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Temperature-related resistance of bonds between wood particleboard and surface finishing materials

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Abstract: *Temperature-related resistance of bonds between wood particleboard and surface finishing materials.* The lateral surfaces of furniture components made of wood particleboard are commonly completed with finishing materials. The aim of this work was to investigate heat-induced changes in resistance of glue joints between finishes (wood veneers, HPL and ABS edge bands) and substrate. The glue we used was a hotmelt ethylene-vinyl-acetate (EVA). The methods for glued joint strength testing were three: following the Standard ČSN EN 311, peel test performed at an angle of 90º (ČSN EN 28510-1) and shear under compression loading at an angle of 45º. The experimental results revealed that the glued joint stability decreased with increasing temperature. The performance of glued joints was significantly affected by temperatures ranging between 50–70 ºC. The temperature also depended on the specific materials glued together with the EVA glue tested. Such temperature, common in closed containers transporting furniture components in summer, may be a serious risk factor lowering the quality of the furniture components during transport.

Keywords: ethylene-vinyl-acetate glue (EVA), particleboard, HPL edge, ABS edge, glued joints, temperature, mechanical loading

INTRODUCTION

Furniture produced in the Czech Republic is exported worldwide: mostly to European countries (95 % of the total export).

The furniture is commonly transported separated into components. This means several profits for the producer: good storage properties, economical use of transport means, lower expenses on assembling. The disadvantage is high price of furniture hardware and lower strength of the disintegrable joints.

To speed up the trans-loading and to minimise manipulation of goods, the merchandise is transported in called „standard units“, such as trailers, semi-trailers, detachable constructions, with the most common ISO containers of class 1 (***Herber 2005***) According to a survey on transport logistic, the transporters use for furniture transport standard containers ISO 1C – 20´ DV, 40´ DV and 40´ high Cube (***Hlavatý 2014***).

On the other hand, the furniture with fixed joints is more difficult to transport and it also means more demands on storage and transport room. The advantage is strong joints. This is why this approach is preferred in production of exclusive furniture made to order: kitchen unit boxes, seats, and similar.

Furniture transported long distances may be impaired mechanically (stress, shaking, vibrations) or due to climatic conditions (moisture, temperature, solar radiation). This damage can be minimized through correct packaging, storage and the way it is packed during transport.

The data from meteorological stations show that the occurrence of tropical days (with air temperature in shadow ≥ 30 °C) is increasing. In these conditions, the temperature inside loaded containers may increase by another 20 to 25 °C compared to ambient air – especially when the containers are dark-coloured and exposed to high temperature on the terminal.

The rising temperature weakens the strength of glued joints, which holds especially for thermoplastic glues (***Clauβ et al. 2011***, ***Frangi et al. 2012***, ***Stoeckel et al. 2013***, and others). ***Clauβ et al. 2011***) observed a dramatic decrease in joint strength glued with PVAc as early as at 50 °C. ***Stoeckel et al. (2013)*** report even a 99% strength reduction of joints glued with thermoplastic PVAc with temperature increasing up to 65 °C.

Elevated temperature, representing a high risk especially for hotmelt glues, may be very common in furniture transport under extreme summer conditions. The temperature inside containers may reach 50–65 °even for several hours in several subsequent days (***Hlavatý 2014***, ***Jivkov et. al. 2008***). Such temperatures may endanger adhesion ABS, HPL edges or veneers used for edge banding of furniture elements, namely in case of hotmelt glues.

Under movement in containers in such conditions, the stored furniture components may move resulting is dislocations in the glued joints. Also the finish material may detach from the substrate, due to stresses generated in the first one. The result is loss of barrier against moisture (***Hlavatý 2013***). The link between the temperature and relative air humidity is strong. With rising temperature, there also rises the capacity of air to absorb water vapour (***Scharnow 1998***). This means that, apart from temperature, also moisture and temperature and moisture interactions are to be considered for their influence on glued joint quality.

Glued joints of furniture may be exposed to heat loading also indoors when the furniture is placed near a heat source (a heating body, an appliance built in a kitchen unit, etc. In this case, however, the temperature loading of furniture is local only and it does not reach extreme values for a long time.

With regard to the increasing demands on the furniture quality require it is very important to understand of the influence of temperature on glued joints quality especially by hotmelt glues. By today, however, there have not been developed methods for testing the durability and resistance of furniture strained during transport. Such methods should assess the suitability of joining individual parts primarily in context of heat effects in transport units (***Brunecký 2009***).

The method for testing of hotmelt glues „Glue resistance against elevated temperature“ used in a drying kiln in the laboratory does not provide enough information on glued joint durability under variable temperature conditions (heat exposure during transport).

The aim of this work was the experimental verification of the instant heat effect on adhesion of finishing (or finishes) materials (veneers, HPL sheets and ABS edges) used for edge banding of furniture components made of wood particleboard.

MATERIAL AND METHODS

The glued joints stability depending on temperature was tested on lateral surfaces of commercially produced three-layered laminate wood particleboard (PBL) used for furniture making. The lateral surfaces of these boards were finished with three types of decoration materials (natural wood veneer, HPL and ABS-based bands), with using hotmelt glue (ethylene-vinyl acetate). The thickness of all three materials was 1 mm.

The adhesion of these materials to the PBL´s lateral surface after heat strained was tested according to the Standard ČSN EN 311”Wood-based panels. Surface soundness. Test method”. The principle of this test is assessing the surface soundness of overlaid wood-based panels and unfaced particleboard. On the surface of the tested material, there were glued metal cylinders 20 mm in diameter. The glue used was epoxide. After the glue had hardened, a chase was milled along the cylinder´s base. This chase stretched through the glued joint down to the substrate at 0.3 ± 0.1 mm. In this test, the whole system PBL – glue – finish material was loaded in tension perpendicular to the interphase glue – adherend. The tensile strength of the loaded system was calculated according to the Equation

$$\sigma = \frac{4F_{\max}}{\pi \cdot d^2} \quad (1)$$

where F_{max} is the force necessary to disturb the system and d is the cylinder diameter

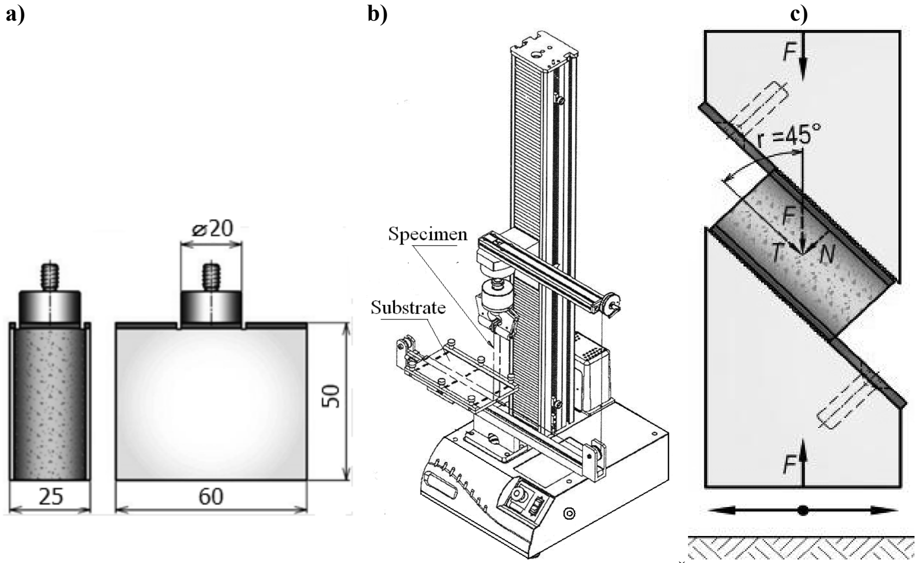

Fig. 1 Mechanical test on adhesion of decoration materials. a) pull-off test (ČSN EN 311), b) peel test at 90° (ČSN EN 28510-1), c) shear test under compression load at 45°

For ABS edges, a peel test was also performed under 90° angle according to the Standard ČSN EN 28510-1 (Fig.1b). The glued sample surface was 25.0 ± 0.5 mm wide and 150 mm long. The speed of jaws shifting was (50+5) mm/min. The average peel-off force was obtained from the local maximum and minimum of the force curve recorded during the testing (Fig. 2).

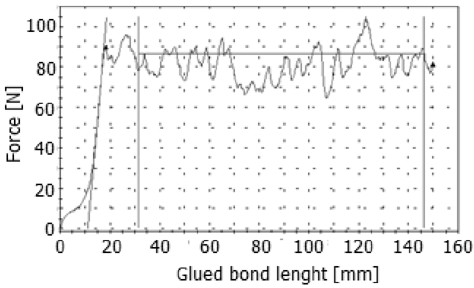

Fig. 2 Glued bond length and peeling force in ABS edges

Furniture components transported in containers are stock-piled against each other. As such, they are loaded and compressed due to their own weight. The stress acts either perpendicular or parallel to the board surface, in accordance with the elements arrangement. During transport and also during movement of container(s), shear force may develop and cause shear to the elements in the container. In this context, we tested the holding-capacity of a HPL sheet in shear under compression load at 45º (Fig. 1c). The theoretical basics for compression and shear stresses under this loading mode as well as the equation derived for calculating shear strength is in (***Dubovský 1990***). The shear strength under this loading mode was tested with specimens with dimensions 50 mm × 50 mm × thickness of the material tested. The shear strength value was calculated according to the equation

$$\tau_s = \frac{F_{\max}}{S \cdot \sqrt{2}} \text{ , (2)}$$

where F_{max} is the maximum force and S in the loaded area of the specimen tested.

With regard to the specimens′ dimensions, the HPL sheets were glued on their upper and bottom surfaces, with using EVA glue.

The holding capacity of finishes or finish materials to PBLs subject to all modes of mechanical loading was studied in the temperature interval from 20 (25) ºC to 70 ºC. In all cases, their heating period was 1 hour.

The tests were performed with testing equipment Instron with a heating chamber guaranteeing the environment required during the testing.

RESULTS AND DISCUSSION

We tested temperature influence on bonding quality of natural wood veneers, HPL and ABS bands glued onto lateral PBLs sides. The test used was pull-off test defined by the Standard ČSN EN 311. The testing results revealed (Fig. 3a-c) that the glued joint strength decreased proportionally with the raising temperature over the entire range inspected. For all three materials, these changes were similar in quality and quantity; however, some differences were discernible.

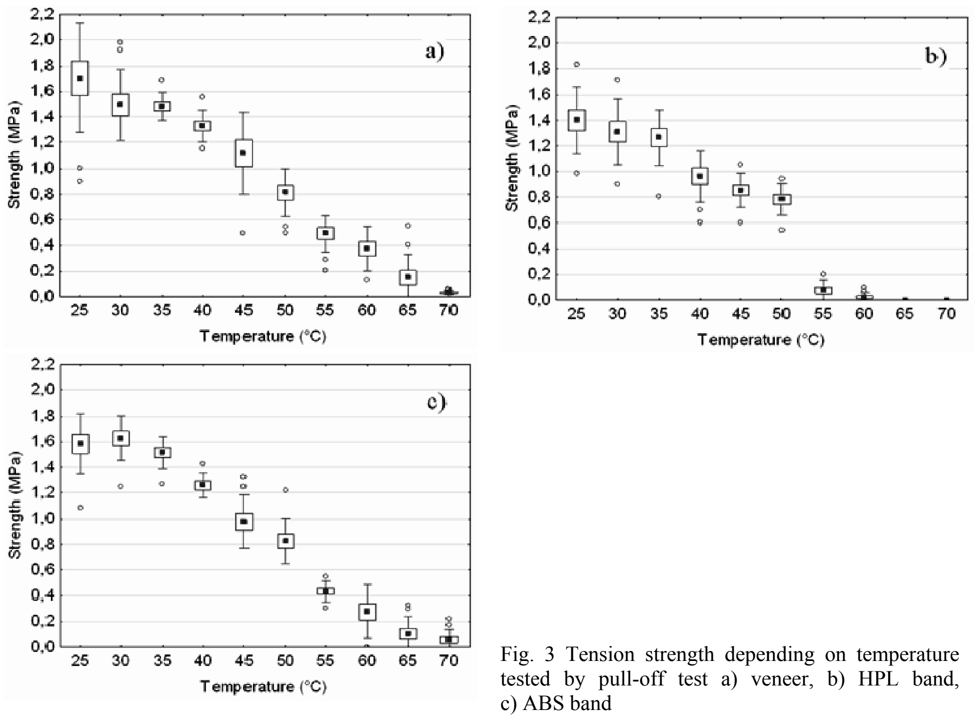

Fig. 3 Tension strength depending on temperature tested by pull-off test a) veneer, b) HPL band, c) ABS band

In case of the wood veneer, failures in the substrate occurred already in the temperature range from 25 °C–40 °C. The reverse surface displayed fragments of torn-off chips. The average strength values corresponding to this temperature interval ranged from 1.7 to 1.3 MPa (Fig. 3a). This strength was significantly higher than the tension strength perpendicular to the board plane. The average tension strength value perpendicular to the board plane over this interval was 0.27 MPa, the same as the strength of the internal board layer.

Beginning at 45 °C, the strength decline was more dramatic, because the glue melted faster and its cohesion dropped significantly. In this case, failures occurred in the glue itself. The strength at 70 °C was nearly zero, the result of complete glue melting.

For pulling-off HPL bands, the strength course dependent on temperature was qualitatively the same as that observed for wood veneer until 35 °C (Fig. 3b). There were not statistically significant differences in strength between the two materials. At about 40 °C, the strength decrease accelerated. A dramatic drop was recorded at 55 °C, with the strength value close to zero. Further heating caused complete loss of the glued joint performance. Higher strength loss in case of the HPL edge was due to the higher thermal expansion coefficient of this material compared to wood. The differences in temperature between these two materials (PBL and HPL edges) induced stress in glued joints negatively reflecting their strength.

Similar strength dependence on temperature as for the wood veneer was observed for the ABS edge (Fig. 3c).

The observed variability of glued joint strength affected by temperature in all three finish materials were in quality very similar to the variability in shear strength reported by CLAUß *et al*. (2011) for a PVAc glue.

The glued joint stability between the PBL and HPL band was also tested in shear under compression load at an angle of 45°. The test results demonstrate (Fig. 4) a moderately decreasing trend in strength with increasing temperature up to 50 °C. The average shear strength values were ca 2 MPa, which in this case, corresponded to the shear strength of the PBL, as the failures occurred only in the BPL, exactly in its central layer – the weakest spot of the system (Fig. 5).

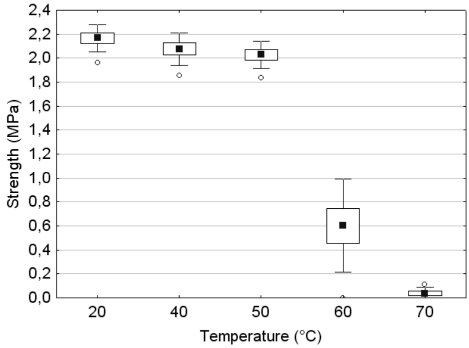

Fig. 4 Shear strength depending on temperature

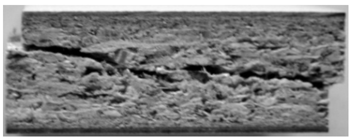

Fig. 5 Shear failure in the PBL central layer.

The failure associated with heating to 60 °C was clearly in the glue, which was resulted through a considerable strength loss. Heating to 70 °C triggered separation of the HPL band from the PBL substrate, as early as during the heating – resulting in band buckling (Fig. 6 a). In most cases, the band separated due to stresses generated during the heating just before the mechanical load. The Fig. 6b illustrates a failure in a glued joint at 60 °C, the Figs 6c and 6d show this phenomenon at 70 °C.

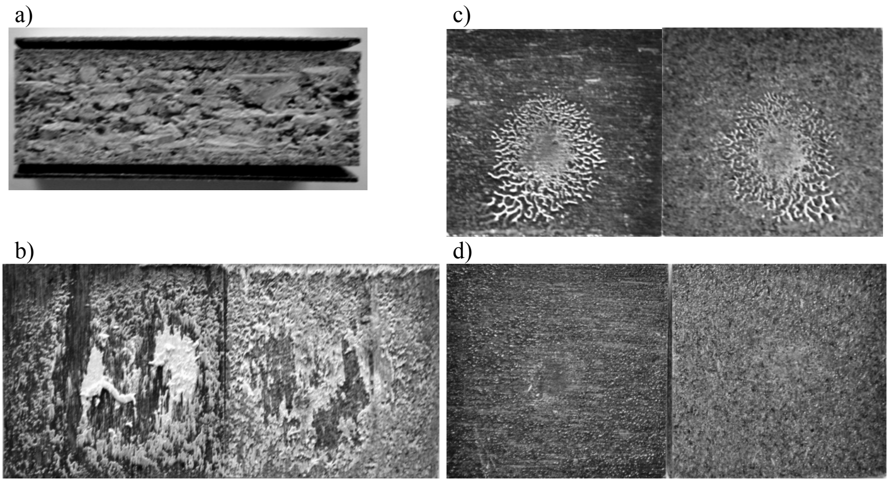

Fig. 6 Glued joint impaired under high temperature. a) Buckling of HPL band,
b) Failure inside glue under 60 °C, c), d) failures inside glues under 70 °C.

The resistance of ABS band under different temperature conditions in dependence on the band flexibility was also tested by a peel test at an angle of 90°. The results show (Fig. 7) that the force necessary for the tearing-off the ABS band was constant up to 40 °C, because during the peel test, the surface layers in PBLs were impaired (Fig. 8a). Also in this case, the temperature increase to 45 °C was associated with a dramatic decrease of force necessary for tearing-off the ABS band and the failure mostly occurred in the glue itself (Fig. 8b). For 50 °C and more, the band separation did not require using mechanical effort. Due to heat strain under these temperatures, the band separated by itself and scrolled.

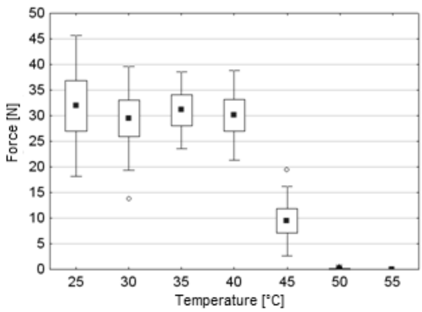

Fig. 7 Temperature and peeling force in the peel test defined by the standard ČSN EN 28510-1

a) b)

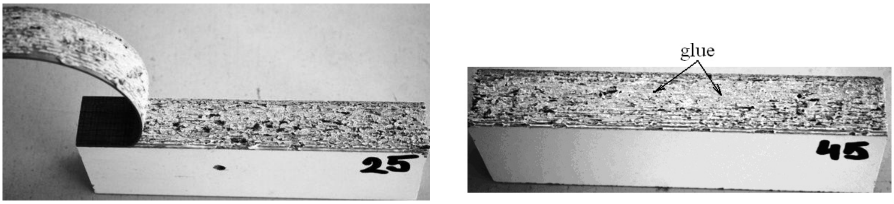

Fig. 8 Glued joint impaired during peel test under different temperatures. a) at 25°C. b) at 45 °C

Examining the air temperature values measured in July and August 2013 in the Czech Republic (Fig. 9), we can see a high number of days with temperature exceeding 30 °C. We may experience this number even increasing in the future. The temperature measured inside the transport containers was higher by 20–25 °C compared to the ambient air (***Hlavatý 2014***). Consequently, the temperature interval of 50–70 °C can represent a very high risk for stability of joints glued with the hotmelt EVA glue. The results of our measurements demonstrate a practical lack of glued joints performance. Consequently, we may suppose that the joints glued with hotmelt EVA glue have poor resistance against impairment. This can affect negatively the furniture component quality. Preventive measures are needed to define and to apply. STOECKEL *et al*. (2013) obtained similar results for temperature influence on glued bond strength for a thermoplastic PVAc glue.

Considering the question which of the methods is the most suitable for this purpose we can say that all the three give well-founded results, complementary to each to other.

Considering possible occurrence of mechanical strain during furniture components transport and manipulation, we recommend combining two tests: peel test carried out at an angle of 90º (ČSN EN 28510-1) and shear under compression load at an angle of 45º. The first is more suitable for flexible materials such as wood veneers and ABS edge bands, the second for stiff and low flexible materials, such as HPL edge bands. In addition, in case of compression shear, the shear force is coupled with normal force, which gives a more precise representation of the load on components stacked on each other during transport.

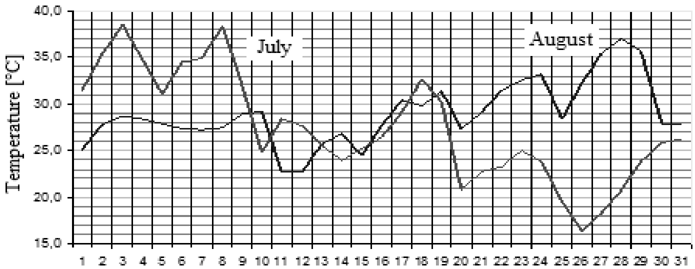

Fig. 9 Temperature maxima for the region Brno in July and August 2013
(Source CHMI, Branch Brno – Hlavatý (2014))

CONCLUSIONS

The experimental results and their analysis allow us to arrive at the following conclusions:

1. Negative influence of high temperature on furniture components quality need to be considered when these products are transported longer distances in summer.

2. In case of joints glued with hotmelt EVA glue, the complete temperature-induced loss of joint stability occurred at the temperature range of 50–70 ºC.
3. Besides the glue alone, the glued joint strength reduction during heat loading was also influenced by the specific materials glued together with the given hotmelt glue as well as by the heating period.
4. For flexible materials (natural wood veneers, ABS edge bands) glued on lateral surfaces of furniture components, we recommend the peel test performed at an angle of 90º; for stiff and inflexible materials, shear test under compression loading at an angle of 45º.

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Streszczenie: *Odporność na działanie temperatury spoiny klejowej pomiędzy płytą wiórową a materiałami wykończenia powierzchni.* Boczne powierzchnie elementów mebli wykonanych z płyt wiórowych są zwykle oklejane materiałami wykończeniowymi. Celem pracy było zbadanie zmian wywołanych podwyższoną temperaturą w połączeniach klejowych między materiałem wykończenia powierzchni (fornirem, HPL i ABS) i podłożem (płyta wiórowa). Wykorzystano klej termotopliwy EVA. Zastosowano metody badania wytrzymałości spoiny: test na odrywanie wykonywane pod kątem 90º, test na ścinanie i ściskaniu pod kątem 45º. Wyniki doświadczalne

wykazały, że stabilność połączenia klejowego zmniejszała się wraz ze wzrostem temperatury. Miało to znaczący wpływ w temperaturach od 50-70°C. Takie temperatury mogą wystąpić podczas transportu mebli w porze letniej, co znacząco zwiększa ryzyko obniżenia jakości komponentów meblowych.

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