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EFFECT OF RADIAL AND TANGENTIAL CUT ON THE STRENGTH WIDTH-JOINT BONDED SOLID WOOD

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Abstract

The anatomical structure of wood and cutting direction is an important parameter in determining the strength of the bonded samples. The main aim of this paper is to research the effect of radial and tangential grain cuts on bonding strength width-joint bonded samples. The combinations of the bonded surfaces were tangential-tangential, tangential-radial, and radial-radial. Beech-wood, steamed beech-wood, and thermally modified beech-wood samples were planed referring to a radial and tangential surface structure of wood. After the machining process samples were bonded with PVA-c class D3 glue and researched. The planing machine was Weinig Unimat 500 and the planing tool had four blades at a feed speed of 15 m·min-1. The cutting depth of the machining grip was 1.00 mm and the rake angle of the tool blade was bio γ =15°, at 6000°/min. The diameter of the cutting blade was Φ = 125 mm. The results obtained in this research show that the lowest bonding strength had the combination of two tangential surfaces thermally modified beech wood and the highest was at the combination of tangential beech wood.

Keywords: anatomical directions; width-joint; fracture; tensile strength.

1. Introduction

The strength of bonded wood joints depends not only on the type and quality of the adhesive and technological process but also on the condition of the wood material and especially on its surface [1]. Özçifçi and Yapici (2008) determined that there was a greater adhesion strength for beech and Scotch pine woods bonded with PVA-c adhesive along the tangential direction than the radial one [2]. Burdurlu et al. (2006) obtained similar results for Calabrian pine wood bonded with PVA-c and polyurethane (PUR) adhesives and recommended performing the bonding process on tangential surfaces with higher pressures [3]. The quality of the machined surfaces of wood depends on the anatomical structure. Feed speed has an important influence on the roughness of the machined surface [4], [5], [6]. Obućina et al., (2010) concluded that better results of the machining performance have been obtained with the decreasing rotation speed [7]. Also, hardwoods' surface structure (ring-porous oak wood and diffuse to semi-ring-porous beech) might affect the bonding quality. Adhesive penetration into the wood was reviewed in detail by Kamke and Lee (2007) [8], who identified several important factors. These are the fluid properties of the resin, anatomical characteristics and permeability of wood, and processing conditions. The main goal when gluing wood is to achieve a combination of high strength and long-lasting strength, which in principle should not be less than the strength of the wood. The strength of the bonded joint depends on the interaction between wood and adhesives (adhesion). The stability of the joints during indoor and mainly outdoor exposures is important. The most essential parameters influencing the overall bonding quality of wood products include the main factors such as wood's species, density, chemical and anatomical structure, physical and strength characteristics, machining parameters determining the surface roughness, grain orientation, moisture content, adhesive's chemical structure, weight solid and viscosity, surface tension, mechanism of hardening, and the bonding technology's pressure, time, and temperature. Aicher et al. (2018) found that the adhesion strength of bonded wood is not always most prominently connected with its density [9]. PVA-c adhesives are commonly used in the wood industry for general assembly applications, film overlay and high-pressure lamination, edge gluing, wood veneer, and edge bonding [10]. They are safe, non-toxic, non-combustible, easily cleanable, without pollution, cured at room temperature, colourless, transparent, and tough after curing and give a high adhesion strength to bonded wood elements. Obučina et al., (2014) found that the quantity of deposited adhesive and the deformation of wood under the influence of external pressure significantly affect the temperature at which bonding is performed, which is directly or indirectly reflected in the necessary amount of glue and internal stress in the joints [11]. In the case of glued laminated beams for building construction should be applied (170 ÷ 220) g/m^2 glue. Sernek et al. (1999) found better penetration of the water-based urea-formaldehyde (UF) adhesive into beech wood in the tangential direction at pressure application, while no significant difference between penetrations in the tangential and radial directions occurred when pressure was not applied [12]. Mihulja et al. (2006) show that the testing method, the form of the test piece, and how force is applied have the biggest effects on the shared strength [13]. This paper will determine and investigate the influence of different cutting directions on the bonding strength of width-joint elements of the solid wood panel (Figure 1).

Fig. 1. Samples of anatomical directions (A-cross, B-radial, and C-tangential).

2. Material and experiment

Wood samples for research were prepared from beech wood (*Fagus sylvatica* L.) in three different ways of hydrothermal treatment, beech wood, steamed beech wood, and thermally modified beech wood. Dimensions of the samples before planing were 200×60×20 mm (Figure 2). The average moisture content of samples was 9,5 %, they were conditioned before planing at 21 °C and relative humidity of 60 ± 5%. The difference in moisture content between elements was not greater than 3%. It was prepared in a total of 180 beech wood samples which were divided into groups of 10 samples for each kind of treatment (Figure 2). The samples were bonded, after the machining process, on different cutting sides with a fluent one-component PVA-c Kleibit 314 bond without additives of solvent and admixture of formaldehyde (Figure 3). The adhesive application was 150 g/m2 and the press pressure was 0.7 MPa. Testing of bending strength of samples, as a function of different cutting directions, is done by creating six different groups of samples for testing.

Fig. 2. Samples prepared for cutting to the required dimensions

The size of the samples was 80x40x20mm and the divided groups were:

- Radial-radial beech wood samples for dry testing, 10 samples (RRBW)
- Radial-radial steamed beech wood samples for dry testing, 10 samples (RRSBW)
- Radial-radial for dry testing, 10 samples (RRTBW)
- Radial-tangential beech wood samples for dry testing, 10 samples (RTBW)
- Radial-tangential steamed beech wood samples for dry testing, 10 samples (RTSBW)
- Radial-tangential thermally modified beech-wood samples for dry testing, 10 samples (RTTBW)
- Tangential-tangential beech wood samples for dry testing, 10 samples (TTBW)
- Tangential-tangential steamed beech wood samples for dry testing, 10 samples (TTSBW)
- Tangential-tangential thermally modified beech-wood samples for dry testing, 10 samples (TTTBW)
- Radial-radial beech wood samples for soaked testing, 10 samples (RRBWS)
- Radial-radial steamed beech wood samples for soaked testing, 10 samples (RRSBWS)
- Radial-radial for soaked testing, 10 samples (RRTBWS)
- Radial-tangential beech wood samples for soaked testing, 10 samples (RTBWS)
- Radial-tangential steamed beech wood samples for soaked testing, 10 samples (RTSBWS)
- Radial-tangential thermally modified beech-wood samples for soaked testing, 10 samples (RTTBWS)
- Tangential-tangential beech wood samples for soaked testing, 10 samples (TTBWS)
- Tangential-tangential steamed beech wood samples for soaked testing, 10 samples (TTSBWS)
- Tangential-tangential thermally modified beech-wood samples for soaked testing, 10 samples (TTTBWS)

Fig. 3. Samples of thermally modified beech-wood bonded on different cutting surfaces

Testing of samples was performed in the climatic conditions in accordance with BAS EN 204-2016 temperature (21 ± 2) ° C and relative humidity (60 ± 5) % [14]. During the testing process of bending, strength was recorded visual assessment of the destruction of samples. The first set of samples was tested as dry, after curing for seven days in constant atmospheric conditions (Figure 4). The second set of samples was tested after curing for seven days and then soaked in water for 96 hours before testing (Figure 5). Testing was performed on a Zwick universal testing machine (Figure 6), equipped with a 5 kN load cell. The samples were tested to failure at a cross-head speed of 10 mm/min [15].

Fig. 4. Sample for dry testing

Fig. 5. Sample for soaked testing

Fig. 6. Testing machine with adapter

Values obtained for bending strength were performed and statistical analysis of data using the student's t-test by testing the equality of means two basic a set of as double-sided distribution (t-Test: Two-Sample Assuming Equal Variances).

3. Results and discussion

In the process of testing bending strength, as the function of the different cutting directions of width-joint bonded samples experiences some deformation and destruction. Destruction occurred in different forms, such as the destruction of wood, the destruction of bonded joints, or a combination of previous forms of destruction. Table 1 shows the mean values of measured bending strength on samples of beech wood. The values of standard deviation are also given in the same table.

Cutting direction	Wood species	Number of samples	σ (MPa)							
			Dry testing				Soaked testing			
			σ mean	σ min	σ max	Std.Dev.	σ mean	σ min	σ max	Std.Dev.
R-R	BW	10	8,912	7,358	10,546	0,820	0,292	0,0785	6,377	0,158
T-T	BW	10	13,006	6,180	12,508	16,225	0,099	0,0196	0,216	0,080
R-T	BW	10	7,922	5,346	9,859	1,515	0,138	0,0589	0,343	0,092
R-R	SBW	10	7,559	9,467	3,483	1,918	0,105	0,0185	0,144	0,073
T-T	SBW	10	8,851	10,693	6,867	1,590	0,248	0,0196	0,500	0,205
R-T	SBW	10	7,436	9,862	4,813	1,589	0,241	0,0392	0,549	0,159
R-R	TBW	10	0,771	1,052	0,428	0,225	0,060	0,0125	0,198	0,063
T-T	TBW	10	0,830	1,177	0,478	0,256	0,230	0,0294	0,461	0,151
R-T	TBW	10	0,602	0,915	0,375	0,214	0,033	0,0162	0,047	0,012

Table 1. Mean values of measured bending strength on samples of beech wood (R-R, radial-radial; T-T, tangential-tangential; R-T, radial-tangential combination. BW-beech wood sample, SBW-steamed beech wood, TBW-thermally beech wood samples)

Figure 7 shows a diagram with summary results of measured bending strengths of BW-beech wood samples, SBW-steamed beech wood samples and TBW-thermally beech wood samples, treated in two different ways and tested in dry and soaked conditions.

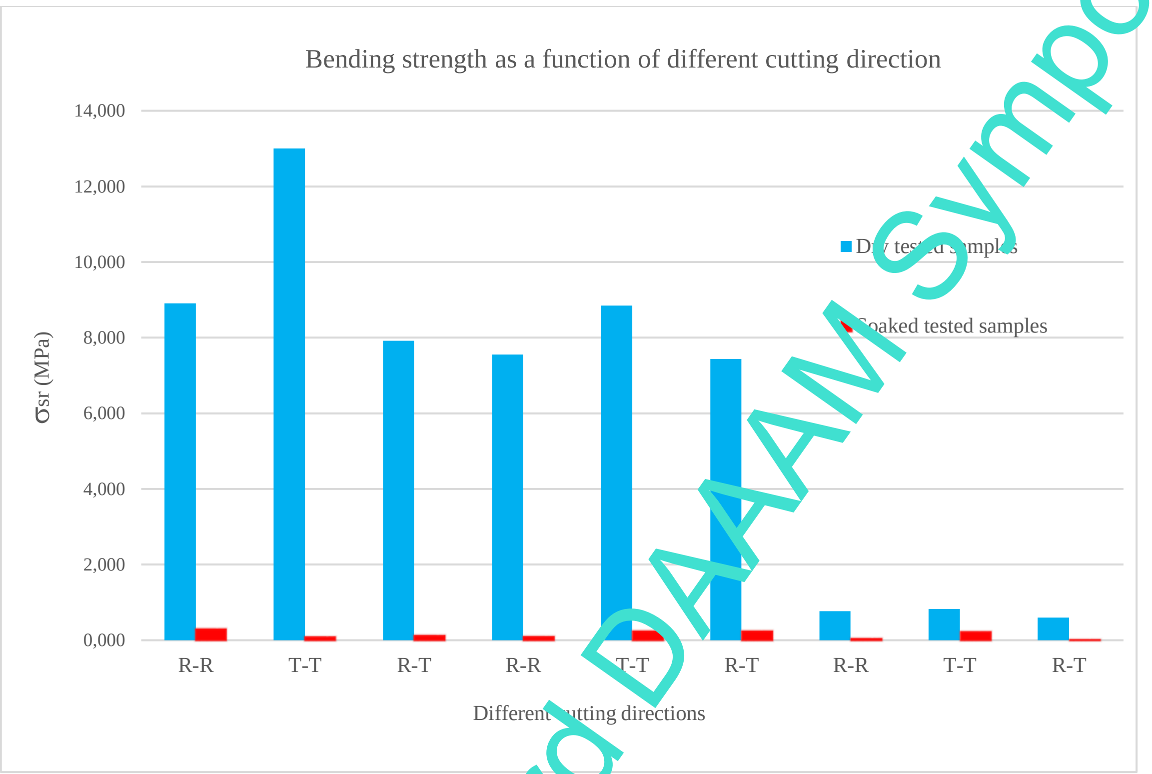

Fig. 7. Summary results of measured bending strengths of beech wood samples (R-R, radial-radial; T-T, tangential-tangential; R-T, radial-tangential combination)

Based on the presented results and diagrams (Figure 7) it is shown that significant differences between the bending strengths of the same anatomical directions, but different tests, are noticeable. The smallest difference is in thermally-treated beech wood. This phenomenon can be explained through the analysis of thermally-treated wood as a material and its characteristics. Considering that the thermally treated wood samples had a significantly lower moisture content, the wetting of the bonding surface resulted in better penetration of the adhesive into the pores of the wood and quality anchoring.

For a better understanding, a student's T-test was performed. Higher values of the t-number indicate that there is a large difference between the two sets of samples. T-test for two groups, the first group was beech, tangential direction, and steamed beech tangential direction (dry test). The second group was beech tangential direction and steamed beech tangential direction (wet test). The T value for strength in the first group was 0,175, and in the second group was 0,469. Other tested groups were beech radial direction with steamed beech radial direction (dry test) with a T value of 0,463 and beech radial direction and steamed beech radial direction (wet test) with T results of 0,645. There is a difference in strength for different types of tests.

These results show that during dry testing there are no big differences in strength between steamed beech and common beech with the same anatomical directions, while in wet testing there are significantly greater differences in strength. During the experiment and based on the results of the dry test, we can notice that the fractures in the tangential direction of steamed beech are mostly due to the adhesive. At the common beech with tangential direction, breaks are mostly over the wood. At the common beech and steamed beech with radial direction, most of the breaks are over the wood. On the soaked tests, all breaks were due to adhesive.

4. Conclusion

The main scope of this paper was to research the effect of radial and tangential grain cuts on bonding strength width-joint bonded samples. Based on this study, it can be concluded that bending strength in relation to the different cuts during bonding is the highest in common beech wood samples bonded in tangential directions. The lowest values of bending strength had samples of thermally-treated beech wood bonded in radial-tangential combination. Also, it can be concluded that there are significant differences between the bending strengths of the same anatomical directions. The smallest difference is in thermally-treated beech wood. Based on the presented results, further research will be continued involving new parameters of machining, and a new type of adhesive with an increased using the number of samples.

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