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EFFECT OF THE HEAT TREATMENT ON THE ADHESION STRENGTH OF WATER BASED WOOD VARNISHES

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ABSTRACT

Effects of heat treatment on the adhesion strength of water based wood varnish were studied using four tree species woods [Anatolian black pine (*Pinus nigra* J.F. Arnold subsp. *nigra* var. *caramenica* (Loudon) Rehder), Calabrian pine (*Pinus brutia* Ten.), Sessile oak (*Quercus petraea* Liebl.) and Sweet chestnut (*Castanea sativa* Mill.)] and two components water based varnish (one-component semi-matte and two-component glossy water-based varnish). Those tree species' woods were selected randomly from timber merchants as test materials because of their wide use in industry. Under atmospheric pressure, the wood samples were subjected to three different temperatures (130, 180 and 230°C) at two different time intervals (2 and 8 h). After that, the wood samples were coated with two components water-based varnish. Adhesion strength of varnish film was then measured with a pull-off test according to the ASTM-D 4541 (1995).

The coatings presented the highest adhesion strength (3.33 MPa) on oak wood, followed of the adhesion strength on chestnut (2.1 MPa) and on pine species (black pine 1.78 and Calabrian pine 1.65 MPa) Sessile oak wood showed the highest adhesion strength (3.33) followed by Sweet chestnut (2.19) and pine species (Anatolian black pine 1.78 and Calabrian pine 1.65 MPa). The adhesion strength of all wood types decreased increasing temperature and time.

KEYWORDS: Adhesion, heat treatment, pull-off test, water-based varnish, wood.

INTRODUCTION

Wood is a sustainable and environmental friendly natural material used for great variety of both structural and non-structural applications (Priadi and Hiziroglu 2013). Wood has excellent mechanical properties although it is known with having some disadvantages such as its hygroscopicity, and there are a lot of different processes to ameliorate these inadequacies in. Heat treatment is one of the processes used to modify the some properties of wood. This technique is not as harmful as chemical processes, so it is known as an environmental friendly method, because of having no chemical agent used during the procedure.

Based on the results of some of the previous studies, it was found that heat treated wood becomes brittle, hardness and strength characteristics of the samples are adversely affected by decreasing range from 10 to 30 %. Therefore, in general heat treated wood would not be an ideal product where high strength properties for constructional applications are desired (Bakar et al. 2013; Ozcan et al. 2012; Tasdemir and Hiziroglu 2014).

Wood surfaces coated with varnishes/paints can be protected from certain adverse situations such as moisture, changes in dimensions and deterioration by microorganisms and fungi. This phenomenon is in particular exhibited by varnishes that are cured by polymerization. The moisture level inherent in wood or the level of absorption wood retains in its currently used form plays a critical role in success of the wood finishing (varnish, coloring, dying) (Wheeler 1983; De Meijer and Militz 2001; De Meijer 2002; Sonmez et al. 2009). The presence of contaminants such as wax, oil and inorganic materials hampers the development of cohesive adhesion bonds between wood substrate and adhesive (Lee at al. 2006). Adequate adhesion of the varnish layer on the wood surface may not be attained if the moisture content is too high (Sonmez and Budakci 2004).

Adhesion strength of a coating can be determined by using various methods, namely the axial pull-off tests, shear test with torque system, block shear test, and semi-quantitative cut or cross hedge test. First two methods are widely used for evaluation of adhesion strength of different types of coatings (Williams et al. 1990; Bardage and Bjurman 1998; Ozdemir and Hiziroglu 2007).

This present study aimed at determining the effects of heat treatment on the adhesion strength of water based wood varnish using four different tree species [Anatolian black pine (*Pinus nigra* J.F. Arnold subsp. *nigra* var. *caramenica* (Loudon) Rehder), Calabrian pine (*Pinus brutia* Ten.), Sessile oak (*Quercus petraea* Liebl.) and Sweet chestnut (*Castanea sativa* Mill.)].

MATERIAL AND METHODS

Material

Anatolian black pine, Calabrian pine, Sessile oak and Sweet chestnut woods were selected randomly from timber merchants as test materials because of their wide use in industry. Special emphasis was given for the selection of wood materials; non-deficient, proper, knotless, and normally grown (without zone line, reaction wood, decay, or damage caused by wood decay fungi) materials were selected.

One-component semi-matte and two-component glossy water-based varnish were used in the experiment. Water-based varnishes contain less solvent than most of the other finishes. They do not pose fire risk, non-yellowing and virtually colorless, and also they can be easily cleaned up with water. On the other hand, the water-based varnishes have drawbacks such as they raise the grain of the wood. They are weather-sensitive during application and also have only moderate resistance to heat (Sonmez and Budakci 2004). The water-based varnish used in this experiment was obtained from private firms. Some properties of the water-based varnish are given in Tab. 1.

Tab. 1: Properties of water based varnish.

Water-based varnish	pH	Density ($g.cm^{-3}$)	Viscosity / DINCup/4 (mm)	Amount used ($g.m^{-2}$)	Solid content (%)	Nozzle gap (mm)	Air pressure (bar)
Filling	9.00	1.020	18	67	38	0.7	1.5
Topcoat-gloss	9.17	1.014	18	70	39	0.7	1.5

Heat treatment

Heat treatment applications were conducted in a temperature controlled small laboratory oven. Three different temperatures (130, 180 and 230°C) and two different times (2 and 8 h) were applied for the four wood species under atmospheric pressure and in the absence of oxygen. Before the heat treatment, the wood samples were conditioned to 7 % moisture contents at 25±2°C and 35±5 % relative humidity to prevent splitting of woods during heat treatment.

Varnishing

The wood samples were coated with water-based (Wb) varnish in accordance with ASTM D-3023 (1998) after sanding (sized grits P300) of wood surfaces to remove the fiber swellings and dusts. Producer's definition is taken into account for the composition of solvent and hardener ratio and two finishing layers were applied after the filling layer. Spray nozzle distance and pressure were adjusted according to the producer's definition and moved in parallel to the samples surface at a distance of 20-25 cm. The samples were coated under the conditions of 20 ± 2°C temperatures and 65 ± 5 % relative humidity.

Adhesion measurement

The coated and dried wood samples were conditioned with 23 ± 2˚C temperatures and 60 ± 5 % relative humidity for a period of 16 hours according to ASTM D-3924 (1996). Stainless steel experimental cylinders (20 mm in diameter) were fastened to the conditioned surfaces at ambient temperature (20˚C) to perform a pull-off test as outlined in the standard. A double component high strength epoxy with no dissolving effect on varnish layers was used 150 ± 10 $g.m^{-2}$ rate. The adhesion strength of varnish layers was determined and calculated (MPa) with a universal test machine as specified in ASTM D-4541 (1995).

Data analysis

Statistical differences in the mean values of parameters carried out in this paper were estimated with two-way analyses of variance (ANOVA) for analysing the effects of heat treatment variations (temperature and time) on the adhesion strength of water based wood varnish using the four tree species. When significant differences were detected with ANOVA, the Duncan test was used to evaluate the relationship between the wood types and temperature and time. All statistical analyses were performed using SPSS ® 20.0 for Windows ® software. Means were considered to be significantly different when $p \leq 0.05$.

RESULTS AND DISCUSSION

Tab. 2 shows the adhesion strength results of Sessile oak, Sweet chestnut, Calabrian pine and Anatolian black pine woods treated at three different temperatures (130, 180 and 230°C) for 2 and 8 hours.

Tab. 2: Change of adhesion strength of water based varnish between the four tree woods under heat treatment conditions.

Wood Types	Control	Heat treatment time (hour)					
		2			8		
		Heat treatment temperature (°C)					
		130	180	230	130	180	230
	Mean (Std. dev.)						
Calabrian pine	2.86 (0.36)	2.76 (0.34)	1.19 (0.03)	1.36 (0.44)	1.62 (0.18)	0.83(0.12)	0.95 (0.29)
Black pine	1.65 (0.22)	1.95 (0.34)	2.11(0.46)	1.65 (0.15)	2.49 (0.38)	1.74 (0.24)	0.92 (0.09)
Oak	3.75 (0.12)	4.90 (0.44)	3.69 (0.81)	2.57(0.81)	3.89 (0.78)	2.96 (1.09)	1.58 (0.04)
Chestnut	2.57 (0.54)	3.13 (0.32)	2.47 (0.31)	1.02 (0.58)	2.52 (0.33)	2.46 (0.43)	1.18(0.24)

Results of multiple variance analyses for impact of wood type, heat treatment temperature and time for surface adhesion strength are given in Tab. 3.

Tab. 3: Multiple variance analysis for impact of wood type+temperature+time for adhesion strength.

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected model	84.997[a]	27	3.148	15.585	0.000
Intercept	406.162	1	406.162	2010.784	0.000
Factor A	32.848	3	10.949	54.208	0.000
Factor B	27.147	2	13.573	67.198	0.000
Factor C	3..972	1	3.972	19.662	0.000
Interaction AxB	6.680	6	1.113	5.512	0.000
Interaction AxC	1.806	3	0.602	2.981	0.039
Interaction BxC	0.112	2	0.056	0.277	0.759*
Interaction AxBxC	2.305	6	0.384	1.902	0.096*
Error	11.312	56	0.202		
Total	518.460	84			
Corrected Total	96.309	83			

a. R2 = 0.883 (Adjusted R^2 = 0.826)

Factor A: Wood type, Factor B: Heat treatment temperature, Factor C: Heat treatment time, *: non-significant.

After 2 h treatment, the adhesion strength was lowest at 180°C for Calabrian pine wood, whereas Anatolian black pine, Sessile oak and Sweet chestnut woods showed the lowest the adhesion strength at 230°C (Tab. 2). Similar results were also seen for 8 h treatment. For all tree woods, the adhesion strength showed a decrease with increasing temperature and time. This could be result of wood surface degradation due to higher temperature (Akyildiz et al. 2009a, b, Ates et al. 2009, 2010). In general, deciduous tree species woods (Sessile oak and Sweet chestnut) had higher the adhesion strength than coniferous tree species wood (Calabrian pine and Anatolian black pine) at all time and temperature treatment.

The factor of wood type (A), heat treatment temperature (B), heat treatment time (C) and interaction of AxB and AxC had an effect on surface adhesion strength of varnish, but the other interactions did not show any effect on adhesion strength (Tab. 3).

Average values according to the wood type, the heat treatment temperature and the heat treatment time and homogenous groups (HG) are given in Tab. 4.

Tab. 4: Surface adhesion strength values according to wood type, heat treatment temperature and heat treatment time and homogenous group.

Wood type	**Mean**	**HG**
Calabrian pine	1.65	c
A. black pine	1.78	c
Sweet chestnut	2.19	b
Sessile oak	3.33	a
Heat treatment temperature (C°)	**Mean**	**HG**
230	1.40	c
180	2.18	b
Control	2.70	a
130	2.90	a
Heat treatment time (hour)	**Mean**	**HG**
8	1.92	b
2	2.39	a
Control	2.70	a

Calabrian pine and Anatolian black pine woods were in the same HG (Tab. 4). They had the lowest adhesion strength (1.65 and 1.78 MPa, respectively); whereas Sessile oak wood (3.33 MPa) had the highest adhesion strength.

According to the results, the coniferous species had lower adhesion strength than the deciduous species. This result is in accordance with the results shown by Budakci and Sönmez 2010 and Demirci et al. 2013. The Sessile oak wood had the highest adhesion strength among the wood types studied. This result can be explained that the Sessile oak wood has better surface roughness depending on its higher density from the other wood types (Karagöz et al. 2011 and Vitosyte et al. 2012). It was reported that it is necessary to minimizing surface roughness for a high adhesion between wood and coatings (Payne 1965). This knowledge supports our result, too.

The surface adhesion strength is one of the most important parameters for limiting the usage of varnishes. Adhesion is determinative in this sense (Atar et al. 2004 and Atar and Çolakoglu 2009).

A number of studies have shown that adhesion strength of varnishes is affected by moisture content in wood materials and extreme moisture content reduces adhesion strength and viscosity and causes defective layer (Sonmez and Budakci 2004, Budakci et al. 2012). Such defects do not occur at the heat-treated wood materials because they have lower equilibrium moisture content (approx. 50 %) according to non-heat-treated woods (Akyildiz and Ateş 2008). Consequently, adhesion strength is positively affected.

According to the heat treatment temperature (Tab. 4), the control woods and the heat treated woods at 130°C were in the same HG (2.70 and 2.90 MPa respectively). When they had the highest adhesion strength, the heat treated woods at 230°C showed the lowest adhesion strength (1.40 MPa). In this case, it can be said that the higher treatment temperature (230°C) had more effect on the structure of wood than the lower temperature. Higher heat-treatment temperature and time cause destruction on the wood structure (Akyildiz et al. 2009a, b, Ates et al. 2009, 2010). It can be due to the destruction of wood under the higher temperature and longer time. Ozalp et al. (2009) found that the lowest varnishes' surface adhesion strength obtained higher heat treatment time and temperature. They also suggest that the heating process shouldn't be applied where the sticking resistance is important.

Increasing the heat treatment time (Tab. 4), the adhesion strength of the heat treated specimens decreased compared with the control specimens. It is possible to say that the treatment time has an important effect on the adhesion strength. In addition to this, Cakicier et al. (2011) have stated that organic surfaces may start combustion above 180°C and this may cause surface roughness and so the surface roughness may cause low adhesion strength of the varnishes.

In general, in this present study it was noted that when the thermal processing temperature and time increased, the adhesion strength decreased. This result has indicated that the mechanical properties of wood types have been negatively affected by the treatment temperature and time as shown in other studies (Akyildiz et al. 2009a, b, Ates et al. 2009, 2010, Demirci et al. 2013). This reduction has a negative effect on the adhesion strength of varnish layers.

CONCLUSIONS

The highest adhesion strength was found for the Sessile oak wood, followed by the Sweet chestnut, Anatolian black pine and Calabrian pine woods. The deciduous tree species woods (Sessile oak and Sweet chestnut) had higher the adhesion strength than coniferous tree species wood (Calabrian pine and Anatolian black pine). Adhesion strength of all wood types decreased with increasing of the heat treatment temperature and time. Therefore, the lower heat treatment temperature and time should be used in order to reach the highest adhesion strength.

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