PROPERTIES OF SELECTED WOOD COATINGS APPLIED ON THM - DENSIFIED NORWAY SPRUCE (PICEA ABIES K.)

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ABSTRACT

The aim of this study was to investigate the performance of diverse wood coating systems on THM-densified spruce wood. For this purpose, Norway spruce [Picea abies K.] was thermo-hydro-mechanically densified in a closed system, under pressure and steam. Five different types of solvent- and water-based coating systems were applied. To assess the interaction of the coatings and the densified wood, following tests were carried out: exposure to UV light, water permeability and climatic variation. The color of densified wood is more stable to UV light than non-treated wood and the coating system has insignificant influence on color change. When specimens are exposed to a short-term change of climatic variation, the total volume change is less than 5% on uncoated densified wood, neglectable if coated. In case of long-term variation, (specimens exposed until constant weight), the protection effect of the coatings is less significant. The total volume change is appr. 8%. Therefore, if coatings are partially preventing moisture and water uptake of densified wood at short term exposure, they confer limited protection at long term exposure. Moreover, there is not significant performance difference within the different kinds of coating systems.

Key words: wood, coating, densification, UV radiation, water permeability, wood modification

1. INTRODUCTION

Chemical and thermal modification has the potential to improve some less favorable properties of wood. Increasing the density of solid wood by means of compression has been applied since the middle of the last century (Stamm & Seborg R.M., 1941; Navi & Heger, 2004; Kutnar & Šernek, 2007; Sandberg, Haller, & Navi, 2013). Higher density generally results in improved mechanical properties. However, thermo-hydro- mechanical process causes changes in surface properties of the wood, like the increase of surface hydrophobicity, that might lower gluing or coating ability (Sandberg & Navi, 2007). In addition to the change of mechanical properties of the wood, aesthetic visual properties are changed. The treated wood becomes a darker color that depends on the process of modification. Furthermore, wood is an anisotropic material and it is dimensionally unstable when it encounters moisture. THM-modification reduces the equilibrium moisture content, inducing a higher resistance against wood destroying organisms and increased service life in exterior conditions might be expected. One way to protect the wood from moisture uptake, weathering, blistering, adhesion failure and degradation via microbiological attack is the surface protection with coatings. Beside the protection function, coatings have aesthetic function as well (Dawson et al. 2005). In the last few decades the use of solvent born wood coatings has been subjected to high environmental pressure. Waterborne coatings are better for the environment and are sustainable. For quantifying the efficiency of a coating to protect the wood from water and moisture, various tests have been developed (Hjort,

1996; Feist et al. 1985). In this study, the influence of the coatings on densified wood is investigated according to liquid water absorption, water vapor absorption, and UV- light resistance. Another focus is to compare the influence of the coating system (water based, or solvent based) on densified wood.

2. MATERIAL AND METHODS
2.1 Materials
2.1.1 Densified wood

Norway spruce [Picea abies K.] from the Jura mountains (Switzerland) with a density of ca. 416 kg/m³ was used for this experiment. Samples of 73mm x 43mm x 44mm (R × T × L) were stabilized at 20°C/65% RH and densified in closed system with pressure and steam (process conditions confidential). After densification, samples were cut to the following dimensions (R × T × L): 10 mm x 24 mm x 40 mm and stabilized at 20°C/65%RH (**Error! Reference source not found.**Figure 1).

Figure 1. *Non-treated (left) and densified specimens (right)*

2.1.2 Coatings

Before coating, specimens' surface was sanded on Homag machine, first with grit size P100 and then P180. The used coating systems, and their characteristics are presented in Table 1.The coatings were prepared according to the data sheet from the manufacturer.

Densified and non-densified specimens were coated with 2 layers and intermediate sanding (grit paper P320), by hand brushing.

Three repetitions of samples have been prepared for each test and each variant (densified and non-densified wood).

Table 1. Coating systems and their characteristics (technical datasheet)

Label of coatings	Solvent 1	Solvent 2	Water based 1	Water based 2	Water based 3
Base	polyurethane acrylate resin	polyurethane acrylate resin	polyurethane-polyacrylate resin	polyurethane acrylate resin	polyurethane acrylate resin
Solvent	solvent based	solvent based	water based	water based	water based
Solid content [%]	23.1	26.6	30.3	30	35
Amount per surface (wet mass)	100-120g/m²	80-120g/m²	100-120g/m²	120-140g/m²	100-120g/m²
Colour	colourless	colourless	colourless	colourless	colourless
Gloss	mat	satin finish	satin finish	mat	satin finish
Mechanical resistance	good	high	good	good	very high
UV resistance	/	/	/	very high	high
Water resistance	/	/	good	good	very high
Chemical resistance	good	good	/	very high	very high

2.2 Methods
2.2.1 Color changes

This test is carried out according to the European standard EN 15187, 2006. Specimens were coated only on one side (24 mm x 40 mm). The color of the specimens was measured with a Spectrophotometer (Byk, Geretsried, Germany, Type: 6834) prior exposure to UV light. Subsequently. specimens were put in a Xenon Test chamber (Haan, Germany, Type: Q - Sun 3100), and the color was measured after 48 h, 96 h and 200 h of exposure. The specimens were measured on the same spot after each period.

The three lamps of the Xenon test chamber emitted 0.45 W/m$_2$ at 340 nm, temperatures of the black panel and inside chamber air were 55°C and 40°C respectively., RH was set at 50%.

Color changes were calculated according to the Commission Internationale de l'Eclairage (CIE), and L*a*b* colored space system. The CIE Lab system evaluates a color on three coordinates in respect to their lightness (L) and their chromatic parameters (a – from red to green, b – from yellow to blue). The global color change E is calculated according to equation 1.

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

(1)

Where:

L1 and L2 are the lightness values measured on the same wood area before and after exposure respectively,

a1 and a2 are the chromatic values in the red to green axis on the same wood area before and after exposure respectively,

b1 and b2 are the chromatic values in the yellow to blue axis on the same wood area before and after exposure respectively.

The evaluation and meaning according the E values are given in Table 2.

Table 2. *Evaluation of color distances E according to DIN 5033 (1966)*

E value	Meaning
0.0-0.5	Almost no difference
0.5-1.0	Difference may be visible to the trained eye
1.0-2.0	Noticeable color difference
2.0-4.0	Perceived color difference
4.0-5.0	Substantial color difference that is rarely tolerated
>5	The difference is perceived as a different color

2.2.2 Water permeability test

Water permeability test is based on the standard DIN EN 927-5, 2007. Coated specimens were conditioned in climate with 20°C/65% RH and were sealed from five sides with Tosanol Seidenglanzlack (70500-002901) from Bosshard (Rümlang, Switzerland). The sealing layer was applied two times, with intermediate drying of approximately 12 h and intermediate sanding (grit paper P320). When the sealer was dry, specimens were left in 20°C/65% RH until constant weight. Subsequently, the specimens were immersed in water appr. 2 mm on the coated side for 72 h. For evaluating the impermeability of the sealer, specimens (10 mm x 24 mm x 40 mm) from non – treated wood were covered from all sides with the sealer and tested together with the treated specimens. After 72 h immersed in water, the weight of the specimens was determined.

2.2.3 Climatic variation

Specimens for this purpose were coated from all sides with coated systems described in
. Coated specimens were kept in climate room with 20°C/65% RH until constant weight. After that, specimens were put in a dry and wet climate, respectively (Figure 2 and 3). The weight and the volume were measured.

This test was performed twice:
Cycle 1 - duration between climate change was 7 days (Figure 2)
Cycle 2 - duration between climate change was until weight constancy on the specimens. (Figure 3)
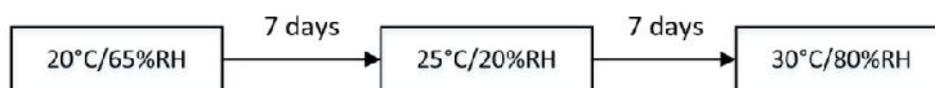
Figure 2. Cycle1-duration of climate variation test - 7 days
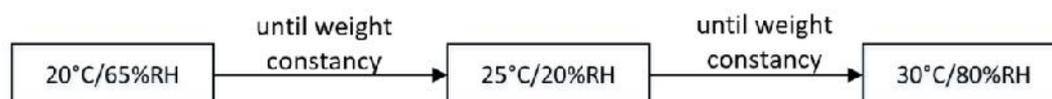
Figure 3. Cycle 2- Duration of the climate variation test - until weight constancy

3. RESULTS AND DISCUSSION

3.1 Color changes

Results of colour change are presented in **Error! Reference source not found.**. Coated untreated wood displays the highest E values from 12.6 to 18.7 after 200 h of UV radiation. Six units difference according to Table 2 is an obvious difference between the colors before and after the irradiation. The general tendency of coatings on untreated wood is to limit the global color change in this timeframe, with exception of Solvent 1. Therefore, untreated wood has the tendency to get yellow in time (b = 9.75 (48h); 10.96 (96h); 11.60 (200h)). The yellowing on the wood is generated by the lignin and lignin derivates, such es quinones, quinone methides and stilbenes (Hon & Glasser, 1979). UV radiation decreased the lignin content in the wood producing vanillin and syringaldehyde (Sanderman. Wilhelm, 1961). In this case the coatings are not preventing the wood from changing the color. Densified wood has a smaller range of E from 4.32 to 5.45. One-unit difference is almost not visible with naked eye (Table 2). Therefore, the two figures show that coatings slow down the color change on not densified samples, while they accelerate the color change on densified samples, even though the densification process itself limits the color change of samples due to UV light.

Previous studies showed that darkening of the wood surface is a result of a heat treatment as a function of treatment temperature and the kind of wood (Bekhta & Niemz, 2003). Hemicelluloses of thermally heated wood degrades and thus the lignin content on heat-treated wood increases proportionally. Thus changes in the wood lightness during heat treatment are observed mainly due to the degrading of hemicelluloses and wood colour becomes darker (Huang et al. 2012). From this test, coatings are not preventing densified wood from UV radiation. Accordingly, there is no difference in the performance between solvent based and water-based coatings on densified wood.

According to Table 2 coated densified wood has smaller change than coated untreated wood. Comparing untreated wood and densified wood, densified wood is much more stable to UV radiation. The best results for the coating are shown with Solvent 2. Figure 5 shows what the wood looks like after different durations of UV light exposure.
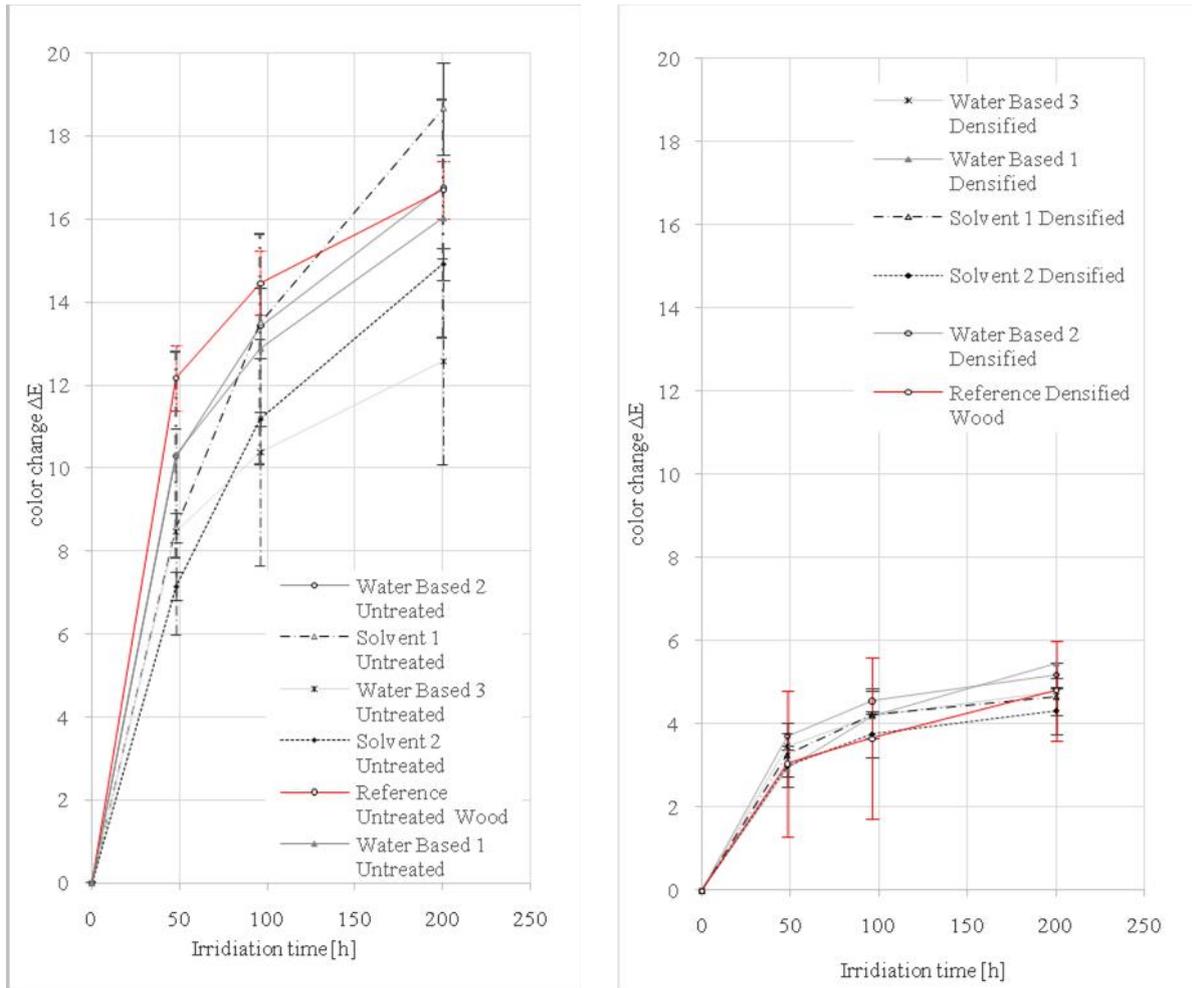
Figure 4. *E on non-treated wood (left) and densified wood (right)*
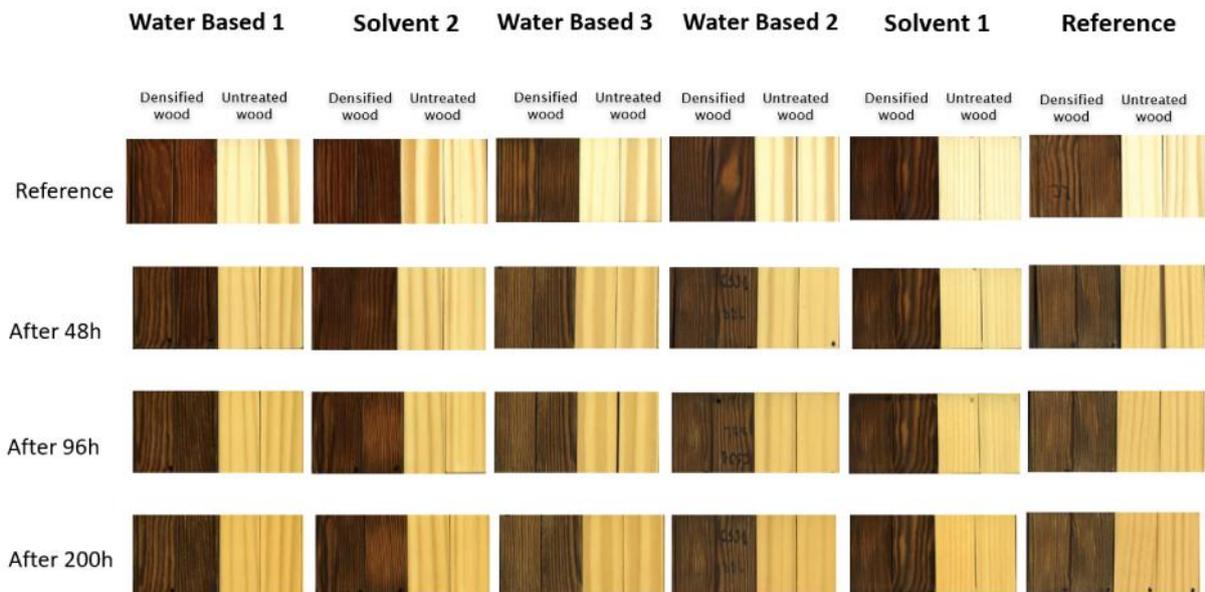
Figure 5. *UV treatment on densified and non - densified wood with different coatings systems*

3.2 Water Permeability Test

Results from water permeability test are presented in Figure 6. The Reference densified specimens without coating display a water uptake of 443.2 g/m2 (±121.6 g/m2), while non–densified specimens have a water uptake of 718 g/m2 (±124.2 g/m2). That shows that densified wood, by the thermo – hydro mechanical process becomes less reactive to liquid water. The reason for that is explained by Tanahashi, et al. 1989. They discovered that steaming results in an increase in cellulose crystallinity, microfibril width and micelle width. When the water is removed from the matrix, hydrogen bonds reform between the polymers in the matrix. As the temperature decreases, the process leads the amorphous fraction to return to the glassy state where the elastic deformation of the microfibrils and the matrix is frozen. Furthermore, from the coated samples, the best results of densified wood are shown with Water based 2 (water uptake 58.9 ± 3.31g/m2) and Solvent 2 (water uptake 70.5 ± 3.4 g/m2). The Reference standard sample has 36.1 ± 4.3 g/m2 which proves that the test is valid. From these results both solvent based and water-based samples have similar permeability properties for liquid water. There is a slight difference between coated densified and non- treated wood, which proves that coatings can prevent the interaction between wood liquid water.
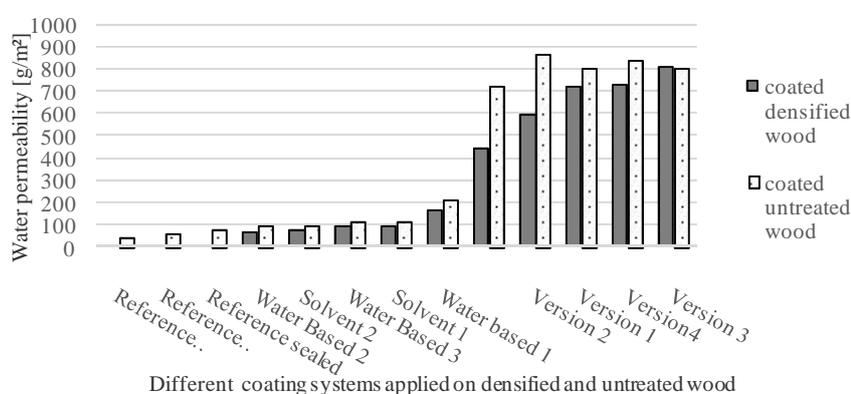
Figure 6. *Water permeablity uptake on densified and non - densified coated specimens*

3.3 Climatic variation

To reveal the inertia of densified and coated samples to react to the environment hygroscopicity, two different exposure cycles have been designed. Cycle 1 mimics a short exposure of densified wood objects to moderate conditions for 7 days, followed by 7 days in a rather dry environment and 7 days in rather wet conditions. Cycle 2 mimics a long-term exposure, where samples have time to reach equilibrium in the same conditions. Details on cycle 1 and 2 are given in chapter 2.2.3.

3.3.1 Climatic variation according to cycle 1

Figure 7 (left row) presents the volume change of samples at the end of each cycle step. In Figure 7A climate changes between 20°C/65% RH and 25°C/20% RH are presented. As expected, volume shrinkage has occurred with all specimens. The maximum shrinkage is observed for the Reference densified and reference non-treated wood with 2.2% (± 0.45%) and 1.84 % (±0.22%), respectively. In Figure 7B is shown the difference between 20°C/65% RH and 30°C/80%RH where swelling has occurred. In Figure 7C is presented the total volume change from the two extreme climates 25°C/20% RH and 30°C/80%RH. From the results, there is not much influence from any coating, and the difference is negligible.

This test showed that densified wood is less reactive to water vapor than untreated wood. Coatings are minimizing the interaction of the densified wood and ambient humidity. From this experiment, coatings by itself are protecting the wood from the vapor humidity. Best performance has Water Based 2. Therefore, the other coatings as Water Based 3, Solvent 2 are not very different in their performance regarding blocking the interaction of the wood and ambient humidity. For water vapor permeability test, there is almost no difference between solvent based and water-based coatings.
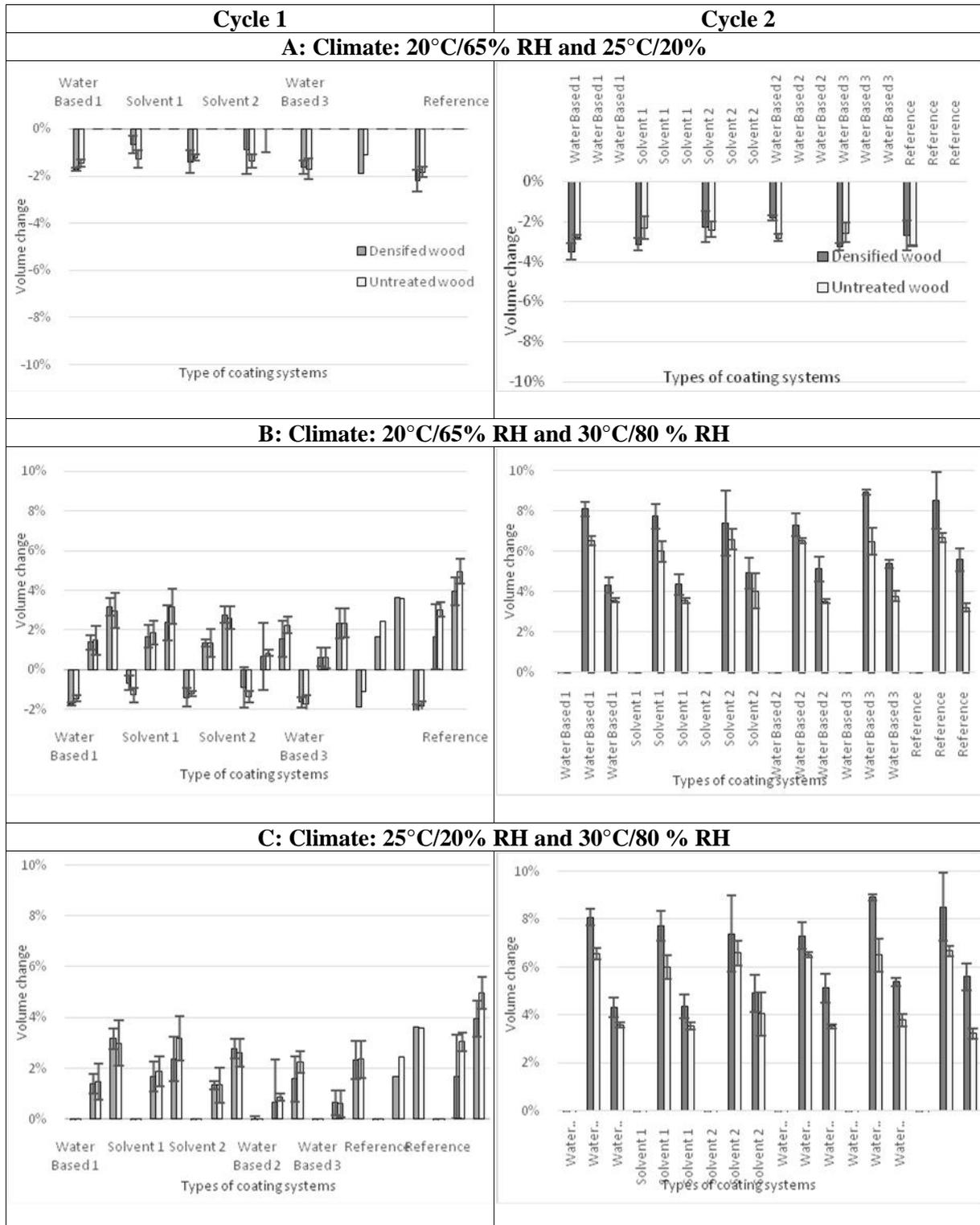
***Figure 7.** Climatic variation of different coatings systems on densified and non – densified wood according to cycle 1 (left row) and cycle 2 (right row) before changing climate with one standard deviation A) 20°C/65% RH and 25°C/20% RH B) 20°C/65% RH and 30°C/80 % RH, C) 25°C/20% RH and 30°C/80% RH*

This experiment shows that in both phases (shrinkage and swelling) densified wood has higher values than untreated wood. The reason for that is the sensitivity of the matrix softened with moisture where partial deformation from the thermo hydro mechanical process was recovered (Tanahashi et al., 1989). The results of densified and non-densified coated wood showed that after moisture equilibrium in certain climate, coatings have very small influence. That means the coatings are not blocking the interaction of water vapor and the wood. Accordingly, there is no clear difference between the performance of solvent based and water-based coating systems according to densified and non-densified wood.

From this aspect, the coatings are lowering the speed of moisture uptake, protecting the densified wood from liquid water for a limited period only.

4. CONCLUSION

From this study the following conclusion can be drawn:

Color change – densified wood is much more stable than untreated wood. The coatings almost have no influence on the color change when densified wood is exposed to UV radiation.

Water permeability – coatings protect densified wood from interaction with liquid water for a limited period.

Dimensional changes: densification conferred to wood a certain inertia in comparison to non-treated wood (smaller swelling in short exposure, bigger swelling in long exposure). Similarly, the coatings evaluated in this paper slow the swelling of densified and non-treated wood, but do not completely prevent it.

There is no clear difference between the performance of water based and solvent based coatings. From this study, Solvent 2 and Water Based 2 coatings would be the best options.

REFERENCES

[1]   DIN EN 15187, E. Furniture – Assessment of the effect of light exposure (2006).
[2]   Bekhta, P., & Niemz, P. (2003). Effect of high temperature on the change in color, dimensional stability and mechanical properties of spruce wood. Holzforschung, 57(5), 539–546. https://doi.org/10.1515/HF.2003.080
[3]   Dawson, B.S.; Göttgens, A.; Hora, G. (2005). Natural weathering performance of exterior wood coatings on Pinus sylvestris and Pinus radiata in Germany and New Zealand. Journal of Coatings Technology Research 2, No.7, 539–546.
[4]   DIN EN 927-5. Paints and varnishes - Coating materials and coating systems for exterior wood - Part 5: Assessment of the liquid water permeability (2007).
[5]   Hjort, S. (1996). Full-Scale Method for Testing Moisture Conditions in Painted Wood Panelling. Journal of Coatings Technology, 68(856), 31.
[6]   Hon, D. N.-S., & Glasser, W. (1979). On Possible Chromophoric Structures in Wood And Pulpsa Survey of the Present State of Knowledge. Polymer-Plastics Technology and Engineering, 12(2), 159–179. https://doi.org/10.1080/03602557908067670.
[7]   Huang, X., Kocaefe, D., Kocaefe, Y., Boluk, Y., & Pichette, A. (2012). A spectrocolorimetric and chemical study on color modification of heat-treated wood during artificial weathering. Applied Surface Science, 258(14), 5360–5369. https://doi.org/10.1016/j.apsusc.2012.02.005
[8]   Kutnar, A., & Šernek, M. (2007). Densification of wood, 82.
[9]   Navi, P., & Heger, F. (2004). C ombined Densification and Mechanical Processing of Wood, (May), 332–336.
[10]   Sandberg, D., Haller, P., & Navi, P. (2013). Thermo-hydro and thermo-hydro-mechanical wood processing : An opportunity for future environmentally friendly wood products. Wood Material Science and Engineering, 8(1), 64–88. https://doi.org/10.1080/17480272.2012.751935.
[11]   Sandberg, D., & Navi, P. (2007). Introduction to Wood Processing.
[12]   Sanderman. Wilhelm, S. F. (1961). Als roh- und.

[13]   Service, F., Feist, W. C., Little, J. K., & Wennesheimer, J. M. (1985). The moisture-excluding effectiveness of finishes on wood surfaces. Research Paper FPL, No. FPL-RP-462 NV - 31, 3, 20 Leaves : Ill., (May).

[14]   Stamm, A. J., & Seborg R.M. (1941). Resin-treated, compressed wood. Transaction of the American Institute of Chemical Engineers, 37, 385–398.

[15]   Tanahashi, M. Goto, T., Horii, F., Hirai, A., & Al., E. (1989). Characterization of steam-exploded wood, 3: Transformation of cellulose crystals and changes of crystallinity. Mokuzai Gakkaishi, 35(7), 654–662.

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