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# Properties of Halogensilane Modified Poly(vinyl acetate) Dispersion

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According to the humidity resistance class corresponding to D3 class of LST EN 204:2004 standard, strength of adhesive joints bonded with poly(vinyl acetate) (PVA) dispersions after 4 days of soaking in water should be not less than 2 N/mm². A considerable higher strength was obtained after modification of the dispersion with special monomers – silica derivatives. Such monomers contain chemically active groups, which after polymerization comprise spatial structures of molecules. Silica derivatives are characterized by high reactivity with compounds containing hydroxylic group, including poly(vinyl acetate). An especially good resistance to humidity was obtained for modified PVA dispersion with silica derivative – halogensilane SFTC. Investigations of the properties of modified dispersion were conducted to determine moisture resistance, duration of initial bond, influence of the dispersion on color change of some wood species widely used in industry, determination of the duration of open and closed exposure until compressing, influence of wood humidity on the strength of adhesive joints. PVA dispersion modified with halogensilane shows better properties than PVA dispersions at present applied in wood industry.

*Keywords:* timber, polyvinyl acetate dispersion, bond strength, splitting stresses, silica derivatives.

## INTRODUCTION

Poly(vinyl acetate) (PVA) dispersion is an important type of industrial adhesives with relatively high adhesion to wood [1]. PVA is widely used in production of water emulsion dyes, in household chemistry, printing industry, production of polymeric cement and concrete, leather haberdashery industry, furniture industry and in the other wooden articles [2]. A wide application of this adhesive are predetermined by its simplicity, universality, chemical neutrality, high adhesion properties, low price of raw materials [3]. PVA dispersions as adhesives are used of different viscosity, unplasticized or plasticized [4]. In the industry of wooden articles PVA dispersions are widely applied in the production of solid wood panels, assembling furniture articles, windows and doors. However, the use of PVA dispersions is limited due to its insufficient water resistance. Adhesive joints, affected by water, start to swell and loose their adhesion properties. The reason of this is the solubility of polyvinyl alcohol, contained in the dispersion, in water medium. It is necessary to modify PVA dispersions to increase their water resistance. Several trends of such modification exist: reduction of polyvinyl alcohol solubility in water [5], changing hydrophylic groups by more hydrophobic ones [6], transformation of the linear polymeric structure in network spatial structure. Earlier it was determined, that for PVA dispersion modification can be used special monomers – silica derivatives [7]. Such monomers have chemically active groups, which comprise spatial structures of molecules after polymerization. Silica derivatives are characterized by high reactivity to compounds with hydroxylic groups, including poly(vinyl acetate). Especially high moisture resistance was obtained using modified unplasticized PVA dispersion with silica derivative – halogensilane SFTC. Molecular absorption spectral analysis of the infrared spectrum and differential thermal analysis [8], showed that this additive changes linear structure of the polymer into spatial one, and the dispersion becomes resistant to water [9].

So, the aim of this investigation was to determine technological parameters of halogensilane SFTC modified dispersion such as pressing, open and closed time durations, influence of dispersion on the color change of some most widely used in industry wood species, influence of moisture content of the wood on the strength of adhesive joints. Latest evaluation of these parameters allows to select class of resistance to humidity according to LST EN 204:1998 and determine field of adhesive application.

## EXPERIMENTAL

Unplasticized PVA dispersion D51 was used in the study and 1 wt.% of halogensilane SFTC was introduced. For the comparison the commercial dispersions X1, X2, and X3 provided by various producers were used during the investigation. Beech wood samples were tested. They were prepared according to LST EN 205:1999 standard. Two unsteamed, planed, straight-grained beech boards of $300 \times 130$ mm and 5 mm of thick were prepared. The angle between the growth ring surfaces and the surfaces to be bonded was between 30° and 90°. The samples were bonded by the modified dispersion, which was coated on the surfaces by a specially shaped palette-knife of the both substrates. Beech boards were placed together and pressed at 0.5 N/mm² for 30 min. After that they were kept for 7 days under standard air conditions (environment temperature 20 ±2 °C, relative air humidity 65 ±5 %), 4 days they were soaked in water at 20 °C temperature. The pressure of 0.2 MPa was used for the samples bonding. After that, initial adhesion strength and strength of adhesive joints after 24 hours were determined. The samples were tested by splitting along the bond line. This corresponds to the typical technological process used in

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Lithuanian wood processing enterprises: after bonding the samples are stored for a 24 hours and only after that is the mechanically processed.

The influence of the studied dispersion on natural oak, beech, pines and birch wood of color was determined. 0.2 mm thick layer of modified dispersion was brushed on small ($300 \times 130 \times 5$ mm) oak, beech, pine and birch planks and left to dry. The planks were observed during 8 months.

According to the first test series of LST EN 204:1998 standard, the duration of open and closed time of the modified dispersion until pressing was investigated. Samples with adhesive layer were kept open for different time intervals before bonding. After that they were kept for 1 hour in the press at 0.5 MPa pressure. The adhesive joints were tested by splitting in the place of the bond line after 7 days.

Moisture content in the wood during bonding is also a very important factor, that affects the strength and quality of adhesive joints. For beech wood samples, before adhesive bonding, maximal moisture content, under which it is possible to obtain a bond, was determined. Samples of different humidity were obtained by soaking them in water. To achieve an even distribution of humidity throughout the whole sample, the samples were kept for 3 days under standard environmental conditions. Moisture content of the samples was measured using hydrometer GANN Hydromette HT65. The strength of adhesive joints was determined according to the 1st test series of LST EN 204:1998 standard.

## RESULTS AND DISCUSSIONS

Bond strength of adhesive joints bonded with poly(vinyl acetate) dispersions according to humidity resistance class corresponding to the requirements of test series No3 and D3 class of LST EN 204:1998 standard, after 4 days of soaking in water should be not less than 2 N/mm². Adhesives of class D3, i.e. adhesives used in interior with short-term exposure to running or condensed water and/or to heavy exposure to high humidity. Testing the D51 PVA dispersion modified with SFTC additive according to the 3rd test series of LST EN 204:1998 standard, 2.52 MPa bond strength was reached. This testifies that the studied modified PVA D2 dispersion corresponds to D3 humidity resistance class. For comparison PVA dispersions of X1, X2, X3 of D3 classes produced by other firms were studied. Results are presented in Table 1.

**Table 1.** Dependence of adhesive strength on PVA dispersion type

| Type of dispersion | Shear strength, MPa |
|---|---|
| X1 | 2.16 |
| X2 | 2.12 |
| X3 | 2.10 |
| With SFTC additive | 2.52 |

The strength of joints bonded with the new modified PVA dispersion is 2.52 MPa and in 17 – 20 % exceeds the strength of bonds by all other dispersions.

One of the most important features of bonding process efficiency is the duration of initial bond, in other words, pressing duration of production. It is the time, during which the bonded production reaches a sufficient initial bonding strength.

Technological data sheets of different firms point out the different pressing duration, which continues from 5 up to 30 minutes (an average is 12 min). This duration depends not only on the type of applied adhesive. Pressing duration is prolonged (up to 50 %) for all PVA adhesives when high humidity (14 % and more) wood being pressed. This process may be explained by a slower penetration of water from the bond line into wood bulk [10]. Meanwhile, increase of pressure, decreases pressure duration. Pressing regimes also depend on the nature of bonded wood. For example, bonding maple wood, initial strength is reached faster than bonding oak, ash, or beech wood. Experimental results obtained using samples from beech wood are presented in Fig. 1. As can be seen, after 6 minutes of pressing a significant increase of initial bond is observed. After 9 minutes of pressing, bond strength stabilizes and with further increase of pressing duration, bond strength changes only insignificantly. During technological process, 9 minutes is pressing duration after which adhesively joined production may be withdrawn and kept in standard air conditions up to gaining final adhesive bond strength.

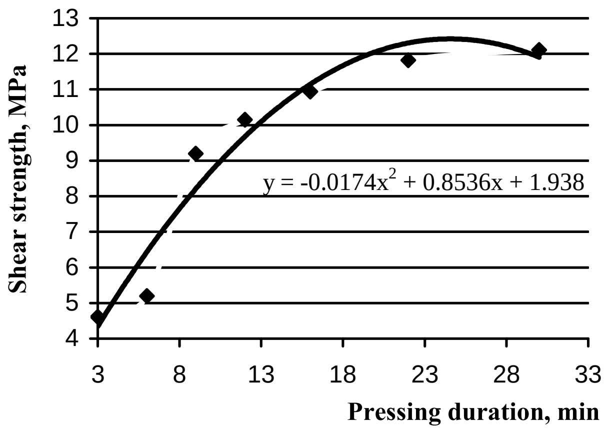


**Fig. 1.** Dependence of the adhesive strength on pressing duration

Meanwhile only after 12 minutes of pressing, adhesive bond exceeds 10 MPa limit. This limit in LST EN 204:1998 standard is foreseen as the least adhesive bond value in test series No1. So, based on the results of the experiment, a rational pressing duration was ascertained, i.e. 9 minutes.

After adhesive bonding some wood species change their natural color. For instance, oak wood affected by dispersion acquires a rather dark color, pine wood becomes red. However, during experiment the color of all species remained unchanged.

All adhesives have a certain duration of open time. It indicates how long adhesives brushed on the surface of an article can be exposed to environment until the moment of bonding. Analyzing PVA dispersions of other producers used in Lithuanian market, it was observed that the open time duration is extremely dependent on air temperature and relative air humidity during adhesive bonding. Increase of air temperature and decrease of relative air humidity decreases open time duration. However, decrease of air temperature and increase of relative air humidity, increases the open time duration, although the bond strength decreases. Especially open time duration is a very important factor in the case of complex adhesive bonds, i.e. when large amount of bonds have to be made at the same time. For PVA dispersion modified with SFTC additive, the open time duration was investigated also (Fig. 2). The obtained dependence of shear stresses on the open time duration shows that the technogically recommended open time duration for the studied dispersion is 20 min. This parameter is much higher than that of other dispersions, for which open time duration varies from 5 up to 10 minutes.

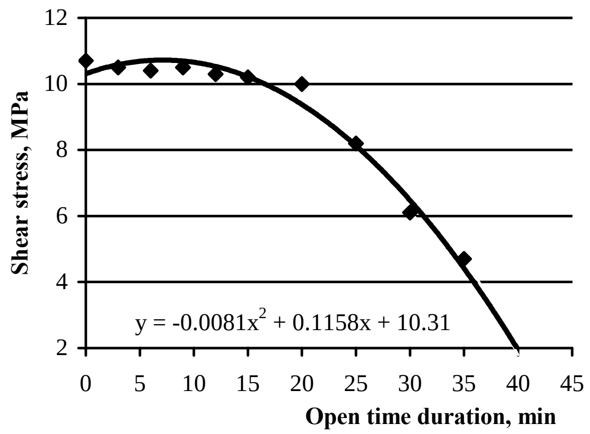


**Fig. 2.** Dependence of the shear stress on the open time duration

Important technological parameter, i.e. duration of the closed time was determined using the same method, also (Fig. 3). Very often this duration during technological process is insufficient, but it is especially important in the production of bonded solid wood panels. For example, when solid wood scantlings are bonded on panels, usually several articles with brushed on adhesives are placed in the press. Quite long time passes between the first and the last panel. If this time period exceeds the duration of closed time foreseen for adhesives, the production is spoiled. The determined closed time duration for the modified dispersion is 38 min.

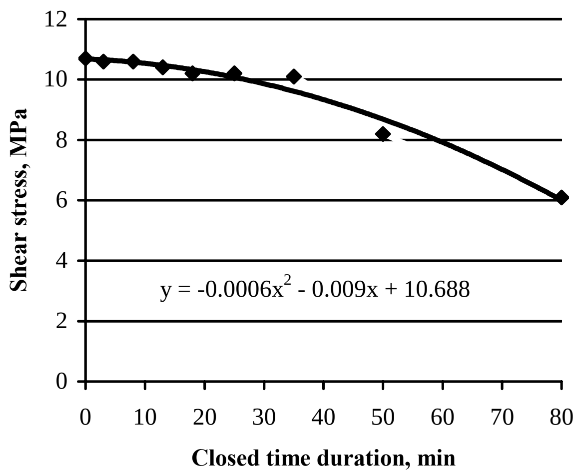


**Fig. 3.** Dependence of the shear stresses on the closed time duration

Moisture content of the wood has significant influence on the strength of adhesive bonds. Technical data sheets of applied in the industry PVA dispersions point out recommended moisture content of the wood up to 12 %. It is believable, that adhesive bond may be insufficiently strong when bonding wood samples exceeds standard relative humidity. Technical data sheets of PVA dispersions used in wood processing industry point out 12 % moisture content of the wood. It was found, that using modified PVA dispersion can be obtained strong adhesive joint, when relative humidity of wood is 15.1 % (Fig. 4). Samples of higher humidity are bonded as well, however, the strength of this bond is lower and does not fulfil the LST EN 204:1998 requirements.

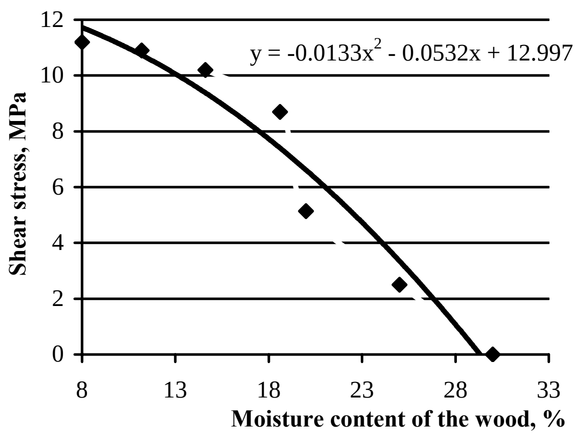


**Fig. 4.** Dependence of the shear stresses on moisture content of the wood

Even initial adhesion was failed when wood of 30 % humidity was bonded. In this case, the samples were disconnected just after pressing.

According to the obtained results it can be suggested that halogensilane modified dispersion can be used for adhesive bonding of door, windows, staircase construction elements and other different kinds of joints.

## CONCLUSIONS

1. Halogensilane SFTC modified PVA dispersion increases the resistance of adhesive bond to humidity from D2 to D3 class (according to LST EN 204:1998).
2. The properties of PVA dispersion modified with halogensilane SFTC are better than PVA dispersions used in wood industry, which correspond to D3 humidity class. Technologically recomended pressing duration for the studied dispersion is 9 minutes, rational open time duration is 20 minutes, closed time duration is 38 minutes, modified PVA dispersion produces a high strength bond in wood of 15.1 % humidity, dispersion has not impact on surface discoloration.
3. Field of application of the modified PVA dispersion could be in heavy exposure to high humidity for different kind of joints.

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