

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

The Influence of Adhesion Temperature to the Shear Strength of Width Glued Wooden Elements

Murco Obucina^{*a}, Enil Gondzic^b, Edib Manso^b

^aFaculty of Mechanical Engineering, University of Sarajevo, V. setaliste 9, Sarajevo 71000, Bosnia and Herzegovina

^bCompany Standard, Bosanski put 103, Sarajevo 71000, Bosnia and Herzegovina

Abstract

This paper examined the effect of temperature of pressing on the strength of width glued elements during the process of production of solid wood panels. It has been used the polyvinylacetate D3 adhesive and solid beech wood (*Fagus sylvatica*). Time of pressing has been determinate separately for each level of temperature of bonding, which amounted to (30°, 40°, 50°, 60°, 70° C). For each level has been formed 20 samples in order to determinate the value of the shear strength of bonded joint. The results were processed using the Student's *t*-test. This research showed that with increasing the temperature and pressing time increases the shear strength of the bonded joint, but non-linear.

© 2015 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of DAAAM International Vienna

Keywords: temperature; shear strength; solid wood panel; bonding of wood

1. Introduction

Bonding of wood is the most used process in the wood industry. During the bonding occur simultaneously more complex physical and chemical processes that are a consequence of the properties of wood and the adhesive used for bonding, the interaction between the timber and the elements of technological regimes.

Wood industry in many cases requires an acceleration of the bonding process. This is achieved by increasing the temperature in the zone of the glue line, which enhances the removal of liquid components of adhesive and speeds up a chemical reaction inside the glue. The temperature is a key factor in the emergence of waterproof glued joint [1]. It has been determined also that better adhesive overflowing at higher temperature due to reduction of viscosity,

* Corresponding author. Tel.: 00387 33 729 827; fax: 00387 33 653 055.

E-mail address: obucina@mef.unsa.ba

results with better penetration into the wood [2].

Technological procedure of bonding affects the physical, mechanical and rheological properties of the elements to be bonded [3], [4]. Warm up during the process of bonding causes also negative consequences. Different intensity warming through the section of the sample to be bonded, resulting in different time of bonding, creates the opposite gradients of moisture and temperature which results in a variety of internal stresses [5].

The shear strength of the bonded joint is an important indicator of the quality of adhesion. Fracture strength means the maximum shear strength in the grain direction. The strength of bonded two wooden elements must be equal to or greater than the shear strength of the wood, otherwise occurs the adhesive fracture. When using quality adhesive fracture occurs at the interface wood – glue [6].

2. Materials and experiment

Experimental measurements were performed on samples of width jointed laminated panels made of beech wood using a single component polyvinylacetate adhesives RAKOLL E-WB 0301. Dimensions of the shear surface of tested samples amounted to 25x20 [mm]. The paper examined the shear strength of the compound at various grades of temperature bonding before and after immersion of samples. The aim of testing is to determine the temperature which achieves the highest shear strength of the adhesive line, which directly affects the quality and class of the product.

Bonding of wood panels was performed at different temperatures and at two separate presses, one of which is vertical cold press (Figure 1 a) and the second hot press with contact heating (Figure 1.b). The panels are glued at different temperatures with temperature class 10° C. The amount of adhesive layer and intensity of pressure on the glue line were constant. Temperature classes were 20, 30, 40, 50, 60 and 70 ° C. It were bonded two panels for each class of temperature. A total of 450 specimens were used.

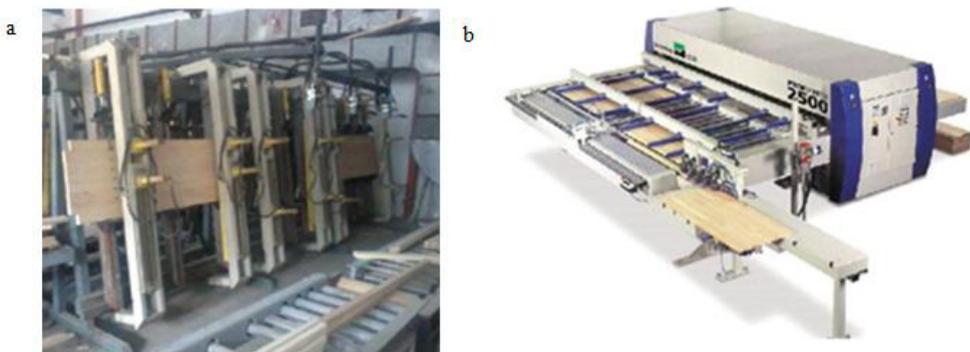


Fig. 1. (a) Cold and (b) hot press.

To test the quality of the strength class of compounds D3 adhesive according to EN 204 standard, the samples were selected from the group of temperature regimes (20, 30, 40, 50, 60, 70 ° C), the 15 specimens for each group. The samples were immersed in distilled water at a temperature of 18 ° C (Figure 2). Time period in which the samples were submerged is four days ie. 96 hours. After the expiry of the sinking, there were first measured dimensions on the glue line surface and then approached to the breaking thereof. The samples need to show shear strength greater than 2 [MPa] in order to meet the requirements according to EN 204 standard for testing regimen D3-3.

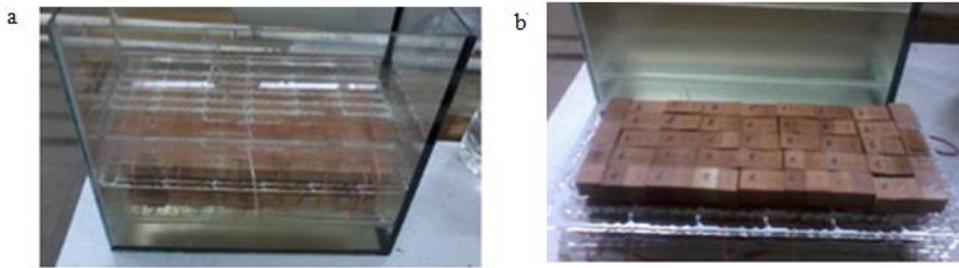


Fig. 2. (a) Aquarium with submerged samples; (b) The samples after submerging.

Testing of shear strength of bonded compound approached after the proper performance of sorting, marking and measuring the width and thickness of the samples. The samples were subjected to shear force on the test machine "ZWICK" after fixing, so that shear force is in the same direction and the opposite direction along the adhesive joint (Figure 3.).

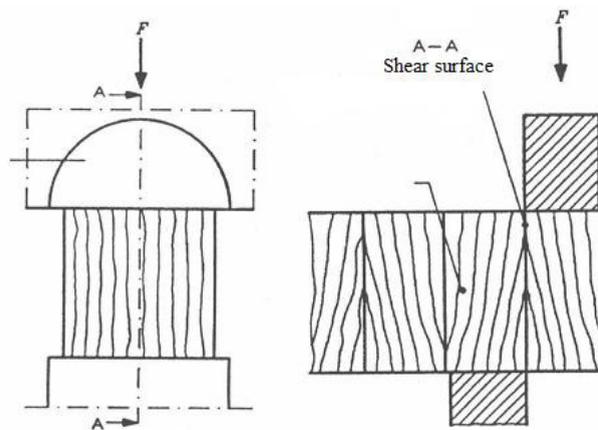


Fig. 3. Testing of shear strength of bonded joint.

Shear strength was calculated according to the following expression:

$$\tau = \frac{F_N}{a \cdot b} [MPa] \quad (1)$$

Where is:

- τ – shear strength [MPa];
- F_N – shear force [N];
- a – width of the sample [mm];
- b – thickness of the sample [mm].

For the obtained values of the shear strength was performed statistical analysis of data using the student's t -test testing the equality of the means of two basic sets and a two-sided distribution (t -Test: Two Sample Assuming Equal Variances). Statistical analysis was performed to determine the significance levels observed between individual influential factors.

Area of acceptance and rejection of the null hypothesis was withdrawn with double t -test given in figure 4.

Statistical T_{test} is calculated according to the expression (2).

$$T_{test} = \frac{\bar{X}_{VF} - \bar{X}_{KL}}{\sqrt{\frac{S_{VF}^{*2}}{n_{VF}} + \frac{S_{KL}^{*2}}{n_{KL}}}} \tag{2}$$

Where is:

- \bar{X} - arithmetic mean;
- n - number of samples;
- S^{*2} - standard deviation.

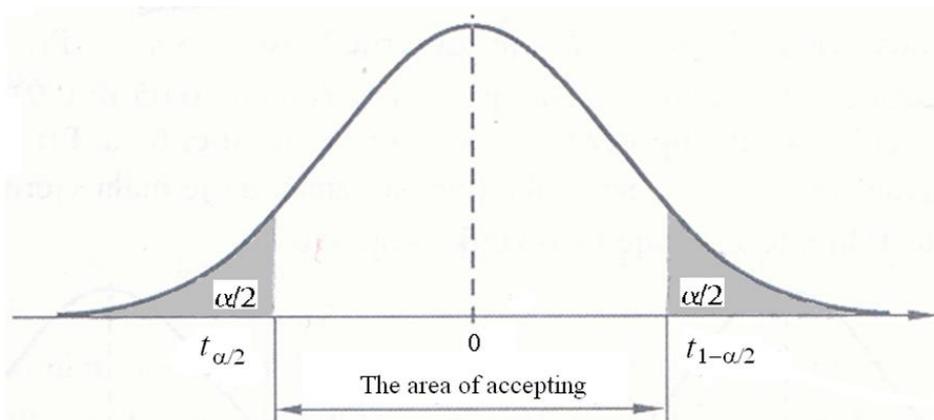


Fig. 4. Area of acceptance and rejection of the null hypothesis with double t -test.

If the $|T| \leq t_{v;0,05}$ then the null hypothesis is rejected and if the $|T| > t_{v;0,05}$, then the null hypothesis is rejected with risk at 5 % and the mean of average values $\bar{X}_{VF} - \bar{X}_{KL}$ is significant.

3. Results and discussion

Shear strength for samples after conditioning on standard climate (dry test according to EN 204) is given in Table 1 and the graph 1.

Table 1. The values of shear strength in the regime of temperature for dry testing of samples.

| Temperature of bonding [°C] | 20 | 30 | 40 | 50 | 60 | 70 |
|------------------------------|-------|-------|-------|-------|-------|-------|
| τ_{mean} [MPa] | 7,24 | 12,17 | 11,56 | 12,20 | 10,71 | 13,92 |
| Standard deviation [MPa] | 3,28 | 3,53 | 2,87 | 2,65 | 2,02 | 1,77 |
| Coefficient of variation [%] | 45,41 | 29,07 | 24,89 | 21,76 | 18,91 | 12,74 |

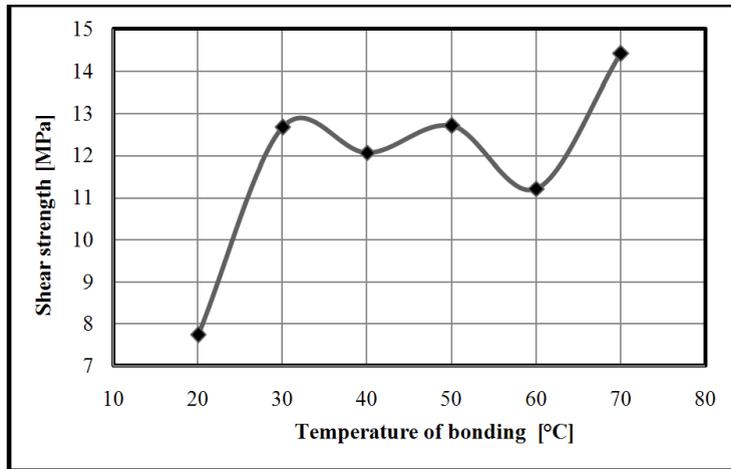


Fig. 5. Shear strength at regime of different values of temperature.

Analyzing the above graph it is apparent that the shear strength increases with increasing temperature bonding. There is a great difference in the field of cold pressing i.e. at temperature of 20°C and after the start of heating at 30°C when there is an increase of shear strength. Following the process and procedure of bonding may provide an explanation for the great difference in shear strength between the wood panels glued at temperature 20°C and panels glued at higher temperature values. The temperature class 30°C has shown the value of shear strength that can compete with the area of hot pressing (temperatures of 40, 50 and 60°C). As reason for the rapid increase in shear strength at a temperature of 30°C can be explained by a temperature higher by 10°C.

Group of temperature class 60°C had a slightly lower value. In the area of hot bonding groups at a temperature of 70°C has met expectations and showed the highest shear strength of the adhesive fuge. All groups, except groups bonded at 20°C showed a value of shear strength greater than the average in pure beech wood, which is 8-9 [MPa].

The destruction of the test samples and the fracture of them occurred in area of wood in more than 45% cases. It tells that the width glued joint has a good quality. Figure 5 presents the destruction of samples per tree.

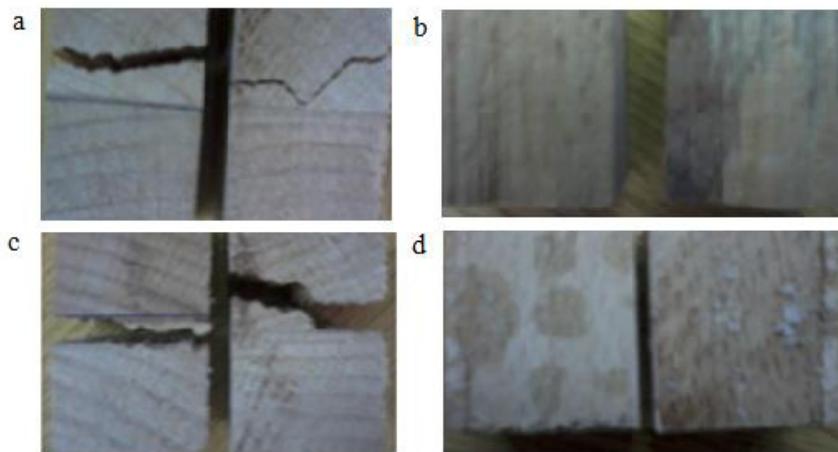


Fig. 6. Deformation of samples: (a) 100% per tree; (b) 70% per tree; (c) 50% per tree; (d) 0% per tree.

Using the *t*-test revealed that the bonding area of the hot heat (40, 50, 60 ° C) there is no significance in the results, while cold (20, 30° C) and hot bonding have shown the significance differences in values of shear strength (table 3). It was found that bonding at temperature of 70° C, which was one of a group of hot bonding, shows a significant difference with a class of temperature 60° C, as with all other temperature classes.

In accordance with standard EN 204 and D3 regimen was carried out a test of the shear strength after the sinking of specimens in distilled water for four days, at a temperature of 20±5° C. Results of the mean values of shear strength, standard deviation and coefficient of variation are presented in Table 2.

Table 2. Results of testing of D3 class of adhesive.

| Temperature of bonding [°C] | 20 | 30 | 40 | 50 | 60 | 70 |
|------------------------------|----|-------|-------|-------|-------|-------|
| τ_{mean} [MPa] | 0 | 0,50 | 0,56 | 0,60 | 0,56 | 0,78 |
| Standard deviation [MPa] | 0 | 0,30 | 0,30 | 0,40 | 0,22 | 0,47 |
| Coefficient of variation [%] | 0 | 65,14 | 54,40 | 67,39 | 38,90 | 60,20 |

Test samples after immersion at necessary time did not meet the required shear strength which must be at least 2 [MPa]. Table 2 shows very low values of shear strength. *t*-test results were analyzed and it was found that there was no significance between the groups pressing temperatures except in comparison with class of 20° C. The samples that were bonded at a temperature of 20° C during immersion experienced deformation of joints by swelling of wood.

Deformation and destruction of joint occurred 100% per joint and 100% per glue (Figure 6). Figure 7 represents the values of shear strength after immersion in distilled water.



Fig. 7. Deformation of test samples after immersion.

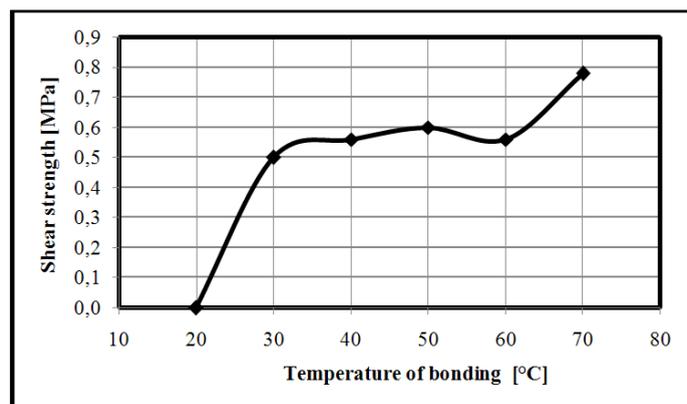


Fig. 8. Values of the shear strength obtained through testing D3 class of adhesive.

During this experiment it was investigated the significance of the results of shear strength after immersion and compared with the significance of values of shear strength of glued joint before sinking. Table 3 presents the values obtained data processing using *t*-test. Above the neutral line are represented by the *t*-test for the regime of temperature, while the lower part of the table is a check of values D3 class of adhesive. Value of *t*-critical for the verification of class D3 for adhesive (28 degrees of freedom) is 2,048. That means that all obtained T_{test} values observing each combination of classes that are greater than 2,048 represent a significance difference (5 %) between tested classes. These values are bolded in table 3.

Table 3. *t*-test of significance of the results of the temperature regime and checks D3 class of adhesive.

| Temperature of bonding [°C] | 20 | 30 | 40 | 50 | 60 | 70 |
|-----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 20 | / | 5,591 | 5,417 | 6,426 | 4,918 | 9,791 |
| 30 | 5,945 | / | 0,731 | 0,033 | 1,966 | 2,417 |
| 40 | 7,120 | 0,505 | / | 0,889 | 1,331 | 3,817 |
| 50 | 5,747 | 0,732 | 0,306 | / | 2,445 | 2,951 |
| 60 | 9,955 | 0,553 | 0,023 | 0,357 | / | 6,533 |
| 70 | 6,434 | 1,910 | 1,550 | 1,152 | 1,693 | / |

Conclusion

This study confirmed the fact that with by increasing the temperature of bonding occurs directly proportional to an increase in shear strength of the bonded joint. The maximum value of shear strength in a given study achieved for bonding temperature value of 70 °C, resulting in the decrease of pressing time. Analysis of the data using *t*-test showed statistical significance between the values of shear strength results by cold and by hot bonding. Significance among results for different values of pressing temperature pressing has a positive and desirable value for suggesting that it is useful to increase the temperature by production of solid wood panels.

In future research should be continued testing of the influence of the temperature on the bonding strength. It could be used more different types of thermostabile adhesives (thermosets) and higher temperature values (over 100 °C). These testing should be carried out using other materials such as metal, ceramics and rubber.

References

- [1] Klasnja B., Kopitovic S., 1992. Lignin-phenol-formaldehyde resins as adhesives in the production of plywood. Holz als Roh- und Werkstoff. 50, 7-8: 282- 285.
- [2] Bradly D. E., Kamke F.A.1988. Efect of hot-presing parameters on resin penetracion. Forest Production Journal, 38, 11/12:63-68.
- [3] Obucina M., Dzaferovic E., Bajramovic R., Resnik J. 2006. Influence of gluing technology on viscoelasticity properties of LVL. Wood Research. 51 (4): 11- 22.
- [4] Obucina,M.; Turk, G.; Dzaferovic, E.; Resnik, J. (2013). "Influence of gluing technology on physical and mechanical properties of LVL". journal Drvna industrija (Wood industry). 64 1., pp.33-38, ISSN 0012-6772.
- [5] Resnik J., Sernek M., Kamke F.A. 1997. High-frequency heating of wood with moisture content gradijent. Wood and fiber science 29,3: 264-271.
- [6] Obucina, M.; Gondzic, E., Smajic, S. (2013). "The influence of amount of layer on the bending strength by longitudinal finger-jointing wood elements". *Annals of DAAAM International 2013*, Volume 24, No.1, ISSN 2304-1382, ISBN 978-3-901509-97-1 Vienna, Austria.