Influence humidity and heat on tensile shear strength of lap joints made of solid fir/spruce wood

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Abstract. Determination of tensile shear strength of lap joints is carried out according to three standards: BAS EN 205:2018 for adhesives used for non-load-bearing structures, and according to BAS EN 302-1:2014 for adhesives used for the manufacture of load-bearing structures and according to EN 14257:2019 for lap joints who are exposed to elevated temperatures. The paper presents the results of tensile shear strength of lap joints made of solid fir/spruce (Abies alba ssp./Picea abies spp). Tensile shear strength was tested in 4 groups of tests samples. The Group 1 consisted the samples were 7 days in standard atmosphere [20/65]. The Group 2 consisted the samples were previously soaked in water at (20 ± 5) °C, then recondition in standard atmosphere [20/65]. The Group 3 consisted the samples were previously 6 h soaked in boiling water 2 h, then soaked in water at (20 ± 5) °C; the samples tested in the wet state. The Group 4 consisted the samples were previously exposed to heat in a preheated fan oven, at (80 ± 2) °C, for (60 ± 2) min. The test results can be applied for gluing windows, doors, stairs, high-frequency gluing, veneering panels, etc.

1. Introduction
Climatic conditions are different in each country. There is also a significant difference in atmospheric conditions in the same area depending on the seasons.

Atmospheric conditions such as temperature and humidity as well as other environmental characteristics have a significant impact on the physical, mechanical and rheological properties of solid wood and wood-based materials. The impact of these parameters on the strength and durability of wood and wood-based materials is significant.

For manufacturers of furniture, construction joinery, interior design equipment, but also for all those who produce wooden elements joined with glue, it is important to know the impact of climate on the strength of joints.

In general, by gluing, i.e. using an adhesive joint, certain advantages can be achieved, such as to obtain a material having better mechanical properties (the strength of the adhesive joint is higher than the strength of the material from which the joint is made), the fabricated composite has low weight given the created structure, greater resistance of the glued joint to the action of biotic and abiotic agents and finally gluing is achieved by reducing the cost of production. In contrast, glued joints also have a number of limiting properties. Eg. the glued joints cannot disassemble, making it difficult to check their strength or lifespan or possibly repair them.

The preparation of the contact surfaces of the bonded materials, as well as the method of processing affect the properties of the bonded joint [5].

Some adhesives have a more or less limited life span under the influence of moisture, elevated temperature, or some chemicals. Formaldehyde-based adhesives have better resistance against the
effects of water. But their application also caused a certain problem - the spontaneous unwanted release of formaldehyde into surrounding environment.

Therefore, formaldehyde-based adhesives are being replaced by other adhesives that have increased resistance to moisture.

Testing of glued joints has been carried out for a long time. Tested of the influence of material properties, such as wood moisture on the strength of the glued joint, were performed [3], [4]. Based on the test results [9], it was found that a slight increase in relative wood moisture (from 12 to 15%) has a relatively small impact on the speed of the hardening of the bonded joint where the PUR adhesive is used.

Some significant tests are the influence of moisture content on the bond strength and water resistance of glued joints [3], the influence of temperature on the strength and stiffness of glued corner joints of frame structural elements [6], influence of the time between machining and assembly of mortise and tenon joints on tension strength of T-type joints [2], strength of furniture joints constructed with biscuits [11], tensile strength of finger joints type T, strength of furniture joints made using dowels and other. Tested the joints were glued with PVAc, PUR adhesives, UF adhesives and other synthetic adhesives depending on the area of application of the adhesive compound.

The tests were conducted in real time, but also with the use of certain regimes of accelerated aging. Real-time testing takes a long time, often several years.

The tests were performed in real time where the glued joint was exposed to the action of the actual climate (atmosphere) of a certain geographical area, but also with the use of appropriate conditioning sequences and regime of accelerated aging. Real-time testing takes a long time, often several years.

However, the request of today's market for wood products requires that the design and characteristics of the product change rapidly and adapt to the requirements of modern customers. It is therefore resorted to testing the properties of bonded joints that have previously been exposed to the effects of appropriate conditioning sequence according to BAS EN 204: 2014. or accelerated aging treatments. These appropriate conditioning sequence can simulate different climatic conditions.

The aim of this paper is to provide more information on the influence of heat (temperature 80°C) and humidity - cold and hot water on tensile shear strength of lap joints made of solid fir / spruce wood. Prior to the tensile shear test, the test pieces were subjected to appropriate conditioning sequence.

2. Experimental study of the influence of humidity and heat on tensile shear strength

Appropriate resources should be provided for each test:
- necessary theoretical knowledge of the desired research - proven information on the desired research issues that can be found in books and similar publications, the results of previous similar research conducted by the author or other researchers and standards and other technical norms necessary for conducting research;
- test material and
- test equipment.

Testing of tensile shear strength by lap joints is performed according to the standards: BAS EN 205:2018 for adhesives used for for non-structural applications, or according to BAS EN 302-1:2014 for adhesives used for the load-bearing timber structures and according to EN 14257:2019 for determination of tensile strength of lap joints at elevated temperature (WATT '91).

We decided to test glued joints for non-structural use, i.e. we used the standards BAS EN 204:2018 and BAS 205:2018, and EN 14257:2019 (WATT '91) to test the tensile shear strength of lap joints at elevated temperature. WATT '91).

Although the standards BAS EN 205:2018 and BAS EN 302-1:2014 are primarily intended for testing the tensile shear strength of lap joints made of beech wood, we wanted to test the shear strength of lap joints made of fir / spruce wood (Abies alba ssp./ Picea abies spp.) with an average density of 0.420 [g/cm³]

The gluing was done with two types of Kleiberit adhesives, namely: Kleiberit 300.0 and Kleiberit 303.0. Both adhesives are PVAc dispersions.
One-component adhesive Kleiberit 300.0 is an industrial adhesive for waterproof joints of durability class D3, which is suitable for gluing windows, doors, stairs, for surface gluing of HPL panels, for veneering, for high-frequency gluing). The technical properties of this adhesive are: density at 20 °C about 1.10 [g / cm3], pH value 3 ±0.5, viscosity at 20 °C - Brookfield RVT Sp 6/20 rpm: 12000 ± 3000 mPa·s, the glue is white and the open time of this glue is (bei 20°C): 6-10 minutes.

Kleiberit 303.0 is an industrial adhesive for waterproof gluing with high requirements, durability class D3 and D4. The glue is used for making windows and doors, making stairs, gluing in shipbuilding, surface gluing on wooden boards (e.g. HPL, CPL, etc.), general construction gluing (e.g. pen-groove joint, toothed joint, etc., gluing hard and exotic wood and for high frequency bonding.

If Kleiberit 303.0 is used as a one-component adhesive then it is a waterproof adhesive of durability class D3. The density of this adhesive is 1.10 [g / cm3], the pH value is approximately 3, the viscosity of the adhesive is at 20 °C: 12,000 ± 2,000 mPa·s (Brookfield RVT spindle 6/20 rpm), the glue is white and the open time is 6-10 min. However, if 5% hardener is added to this adhesive, the durability class of the adhesive changes and becomes D4 and the adhesive is waterproof, with similar technical properties as the adhesive of durability class D3, but in this case the adhesive joint can withstand (be exposed to) and high temperatures 80 °C).

Tests were performed in accordance with the standard BAS EN 205:2018. The appearance and dimensions of the test pieces are shown in Figure 1.

Key

- h = 150 ±5 mm total length of test pieces
- b = 20,0 ±0,1 mm width of test pieces (width of tested surface)
- l2 = 10,0 ± 0,1 mm length of overlap (length of tested surface)
- s = 5,0 ± 0,1 mm thickness of the panels
- α = 30° to 90° angle between growth ring and surface s to be bonded
- a = 1,0 ± 0,1 mm thickness of the thick glue line

Figure 1. Lap joint test pieces a) with thin glue line and b) with thick glue line.
After pressing the bonded assemblies, and before cutting the test piece and testing, the assemblies are conditioned in a standard atmosphere (temperature 20 ± 2°C relative humidity 65 ± 5% - standard atmosphere 20/65) for a minimum of 7 days.

After cutting the test pieces from the conditioned glued assemblies, a number of test pieces (minimum 10 test pieces) are subjected to appropriate conditioning treatments - conditioning sequences in accordance with BAS EN 204:2018 ensuring that the test pieces are in horizontal plane and do not touch or support each other, so that they are not affected by stress.

Prior to the tensile shear strength test, a minimum of 10 test pieces for each test were subjected to a specific conditioning treatment - conditioning sequence:

- first group - test pieces are only conditioned in the conditions of standard atmosphere (20/65) for 7 days - T1 conditioning sequence;
- second group - test pieces were conditioned for 7 days in standard atmosphere (20/65), then soaked for 4 days in water at 20 ± 5°C and then conditioned in standard atmosphere [20/65] for 7 days - T4 conditioning sequence;
- third group: test pieces are exposed to the following conditions: 7 days in a standard atmosphere, 6 hours in boiling water and 2 hours in water at a temperature of 20 ± 5°C; - T5 conditioning sequence;
- fourth group: after conditioning in a standard atmosphere [20/65] for 7 days, the test samples were exposed to an elevated temperature of 80 ± 2°C for 60 ± 2 minutes - W conditioning sequence.

Prior to the shear tensile test, at least 10 pieces for each test were subjected to climatic treatment according to the specific treatment - conditioning sequence.

The tensile shear strength test of the lap joints was performed on a SHIMADZU test machine, type SIL-50NAG.

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\sigma = \frac{F_{\text{max}}}{A} = \frac{F_{\text{max}}}{l_2 \cdot b}
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**Figure 2.** Test machine SHIMADZU, type SIL-50NAG and fracture force display on test piece 7.
where
\( F_{\text{max}} \) = the applied maximum force in Newton (N)
\( A \) = the bonded test surface in square millimetres (mm\(^2\))
\( l_2 \) = the length of the bonded test surface in millimetres (mm)
\( b \) = the width of the bonded test surface in millimetres (mm).

3. Results and discussion

Lap joints that were glued with adhesives that according to EN 204 are in stress group D3 - Kleiberit 300.0 - D3 adhesive and Kleiberit 303.0 - D3 adhesive were subjected to conditioning treatment before the tensile shear strength test (conditioning sequence) T1, T4 and W.

Lap joints made using Kleiberit 303.0 - D4 adhesive before the tensile shear strength test were subjected to conditioning treatments (conditioning sequences) T1, T5 and W.

The results of the fracture force test are shown in Table 1.

Table 1. Results of measurement of fracture force and tensile shear strength values of lap joints.

| No. | Type of glue | Stress group | Conditioning sequence | Fracture force [N] | Tensile shear strength [N/mm\(^2\)] |
|-----|--------------|--------------|-----------------------|-------------------|------------------------------------|
|     |              |              |                       | min               | max                  | average                           |
| 1.  | Kleiberit    |              | T1                    | 1,732.22          | 1,967.10             | 1,848.923                         | 9.24461                           |
| 2.  | 300.0 – PVAc | D3           | T3                    | 1,720.04          | 1,891.92             | 1,791.493                         | 8.95746                           |
| 3.  | dispersion   |              | W                     | 1,295.11          | 1,459.18             | 1,382.370                         | 6.91185                           |
| 4.  | Kleiberit    |              | T1                    | 1,916.13          | 2,047.55             | 1,981.840                         | 9.90920                           |
| 5.  | 303.0 – PVAc | D3           | T3                    | 1,867.10          | 2,021.71             | 1,931.937                         | 9.65968                           |
| 6.  | dispersion   |              | W                     | 1,559.73          | 1,727.64             | 1,628.110                         | 8.14055                           |
| 7.  | Kleiberit    |              | T1                    | 2,164.80          | 2,216.71             | 2,190.755                         | 10.95377                          |
| 8.  | 303.0 – PVAc | D4           | W                     | 1,579.85          | 1,711.15             | 1,648.510                         | 8.24550                           |
| 9.  | dispersion   |              | T5                    | 792.01            | 955.72               | 865.750                           | 4.32875                           |

Figure 3. Graphical representation of the results of the fracture force test.
Analyzing the results of the experimental examination of the fracture force, it is noticed that the samples glued with Kleiberit 303.0 D4 adhesive had the highest force value, about 18.4% higher force value than in the other two cases (gluing with Kleiberit 300.0 D3 adhesive and Kleiberit 303.0 D3), in case the samples were exposed to conditioning only in accordance with T1 conditioning treatment.

The action of water (cold, and especially the combined action of hot and cold water) caused a decrease in the value of the fracture force.

In the case that the samples after conditioning in a standard climate were also exposed to the action of heat - temperature 80° C (conditioning sequence W) the reduction in the force value was from 17.84% (Kleiberit 303.0 D3) to 25.23% (for Kleiberit 300.0 D3 adhesive).

The combined action of cold and hot water has a significant reduction in the value of the fracture force, which can be seen in the example of test results of tests performed with Kleiberit 303.0 D4 adhesive.

4. Conclusion
Experimental testing has shown that the action of elevated temperature and humidity (cold and hot water) negatively affects the value of tensile shear strength.

Even in the case of gluing with adhesives that according to BAS EN 204:2018 belong to the group of adhesives that can be used for external conditions of use, it should be known that there will be a decrease in the value of strength.

This means that when designing and making the glued joint using PVAc dispersions that can be purchased on the Bosnian market, it should be taken into account that the strength value of the glued joint will decrease by about 20 ± 5% depending on environmental conditions and treatment duration.

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