

## Effect of thermal aging on adherence of coating systems for red meranti wood used in windows joinery

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**Abstract:** *Effect of thermal aging on adherence of coating systems for red meranti wood used in windows joinery.* The aim of this work was to investigate the formation of adherence under accelerated thermal aging test selected lacquer systems formed on the meranti wood. Window elements were finished with modified acrylic lacquer systems including the impregnate, primer, and inter- and top lacquer layer in cypress color. The range of investigations included adherence (pull-off method) of coatings to substrate. Based on the contact angle, the values of surface free energy ( $\gamma_s$ ) were calculated, together with their dispersion and polar shares. On the basis of carried out experiments it was stated among others, that tested lacquer coatings showed good adhesion to the substrate. In turn  $\gamma_s$  parameter indicated to the occurrence a strong adhesion interactions in substrate and particular layers in lacquer coating system. Aging process didn't influence in significant manner on obtained relations.

*Keywords:* red meranti wood, coating system, aging test, contact angle, adherence

### INTRODUCTION

The demand on windows produced from wood is positively shaped both from the point of view of specific properties of this raw material, as and also in the aspect of widely understood ecological aspects of products, in this also with the regard of requirements within the range of LCA procedure. The important meaning in the production of wooden windows elements, so in the global approach as and domestic exotic wood species – particularly meranti wood (*Shorea* spp.). Exotic wood species in relevance to native are characterized with better useful properties and interesting decorative values [Dzbeński 1998, Kozakiewicz 2008, Kozakiewicz, Kościelniak, Zakrzewska-Rudzińska 2008, Proszyk, Przybylak 1986, Turowski 1989]. It shows also the specific chemical composition, particularly in reference to the content of extractive substances contents which appear in the form, among others natural resins, essential oils, waxes, fats, tans, dyes, proteins, carbohydrates, mineral substances, alkaloids and flavonoids. The content of extractive substances in exotic wood is characteristic of individual trees and can in the quantitative amount exceed even the level 30%. As it gets out of the literature data components of extractive woods can influence both on the course of the solidifying process of each lacquer systems, as and particularly properties of obtained coatings in the relevance to the useful-utility features and durabilities [de Windt et al. 2014, Hse, Kuo 1988, Krystofiak, Proszyk 2001, Sudoł, Policińska-Serwa 2011, Patel A.Y. and C.J. 2007]. It is presumed that influences of extractive substances with the lacquer products can have the multiparametric synergism character. Some of specified extractive components, especially these about the hydrophobic character, particularly from the group of waxes and fats, migrate surface ward limiting the wettability and the adhesion of the lacquer products to the protected substrate.

In the above-context one undertook investigations whose aim was the recognition of the phenomenon of the adhesion of designated experimentally on the basis of pull-off methods and at the regard of fundamental criterion of the adsorption theory of the adhesion for the chosen finishing's on the basis of the multilayer, commercial lacquer system, applied in on line conditions on red meranti wood. The formation of the adhesion one analysed in the function of the number of cycles of the thermal aging in the version of changing temperatures.

## MATERIALS

Semi-finished products got in industrial conditioning from the timber of the meranti wood constituted experimental material, linked to the length with finger joints, and glued together into three-layers elements with using one-component PVAC adhesive (D3 durability class). Elements were improved with four layers of modified acrylic lacquer systems including the impregnate, primer, and inter- and top lacquer layer in cypress color. Detailed information of these products is covered by the clause of total confidentiality.

Investigations thermally aging of the lacquer coatings in artificial conditions according to the PN-88/F-06100/07 standard (method A) in the function of the number of cycles of changing temperatures version, properly after 3, 6 and 9 were performed.

The investigation of contact angle ( $\theta$ ) of the surface coatings were performed according to the procedure described in PN-EN 828 standard. For that, a microscope of magnification of X56, equipped with goniometric head was used. Redistilled water of number 10 drops of 3.5  $\mu\text{l}$  volume was put on tested surfaces with chromatographic syringe. The measurements of  $\theta$  angle were done in statically manner after 5 s from the moment of drop application. Investigations were performed versus number of aging cycles. Based on the  $\theta$  angle, the values of surface free energy ( $\gamma_s$ ) were calculated (Kloubek 1974, Liptáková and Paprzycki 1983), together with their dispersion ( $\gamma_s^d$ ) and polar ( $\gamma_s^p$ ) shares, according to formulas given in literature.

Investigations of adherence of coatings to the substrate with the pull-off method, basing on procedure described in PN-EN ISO 4624 standard were passed, allow to determination of the minimum tension stretching necessary to the tear off the coating at the exertion of loading in perpendicular toward direction to the substrate. Aluminium stamps were bonded with the two-component silane-epoxy adhesive. After 7 day of the conditioning the adhesion in the testing-apat *PosiTest AT* was performed. On the electronic display values in MPa were recorded. Each time after realization of investigations were determined the surface of delaminated system, appropriate after both of the side of the stamp to surface coatings and the substrate were carried out.

## RESULTS

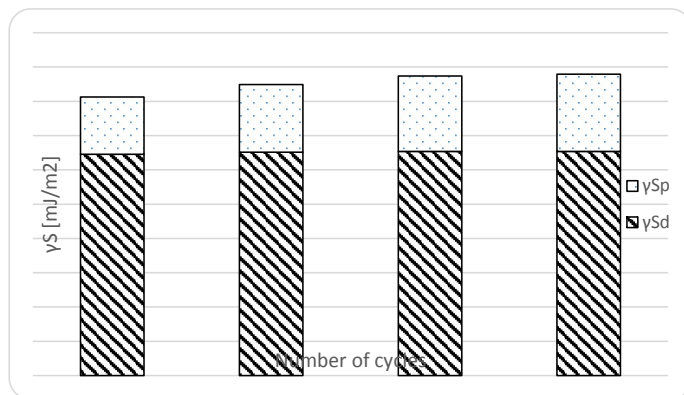
Results of the measurement of the angle  $\Theta$  for tested system before- and after the thermal aging together with the Basic statistical estimation one put together in the Table 1.

**Table 1.** The course of the  $\Theta$  angle for lacquer coatings vs. number of aging cycles

Number of cycles	Statistical data <sup>*)</sup>			
	$x_{\min.}$	$x_{\text{av.}}$	$x_{\max.}$	v
	[deg]			[%]
0	67.24	71.72	74.30	3.73
3	63.30	68.55	76.28	8.35
6	59.54	66.37	71.39	7.46
9	63.45	65.97	67.34	1.86

$x_{\min.}$  – minimum value,  $x_{\max.}$  – maximum value,  $x_{\text{av.}}$  - arithmetic average, v – coefficient of variation

Values of the coefficient of variation containing within the range of values 1.86÷8.35%, indicate the good repeability of the measurements. For the surface processed of changing temperature cycles to make the increasing of the  $\Theta$  angle within the range 3.17- 5.75 deg, what involves with the minor reduction of the hydrophobicity. On the basis of the  $\Theta$  angle values and theoretical formulas Fasing on the Assumption of the adsorption theory of adhesion of polymers to wood one designated values of  $\gamma_s$ . On Fig. 1 the course of the formation of the  $\gamma_s$  parameter together with  $\gamma_s^d$  and  $\gamma_s^p$  shares were presented.



**Figure 1.** The course of  $\gamma_s$  with the  $\gamma_s^d$  and  $\gamma_s^p$  shares for lacquer coatings vs. number of aging cycles

In the function of the number of carried out aging tests generally it was stated that the minor increase of the  $\gamma_s$  value. The large influence on the course of this parameter exerted  $\gamma_s^d$  which was shaped on the level 74÷79%. In turn the participation  $\gamma_s^p$  was significantly smaller and was situated within the range 21÷26%. This testifies about the large hydrophobicity of the surface. From the point of view of theoretical assumption of the adsorption theory of the adhesion of polymers to wood obtained results  $\gamma_s$  of analysed system wood – coating belongs as favourable bearing in mind criteria. The  $\gamma_s$  value of the substrate should be higher from this parameter for solidified lacquer.

Results of the investigations of the adherence of coatings to the substrate together with the basic statistical estimation and kinds of the delaminations were given in the Table 2.

**Table 2.** The course of the adherence of lacquer coating to red meranti wood vs. number of aging cycles

Number of cycles	Statistical data <sup>*)</sup>				
	$X_{min.}$	$X_{av.}$	$X_{max.}$	$v$	Kind of delaminations
	[MPa]			[%]	[%]
0	0.73	0.84	1.06	14.60	25A,75-/Y
3	0.95	1.10	1.23	11.18	90A, 10-/Y
6	1.11	1.19	1.28	6.26	95-/Y, 5A
9	1.09	1.20	1.33	8.30	90-/Y, 10A

<sup>\*)</sup>  $X_{min.}$ - minimum value,  $X_{max.}$ - maximum value,  $X_{av.}$ - arithmetic average,  $v$ -coefficient of variation

<sup>\*\*)</sup> A - cohesive in substrate, -/Y - adhesive of the last coating and adhesive

The general evaluation of obtained data indicates that tested coating system is characterized with the favourable adherence to the substrate. The average value of this parameter for the control samples of the considered variant was shaped on the level 0.84 MPa. Analysing experimental dependences were found, that in consequence of the aging followed the favourable tendency of the increase in value of the adherence to the substrate. Delaminations of tested system, at failure loadings were diversified. One registered mainly destructions between the last coating and the adhesive and the cohesion mechanism in the substrate.

## CONCLUSIONS

1. Lacquer coatings from the four-layer acrylic lacquer system showed the good adherence to the red meranti wood. This parameter had been stable and showed the minor up tendency during thermal aging.

2. The course of the  $\gamma_s$  of tested coatings was on the level approx. 42 mJ/m<sup>2</sup> at the dominant participation of the  $\gamma_s^d$  share. In the function of the number of aging cycles the  $\gamma_s$  value of coatings surrendered to the increase. On the size of noted down  $\gamma_s$  was exerted.
3. The value of the  $\gamma_s$  parameter for tested coating system indicates the occurrence of good adhesion influences between wood and with the coating system.

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**Streszczenie:** *Wpływ starzenia termicznego na przyczepność systemów powłokowych do drewna red meranti stosowanego w stolarce budowlanej.* Celem pracy było poznanie kształtowania się przyczepności w warunkach przyspieszonego testu starzenia termicznego wybranego systemu lakierowego uformowanego na drewnie red meranti. Elementy okien uszlachetniono modyfikowanym akrylowym systemem lakierowym, obejmującym impregnat, wyrób gruntujący, międzywarstwowy oraz nawierzchniowy w wersji kolorystycznej cyprys. Zakres pracy obejmował wyznaczenie na podstawie pomiarów kąta zwilżania swobodnej energii powierzchniowej ( $\gamma_s$ ) oraz badania przyczepności powłok do podłoża metodą pull-off. Na podstawie uzyskanych rezultatów stwierdzono m.in., że testowane powłoki lakierowe wykazały dobrą przyczepność do podłoża. Z kolei parametr  $\gamma_s$  wskazał na występowanie silnych oddziaływań adhezyjnych między podłożem i poszczególnymi warstwami systemu lakierowego. Procesy starzeniowe nie wpłynęły w sposób znaczący na uzyskane relacje.

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