ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 11 N° 1 2015
pp. 26-31

PROTECTIVE EFFECT OF COATING ON MECHANICAL PROPERTIES OF WOOD MATERIALS EXPOSED TO NATURAL WEATHERING

Özlem ÖZGENÇ [*]
Lecturer Dr.- Karadeniz at Technical University, Turkey
Address: Karadeniz Technical University, Faculty of Forestry, 61080/Trabzon TURKEY
E-mail: ozlem_ozgenc@hotmail.com

Ümit C. YILDIZ
Prof.Dr.- Karadeniz at Technical University, Turkey
Address: Karadeniz Technical University, Faculty of Forestry, 61080/Trabzon TURKEY
E-mail: yildiz@ktu.edu.tr

Sibel YILDIZ
Prof.Dr.- Karadeniz at Technical University, Turkey
Address: Karadeniz Technical University, Faculty of Forestry, 61080/Trabzon TURKEY
E-mail: sibelyildizz@gmail.com

Abstract:
The objective of this study was to investigate the protection effect of acrylic coating systems on mechanical properties of some wood species exposed to natural weathering. Beech (Fagus orientalis L.), scots pine (Pinus sylvestris L.) and oriental spruce (Picea orientalis L.) wood samples were coated with a new generation of acrylic resin including two different UV absorbers (organic and inorganic) and subjected to natural weathering tests for 15 months in Uzungöl and Hıdırnebi plateau located in the north of Turkey. Changes in mechanical (compression strength parallel to fibers, static bending strength and modulus of elasticity) properties were investigated and compared with non-coated wood samples. The result of this research demonstrated that the mechanical strength losses of specimens coated with acrylic resin decreased after the 15-month natural weathering test. Under outdoor conditions, the best protection is provided by the organic UV absorber for oriental spruce and by the inorganic UV absorber for oriental beech. The influence of acrylic resin including UV absorbers (organic and inorganic types) were similar to each other for scots pine. The wood samples had higher rates of mechanical strength loss in Uzungöl plateau when compared to the ones from Hıdırnebi plateau.

Key words: *acrylic resin; mechanical strength; natural weathering; UV absorber; wood.*

INTRODUCTION

Wood is a natural, durable material which is used for aesthetic, engineering and structural applications. However, the unprotected wood surface is susceptible to weathering which may result in physical deterioration, color change, surface roughening, cracking and damaging of the wood microstructure (Williams 2005). All of these effects arise from a combination of light, water, and heat, which are encompassed in the weathering process (Feist 1989). The color of wood changes easily, though this does not give any indication about how much the other properties have changed compared to untreated wood exposure weathering (Feist and Hon 1984). Mechanical properties of wood are also negatively affected by the weathering process (Ozgenc *et al.* 2013). Weathering may significantly reduce the dimensional stability and exterior performance of wood as well as mechanical and physical properties (Bhat *et al.* 2010).

Multiple methods have been suggested to make wood more resistant to photo-degradation by preventing degradation and color alterations occurring in wooden materials under the effect of natural weather. These methods are; protective treatment, thermal and chemical alteration applications and certain surface coatings (Feist and Hon 1984, Williams 2005). One way to inhibit weathering of natural wood is to use protective finishes. Results of many studies reveal that increased UV levels cut off efficacy of clear coatings alleviated photo-yellowing and photo-degradation of clear-coated wood to extend service life of wood materials (Allen *et al.* 2002, Chou *et al.* 2008).Various surface coatings such as polyurethane varnish, polyester varnish, acrylic resin, UV absorbent contain surface coating materials. In recent years, clear coats have been in the focus of interest of numerous coating producers (Forsthuber *et al.* 2013). They are usually coated with various protective and decorative finishes such as paints, transparent stains and penetrating finishes or film forming clear varnishes (Hayoz *et al.* 2003). In the last decade, organic and inorganic absorbers have received great attention for transparent wood coatings because of their excellent properties as UV blockers. It is known that there is no significant difference between acrylic clear-coats containing the

[*] *Corresponding author*

organic and inorganic UV absorbers for stabilizing wood color and protecting the quality of the surface (Ozgenc *et al.* 2012). Yalınkılıç *et al*. According to the studies performed, polyurethane-coated surfaces are harder and more stable than others coated with synthetic varnish, before and after weathering (Yalınkılıç *et al.* 1999, Chang *et al.* 2004).

OBJECTIVE

The objective of this study was to investigate the protective effect of new generation acrylic coating systems on mechanical properties of oriental beech, scots pine and oriental spruce wood species exposed to natural weathering.

METHODS

Preparation of samples

Defect free samples with dimensions of 300mm length by 70mm width by 20mm thickness from the sapwood of three species, namely oriental beech (*Fagus orientalis* L.), scots pine *(Pinus sylvestris* L.*)* and oriental spruce (*Picea orientalis* L.) were conditioned within a climate room having a temperature of 21^0C and relative humidity of 65% until they reached a moisture content of about 12%. Later samples were lightly sanded with a 120 grit sandpaper.

Formulation of the coating systems

The UV absorbers were synthesized by the Ciba company (which is now part of BASF) and the Sachtleben company. Topcoats were formulated from the same commercial acrylic resin, a poly-(methylacrylate/methylmethacrylate/butylacrylate) copolymer dispersion. To exclude effects of other additives on the photo-stabilization performance, only a small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate (texanol) as a coalescending agent were used in the formulations.

Coating process

Firstly; the water-based impregnation agent, having active ingredients of 1.20% propiconazol, and 0.30% iodopropynyl butylcarbamat, was used at a spread of 120g/m² using a brush for the protection of the samples against biological deterioration. Two types of absorbers were used. One of them was a UV screener; from the UVA of hydroxyphenyl-striazines class, as an organic UV absorber (UV1) and TiO_2, used as an inorganic UV absorber (UV2). A commercially produced finishing having acrylic resin properties and a copolymer dispersion of methylacrylate/methylmethacrylate/butylacrylate, was used as a top coat for the specimens. Three layers of top coats were also applied to each sample at a spread rate of 100g/m² by brush.

Natural weathering test

Firstly for the natural weathering test, moisture was removed from the wood samples. And then samples were painted with 2-Epoxy white paint as shown by the EN 927-3 standard (2007). Later, the wood samples were stored for approximately 2 weeks in an atmosphere with a temperature of 20^oC and relative humidity of 65±5% prior to the natural weathering test. Natural weathering test assemblies were installed in the plateaus with various altitudes in Trabzon of the Black Sea Region counties of Turkey-Uzungöl (altitude: 1090km) and Hıdırnebi (altitude: 1600km) plateaus. The natural weathering test continued for 15 months.

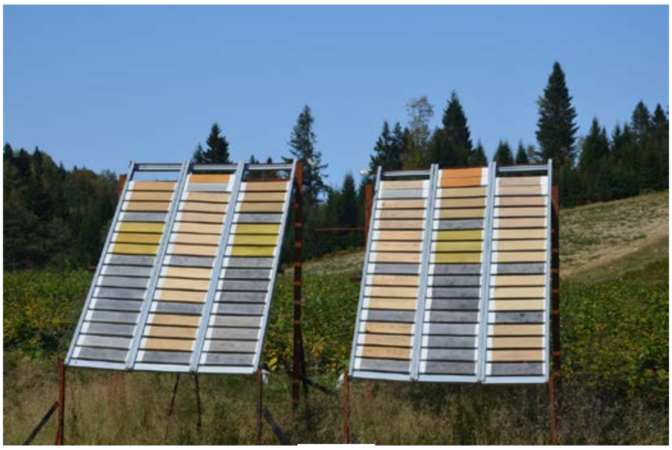

Fig. 1.
Natural weathering experimental stand.

Mechanical tests

Mechanical property compression strength parallel to grain (CS), modulus of rupture (MOE) and modules of elasticity (MOE) of un-weathered and weathered wood samples were performed according to the following test standards. The CS test was performed in accordance with ASTM D 143 (1992) in a universal testing. The MOR and MOE were determined by 3-point bending according to TS 2595 (1977) in a universal testing equipment type MTS Alliance RT/30.

RESULTS AND DISCUSSION

Effects of weathering test on CS

Table 1 shows the effect of weathering on compression strength in different plateaus compared to the un-weathered samples. It was determined to have similar CS values of uncoated and coated wood samples in the ‘before weathering test’. The lowest CS values were obtained from the wood samples coated with acrylic resin including inorganic UV absorber in before and after weathering test.

Table 1

Compression strength values of wood in before and after outdoor exposure (N/mm^2)

	Samples	Beech	St. sp.	Pine	St. sp.	Spruce	St. sp.
Before weathering test	Control	51.0	10.2	37.6	7.6	32.7	7.1
	Organic UVA	45.7	8.4	39.0	6.8	31.2	5.8
	Inorganic UVA	41.9	8.1	36.0	6.9	31.6	6.3
Weathering in Uzungöl	Control	41.2	8.7	29.3	4.7	27.8	4.4
	Organic UVA	43.2	7.4	29.4	5.3	28.3	5.1
	Inorganic UVA	38.4	7.1	35.3	6.8	29.2	5.7
Weathering in Hıdırnebi	Control	43.9	8.2	29.9	5.7	27.7	4.3
	Organic UVA	43.6	7.1	31.5	7.0	25.6	5.9
	Inorganic UVA	41.7	7.3	33.6	6.2	26.2	6.1

The rates of CS loss are shown in Fig.2. The highest CS values were seen in beech wood samples subjected to a 15-month natural weathering test in Uzungöl and Hıdırnebi plateaus.

As seen in Fig. 2., the lowest CS losses were observed in spruce wood samples coated with acrylic resin including organic UV absorbers. The best protection is provided by the organic UV absorber for oriental spruce and by the inorganic UV absorber for oriental beech in outdoor conditions. The CS loss of acrylic resin including UV absorbers (organic and inorganic types) was similar to each other for scots pine. Several researches have shown that the coating penetration increases with higher coating absorbency for softwood surfaces. The organic UV absorber represents an outstanding stabilization potential for high-performance coatings (Ozgenc *et al.* 2012, Bulcke *et al.* 2008).

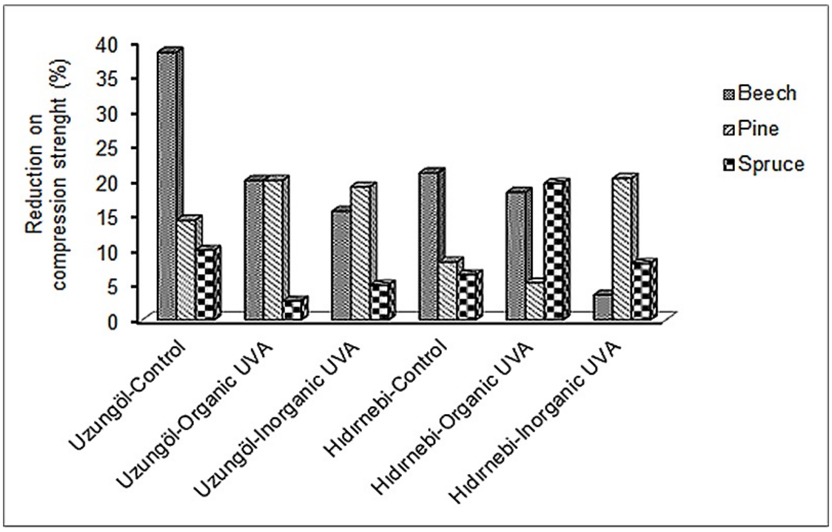

Fig. 2.
Reduction on the compression strength of wood in outdoor conditions (%).

The rates of CS losses in Uzungöl and Hıdırnebi plateaus for beech samples coated with acrylic resin including the inorganic UV absorber were found as 15.6% and 3.6%, respectively. The diminutions in the strength properties were related to the rate of surface degradation post weathering test, especially in control samples. Clear coat from acrylic resin with the addition of the UV absorber can form a protective layer on the surface of wood cells, which decreases the water uptake of wood (Schaller *et al.* 2008). For this reason, it can be said that the acrylic resin coating including the UV absorber on wood surface provides great protection in outdoor conditions (Özgenç 2014).

Effects of weathering test on MOR and MOE

Table 2 shows that the MOR and MOE values of control uncoated and coated samples before weathering were similar. However, it was observed that the MOR and MOE of un-weathered samples were lower than weathered control samples, while similarly MOR and MOE values of un-weathered and weathered coating samples. The highest MOR and MOE values were found in wood samples coated with acrylic resin including the inorganic UV absorber after weathering exposure in Uzungöl plateau (Table 2). However, the best protection was provided by acrylic resin including the organic UV absorber in weathering exposure in Hıdırnebi plateau (Table 2). In addition, as can be seen from Table 2, after the natural weathering test the surface of wood samples had higher rates of erosion in the Uzungöl plateau when compared to the ones from Hıdırnebi plateau. This erosion is caused primarily by moisture or rain Feist 1989). The wood surface coating is protected from rain and humidity effects. Thus, surface erosion on wood surfaces coated with the acrylic resin including UV absorber prevented the formation of surface cracking and splitting of wood. Wood loss in the mechanical resistance was also prevented (Fufa *et al.* 2012).

Table 2

MOR and MOE values of wood samples before and after outdoor exposure

	Variations	Beech		Pine		Spruce	
		MOR (kp/mm^2)	MOE (kp/mm^2)	MOR (kp/mm^2)	MOE (kp/mm^2)	MOR (kp/mm^2)	MOE (kp/mm^2)
Before weathering test	Control	11.950 (4.1)	1190.50 (84.7)	8.040 (3.7)	873.50 (46.7)	6.890 (3.6)	651.00 (64.2)
	Organic UVA	12.000 (3.7)	1210.20 (95.3)	9.500 (4.6)	854.20 (68.9)	7.900 (4.1)	784.40 (53.7)
	Inorganic UVA	11.340 (3.9)	1154.10 (72.7)	9.940 (3.1)	884.50 (45.1)	7.500 (3.7)	715.60 (52.4)
Weathering in Uzungöl plateau	Control	7.350 (3.2)	723.60 (53.4)	6.890 (2.8)	523.40 (51.7)	6.200 (3.3)	521.10 (44.7)
	Organic UVA	9.570 (4.7)	923.80 (74.2)	7.590 (2.1)	541.20 (62.3)	7.680 (2.7)	612.40 (65.3)
	Inorganic UVA	9.840 (3.9)	965.40 (66.7)	8.040 (4.8)	578.30 (44.6)	7.120 (4.2)	685.70 (78.3)
Weathering in Hıdırnebi Plateau	Control	9.420 (4.8)	904.60 (91.1)	7.370 (3.7)	682.70 (62.2)	6.350 (2.4)	582.70 (52.8)
	Organic UVA	11.800 (5.1)	984.90 (73.7)	8.990 (4.3)	795.30 (54.9)	6.890 (2.1)	692.20 (62.4)
	Inorganic UVA	10.930 (4.9)	1034.80 (84.3)	7.920 (2.1)	780.60 (64.7)	6.440 (1.7)	650.70 (53.1)

*Values in parenthese are standard deviations.

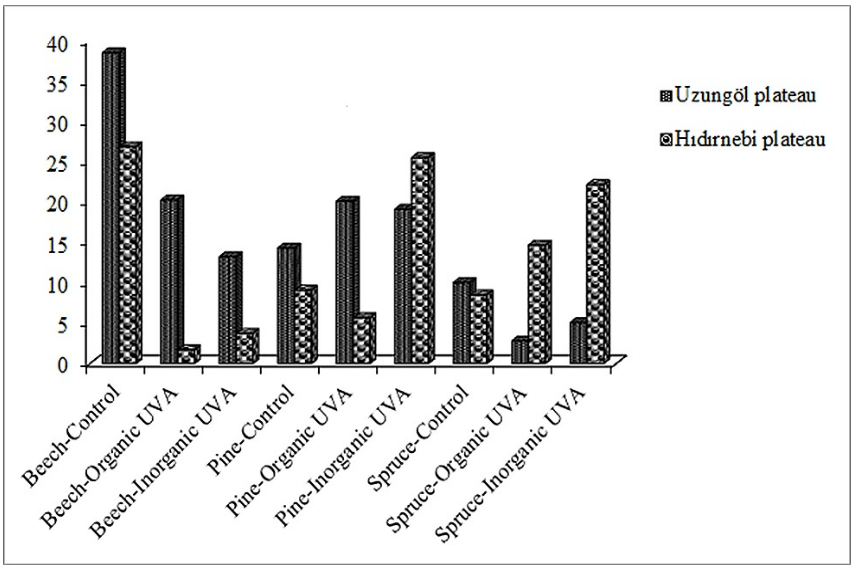

Fig. 3.
Reduction in MOE (%).

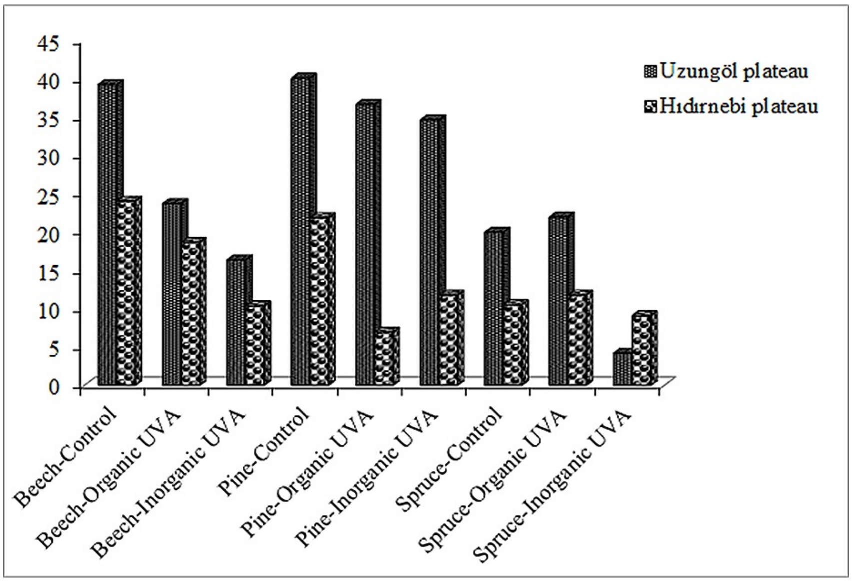

Fig. 4.
Reduction in MOR (%).

According to Fig. 3 and 4, it was determined that the MOR and MOE loss of control samples in weathering conditions were higher than coated wood samples. Control samples showed surface cracking after natural weather testing. In addition, swelling and shrinking of the wood after absorbing and desorbing moisture apparently resulted in voids at the wood interface. Surface cracking and destruction of interfacial properties continued as weathering time increased. The surface of the wood allegedly began to flake off. After plentiful weathering, the chain scissions become sufficient enough to affect the tie molecules, and the crystallinity decreases. Both a decrease in the crosslinking and a decrease in the crystallinity result in an decline in MOE (Stark *et al.* 2004).

The weathering process affects only the surface of the wood. After the 15-month weathering test, the rates of mechanical loss on test and control samples from Hıdırnebi plateau was found to be higher in comparison to those from the Uzungöl plateau (Fig. 2 and 3). This is due to the fact that when compared to the Hıdırnebi plateau, samples from the Uzungöl plateau were found to have higher moisture according to a study performed by Williams (Williams 2005).

CONCLUSIONS

Increasing concerns on the durability of wood material as well as environmental damage caused by weathering conditions require better technology for the protection of wood. Applying transparent coatings helps to extend the service life of wood without affecting its natural look, also with lowered environmental impacts. However, for longer performance of these coatings in outdoor conditions improvements of the coatings are crucial. This study investigated the protection effects of new generation acrylic coating systems on mechanical properties of beech, scots pine and oriental spruce wood species exposed to natural weathering. Uncoated specimens exhibited lower mechanical strength than coated specimens in outdoor conditions. The highest mechanical strength in coated specimens was obtained from the beech wood samples. Acrylic resin including the inorganic UV absorber provided greater protection than the organic UV absorber for oriental beech wood in outdoor conditions. Nevertheless, the highest protection on oriental spruce was obtained from acrylic resin including inorganic UV absorber. The influence of organic and inorganic UV absorbers on mechanical strength loss of scots pine were similar to each other.

ACKNOWLEDGEMENTS

The authors would like to thank Karadeniz Technical University, Research Fund (Project No: 2009.113.002.1), in Turkey which provided support.

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