WOOD RESEARCH
59 (3): 2014
421-430

COLOUR STABILITY AND SURFACE DEFECTS OF NATURALLY AGED WOOD TREATED WITH TRANSPARENT PAINTS FOR EXTERIOR CONSTRUCTIONS

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(Received April 2014)

ABSTRACT

Wooden constructions and their parts in the exterior, e.g. houses, cottages, bowers, bridges, claddings, decking, windows or garden furniture, are degradable by bio-agencies, fire and weathering. Their service life can be increased by well-designed construction systems, by using of more durable wood species and composite materials, and also by convenient biocides and anti-weathering paints. In experiments, the colour changes (valued by CIELab) and surface defects (valued at 10x magnification) in wood samples during their 3-year's outdoor weathering at 45° were determined in an accordance with the EN 927-3 2000, taking into account these variable factors: 1) two wood species (black locust, Norway spruce); 2) four transparent coating systems (PerlColor, PerlColor + AquaStop, OsmoUV-Protection Oil 420, OsmoUV-Protection Oil 420 + AquaStop); 3) two roughness of wood (grinded with 60 or 120 sandpaper). Generally at natural weathering, the colours of the black locust wood untreated and treated with transparent paints were more stable than of the Norway spruce one. The OsmoUV-Protection Oil 420 ensured good colour stability to the black locust samples, and its combination with the AquaStop also to the Norway spruce ones. The top water repellent paint AquaStop put off degradation of the PerlColor and OsmoUV-Protection Oil 420 paints, with significant colour stability increase of the Norway spruce samples. A higher initial roughness of wood surfaces had usually a negative influence for the colour stability of coated wood and its surface quality.

KEYWORDS: Construction wood, paints, weathering, colour stability, surface defects.

INTRODUCTION

Correctly planed design, applying of suitable wood species or wooden composites, and also applying of biocides, anti-weathering paints or other preservatives at protection of wooden constructions was known in the past (Vařeka and Frolec 2007) and is used also in the presence (Feirer and Hutchings 1986, Štefko and Reinprecht 2004, Reinprecht 2008). All these methods have a great importance for prolongation of service-life and aesthetic function of wood houses, cottages, bowers, bridges and other wooden structures in outdoor exposures. Similarly, small construction details can increase life-time of windows, garden furniture and other wooden products.

Wood is a bio-degradable material. Its durability against wood-destroying fungi and insects is presented in the European standard EN 350-2 (1994) and in more articles (e.g. Van Acker et al. 2003, Alfredsen et al. 2007). Wood species containing tannins, terpenoids or similar extractives have a higher natural durability. This fact is a potentially useable also for ecology friendly protection of wood products (Huang et al. 2004, Amusant et al. 2005, Asamoah and Antwi-Boasiako 2007).

The most durable wood species in Central Europe is the black locust (*Robinia pseudoacacia* L.), which in future has a high potential for using in constructions, garden furniture and other wooden products in exteriours. Its disadvantage, in comparison with the cheaper and more traditional building wood species Norway spruce (*Picea abies* L. Karst.), is its higher density, worse shape stability and easier creation of cracks in outdoor exposures.

At outdoor weathering of wood above ground, the abiotic degradation of wood components is caused by sun-light and its individual spectra (UV, visible-light, IR), humidity, air-flow, water, temperature changes, acid rains, smog and other particles from human activity – mainly in industrial areas. They cause slow but permanent degradation of surface layers of wooden products. Colour changes are visually observed already after a few weeks of exposition of untreated wood (Reinprecht et al. 2011). Cracks in wood can be created also a very fast. The best way how to protect wood against up mentioned agencies is using of suitable anti-weathering paints.

Older and newer types of paints for wooden products exposed in various climatic exterior expositions were tested in a lot of works. These tests are important also today in connection with climatic changes and production of new paint products. The quality and durability analyses of new paints in exterior conditions could give relatively exact results of their suitability for a given exposure (EN 927-3 2000, Ozgenc et al. 2012, Matan and Matan 2012). The most important are colour analyses (e.g. CIELab using Colour Reader by ISO 7724 1984), visual – microscopic analyses, or adhesion tests of wood treated with paints, which should be performed in various times of weathering with the aim to eliminate subjective factors about their ageing (Oltean et al. 2010, Reinprecht and Pánek 2013).

The aim of this work was to evaluate colour protection of wood treated with selected transparent paints useable for wooden constructions in exterior conditions and defects in paints during ageing. Transparent paints can potently preserve the natural colour of wood, however in practice they are less stable as pigmented ones.

MATERIAL AND METHODS

Samples from black locust (*Robinia pseudoacacia* L.) and Norway spruce (*Picea abies* L. Karst) wood species with dimensions of 375x80x20 mm (LxTxR), in accordance with the EN 927-3

2000, were used in the experiment.

Top surface of each sample had two different roughness parts with length of 187.5 mm: a) grinded by sandpaper with grain 60 (Rough); b) grinded by sandpaper with grain 120 (Smooth).

Paints used in the experiment are recommended for wood in outdoor exposures: PerlColor, Osmo UV-Protection Oil 420, and AquaStop. These paints were supplied by Böhme AG, Switzerland. Following are specified their basic characteristics:

PerlColor – transparent stain containing nanoscale particles (UV absorber) and oil-based synthetic resin modified with ASS-Chelat (UV protection), applied as a water system. Additives: IPBC fungicide.

Osmo UV-Protection Oil 420 (*OsmoUV*) – satin-matt oil, clear finish for exterior application. It is based on natural vegetable oils (sunflower and soybean oils) in dis-aromatized white spirit (benzene-free), which penetrates deeply into the wood. It is moisture regulating, reduces swelling and shrinking of wood, and is water and dirt resistant.

AquaStop – clear water-repellent and sunblocker modified with ASS-Chelat (UV protection), applied as a water system for higher UV, weather and rain protection of wood and basic paints.

Four coating systems – combinations of up-mentioned paints were used in the experiment: a) *PerlColor* (2 layers); b) *PerlColor* (2 layers) + *AquaStop* (1 layer); c) *OsmoUV* (2 layers); d) *OsmoUV* (2 layers) + *AquaStop* (1 layer). Paints were applied in amount of 120 $g.m^{-2}$ by a low-pressure air spraying (*PerlColor, AquaStop*) or in amount of 80 $g.m^{-2}$ by a painting (*OsmoUV*). Lateral areas of samples were treated with silicone.

Control – references of untreated black locust and Norway spruce samples were tested, as well.

Natural ageing of samples in exterior conditions was performed in metal stands under angle of 45° in south orientation by the EN 927-3 2000. Three replicates for each kind of wood species and kind of paint were exposed to weathering during 0, 6, 12, 24 and 36 months in the town Zvolen – Slovakia, Central Europe, in height above sea level 290 metres. This town is located in hollow with high occurrence of foggy days, smog and high temperature differences between summer (to about 35°C) and winter (to about -25°C).

Colours of wood samples before and after natural ageing were measured by the Colour Reader CR-10 Konica Minolta (Japan). Evaluation of the total colour difference ΔE (CIE 1986) has been done by the Eq. 1, from individual colour differences between aged and non-aged surfaces: ΔL – white/black; Δa – red/green; Δb – yellow/blue:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Totally 1440 measurements of the colour (2 wood species, 2 roughness, 4 coating systems, 5 times of weathering, 3 samples in one series, 6 measurements for one sample) were performed.

The quality of paints and their damaging at weathering (after 12, 24 and 36 months) were evaluated visually by magnifier, using 10-magnification. Totally 144 measurements of the surface defects (2 wood species, 2 roughness, 4 coating systems, 3 times of weathering, 3 samples in one series), by the methodology of Van Acker et al. (1992) which was used also in the work of De Windt et al. (2014), were performed.

Analyses of obtained data were done using the programs STATISTICA (Duncan´s tests) and MS EXCELL (line plots, mean values, standard deviations).

RESULTS AND DISCUSSION

The ΔE mean values obtained after exterior exposition of samples are shown in graphs (Fig. 1). Mean values, standard deviations and statistical analyses of data by Duncan´s test are in tables (Tab. 1 – 5). Visual observations of defects are evaluated in Tab. 6.

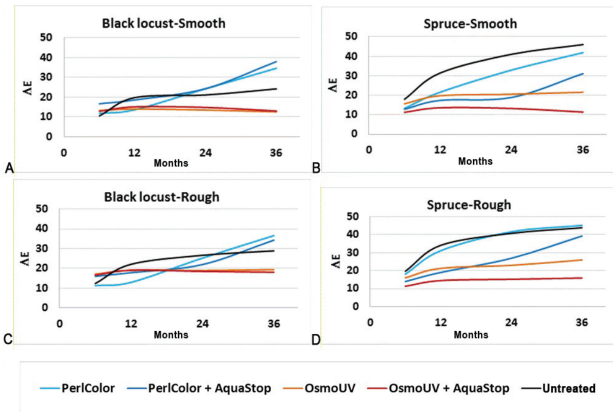

Fig. 1: Influence of wood species (A, C versus B, D) and their roughness (A, B versus C, D) for the total colour changes (ΔE) of the black locust and Norway spruce samples treated with 4 coating systems and of1 untreated references at their 6 to 36 month's weathering by the EN 327-3 2000.

Tab. 1 – 4: Statistical analyses of the colour changes ΔE of "Smooth" wood samples during their natural weathering from 6 to 36 months based on the p-values of the Duncan´s tests, i.e. in relation to the following effects: - the AquaStop paint present also in the coating system (Tab. 1), - the wood species (Tab. 2); - the kind of coating system (Tab. 3 and 4).

Tab. 1: Duncan´s test – effect of the AquaStop (Reference = PerlColor or OsmoUV).

Black locust	***PerlColor + Aquastop***	***OsmoUV + AquaStop***
6 m.	16.7 (1.9)^{a}	12.9 (1.9)^{d}
12 m.	18.6 (2.4)^{a}	15.2 (2.7)^{d}
24 m.	24.4 (4.4)^{d}	14.8 (3.1)^{d}
36 m.	38.0 (3.5)^{b}	13.0 (3.2)^{d}
Spruce	***PerlColor + Aquastop***	***OsmoUV+ Aquastop***
6 m.	12.9 (1.6)^{d}	11.3 (2.6)^{b}
12 m.	17.4 (1.7)^{b}	13.6 (4.3)^{a}
24 m.	18.9 (2.4)^{a}	13.3 (5.0)^{a}
36 m.	31.1 (6.8)^{a}	11.4 (5.8)^{a}

Tab. 2: Duncan´s test –effect of the kind of wood (Reference = Spruce).

Black locust	***PerlColor***	***OsmoUV***
6 m.	11.8 (1.7)^{d}	13.3 (3.6)^{d}
12 m.	13.7 (2.9)^{a}	14.0 (4.7)^{a}
24 m.	24.3 (7.4)^{a}	13.5 (4.5)^{a}
36 m.	34.7 (3.9)^{a}	12.6 (4.6)^{a}
Black locust	***PerlColor+ AquaStop***	***OsmoUV+ AquaStop***
6 m.	16.7 (1.9)^{b}	12.9 (1.9)^{d}
12 m.	18.6 (2.4)^{d}	15.2 (2.7)^{d}
24 m.	24.4 (4.4)^{a}	14.8 (3.1)^{d}
36 m.	38.0 (3.5)^{a}	13.0 (3.2)^{d}

Tab. 3: Duncan´s test – effect of the kind of paint (Reference = PerlColor).

Black locust	*PerlColor + AquaStop*	*OsmoUV*	*OsmoUV + AquaStop*
6 m.	16.7 (1.9)[a]	13.3 (3.6)[d]	12.9 (1.9)[d]
12 m.	18.6 (2.4)[a]	14.0 (4.7)[d]	15.2 (2.7)[d]
24 m.	24.4 (4.4)[d]	13.5 (4.5)[a]	14.8 (3.1)[a]
36 m.	38.0 (3.5)[b]	12.6 (4.6)[a]	13.0 (3.2)[a]
Spruce	*PerlColor + AquaStop*	*OsmoUV*	*OsmoUV + AquaStop*
6 m.	12.9 (1.6)[d]	15.6 (1.4)[d]	11.3 (2.6)[d]
12 m.	17.4 (1.7)[b]	19.8 (1.6)[d]	13.6 (4.3)[a]
24 m.	18.9 (2.4)[a]	20.6 (2.0)[a]	13.3 (5.0)[a]
36 m.	31.1 (6.8)[a]	21.6 (2.3)[a]	11.4 (5.8)[a]

Tab. 4: Duncan´s test – Effect of the kind of paint (Reference = OsmoUV).

Black locust	*PerlColor*	*PerlColor + AquaStop*	*OsmoUV+ AquaStop*
6 m.	11.8 (1.7)[d]	16.7 (1.9)[c]	12.9 (1.9)[d]
12 m.	13.7 (2.9)[d]	18.6 (2.4)[b]	15.2 (2.7)[d]
24 m.	24.3 (7.4)[a]	24.4 (4.4)[a]	14.8 (3.1)[d]
36 m.	34.7 (3.9)[a]	38.0 (3.5)[a]	13.0 (3.2)[d]
Spruce	*PerlColor*	*PerlColor + AquaStop*	*OsmoUV+ AquaStop*
6 m.	13.3 (1.2)[d]	12.9 (1.6)[c]	11.3 (2.6)[b]
12 m.	21.6 (3.1)[d]	17.4 (1.7)[d]	13.6 (4.3)[a]
24 m.	32.9 (6.1)[a]	18.9 (2.4)[d]	13.3 (5.0)[a]
36 m.	41.9 (2.3)[a]	31.1 (6.8)[a]	11.4 (5.8)[a]

Statistical evaluations of the colour changes (ΔE) of "Smooth" wood samples are shown by: 1) mean values from 18 replicates; 2) standard deviations in parentheses; 3) Duncan´s test in relation to the "References" at the 99.9 % significance level (a), 99 % significance level (b), 95 % significance level (c), and without an evident significant difference at $p \geq 0.05$ (d).

Tab. 5: Statistical analyses of the colour changes ΔE at 6 to 36 month's weathering of "Rough" wood samples based on the p-values of the Duncan´s tests, i.e. in relation to the roughness effect of wood surfaces treated with 4 kinds of coating systems (Reference = Smooth samples).

Black locust Rough	*PerlColor*	*PerlColor+ Aquastop*	*OsmoUV*	*OsmoUV + Aquastop*
6 m.	11.3 (3.0)[d]	16.0 (2.1)[d]	17.1 (2.1)[b]	16.7 (4.4)[b]
12 m.	13.0 (3.2)[d]	17.9 (2.3)[d]	19.1 (2.6)[a]	19.1 (4.0)[b]
24 m.	25.2 (8.0)[d]	22.0 (4.2)[d]	19.0 (2.6)[a]	18.5 (3.2)[b]
36 m.	36.6 (3.9)[d]	34.3 (4.3)b	19.4 (2.7)[a]	18.1 (3.7)a
Spruce Rough	*PerlColor*	*PerlColor + Aquastop*	*OsmoUV*	*OsmoUV + Aquastop*
6 m.	18.0 (3.5)[a]	13.9 (1.2)[d]	16.0 (1.8)[d]	11.3 (1.8)[d]
12 m.	31.1 (3.0)[a]	19.0 (1.3)[d]	21.2 (2.3)[d]	14.5 (3.0)[d]
24 m.	41.6 (2.8)[a]	26.9 (6.3)[a]	22.9 (2.6)[d]	15.2 (3.3)[d]
36 m.	45.1 (2.1)[b]	39.2 (5.7)[a]	25.9 (2.7)[a]	15.9 (3.8)[a]

Statistical evaluations of the colour changes (ΔE) of "Rough" wood samples are shown by: 1) mean values from 18 replicates; 2) standard deviations in parentheses; 3) Duncan´s test in relation to the "References" at the 99.9 % significance level (a), 99 % significance level (b), 95 % significance level (c), and without an evident significant difference at $p \geq 0.05$ (d).

Tab. 6: Visual rating of the coating systems on the black locust and Norway spruce samples after 12, 24 and 36 months of weathering.

Wood species	Time of ageing (months)	Kind of paint and type of wood roughness							
		PerlColor		*PerlColor + Aquastop*		*OsmoUV*		*OsmoUV + Aquastop*	
		Rough	Smooth	Rough	Smooth	Rough	Smooth	Rough	Smooth
Black locust	12	6	6	5	4	4	4	4	2
	24	10	7	6	6	4	4	4	3
	36	10	10	10	10	6	4	5	4
Norway spruce	12	10	7	6	4	4	3	3	2
	24	10	10	8	7	5	4	4	3
	36	10	10	10	10	8	5	4	3

Mean values from 3 replicates.

Evaluation based on the work of De Windt et al. (2014) (Note: – shown in Tab. 2 on the page 264 in cited publication, i.e. 0 = None degradation; 2 = Small aesthetical changes; 4 = Mild changes (easy to retreat); 6 = Moderate changes (maintainable); 8 = Striking (maintenance is difficult); 10 = Advanced degradation (a maintenance coat cannot restore the defects)).

Transparent paints applied on the black locust wood have shown for this wood species a better colour stability and less rate of destruction than for the Norway spruce in most cases. It has two possibilities for explanation:

1) Different anatomical structure and surface properties of black locust hardwood in comparison with Norway spruce softwood.
2) Different extractives in black locust (tannins) than in Norway spruce (terpenoids), and then possibility of different chemical reactions and physical bonds of these wood species with used paints.

Influence of surface properties at different wood species for quality of coating systems observed also De Windt et al. (2014).

The total colour changes ΔE of samples were above 10 already after ½ year of natural weathering (Tabs. 1-5). Concurrently should be emphasised that after 3 years of weathering at samples treated with the PerlColor coating system the ΔE values achieved more than 30 (Tabs. 1-5).

Generally, a higher positive effect for saving the natural colour of wood had the paint OsmoUV as the paint PerlColor, for both wood species – the black locust and Norway spruce – at weathering lasting more than 12 months (Fig. 1, Tabs. 3 and 4, and mean values also in Tab. 5).

Colour stability of wood surfaces was usually improved when using also the top water repellent paint AquaStop. A higher positive effect of this top layer was observed mainly at the Norway spruce samples, more apparently at longer times of their weathering (Fig. 1, Tab. 1, and mean values also in Tabs. 1, 3, 4, and 5).

A better behaviour of the transparent coating systems on the black locust wood comparing to the Norway spruce wood was significant already after 12 months of natural weathering for both basic paints – the PerlColor and OsmoUV. On the other hand, at using the coating system PerlColor + AquaStop the colour stability of the Norway spruce showed better while the coating system OsmoUV + AquaStop had similar colour stabilization effect for both wood species (Tab. 2, and mean values also in Tabs. 1, 3, and 4).

Effect of the different roughness of wood surfaces for the colour stability of coating systems was not always clear. Different results obtained for the black locust and Norway spruce samples have shown influence of wood species at the roughness effect for colour stability of coated wood.

For the black locust, its different roughness had not an evident influence for the different colour changes at using the coating systems PerlColor and PerlColor + AquaStop (Tab. 5), however, at using the coating systems OsmoUV and OsmoUV + AquaStop the colour stability of smooth black locust samples was significantly higher in comparison to its rough ones (Tab. 5, and mean values also in Tab. 3). On the other hand, for the Norway spruce its different roughness had not usually influence for different colour changes at using the paints OsmoUV and OsmoUV + AquaStop (Tab. 5) – but the paints PerlColor and PerlColor + AquaStop ensured significantly better colour stability for smooth samples (Tab. 5, and mean values also in Tab. 4). Obtained results could confirm up mentioned theory about different molecular-anatomical-morphological structure of spruce and black locust woods together with their actual roughness on the colour stabilization effect of different coatings.

Visual rating of destruction the coating systems has shown (similarly with colour analyses) a better stability of the coatings OsmoUV and OsmoUV + AquaStop in relation to the coatings PerlColor and PerlColor + AquaStop (Tab. 6). Effects of the wood species (black locust and Norway spruce) and their different roughness (Rough and Smooth) were usually negligible at destruction of coatings. However, the PerlColor on the black locust samples was partly more stable than on the Norway spruce ones, or a negative influence of higher roughness was observed at both wood species. The top layer AquaStop had a positive effect on the quality of aged surfaces in all cases of carried out experiments (Tab. 6).

Finally it is possible to say that suitable transparent paints with a higher amount of UV stabilizers can decrease colour changes of wood in exterior conditions. However, using of pigments in paints has a more expressive colour stabilization efficacy in accordance with other experimental works (e.g. Evans and Chowdhury 2010, Reinprecht and Pánek 2013).

Data of present work could give a good encouragement for using of black locust wood in exterior wooden structures. Its great advantage is also a higher natural durability against wood destroying fungi and insects in comparison with traditional construction wood species as are Norway spruce, Douglas fir, Scots pine, and some others.

CONCLUSIONS

- Transparent paints with a higher amount of UV stabilizers can partly decrease colour changes of wood in exterior conditions.
- From used paints, there at outdoor weathering evidently better results shown the Osmo UV-Protection Oil 420 (alone and for Norway spruce more evidently in combination with the top layer AquaStop) as the PerlColor.
- The paint AquaStop, used as top layer, usually positively influenced the colour stability and rate of destruction of both basic paints (OsmoUV and PerlColor) during their 3-year's weathering. The AquaStop in more cases decreased also a negative influence of higher roughness of wood surfaces on their larger colour changes and visual defects.
- From two wood species, the black locust occurred usually as better wood substance for transparent paints in comparison with the Norway spruce wood, evaluating colour stability and rate of surface destruction at natural weathering.
- Different roughness of wood surfaces treated with coating systems had not always a clear effect on their colour stability – but nevertheless the colour stability was usually higher for smooth surfaces of wood.
- Visual defects in coated surfaces occurred in a lesser extend when the wood was smoother.

ACKNOWLEDGMENT

The authors would like to thank the Grant Agency of the Slovak Republic (Project VEGA No. 1/0574/12) and Internal Grant Agency of Czech University of Life Sciences, Prague (Grant No. 20124350) for the financial support of this work.

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