

THERMAL AND HYDROTHERMAL STABILITY OF HOT-MELT ADHESIVE COMPOUNDS, USED TO ADHERE PLASTIC EDGE BANDING MATERIALS TO PARTICLEBOARDS

Dimitar ANGELSKI

University of Forestry, Blvd. Kliment Ohridski 10, Sofia, Bulgaria
E-mail: d.angelski@ltu.bg

Pavlin VITCHEV

University of Forestry, Blvd. Kliment Ohridski 10, Sofia, Bulgaria

Vladimir MIHAILOV

University of Forestry, Blvd. Kliment Ohridski 10, Sofia, Bulgaria

Abstract:

Nowadays, most of the furniture constructive elements are made out of laminated particleboards whose edges are banded with plastic banding material. The edge banding process of furniture boards predominantly uses EVA hot-melt adhesives. The adhesives based on EVA hot-melts provide relatively low strength, thermo- and moisture resistance. Furniture is often exposed to environments of high temperature and humidity. These conditions often result in a decrease of the adhesion strength followed by the removing of the edge banding material. Therefore, the influence of high temperature, water and water-saturated vapors on the adhesive strength is important to be known. On the basis of this information, the objective of the current study was to investigate the influence of high temperature, water and water-saturated vapors on the adhesive strength of EVA-based adhesives, used to connect plastic banding material to particleboards. The following three experiments have been carried out: (i) one factorial experiment to measure the adhesion strength of the compounds after being soaked in water for 2 up to 58min, at 20°C; (ii) one factorial experiment to measure the adhesion strength of the compounds after hydrothermal treatment of the adhesives (2 to 20min duration of treatment); (iii) two factorial experiment to evaluate the thermal stability of the adhesives, measured at various temperatures of convective heating in air (50, 100 and 150°C) and treatment durations (5, 20, 35min). The experimental data have been analyzed by regression analysis and a mathematical equation, describing the relationship between the different factors, and the adhesion strength of the adhesives has been derived. All the experiments were carried out with two edge banding materials: ABS with thickness of 2mm and PVC with thickness of 0.45mm. The influence of high temperature and water-saturated vapors on the adhesive strength of the tested compounds was assessed by the changes in the tensile strength of the adhesives, measured perpendicular to the edge surface. The obtained results were analyzed and graphically represented.

Key words: edge banding; EVA; adhesion strength; PVC; ABS.

INTRODUCTION

Edge banding of the furniture constructive elements is predominantly done by adhesion. The adhesive process involves first the application of the glue, heated to a certain temperature, and the consecutive cool-down of the adhesive layer during the pressing process (Albin 1995). The edge banding process is based on the use of hot-melt glues. Hot-melt adhesives are environmentally friendly glues containing no solvents. The edge banding process of furniture boards predominantly uses Ethylene-co-vinyl acetate (EVA) hot-melt adhesives and plastic banding material (PVC or ABS). EVA is a 100% solid, transparent and flexible adhesive. EVA hot-melt adhesives are constituted essentially of mixtures of EVA, tackifier, and wax. It is normally categorized by percentage of vinyl acetate (VA) content and melt flow rate (MFR) or melt index (MI). Most commonly used EVAs contain between 19% and 28% VA (Paul 2003).

With hot-melt adhesives, the change from solid to liquid is reversible, and controlled by temperature. The wood composite should be dry enough so that even if moisture is added during bonding, the moisture content of the product is at about the level expected for the assembly in service (Vick 1999).

For optimum adhesion, it is therefore absolutely essential to ensure good wetting by the coating material applied, thus creating ideal conditions for causing the film-forming agent molecules to approach the substrate (Butt et al. 2008). Compounds with hot-melt adhesives have lower strength than conventional wood adhesives (Frihart and Hunt 2010). Furthermore, the adhesives based on EVA hot-melts provide relatively low thermo- and moisture resistance.

One of the main factors used for evaluation of the adhesive compounds is the adhesive strength. The latter is defined as the resistance of the laminating material against mechanical separation from the substrate. Typical adhesion mechanisms are chemical, mechanical, electrostatic and acid-base adhesion

(Rijckaert et al. 2001; Jaic and Zivanovic 1997; Ozdemir and Hiziroglu 2007; Nelson 1995). There are different tests used to measure the adhesive strength. All are based on different methods of separation of a laminating material from its substrate at a particular load. One of the most reliable and therefore frequently used is the axial pull-off adhesion test. The test determines the greatest perpendicular force (in tension) that a surface area can bear before a piece of material is detached. Sometimes the laminating material is separated from the substrate not along their bonding interface, but throughout one of the materials (laminated or substrate) - by the mechanism of cohesive failure (internal failure of the adhesive layer).

The adhesive compounds not only need to meet minimum adhesive strength requirements, but they also have to be resistant to different conditions. Quite often, furniture constructive elements with EVA glues are used in high-temperature and humid environments, e.g. bathrooms, basins, attics. In addition, in such premises, there are high daily and seasonable fluctuations in temperature and humidity. Thus, additional functional properties of the adhesive compounds have to be evaluated as well.

Usually, the ones that are directly related to the particular operating conditions are chosen for evaluation. For example, by using heating appliances located close to or integrated in the furniture, considerable heat can accumulate in the edge banding glue compounds. As a result of this, a decrease in strength was reported and in some cases the laminating material could detach from the particleboard without mechanical impact.

Often, the adhesives are subjected to a combination of high temperatures and water-saturated vapors (hydrothermal impact), e.g. heating of water in electric kettles, formation of superheated steam during cooking etc. For the operational stability of the furniture components, it is also important to determine the influence of water on the adhesive compounds depending on the duration of the contact. This means that the edge banding glue compounds should be evaluated also based on indicators for evaluation of properties such as resistance to low and high temperatures, variable temperatures, water and hydrothermal resistance. In addition, the continuous operation of the edge banding compounds in hot temperature and/or high moisture environments results in decrease of their adhesive strength. Thus, it is also important to know the influence of extreme environments on the adhesive strength of the edge banding compounds.

The purpose of this research was to determine the influence of extreme operating conditions on the adhesive strength of edge banding glue compounds between particleboards and plastic edge banding materials. For achieving this target, evaluation has been made on the influence of the temperature, water and hydrothermal impact on the adhesive strength of the edge banding glue compounds. It was assumed that by measuring the adhesion of the glue compounds before and after a certain influence (of water, high temperature or steam) the resistance of the compound to this impact could be indirectly determined.

EXPERIMENTAL SECTION

Materials

For the current study, particle boards (delivered by the Kronospan Company, Burgas, Bulgaria) with the dimensions 2800x2070x18mm and a density of 680kg/m³ have been used. Two laminating (edge-banding) materials: acrylonitrile butadiene styrene (ABS) and polyvinylchloride (PVC) have been tested. The width of the laminating (edge-banding) materials was 22mm and the thickness (δ) was 2mm for ABS and 0.45mm for PVC. For edge banding, a hot-melt adhesive system (Kleiberit 788.7) based on ethylene vinyl acetate (EVA) was used. The glue system has a melting point of approximately 90°C and a heat resistance interval of 65÷70°C. The operating temperature, recommended by the manufacturer, is between 130°C and 190°C, and the quantity of the applied glue ranged from 150 to 300g/m².

Preparation of the samples

The samples (65x30x18mm) were edge banded through feed at an automatic single-sided edge-banding machine (Biesse Akron 440-AX). The operating system of the machine regulates the main technological factors as follows: the glue temperature (190°C), the feeding speed (25m/min), the quantity of glue (185g/m²) and the force of the metal rollers (860N). The samples with edge temperature of approximately 25°C and 10% moisture content then enter the edge-banding area. Hot melt glue is applied onto the surface of the panel's edge a few seconds before the edge-banding material is bound to it. The control system provides the accurate glue line. As the substrate passes through the edge-banding area, many metal rollers press it. After that, trimming stations remove any edge-banding material overhang.

Factor experiments

To determine the impact of the following factors: water, high temperature and hydrothermal influence on the bonding strength between plastic edgings (PVC and ABS edge-banding materials) and particle boards, the following experiments have been performed:

- Mono-factorial experiment to evaluate the water-soaking resistance of the plastic edgings. The samples were banded on all sides. The study time interval was from 2 to 58 min and the water temperature was 20°C;

- Mono-factorial experiment to evaluate the hydrothermal resistance of the plastic edgings. The samples were put for an interval of 2 to 20 min in laboratory autoclave at a temperature of 90°C. Then, the samples were left to cool down for 24h at room temperature (20°C) and 65% rel. air humidity;
- Two-factorial experiment to evaluate the thermal resistance of the plastic edgings, assessed in wide temperature and time ranges. The variable factors are: temperature of heating t (convective heating in air environment) and duration of thermal treatment σ .

To determine the influence of the variable factors on the adhesion strength of the adhesive substance, a method of regression analysis was used. The changes of the output value, depending on the changing values of the regime factors, can be represented by a parabolic regression equation of second order. On this basis, a matrix composition plan of Box et al. 1951, with technical factors strongly influencing the adhesion, has been designed and performed. The factors with less influence on the adhesion exert constant values and are beneficial for the adhesive process. Based on the above-mentioned recommended values of the factorial ranges of variance, the interval in the two-factorial experiment was pointed out. In the matrix composition plan, the variables vary at three levels – maximum, medium and minimum. For convenience of the mathematical analysis of the data, the factors in the experimental matrix are given with the following codes: maximum (+1); medium (0); minimum (-1). The non-coded values of the factors obtained during the experiment are as follows:

- temperature of heating, t (X_1) – 50, 100 and 150°C;
- duration of thermal treatment, σ (X_2) – 5, 20 and 35 min.

The results are expressed as averaged values of eight experiments. The statistical program “Qstatlab 5” was used for analysis of the data and calculation of the regression coefficients.

Test method

Various test methods for adhesion property are available. The current study has used a method by which the adhesive compound is applied with a tensile load perpendicular to the edge-banding surface. The tensile strength, perpendicular to the edge-banding surface, was used as the main criterion in results evaluation. This method is similar to the pull-off test for coating adhesion and it is presented in Fig. 1 (Merdjanov 2016).

The tensile forces are spread via a T-shape steel body (stamp), attached to the edge material by a cyanoacrylate adhesive. On both sides of the stamp (3), the edge-banding material is interrupted by a cut equal in depth to the thickness of the edge-banding material and the adhesive. Next to the mobile bar (7) of the testing machine “Heckert – FP 100” – Germany, “U”- shaped clips (6) are attached. The fixed part of the machine is embedded with a chain (1), whose second end is secured to the steel body via a nail (2) that passes through the chain and stamp holes. The clip shoulders are clamped on the sample from the side of the cut edge-banding material. The speed at which the adhesive compound is tensile loaded is 20mm/min. The load applied to the sample is increased gradually, until the edge-banding material is separated (pulled off) from the particleboard.

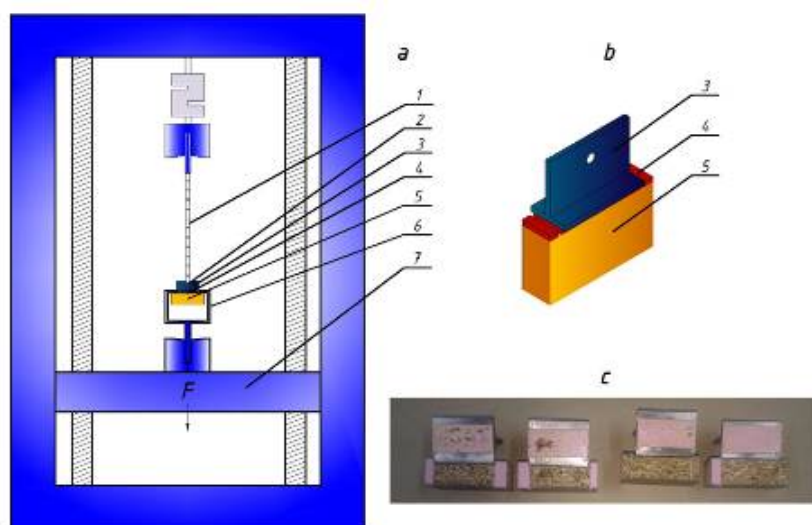


Fig. 1.

a - Test method, b - T-shape steel stamp connected to sample, c - Tested sample, dimensions (L x b x h): 65x30x18mm.

The destruction of the adhesive compound can be adhesive (between the substrate and adhesive layer) or cohesive (within the adhesive layer itself). By the reported destruction force, the adhesive strength of the edge-banding compound can be determined.

RESULTS AND DISCUSSION

After conducted test method, similar to the pull-off test for coating adhesion (EN 4624 standard), the adhesion strength mean values of the control specimens are as follows: PVC coating, 0.45mm-2.04N/mm²; ABS coating, 2mm-2.1N/mm².

Results from the two-factorial experimental evaluation of the impact of high temperatures on the adhesion strength of the adhesive compounds

The matrix composition plan and the average values obtained from the pull-off test are presented in Table 1. The second order equations from which the regression coefficients have been derived are as follows:

$$Y_{PVC/0.45} = 1.675 - 0.220X_1 - 0.263X_2 + 0.131X_1^2 - 0.148X_2^2 - 0.289X_1X_2 \quad (1)$$

$$Y_{ABS/2} = 1.560 - 0.246X_1 - 0.170X_2 + 0.132X_1^2 + 0.113X_2^2 - 0.096X_1X_2 \quad (2)$$

Table 1

Matrix of two-factor composite experimental plan and average values from the pull-off test for evaluation of the impact of high temperatures on the adhesion strength

№	$t \equiv X_1$ °C	$\tau \equiv X_2$ min	$\sigma_{PVC/0.45}$ N/mm ²	$\sigma_{ABS/2}$ N/mm ²
1	150 (+)	35 (+)	0,8087	1,2835
2	50 (-)	35 (+)	1,8878	1,9501
3	150 (+)	5 (-)	1,9515	1,8053
4	50 (-)	5 (-)	1,8736	2,0886
5	150 (+)	20 (0)	1,7003	1,4860
6	50 (-)	20 (0)	2,0206	2,0036
7	100 (0)	5 (-)	1,8043	1,9035
8	100 (0)	20 (0)	1,5653	1,4626
9	100 (0)	35 (+)	1,3578	1,5422

The changes in the adhesion strength of the adhesive compounds as a result of continuous thermal impact are shown in Fig. 2 and 3.

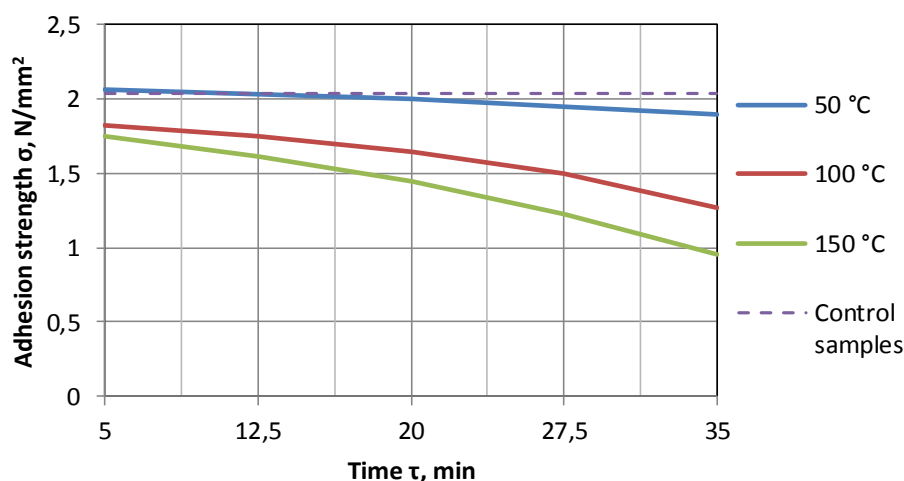


Fig. 2.

Impact of high temperatures (50, 100 and 150°C) on the adhesion bonding between PVC edging ($\delta = 0,45\text{mm}$) and particleboards.

For up to 10 minutes of treatment with high temperatures (from 100 to 150°C), the edge banding adhesive compounds showed an adhesive strength of over 1.7MPa. Therefore, they cover the minimal adhesive requirements according to the technical guidelines. After 12min of treatment, however, their adhesive strength significantly decreased. The minimal adhesive strength for the adhesives with ABS edging is measured to be 0.95N/mm² and for those with PVC edging – 1.2N/mm². Both are measured after 35min of

heating at 150°C. Under these conditions, the adhesive strength of the edge-banding compounds is very low, since its value is lower than 1.7N/mm². On the other hand, the adhesive strength of the edge-banding compounds did not change at a temperature of 50 °C. Event during the longest period of treatment (35min), the adhesive strength was over 1,7N/mm². In the time range from 5 to 35min, the maximum decrease of the adhesive strength was by 5.4% for the adhesives with ABS edging and by 6.6% for those with PVC edging. This could be explained by the good thermal stability of the adhesives at temperatures below 65-70 °C.

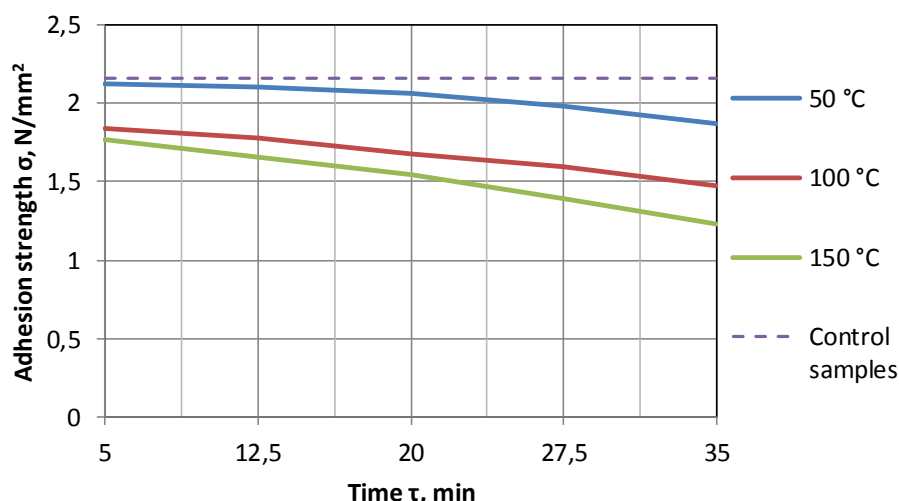


Fig. 3.
Impact of high temperatures (50, 100 and 150°C) on the adhesion bonding between ABS edging ($\delta = 2\text{mm}$) and particleboards.

The edge-banding compounds with edge thickness of 2mm are characterized by higher thermal resistance; therefore, their adhesive strength decreases less compared to the adhesive strength of the edge-banding compounds with edge thickness of 0.45mm. Thermal impact at 150°C resulted in decrease of the adhesion strength of the adhesive compounds with PVC edging (0.45mm) by 1N/mm². This could be explained by the relative fast heating of the thin edge-banding materials, leading to faster deterioration of the adhesive properties of the adhesive compound.



Fig. 4.
Self-delamination of PVC edge from edge banding compound after impact of high temperature.

Heat accumulation in the edge-banding compound above the thermal resistance limits of the adhesive results in self-delamination of the edging material (Fig. 4). This process is a result of deteriorated adhesion and generated inner tension in the edge-banding material. It is well-known that thicker edge-banding materials tend to accumulate high inner tension during rolling. With a significant reduction in adhesion, the tension in the edge-banding material overcomes the adhesive forces and destroys the adhesive compound.

Results from mono-factorial experimental evaluation of the influence of the hydrothermal impact on the adhesion strength of the adhesive compounds

The impact of saturated water vapors heated up to 90°C on the adhesive strength of the adhesive edge-banding compounds with EVA is shown in Fig. 5.

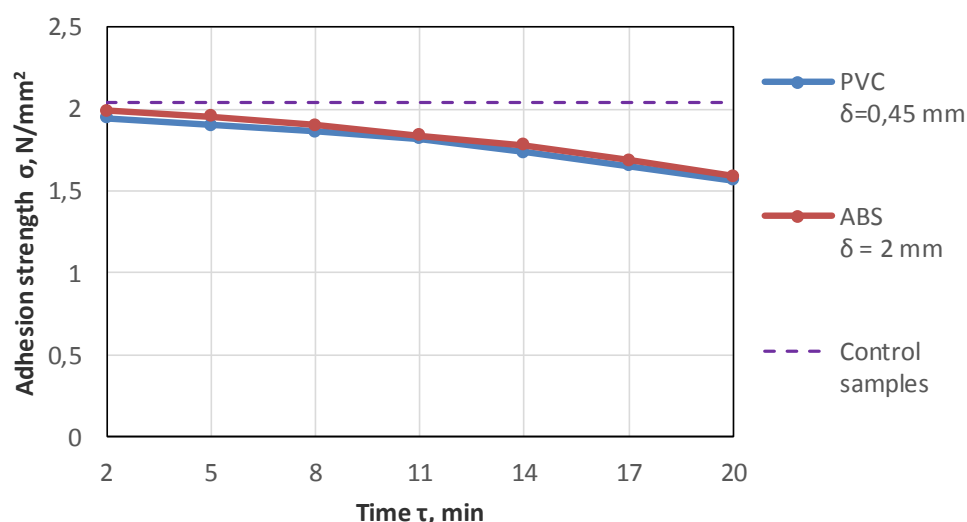


Fig. 5.

Hydrothermal impact of saturated water vapors at 90°C on the adhesion bonding between plastic edgings (PVC and ABS edge-banding materials) and particleboards.

After hydrothermal treatment for 10-12min, the adhesive strength of the edge-banding compounds decreased below 1.7N/mm². Based on the results, it has been determined that hydrothermal treatment for about 1min decreased the adhesive strength by 1%.

On Fig. 5 it is visible that the bonding strength is relatively similar for the adhesives with thin and thick bands. The adhesive strength for the edge-banding material with edge thickness of 2mm is 2-3% higher than that of the edge-banding material with edge thickness of 0.45mm. This means that the thicker banding materials do not diminish the changes in the adhesive strength of the glues and therefore do not provide better protection against the hydrothermal impact.

Results from mono-factorial experimental evaluation of the influence of water on the adhesion strength of the adhesive compounds

The impact of the water soaking of the specimen details on the adhesion bonding between plastic edgings (PVC and ABS edge-banding materials) and particleboards is presented in Fig. 6. From the results, it is visible that the values of the adhesive strength are similar for the given time interval. This could be explained by the high water resistance of EVA polymers. The observed variations are probably due to some adverse factors, such as swelling of the particleboards, uneven water penetration in the particles etc. that may negatively influence the adhesion strength. In practice, water soaking for 1 h does not have a negative impact on the adhesive strength of the edge-banding compounds.

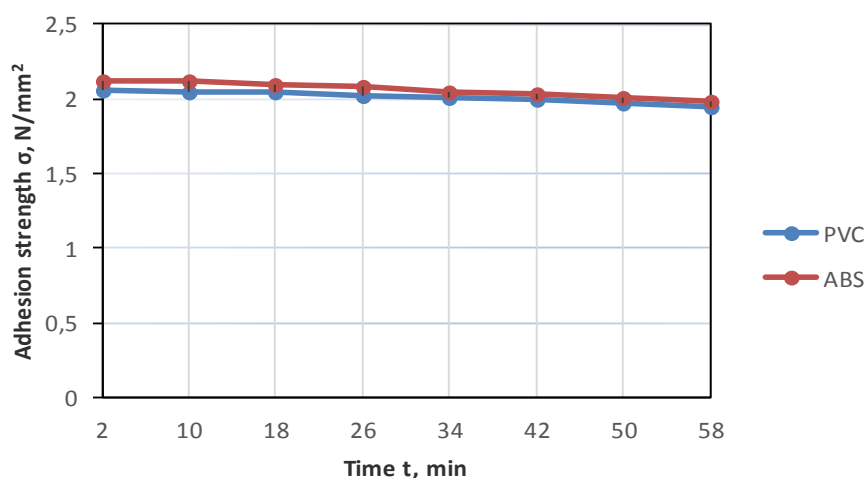


Fig. 6.

Impact of water soaking at 20°C on the adhesion bonding between PVC and ABS edge-banding materials and particleboards.

CONCLUSIONS

Based on the results obtained at lab scale and under the conditions of the experiments herein, the following conclusions could be specifically for the above-mentioned edge-banding materials and EVA hot-melt adhesive system Kleiberit 788.7:

- Heating at high temperatures (from 100 to 150°C) significantly decreased the adhesive strength of the edge-banding compounds. Their strength covers the minimal guideline requirements of 1.7MPa only within the first 10min of heating;
- The continuous thermal treatment (at 50 °C) did not significantly decrease the adhesive strength of the edge-banding compounds. In the time range from 5 to 35min, the maximum decrease of the adhesive strength is by 5.4% for the adhesives with ABS edging and by 6.6% for those with PVC edging. This is a result of the relatively high thermal resistance of the adhesives at temperatures below 65-70 °C;
- After hydrothermal treatment with water-saturated vapors (at 90°C), the adhesive strength of the edge-banding compounds was significantly decreased. Their strength covers the minimal guideline requirements of 1.7MPa only within the first 12min of treatment. The kinetic behavior of the adhesive strength during hydrothermal treatment is analogous to that during the thermal treatment (100 and 150°C);
- During hydrothermal treatment with water-saturated vapors (90°C), the adhesive strength of the edge-banding compounds with thin and thick bands was similar;
- The adhesive strength of the edge-banding compounds did not significantly change after 1h soaking in water at 20°C. Despite the negative impact of the water on the particleboards, the adhesion was preserved, due to the high water resistance of the EVA polymer.

ACKNOWLEDGEMENTS

This document was supported by the grant No BG05M2OP001-2.009-0034-C01 "Support for the Development of Scientific Capacity in the University of Forestry", Sofia, Bulgaria financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the European Union through the European structural and investment funds.

REFERENCES

- Albin R (1995) Grundlagen des Möbel- und Innenausbaus. Leinfelden-Echterdingen: DRW-Verl. Weinbrenner.
- Box GEP, Wilson KB (1951) On the experimental attainment of optimum conditions. Journal of the Royal Statistical Society, Series B13:1-45.
- Box GEP, Liu PYT (1999) Statistics as a catalyst to learning by scientific method. Part I - an example, Journal of Quality Technology 31:1-15.
- Butt MA, Chughtai A, Ahmad J, Ahmad R Majeed U, Khan IH (2008) Theory of Adhesion and its Practical Implications: A Critical Review. Journal of Faculty of Engineering & Technology. 2007-2008:21-45.
- Frihart CR, Hunt CG (2010) Wood Handbook, Wood as an engineering material, Centennial Edition, Chapter 10–15 Adhesives with Wood Materials: Bond Formation and Performance, Bonding Process, Moisture Content Control, General Technical Report FPL-GTR-190, pp. 10.1-10.24.
- Jaic M, Zivanovic R (1997) The influence of the ratio of the polyurethane coating components on the quality of finished wood surface, Holz als Roh-und Werkstoff, 55:319-322.
- Merdjanov V (2016) Optimization of technological parameters for continuous edgebanding of furniture panels, PhD Thesis, University of Forestry, Sofia (in Bulgarian).
- Nelson GL (1995) Adhesion, Chapter 44, Paint and Coating Testing Manual, ASTM Special Technical Publication, Philadelphia, PA., pp. 513-523.
- Ozdemir T, Hiziroglu S (2007) Evaluation of surface quality and adhesion strength of treated solid wood, J. Mat. Processing Technol.186:311-314.
- Paul CW (2003) Hot-melt adhesives. MRS Bulletin: 440-444.
- Rijckaert V, Stevens M, Acker JV (2001) Effect of some formulation parameters on the penetration and adhesion of water-borne primers into wood, Holz als Roh-und Werkstoff, 59:344-350.
- Vick CB (1999) Adhesive bonding of wood materials. In: Wood handbook – wood as an engineering material.US Department of Agriculture, Forest Products Laboratory, Madison, WI.