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COMPARING DURABILITY OF WOOD MATERIAL IN NATURAL AND ARTIFICIAL WEATHERING CONDITIONS

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Abstract:
The performance of pre-treated and non-treated wood material samples (Fagus orientalis L. and Pinus sylvestris L.) subjected to outdoor conditions were examined in this study. A thermal treatment method, impregnation with MCQ and acrylic resin containing UV absorbers were used for wood protection and coating in the preservation process. The colour change parameters and the decrease rates of the compression strength were determined for the samples exposed in the outdoor tests. The natural weathering test applied to wood samples in the Sürmene coastal in the province Trabzon in Turkey was simulated artificially in QUV test cabinet. As a result the 50-60% similarity rate between the surface degradation of wood samples exposed to natural weathering and QUV test cabinet was determined by the statistical analysis.

Key words: *weathering conditions; wood coating; wood preservation; thermal treatment; UV absorber.*

INTRODUCTION

Wood is a durable material in appropriate conditions and used as structural material at exterior and interior applications of buildings since centuries. The service life of the wooden material used at building outdoor applications decreases when it is subjected to natural weathering conditions since it trends to environmental degradations as it is the case for other biological materials (Feist 1990). The degradation of the wooden materials in outdoor conditions due to the composition of the chemical, mechanical and light energy factors is defined as “weathering”. This weathering process is initiated by the UV rays and humidity, temperature, oxygen, wind, pollution and other similar factors prevailing in exterior environment conditions increase the decomposition in question (Williams 2005). It is determined in the studies conducted during the recent years that gases like SO_2, NO_2 and O_3, which cause atmospheric pollution, are rather contributing to the degradation of wood in outdoor conditions (Anderson *et al.* 1991).

The decomposition of wood in outdoor conditions is a rather complex process. Reactions, which start on the wood surface by the influence of UV rays cause results like colour change, gloss loss and changes of the surface texture. The physical, chemical and mechanical features of all wood polymers (cellulose, lignin, hemicelluloses) capable to absorb UV rays change considerably (Teacă *et al.* 2013). The UV rays chemically degrade the structural components of wood (lignin and carbohydrate) with an efficient energy and cause surface changes. Stresses and cracks incur on the wood surface because of humidity increase or loss due to the relative humidity, rain and dew (Feist and Hon 1984). There are many different methods applied in order to prevent the erosion and colour change at the wood surface due to the influence of the outdoor conditions and to convert wood more resistant against outdoor conditions (Williams 2005). The general purpose of these methods can be summarized as prevention of UV rays, modification of the light absorbing units within the structure of wood, elimination of colour change causing structures, removal of oxygen or reduction of the O_2 reaction, elimination of the free radicals, which develop by the effect of light (Özgenç 2014).

Wood preservation surface treatment materials and methods compatible with the existing and potential two types (scots pine and oriental beech) in the Eastern Black Sea Region and which increase their resistance against outdoor conditions was determined. During the performance of this determination, the practical applicability and the economic criteria of the materials and methods were prioritized. Beside this, the results of the natural and artificial weathering conditions were evaluated together and the the Sürmene coast’s climate conditions were simulated in QUV test cabinet. It was determinated to a similarity used the colour change values and reduction ratio on the compression strength parallel to fibers (CSPF) by the correlation analysis.

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Experimental procedure

The oriental beech (*Fagus orientalis* L.) and scots pine (*Pinus sylvestris* L.) were used in the study as defect free samples. The wood samples were prepared with dimension of 300mm in length by 70mm wide by 20mm thick for natural weathering and 150mm length by 70mm width by 20mm thickness for artificial weathering.

Thermal and impregnation treatment

The Micronized Copper Quaternary (MCQ) is the use of very small particles of solid copper, usually copper carbonate, rather than soluble copper in the solution being injected into the wood. MCQ is a water-based wooden preservative that contains a copper-based fungicide and an organic co-biocidea quaternary ammonium compound). The preservative was supplied by the Osmose Company (Turkey) (Ozgenc and Yildiz 2014).

MCQ as water based wood preservative was used to treat the samples. Four samples from each species were treated with MCQ having a concentration of 1%, employing full cell method in a laboratory type tank. Treatment schedule consisted of initial vacuum of 600mm Hg for 15min followed by pressure of 8 bar for 45min before samples were removed from the tank. All specimens were lightly wiped to remove excessive solution from their surface and weighed at an accuracy of 0.01g to determine retention value according to AWPA U1 standard (2009) using following Eq.(1):

$$R= [(GxC) /V] x10 \text{ kg/m}^3 \qquad (1)$$

where: G is amount of treating solution absorbed by the sample based initial and final weight of each block in grams;

C – concentration of the preservative solution in 100 g of the treating solution;

V - the volume of sample.

Thermal treatment as another pre-protection was applied on the four samples from each species in an oven controlling the temperature ±1^{0}C sensitivity, at two different temperatures (190^{0}C for oriental beech and 212^{0}C for scots pine under atmospheric pressure and in presence of air (so-called)). The mass loss of wood after to thermal-treatment process was calculated according to following Eq.(2):

$$\text{Mass loss of wood (\%)} = [(m_0 – m_d) / m_0] \times 100 \qquad (2)$$

where: m_0 is the dry weight prior to test;

m_d is the dry weight after to test.

Table 1 displays mass loss percent of thermal treated wood and retention values of the samples treated with MCQ.

Table 1

The retention of MCQ treated and the mass loss of thermal treated wood samples

Outdoor test	Retention (kg/m^3)		Moss loss of wood (%)	
	Oriental beech	Scots pine	Oriental beech	Scots pine
Natural weathering	4.1 (0.7)*	4.0 (0.9)*	14.5 (1.1)*	17.4 (0.8)*
Artificial weathering	4.08 (0.8)*	4.3 (1.2)*	14.7 (0.9)*	17.3 (1.0)*

**Values in parentheses are standard deviations.*

Coating processes of the wood samples

The water based impregnation agent having active ingredients of 1.20% propiconazol, 0.30% iodopropynyl butylcarbamat was used as primer for protection of the samples against biological deterioration including soft rot and blue stain. The primer was applied to the samples at a spread of 120g/m² using a brush. The UV screener TiO_2 as inorganic UV absorber and the UVA of hydroxyphenyl-s-triazines class as organic absorber were used as two types of UV absorbers.

Commercially produced finishing having acrylic resin a copolymer dispersion of methtlacrylate/methylmethacrylate/butylacrylate was used as topcoat for the specimens. Small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate, texanol as coalescending agent was added in topcoat formulation to reduce effect of other additives on the photo stabilization performance. Three layers of topcoats were applied to each sample at a spread rate of 100 g/m² by brush. Later the specimens were sanded with a 240 grit size sandpaper and kept in room temperature for two days before applying the second topcoat layer.

Natural and artificial weathering test

For the purposes of the natural weathering test, 300x70x20mm wood samples were prepared by removing moisture to prevent decay and painting them with 2-Epoxy white paint in sections as shown by the EN 927-3 standard. The natural weathering test continued for 15 months in Trabzon of the Black Sea Region coastal of Sürmene.

This experiment was performed with the artificial exterior environment test device of the brand QUV-Lab Product by simulating the exterior environment conditions based on the climate conditions of Trabzon in laboratory conditions (ASTM G 53-96). The weather condition averages of the province Trabzon between 2006-2012 years were simulated in laboratory conditions and a test device suitable climate program was established (Table 2). This climate program was developed as a result of numerous experiments based on the colour change of the wood surface. It has been determined that the colour change on the wood surface during the 1 month exposure period under natural outdoor conditions occurs during the 1 day exposure period in the artificial artificial tester. The wood samples were exposed to a test for a period of 16 days pursuant to the climate program prepared at the artificial weathering conditions testing device. Artificial weathering of the samples was performed in a QUV/spray accelerated weathering test with UVA 340nm lamps unit manufactured by Q-Panel Lab Products, Cleveland, USA.

Table 2

Artificial weathering test conditions and colour measurement periods

Exposure time	UV temperature	Water spray	Condensation
Summer-2011(June-July-August)	1h 50^{0}C	36 min	2 h 50 ^{0}C
Autumn-2011(September-October) November)	1h 45^{0}C	45 min	2 h 40 ^{0}C
Winter-2011-2012 (December-January)	1h 45^{0}C	60 min	None
Winter-2012 (February-March)	1h 45^{0}C	60 min	1 h 40 ^{0}C
Spring-2012 (April-May)	1h 50^{0}C	45 min	2 h 40 ^{0}C
Summer-2012 (June-July-August)	1h 60^{0}C	36 min	2 h 50 ^{0}C
Autumn-2012 (September-October)	1h 50^{0}C	36 min	2 h 50 ^{0}C

Colour measurement

Colour measurements were performed with a Konica Minolta CM-600d instrument. The reflection spectrum was acquired from a measuring area of 8 mm in the 400–700nm wavelength range; where at six measurements at precisely defined points on the weathered surfaces of each sample were carried out periodically. The CIE (Commission International de l'Eclairage) colour parameters L* (lightness), a* (along the X axis red (+) to green (-)) and b* (along the Y axis yellow (+) to blue (-)) were calculated using the Konica Minolta Colour Data Software CM-S100w SpectraMagic^{TM} NX Lite (ISO 7724 standard, 1984), from which the colour differences (ΔE*) were calculated according to Eq. (3):

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \quad (3)$$

Compression strength parallel to fibers (CSPF)

Compression strength parallel to fibres (CSPF) tests was conducted according to TS 2595 standard (1977). 20x20x30mm (radial, tangential, in the length) sized test and control samples were prepared, being 20 pieces for each variation.

Statistical analysis

The data was analysed by utilizing the SPSS 11.5 statisticals package program and based on a reliability level of 95% (http://www.ibm.com/analytics/us/en/technology/spss/). Primarily, in order to determine the simulation correctness of the natural and artificial weathering conditions, whether the colour change values showed a normal distribution or not was determined by the Kolmogorov-Smirnov test. Therefore was whether there is similarity between the natural and the artificial weathering conditions evaluated by the Mann-Whitney U test based on the colour changes (Özdamar 2004). Moreover, the similarity percentage of the in compression strength parallel to fibres values of the samples exposed to the natural and the artificial weathering conditions was determined by the simple correlation test (Özdamar 2004).

RESULTS AND DISCUSSION

Colour change

As to be seen in Fig. 1 and 2; the best colour stability among the sample groups exposed to natural (Sürmene coastal) and artificial weathering test was obtained at the oriental beech and scots pine samples with inorganic UV absorber containing acrylic resin applied surfaces. It was determined that the colour stabilization at the oriental beech sample groups exposed to natural weathering conditions at Sürmene coastal with inorganic UV absorber containing acrylic resin applied surfaces after thermal treatment was better compared with the other sample groups. And among the sample groups exposed to artificial weathering tests; the best colour stabilization was obtained at all sample groups with organic UV absorber containing acrylic resin applied after being impregnated with MCQ, with inorganic UV absorber containing acrylic resin applied surfaces without pre-preservation and with inorganic UV absorber containing acrylic resin applied surfaces after thermal treatment. Similar results were obtained in many studies conducted during the recent years (Ozgenc *et al.* 2012, Saha *et al.* 2013).

The colour stabilization of oriental beech and scots pine samples was further improved with organic or with inorganic UV absorber containing acrylic resin applied surfaces after being impregnated with MCQ or thermal treated compared with only MCQ impregnation and thermal treatment against weathering (Fig. 1 and 2). It was revealed in many conducted studies that the application of UV absorber containing acrylic resin on the wood surface after being impregnated with copper containing preservative and thermal treatment increased the outdoor performance of the wood (Nzokou *et al.* 2011, Nejad 2011, Humar *et al.* 2011).

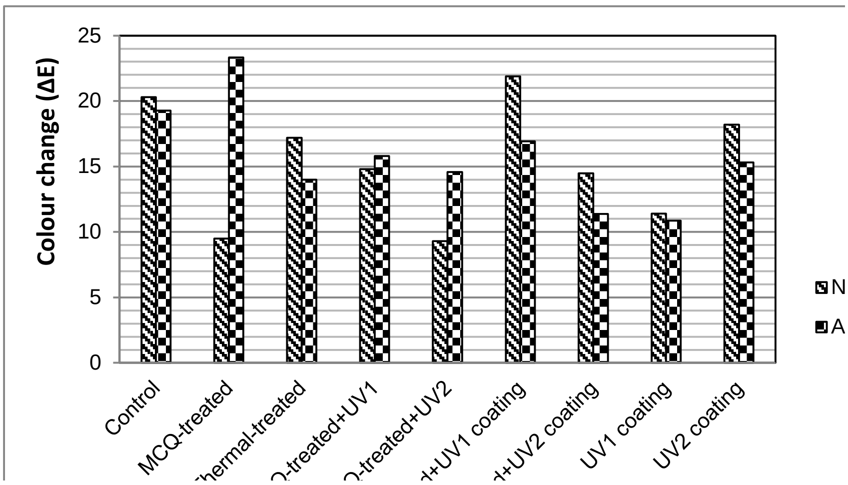

Fig.1.
The colour change parameter of oriental beech wood samples in weathering exposure.

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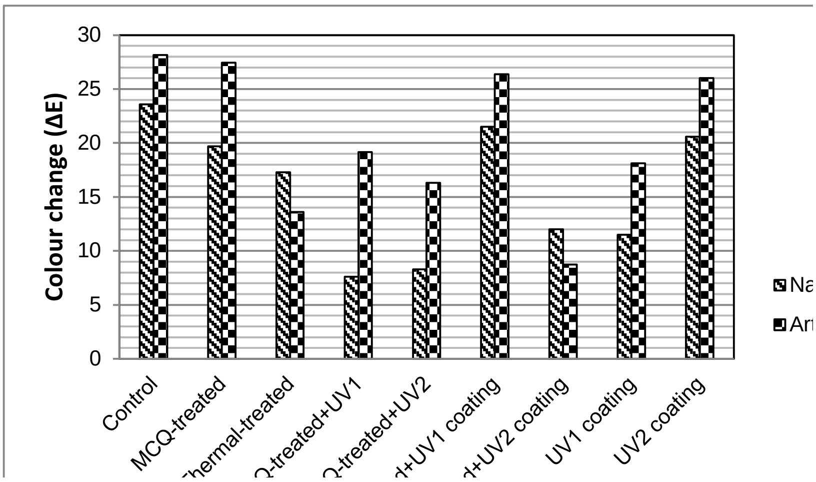

Fig.2.
The colour change parameter of scots pine wood samples in weathering exposure.

It was determined that the colour stabilization of the inorganic UV absorber containing acrylic resin application on wood surfaces with previously exposed to preservation process or without any performed preservation process was much higher than the application of organic UV absorber containing acrylic resin (Fig. 1 and 2). This situation could state based on the conducted studies that the colour stabilization efficiency of inorganic UV absorber mixed acrylic resin was much better than that of organic UV absorbers (Ozgenc *et al.* 2012, Fufa *et al.* 2012, Forsthuber *et al.* 2013).

As to be seen in Table 3, the colour change values of the oriental beech and scots pine samples exposed to weathering tests in the Sürmene coastal and in laboratory environment were showed normality according to the Kolmogorov-Smirnov normality test (p<0.05).

Table 3

Results of descriptive test the distribution of colour change parameters

Weathering Test	df	Sig.
Natural	84	0.01
Artificial	84	0.05

Since the colour change values of the oriental beech and scots pine samples exposed to weathering test in the Sürmene coastal section and in laboratory environment was showed a normality; the similarity of both two different regions was examined by the Mann – Whitney U test. In Table 4, it was indicated to be a significant similarity among the colour change values of the samples after the weathering tests under two different conditions (p>0.05).

Table 4

Mann-Whitney U test results between colour change parameters

Weathering Test	df	Mean Square	Sum of Squares	U-Test	Sig.
Natural	84	85.79	7206.50	3251.500	0.534
Artificial	84	81.15	6654.50		

As to be seen from the table, according to the Mann-Whitney U test results, there is a similarity ratio of 54% between the colour change effects of the natural and accelerated weathering tests on the wood surface. When the climate conditions of the Sürmene region were simulated in laboratory conditions and applied artificially, greater erosion was determined at the wood samples compared with the natural environment.

Compression strength parallel to fibers (CSPF*)*

As to be seen in Table 5, there was a rather significant reduction at the compression strength parallel to fibres in the control groups after the natural and artificial weathering tests. The best preservation against the reduction at the CSPF at the wood types subjected to natural and artificial weathering test was provided by the thermal treatment method. The amount of the high level organized crystal-like cellulose increases due to the decomposition and/or crystallization of the amorphous cellulose because of the thermal treatment application. Its solid and rigid structure provides the increase of the CSPF in the length since the crystal-like cellulose shows an anisotropic structure. In addition, the increase in the cross-bond of the lignin polymer net increases the CSPF in the length (Kocaefe *et al.* 2008). The increasing of CSPF for thermal treated wood an increased CSPF becomes more resistant against surface cracks when it was exposed to outdoor conditions. Correlated with the decrease of the crack development on the thermal treated wood surface, which was exposed to outdoor conditions, also the reduction ratio of the CSPF (Korkut *et al.* 2012, Korkut *et al.* 2013, Yıldız *et al.* 2013).

Table 5

Kendall's Tau-b test results between CSPF values

Weathering Test	Df	Kendall's Tau-b Test	Sig.
Natural-Artificial	27	0.645	0.000

It was to be seen in Fig. 3 and 4 that the impregnation process with MCQ did not have a preservative effect regarding the reduction ratio of the CSPF of the wood after the weathering test.

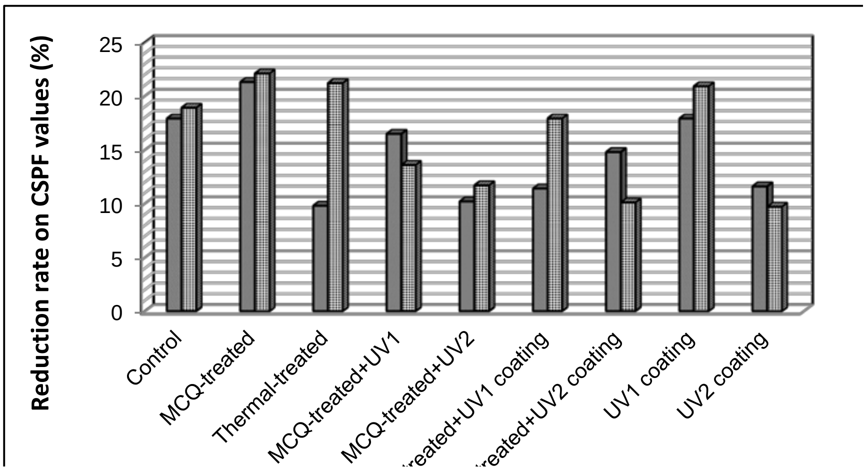

Fig.3.
Reduction on CSPF of oriental beech wood samples exposed weathering.

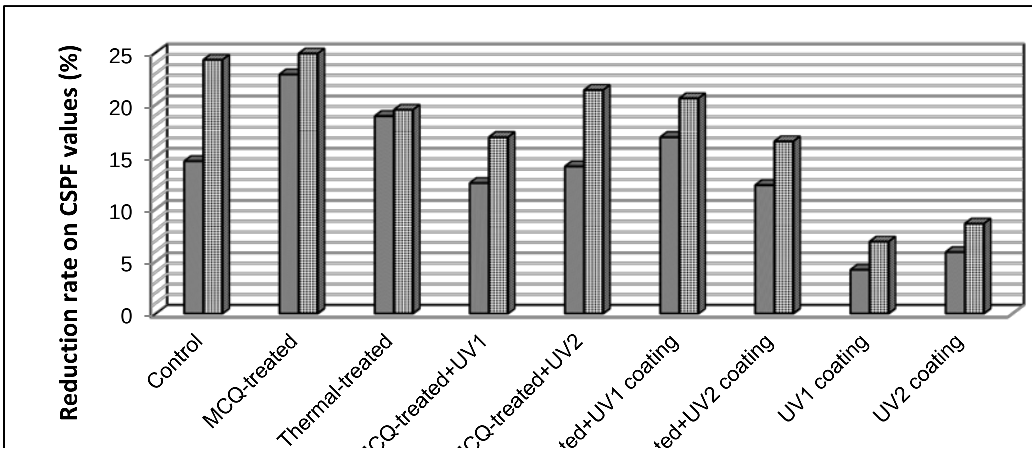

Fig.4.
Reduction on CSPF of scots pine wood samples exposed artificial weathering.

Barnes *et al.* (2008) revealed in the study they conducted that the impregnation process with MCQ did not to have any influence on the strength and rigidity values of the wood samples. The reason why impregnation materials caused some strength loss at the wood was related to the chemical structure of the impregnation materials and the fixation reactions with the wood (Srivinas and Pandey 2012). About the results of the studies in the literature, it was assessed that the impregnation process with MCQ did not to have any preservative effect against the strength loss due to the weathering test. But, it was determined that the application of UV absorber (particularly organic) containing acrylic resins to the wood surface after impregnating with MCQ provided a preservation against the loss of the compression strength parallel to the fibres (Aloui *et al.* 2007). It was seen that the application of inorganic UV absorber containing acrylic resins to the surfaces without the application of preservation to oriental beech and scots pine was rather effective concerning reducing the loss of the CSPF after the natural and artificial weathering tests. That the application of UV absorber containing acrylic resins to the wood surface would prevent the crack development and reduce the loss of the CSPF was demonstrated based on some studies (Williams 2005, Williams and Feist 1999).

As to be seen in Table 5, The compression strength parallel to fibres values of the oriental beech and scots pine samples exposed to weathering tests in the Sürmene coastal section and in laboratory environment have shown a similarity by 64.5% with an error share of 1% ($P>0.01$).
A reduction at nearly same ratio was determined at the loss of the CSPF of the oriental beech and scots pine groups after the tests applied under natural conditions. The loss of the CSPF after artificial weathering conditions was nearly the same with those of the control samples subjected to a natural weathering test. However, compared with the natural weathering test, there were rather high losses of the CSPF determined at the scots pine samples subjected to artificial weathering conditions. Scots pine wood works more and cracks depending on the relative humidity due to its anatomic structure compared with oriental beech wood. In addition, the rain effect in the natural environment was simulated by the water spray method at the artificial weathering test. Direct water spraying was performed on the wood surface by the spraying method and there were no decelerating factors between the water and the wood. Thus, both the oriental beech and the scots pine samples received more water on their surfaces at the natural weathering test at the Sürmene coastal and rather many cracks developed compared with the artificial weathering test.

CONCLUSION

When the Sürmene coast's climate conditions are simulated in laboratory environment and the control and test samples are subjected to an artificial weathering test; there was a similarity of 40.6% determined at the colour change and a similarity of 64.5% was determined at the reduction ratio of the CSPF by the correlation analysis. There are significant differences determined concerning the colour change and CSPF values of the samples subjected to the Sürmene coastal and artificial weathering conditions. It was demonstrated that the reason for this was the presence of factor like air pollution, biological pests and snow along with factors like UV rays, rain and humidity under natural conditions.
It was concluded after the natural and artificial weathering tests that only at impregnated test samples the wood surface of oriental beech and scots pine were only preserved at a grade by particularly the impregnation process with MCQ. But it was determined that the colour change values and the reduction percentage of the CSPF was rather low for the wood samples with UV absorber containing acrylic resins applied on their surface. Whilst, compared with the impregnated samples, the surface colour change of the test samples with UV absorber containing acrylic resins applied on their surface without impregnation was rather high; the loss of the CSPF was determined to be rather low.

The colour changes of 2-hydroxyphenyl-s-triazine based organic UV absorber containing acrylic resins applied on the impregnated and non-impregnated wood surface of test samples were found to be higher compared with those with micronized TiO_2 based inorganic UV absorbers applied. Whilst there were breakages at the corners at the organic UV absorber containing acrylic resin coatings applied on the sample surface due to the natural weathering conditions, it was seen that the inorganic UV absorber containing acrylic resin coating was much more durable. The reduction of the CSPF of the wood samples coated with organic UV absorber containing acrylic resin having a lesser surface preservation effect was found to be higher.

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