B. insigne* as the maximum tangential water uptake was reduced from 6.3 kg/m^2 to 2.8 kg/m^2, but the time to reach half its maximum water uptake (1.4 kg/m^2) was prolonged from 121 hours to 225 hours when it attained a WPG of 36.4% (Fig. 5).

4. Conclusions

The effect of treatment of *B. ceiba* and *B. insigne* heartwood with melamine resin can be summarized as follows:

- *B. ceiba* and *B. insigne* woods were easily treatable with water soluble melamine resins. Their treatability was demonstrated by higher values of solution uptake, weight percent gains and solid resin retention.

- The ASE increased with increasing WPGs of up to 35 to 40% in *B. ceiba* and *B. insigne*. WPGs above 40% did not increase ASE but rather reduced it due to water uptake by the lumen-deposited melamine, and hence subsequent swelling. Higher curing temperature (120ºC) resulted in higher ASE than lower curing temperature, indicating the need for higher temperatures for melamine resin to cure and cross-link with the cell wall constituents.
- The EMC based on the oven-dry weight of specimens after impregnation with melamine showed a minor reduction at RH ≤90%, but a significant reduction at 95% RH. However, this small reduction in EMC should rather be attributed to the weight of melamine resin as the EMC of treated and untreated specimens, when measured on the basis of the oven-dry weight before impregnation, was the same at varying relative humidity.
- Fiber saturation point of treated specimens was reduced, no matter by what method it was calculated - based on the oven-dry weight before or after modification, confirming the higher water resistance of treated products in humid environments.
- Capillary water uptake was significantly reduced by the treatment for short duration. In the long run, *B. insigne* showed higher water repellency efficiency values than *B. ceiba* even at lower WPGs.



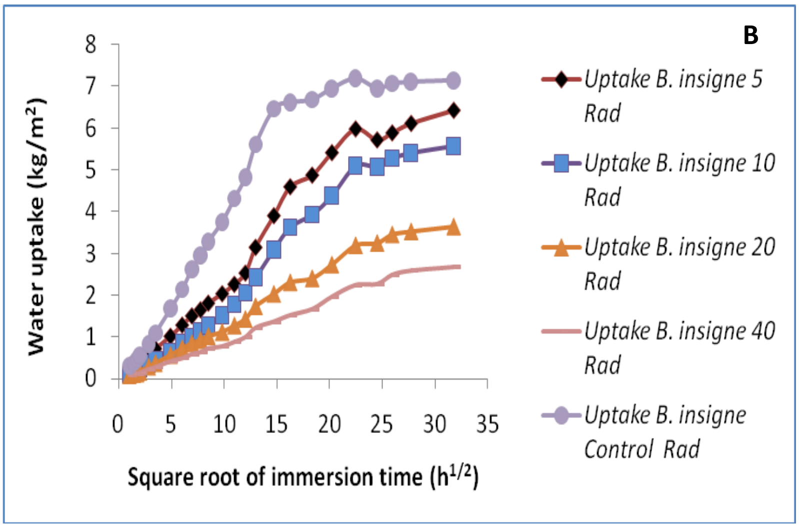


Figure 5: Water uptake of treated and untreated *B. insigne* heartwood in tangential (A) and radial direction (B); *Tan* = tangential direction; *Rad* = Radial direction; 5, 10, 20, and 40 = Specimens treated with 5%, 10%, 20% and 40% melamine solutions, respectively.

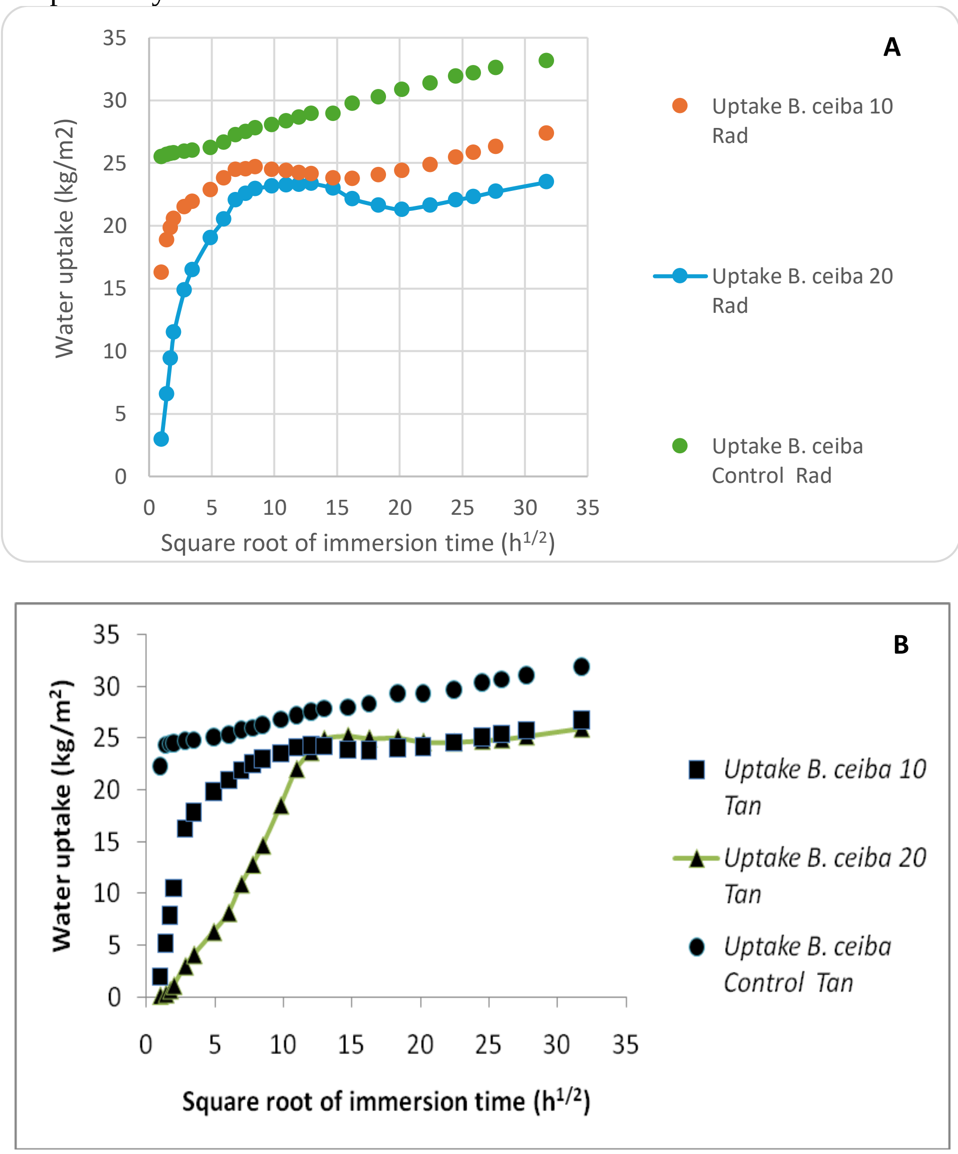


Figure 6: Water uptake of treated and untreated *B. ceiba* heartwood in tangential (A) and radial direction (B); *Tan* = tangential direction; *Rad* = radial direction; 10 and 20 = Specimens treated with 10% and 20% melamine solutions, respectively.

References

Bowyer J.L., Shmulsky R. Haygreen J.G. 2007. Forest products and wood science: An introduction. Fifth edition, Blackwell Publishing Ltd. Oxford, UK

Chirkova J., Andersons B., Andersone L., Militz H. 2005. Water absorption properties of thermo-modified wood. In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 65-69

Christmas J., Sargent R., Tetri T. 2005. Thermal modification of New Zealand Radiata Pine. In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 83-86

Conner A.H. 2001. Wood: Adhesives. Encyclopedia of Materials: Science and Technology, 9583-9599

Deka K., Saikia C.N. 2000. Chemical modification of wood with thermosetting resin: Effect on dimensional stability and strength property. Bioresource Technology, 73 (2): 179-181

Deka M., Gindl W., Wimmer R. Christian H. 2007. Chemical modification of Norway spruce (Picea bies (L) Karst) wood with melamine formaldehyde resin. Indian Journal of Chemical Technology, 14 (2): 134-138

Dinwoodie J.M. 2000. Timber: Its nature and behavior. E & FN Spon, New York

Dreher W.A., Goldstein I.S., Cramer G.R. 1964. Mechanical properties of acetylated wood. Forest Products Journal, 14: 66-68

Epmeier H., Johansson M., Kliger R., Westin M. 2007. Material properties and their interrelation in chemically modified clear wood of Scots pine. Holzforschung, 61: 34–42

Epmeier H., Westin M., Rapp A. 2004. Differently modified wood: Comparison of some selected properties. Scandinavian Journal of Forest Research, 19(5): 31-37

Esteves B., Domingos I., Pereira H. 2005. Technological improvement of Portuguese eucalypt and pine woods. In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 91-94

Forest Products Laboratory. 1999. Wood Handbook – Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 463 p

Frihart C.R. 2005. Wood adhesion and adhesives. In: (Ed.) Rowell. R.M. Handbook of wood chemistry and wood composites. CRC Press, Florida

Frihart C.R. 2006. Wood structure and adhesive bond strength. In (Ed.) Stokke D.D., Groom L.H. Characterization of the cellulosic cell wall. Proceeding of a workshop co-sponsored by the USDA Forest Service-Southern Research Station, the Society of Wood Science and Technology, Iowa State University, August 25-27, 2003, Grand Lake, Colorado USA

Gindl W., Gupta H.S. 2002. Cell-wall hardness and Young's modulus of melamine-modified spruce wood by nano-indentation. Composites Part A: Applied Science and Manufacturing (Incorporating Composites and Composites, Manufacturing), 33 (8): 1141-1145

Gindl W., Mueller U., Teischinger A. 2003. Transverse compression strength and fracture of spruce wood modified by melamine-formaldehyde impregnation of cell walls. Wood and Fiber Science, 35 (2): 239-246

Goldstein I.S., Jeroski E.B., Lund A.E., Nielson J.F. 1961. Acetylation of wood in lumber thickness. Forest Products Journal, 11 (8): 363-370

Hansmann C., Deka M., Wimmer R., Gindl W. 2006. Artificial weathering of wood surfaces modified by melamine formaldehyde resins. Holz als Roh- und Werkstoff, 64: 198-203

Hill C.A.S., Farahani M.R.M., Hale M.D.C. 2004. The use of organo alkoxysilane coupling agents for wood preservation. Holzforschung 58:316–325

Homberg K. 1984. Low temperature acid catalyzed curing of melamine resin systems. Polymer Bulletin, 11:81-84

Johansson D., Moren T. 2006. The potential of colour measurement for strength prediction of thermally treated wood. Holz als Roh- und Werkstoff, 64: 104-110

Jorissen A., Bongers F., Kattenbroek B., Homan W. 2005. The influence of acetylation of Radiata pine in structural size on its strength properties. In (Ed.) Militz H., Hill C. Wood modification: Process, Properties and Commercialization. Göttingen, Germany, 108-115

Krause A., Hof C., Militz H. 2004. Novel wood modification processes for window and cladding products. Proceedings of the 35th annual meeting of the international research group on wood preservation, Ljubljana, Slovenia, IRG/WP 04-40285

Larsson P., Simonson R. 1994. A study of strength, hardness and deformation of acetylated Scandinavian softwoods. Holz als Roh- und Werkstoff, (52): 83-86

Lukowsky D. 2002. Influence of formaldehyde content of water-based melamine formaldehyde resins on physical properties of Scots pine impregnated therewith. Holz als Roh- und Werkstoff, 60: 349-355.

Metsä-Kortelainen S. 2005. The water absorption of thermally modified sapwood and heartwood of Scots pine and Norway spruce, In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 70-73.

Minato K., Takazawa R., Ogura K. 2003. Dependence of reaction kinetics and physical and mechanical properties on the reaction systems of acetylation II: physical and mechanical properties. Wood Science, 49: 519-524

Miroy F., Eymard P., Pizzi A. 1995. Wood hardening by methoxymethyl melamine. Holz als Roh- und Werkstoff 53: 276.

Müller U., Steiner M. 2009. Colour stabilisation of wood composites using polyethylene glycol and melamine resin. European Journal of Wood and Wood Products, DOI 10.1007/s00107-009-0386-1

Narayanamurthi D., Handa B.K. 1953: Acetylated woods. Das Papier 7:87-92

Papadopoulos A.N. 2008. The effect of acetylation on bending strength of finger jointed beechwood (*Fagus sylvatica* L.). Holz als Roh- und Werkstoff, 66: 309–310

Pearson SR, Brown HR (1932) Commercial timbers of India Vol I. Govt. of India, Central Publication Branch, Calcutta

Pittman C.U., Kim M.G., Nicholas D.D., Wang L., Kabir F.R.A., Schultz T.P., Ingram L.L. 1994. Wood enhancement treatments 1. Impregnation of southern yellow pine with melamine-formaldehyde and melamine-ammeline-formaldehyde resins. Journal of Wood Chemistry and Technology, 14(4): 577-603

Pizzi A. 2003. Melamine-formaldehyde adhesives. In (Ed.) Pizzi A., Mittal K.L. Handbook of adhesive technology, Second edition, revised and expanded, CRC Press, New York, USA.

Ramsden M.J., Blake F.S.R., Fey N.J. 1997. The effect of acetylation on the mechanical properties, hydrophobicity, and dimensional stability of *Pinus sylvestris,* Wood Science and Technology, 31: 97-104.

Rapp A.O., Peek R.D. 1995. New principles for the protection of wood: Impregnation with water-borne resins. Proceedings of 26th annual meeting on the international research group on wood preservation. Helsengor, Denmark. IRG/WP 95-40047

Rapp A.O., Peek R.D. 1996. Melamine resins as preservatives – Results of biological testing. Proceedings of 27th annual meeting on the international research group on wood preservation. Hamburg, Germany. IRG/WP 96-40061

Rowell R.M. 2005. Moisture properties. In: (Ed.) Rowell. R.M. Handbook of wood chemistry and wood composites. CRC Press, Florida.

Rowell R.M. 2006. Acetylation of wood: Journey from analytical method to commercial reality. Forest Products Journal, 56 (9): 4-12

Rowell, R.M., Ibach R.E., McSweeny J., Nilsson T. 2009. Understanding decay resistance, dimensional stability and strength change in heat-treated and acetylated wood. Wood Material Science and Engineering, 4 (1): 14 — 22

Scheiding W., Kruse K., Plaschkies K., Weiß B. 2005. Thermally modified wood for playground toys: Investigations on industrially manufactured products. In (Ed.) Militz H., Hill C. Wood Modification: Processes, Properties and Commercialization. Göttingen, Germany, 12-18

Siau J.F. 1984. Transport process in wood. Springer-Verlag, Berlin.

Thygesen L.G., Engelund E.T., Hoffmeyer P. 2010. Water sorption in wood and modified wood at high values of relative humidity. Part I: Results for untreated, acetylated and furfurylated Norway spruce. Holzforschung, DOI 10.1515/HF.2010.044

Tremblay C. Lihra T. 2005. Physical properties of thermally modified Balsam fir and Jack pine. In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 74-78.

Westin M., Rapp A., Nilsson T. 2006. Field test of resistance of modified wood to marine borers. Wood Material Science and Engineering, 1: 34-/38

Yildiz S. Yildiz Ü., Dizman E., Gezer E., Temiz A. 2005. A laboratory scale evaluation of heat treatment for some aspects in two important timber species in Turkey. In. Militz H., Hill C. (Ed.) Wood modification: processes, properties and commercialization. Göttingen, Germany, 47-52