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Full Length Research Paper

Effects of application methods and species of wood on color changes of varnishes

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In this study, the color effects of wood materials to coloring with different application methods (brush, roller sponge and spray gun) and waterborne varnishes were investigated according to ASTM-D 2244. For this purpose, the experimental samples of Scots pine (*Pinus silvestris* L.), oriental beech (*Fagus orientalis* L.) and oak (*Quercus petreae* L.), which are commonly used woods in the carpentry and furniture industry in Turkey, were prepared and varnished with one and two-pack waterborne varnishes in accordance with ASTM D 3023. According to the result of the research, significant color changes in coloring as red and yellow tones on the sample surfaces of varnished wood materials were found. The highest color change was obtained in the samples of oak, when varnished with brush and spray gun while the lowest value was obtained in roller sponge in respect to the application methods for waterborne varnishes. However, the application method of spray gun for self crosslinked polyurethane, topcoat-clear, (SCPt) gave the highest metric chroma value among the three different application methods.

Key words: Waterborne varnishes, application methods, wood materials, color change.

INTRODUCTION

Wood is widely used as a natural raw material in building, construction, carpentry, furniture and decoration industries. Its physical properties and its warm appearance distinguish it in many areas from competitive materials such as concrete, metals and plastics. At the present, wood species like oak, fir, pine, birch, beech and maple are in trend in the respective sectors. However, wood is an organic material and is usually protected for long life, because furniture made with wood materials and uncoated with varnish and paint have surface protection only for 2 years (Evans et al., 1992). In spite of high need for wood protection and maintaining its natural appearance in the related sectors, however, there are number of factors to reach and maintain the desired natural appearance of wood.

Color distinction, as one of the main parameter, may occur because of bruises on living parts of the tree, formation of dead knots, diseases and so forth. Particularly, wood defects on wood with knots, cracks and rots due to external impacts and irregularities of the wood growth exist due to inappropriate storage conditions which give negative effects in wood coloring (Budakci and Cinar, 2004). In addition, the oxidation of some chemicals in wood, the formation of heartwood in older trees and metal contact with tannin wood is also known to cause changes in the natural color of wood. Furthermore, differences between the specific weights of the growing rings may also result in color distinction (Colakoglu, 2006; Shigo and Hills, 1973). In wood, by the chemical degradation of extractive materials and lignin in wood, yellow and brown colors occur and these modifications accelerate in open air conditions (Anderson et al., 1991).

To protect the wood from adverse factors such as visible

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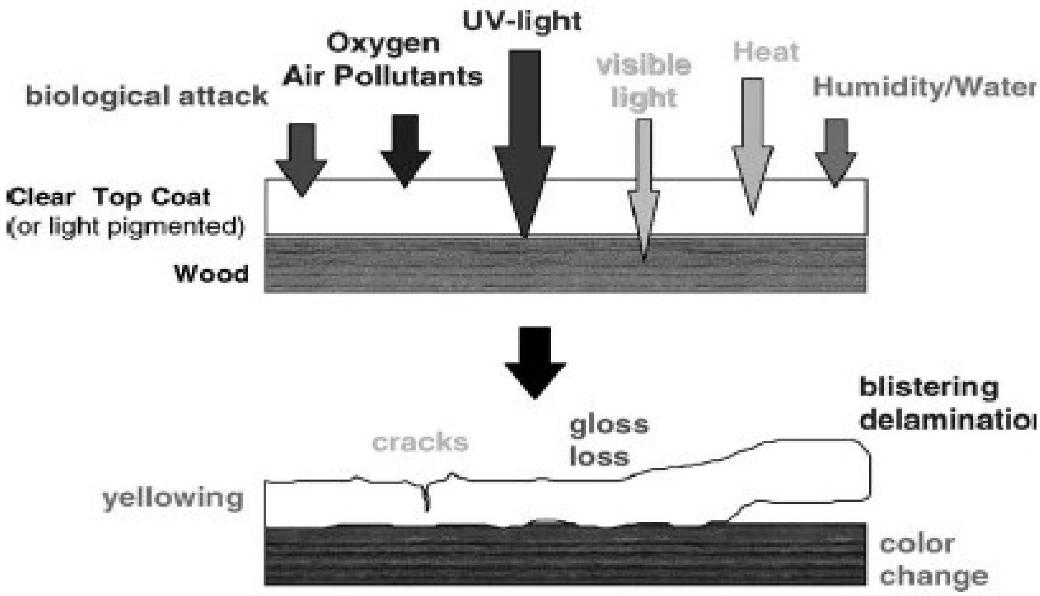

Figure 1. Factors influencing wood and coating (Hayoz et al., 2003).

light, UV-light, oxygen, heat, moisture and water, biological attack and air pollutants, wood is usually coated with various protective and decorative finishes such as paints, transparent stains and penetrating finishes or film forming clear varnishes (Figure 1) (Hayoz et al., 2003). Transparent systems, which allow the natural features of the wood (e.g. color, texture) to remain visible, are attracting interest and the demand for them has been increasing (Sanivar, 1978). On the other side, the protective coating has to be stabilized itself to avoid yellowing, cracking, blistering, delaminating and loss of gloss; and on the other side, the discoloration of the wood has to be diminished to keep its natural color appearance.

In the literature, there has been a great deal of research focused on replacements for solvent-borne wood varnishes (Bardage and Bjurman, 1998; De Meijer et al., 2001; De Meijer and Militz, 2000; De Meijer, 2001; Yildiz, 1999; Nussbaum et al., 1998). Waterborne varnishes are popular replacements that promote tannin bleeding on dark woods like western red cedar and redwood (Donegan et al., 1999). Tannins are naturally occurring water-soluble phenolic or polyphenolic compounds (Sjöström, 1993). When exposed to moisture, tannins penetrate through wood substrates and water-based coatings, depositing on the coating surface and creating yellow or brown discolorrations (Donegan et al., 1999).

From the perspective drawn, another parameter to have good natural appearance for wood could be the application methods of coatings and varnishes to wood surfaces. It is interesting to find out if application methods could affect the color appearance with different varnish types. This research aims to investigate the effects of color changes by using different application methods (brush, roller sponge, spray gun) and waterborne varnishes on wood materials to coloring with one and two pack waterborne varnishes on the sample surfaces of scots pine (*Pinus silvestris* L.), eastern beech (*Fagus orientalis* L.), oak (*Quercus petreae* L.), which are commonly used trees in the carpentry and furniture industry of Turkey.

EXPERIMENTAL

Wood materials

For the experiment preparation, the samples from Scots pine (*P. silvestris* L.), oriental beech (*F. orientalis* L.) and oak (*Q. petraea* L.) were selected according to the provisions of Turkish Standards TS 2470 (1976) from the randomly selected first class wood material.

According to (3 x 3 x 3 x 8 = total 216) test pattern, composed of 8 per 3 wood types, 3 varnish types, 3 application types were prepared. The samples under air humidity were roughly cut into 110 x 110 x 12 mm size and conditioned until reaching constant weight in a conditioning room with 20 ± 2℃ and 50 ± 5% relative humidity in order to obtain moisture value on internal environmental conditions according to TS 2471 (1976). Average moisture content of the samples was determined as 9 ± 0.5% on 10 randomly selected samples. Then, the samples were cut with the dimensions of 100 x 100 x 10 mm, and they were sanded with 80 and 100 grit (on Norton scale) sandpaper, respectively. Dusts from the sample surfaces were cleaned with a soft haired brush for finishing processes.

Varnishes and application methods

Waterborne varnishes, belonged to two different firms, were used

Table 1. Some properties of the waterborne varnishes.

Type of varnishes	Code	Solid contents (%)	pH	Density (g/ml)
Acrylic Copolymer (primer filling)	AC	14	9.17	1,014
Self Crosslinked Polyurethane (filling)	SCPf	34	9.30	1,015
Self Crosslinked Polyurethane (topcoat-clear)	SCPt	37	8.88	1,025
Acrylic Modified Polyurethane (two component topcoat-clear)	AMP	32	8.71	1,031
Acrylic Emulsion Modified by Polyurethane Dispersion (topcoat-clear)	AEMPD	36	8.50	1,07

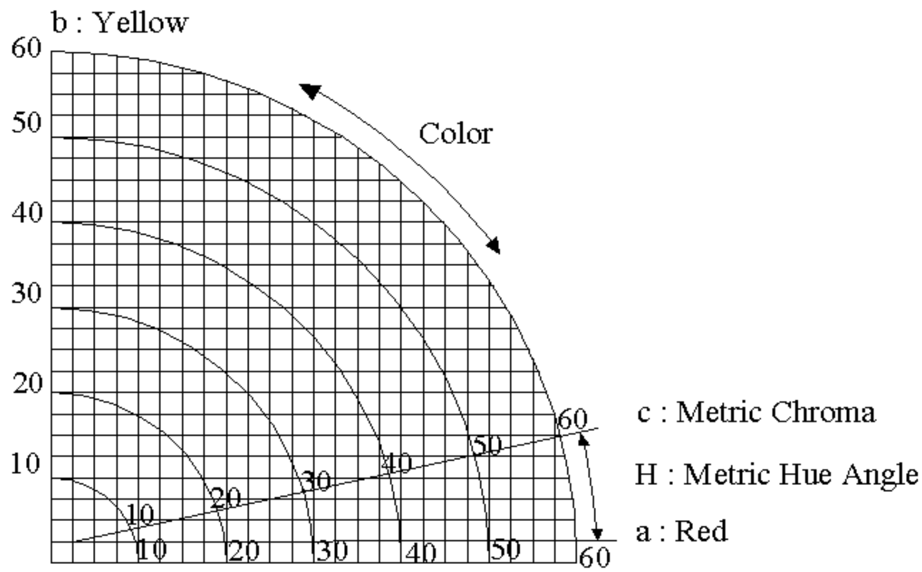

Figure 2. Determining of color principle.

for the experiments. Varnishes were applied in accordance with ASTM-D 3023 standards (1998). According to the advice of the Producer Firm, varnishes were applied to the surfaces of samples with the brushes having medium hardness, the roller sponge and the spray gun in the conditioning room at 20°C. Some properties of the waterborne varnishes used for the experiment are given in Table 1.

First, acrylic copolymer (AC) was applied on the surface of the samples and then self cross linked polyurethane for filling (SCPf) was applied both vertical and horizontal to the grain with the primary purpose to fill in the gaps of the samples' surfaces before succeeding the self cross linked polyurethane for top-coat clear (SCPt) and acrylic modified polyurethane (AMP) varnishes. Acrylic emulsion modified by polyurethane dispersion (AEMPD) varnish was used both as a filling and topcoat varnish. The amount of applied varnish was determined by weighting with a sensitive analytical balance scale ± 0.01 g. The filling coated samples were held in conditioning room at 20°C temperatures for drying in clean air circulation for 24 h. Following that, the dried samples were subjectted to sanding process with 320 grit (on Norton scale) sandpaper. After cleaning the dusts from the surfaces with a smooth haired brush and vacuum method, the samples were again weighed with the sensitive analytical scale ± 0.01 g. The samples were subjected for topcoat application and they were held for drying for 3 weeks. Finally, the color measurement tests were applied.

Color measurement

Samples were conditioned at 23 ± 2°C temperature and 50 ± 5% relative humidity for a period of 16 h according to ASTM D-3924 (1996) before color assessment experiment. Color assessments were performed complying with principles referred under ASTM D 2244-93 (2000) with using Minolta CR - 231 colorimeter (Tristmulus colorimeter).

The test machine was calibrated in a manner to be a = 4.91, b = -3.45, C = 6.00 and H = 324.9° according to white color. For determining the color differentiations, the first measurement was carried out on the natural samples' and the second was carried out on the varnished samples' surfaces. Finally metric chroma (C) value was used as determining agent during assessment of the data (Figure 2).

Statistical evaluation

In the evaluation of data, statistic package software was used. In the analysis, the values of factor effects based on the wood type, varnish type and application method were determined as a result of multiple variance analysis, ANOVA, and in cases where factor effects were significant with an error, $\alpha = 0.05$ according to variance analysis "ANOVA" results. Least Significant Difference (LSD) critical

Table 2. Multiple variance analysis results.

Factors	Degrees of freedom	Sum of squares	Mean square	F value	Prob.
Wood type (A)	2	431.653	215.826	119.2136	0.0000*
Varnish type (B)	2	418.482	209.241	115.5761	0.0000*
Interaction (AB)	4	360.819	90.205	49.8254	0.0000*
Application method (C)	2	18.788	9.934	5.1888	0.0064*
Interaction (AC)	4	12.699	3.174	1.7535	0.1400
Interaction (BC)	4	72.478	18.120	10.0085	0.0000*
Interaction (ABC)	8	30.720	3.840	2.1211	0.0357*
Error	189	342.169	1.810		
Total	215	1687.807			

*Significant at 95% confidence level.

Table 3. Wood type, varnish type and application method, single comparison.

Wood type					
Scots pine		**Oriental beech**		**Oak**	
$\overline{x}$	*HG*	$\overline{x}$	*HG*	$\overline{x}$	*HG*
9.67	B	7.10	C	10.39	A*
Varnish type					
AEMPD		**SCPt**		**AMP**	
$\overline{x}$	*HG*	$\overline{x}$	*HG*	$\overline{x}$	*HG*
8.02	B	11.02	A	8.12	B
Application method					
Brush		**Roller sponge**		**Spray gun**	
$\overline{x}$	*HG*	$\overline{x}$	*HG*	$\overline{x}$	*HG*
9.24	A	8.64	B	9.28	A
LSD±0.4423					

*The highest metric chroma value; $\overline{x}$: Average value; HG: Homogeneous Group.

values were used and causing factors were determined. The letters of A, B, C, D indicate the classification of Least Significant Differences (LSD) for critic values. In other words, while A value shows the highest metric chroma value, M value (Table 7) shows the lowest value. The letters between A and M values explain the statistical hierarchy/classification of the results of the arithmetic averages in accordance with the LSD critic values.

RESULTS

The results of multiple variance analysis of metric chroma value for determining the effects of application method and waterborne varnishes on wood samples' surfaces are given in Table 2. According to the table, the metric chroma values for varnishing the different wood types with different applying methods were statically found meaningful at 95 % confidence level (α = 0.05) with the exception of wood type and application method interaction.

According to Duncan test results, the values of the wood species, varnish type and application methods are given in Table 3. For the wood species, the highest metric chroma value was found on the oak samples. For the varnish types, the highest metric chroma value was found on the SCPt varnished samples. However, for the application methods, the methods of brush and spray gun gave the best result for metric chroma value. The results of Duncan test, double comparison for the wood types and varnish types are given in Table 4. The highest metric chroma value was obtained in the samples of varnished Scots pine with SCPt, while the lowest value was obtained in the samples of varnished oriental beech with AEMPD.

According to Duncan test results, the values of double comparison for the wood species and application methods are given in Table 5. The metric chroma value was found not meaningful according to the result of multiple variance analysis concerned with the interaction between wood type and application method (α = 0.05).

According to Duncan test results, the values of double comparison according to varnish type and application method are given in Table 6. According to the table, the metric chroma values were found different on the level of varnish type in respect to application methods for waterborne varnishes. However, the application method of spray gun for SCPt gave the highest metric chroma value among the three different application methods.

According to Duncan test results, the values of total comparison for wood type-varnish type-application type are given in Table 7. According to the table, the highest metric chroma value was obtained from the Scots pine samples, while the highest result for metric chroma value was also obtained from the SCPt which was applied with a brush and spray gun. However, the lowest value was

Table 4. Wood type - varnish type, double comparison.

Wood type	Varnish type					
	AEMPD		SCPt		AMP	
	$\overline{x}$	HG	$\overline{x}$	HG	$\overline{x}$	HG
Scots pine	6.99	E	13.45	A*	8.90	D
Oriental beech	5.47	F	8.86	D	6.96	E
Oak	11.59	B	10.75	C	8.82	D
LSD±0.7661						

*The highest metric chroma value; $\overline{x}$: Average value; HG: Homogeneous Group.

Table 5. Wood type - application method, double comparison.

Wood type	Application method					
	Brush		Roller sponge		Spray gun	
	$\overline{x}$	HG	$\overline{x}$	HG	$\overline{x}$	HG
Scots pine	10.31	AB	8.96	C	9.77	B
Oriental beech	7.18	D	6.69	D	7.42	D
Oak	10.24	AB	10.27	AB	10.67	A*
LSD±0.7661						

*The highest metric chroma value; $\overline{x}$: Average value; HG: Homogeneous Group.

Table 6. Varnish type - application method, double comparison.

Varnish type	Application method					
	Brush		Roller sponge		Spray gun	
	$\overline{x}$	HG	$\overline{x}$	HG	$\overline{x}$	HG
AEMPD	8.05	DE	8.20	DE	7.79	E
SCPt	10.86	B	9.88	C	12.32	A*
AMP	8.81	D	7.82	E	7.74	E
LSD±0.7661						

*The highest metric chroma value; $\overline{x}$: Average value; HG: Homogeneous Group.

obtained from the AEMPD, which were applied, with a brush and roller.

DISCUSSION

The research determines that different application methods and waterborne varnishes to the surfaces of wood materials have color changing effects on defining the metric chroma values. One of the reasons for color changes could be the high existence of pH (Table 1), which gives chemical coloring with the waterborne varnishes. Another reason could be the existence of water within the waterborne varnish compositions. This might cause fiber rising on the wood material and the raised fibers can give negative effects on smoothness of the surface while reducing the layer brightness and color. The results of the research are supported by the available literature arguments (Anderson et al., 1991; Yakin, 2001; Budakci, 2003; Budakci and Cinar, 2004).

According to the wood species, the highest color change (10.39) occurred on the oak samples. This result for color change on the oak samples might have occurred due to the tannin, which reacts with the basic waterborne varnishes and the chemicals. The existence of tannin in oak wood structure might cause the darkness (Donegan et al., 1999; Sjöström, 1993; Budakci, 2003; Gurua et al., 2004).

Table 7. Wood type - varnish type - application method, total comparison.

Varnish type		AEMPD			SCPt			AMP		
Application method		**Br**	**Rs**	**Sg**	**Br**	**Rs**	**Sg**	**Br**	**Rs**	**Sg**
Wood type										
Scots pine	$\bar{x}$	7.44	7.07	6.45	14.32	11.69	14.35	9.14	8.11	8.50
	HG	IJK	JKL	KLM	A	BCD	A*	FGH	HIJ	GHIJ
Oriental beech	$\bar{x}$	5.11	5.40	5.89	8.28	7.71	10.59	8.15	6.94	5.78
	HG	M	M	LM	HIJ	HIJK	CDE	HIJ	JKL	LM
Oak	$\bar{x}$	11.60	12.14	11.04	9.97	10.25	12.03	9.12	8.41	8.94
	HG	BCD	B	BCDE	EFG	DEF	BC	FHG	HIJ	FGHI
LSD ± 1.327										

*The highest metric chroma value; $\bar{x}$: Average value; HG: Homogeneous Group.
Br, Brush; Rs, Roller sponge; Sg, Spray gun.

On the varnish type, the highest color change (11.02) was found on the SCPt varnished samples. This might be because of the existence value of the pH in primary, filling and topcoat layer of the SCPt varnish, which had higher pH in comparison with the AEMPD and AMP varnishes. So, its pH might have caused the highest color change. However, on the application method, the best result for color change was obtained from the application methods of brush and spray gun while the lowest result was obtained from the roller sponge. In a similar study (Yakin, 2001), the highest red color tone (15.21) was obtained in oriental beech wood. Their results support the results of this research. The structure of vessels and tracheid gaps might have caused the highest color change, which could have not sufficiently be filled during the applications. The roller grazes cannot make a smooth surface for varnish by penetrating the resin molecules into the structural gaps of the cell. As argued by Sanivar (1978), color and brightness of varnish layers were mostly connected with the smoothness and light reflection ability of the surface.

In respect to the conclusions and discussions of the research, the following recommendation can be made: In case of obtaining a homogeneous surface, for the application of water borne varnishes, it is possible to suggest the use of a brush (soft bristles) or spray gun methods although they cause an increase on metric chroma values.

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