Researches on influence of wood sanding direction on wood gluing

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Abstract The wood surface quality is most determined by the way in which it has been processed before and by the tools used for this purpose. Machining has its effect primarily on the structural shape of the surface formed after the tool–wood contact and also on the roughness of the surface obtained after a specific process. In most cases, wood surfaces of elements which are materials or semi-finished products used for further processes, including gluing or painting, are sanded with sandpaper of various grit sizes on belt sanders. This causes the structure formed on the wood surface to be unidirectional. No information is available in the literature on the influence of the direction of the post-processing structure of the glued surfaces on the gluing process. Therefore, this was the subject of this research study. Two kinds of wood glues were used, and three gluing pressures were applied. Contrary to what was expected, the effect of the mutual position of post sanding surface structures during the gluing operation on the amount of glue in the connection turned out to be of small significance. In an extreme case, the difference of a necessary minimum amount of glue was 15.1% for the same type of connection and a different position of the glued surfaces against each other. However, the kind of the glue being used and the gluing pressure have been found to have a significant effect on its amount necessary to produce a good connection.

Keywords Wood gluing · Wood structure · Wood roughness · Plywood · Plywood gluing · Glue dosing

Introduction

Machined wood can have various surface structures (Glebov 2009; Navi and Sandberg 2012). In most cases, they are unidirectional (Lisowski 1998). In the unidirectional structure, one can distinguish a parallel or perpendicular structure which can be obtained after carving (Walker 2006), milling with side milling cutters (Kvietkova et al. 2015) or sanding on belt sanders (Varasquim et al. 2012), as well as a concentric structure being a product of turning (Benamar 2013). However, after milling or face grinding, the surface structure is multidirectional (Wei et al. 2018). Contrary to metal surfaces machined by the electrical discharge machining method or the electrical chemical machining method, it is extremely rare for wood surface to have a non-directional structure after machining. The wood surface roughness value is mostly determined by the type of machining applied to the wood (Csanady and Magoss 2013; Dundar et al. 2008), the cutting tool type (Aslan et al. 2008; Bembenek et al. 2021), its geometry (Gurau et al. 2007; Moura and Hernandez 2006) and machining specification (Magoss 2015; Pinkowski et al. 2013; Skaljic et al. 2009; Varasquim et al. 2012). In the case of wood, it is also important that wood, being an anisotropic material, in some cases of processing has an anatomical roughness that should be removed in the subsequent stages of processing. The literary sources also contain information that the seasoning of wood has an effect on its surface roughness indicators (Ostman 1983). Considering the post-machining surface quality, the species of the machined wood is important (Usta et al. 2007; Zhong et al. 2013) as is,
considering the anisotropic properties of wood, the direction of machining with regard to the grain structure (Kiliç 2015). According to Smith (2016), the wood surface roughness is also determined by various kinds of protective coatings, including, acc. to Ayrlmisa et al. (2016), fire-proof agents applied onto the surface. The surface roughness values after the machining of wood are determined by the direction in which the measurement was done, which results from the tests performed by Kılıç et al. (2018) or Waksmundzki and Zych (2015). The surface roughness has an effect on the strength of the glued bond, which has been proved by Söğütlu (2017) and Hiziroglu et al. (2013). However, there are no literary data available on whether the mutual position of surface structures after sanding has an effect on the wood gluing process. Therefore, this was the subject of this research study.

Materials and methods

To test the effect of the surface structure on the gluing process, 15 × 15 mm samples made of waterproof birch plywood with a unidirectional surface structure after sanding were used. Figure 1a shows a photo of the surface structure, while Fig. 1b shows a 3D surface projection made with a Keyence VH-ZST RZ microscope at 300× magnification.

The TOPO L50 modular system for the measurement and analysis of surface topography was used to measure the 2D profile roughness in directions which are parallel and perpendicular to the surface structure direction based on the R profile type and the length of 5 elementary sections. The results of measurement are provided in Figs. 2 and 3 and in Table 1. Then, 120 samples in the shape of a square with a 15 mm side and a thickness of 3 mm were prepared from a plywood sheet. They were cut out by means of a plotter with a laser head so as to ensure that the surface structure is parallel to one of the sides. Before starting the tests, the samples were thoroughly cleaned of dust. Two kinds of wood glues Soudal and Pattex, the parameters of which are presented in Table 2, were used for the tests. Each experiment required two pieces of pre-cut plywood which had been weighed before the experiment. Prior to the tests an initial estimate of the minimum amount of glue which would be necessary to make a secure joint of the two pieces was determined. A suitable amount of glue was experimentally arrived at which enabled the glue to be distributed over the entire surface of the samples being glued under a pressure of 0.22 MPa. It turned out to weigh approx. 0.06 g. The proper test consisted in applying a specific amount of the glue on the first of the samples (Fig. 4a) by means of a syringe with a needle (the average amount of glue which was applied on the samples during the tests was 274.8 g/m²) and in it being uniformly distributed over the surface by means of a plastic spatula. Then the second sample was applied to the surface on which glue had already been applied and both plywoods with the glue were weighed (Fig. 4b). While the surfaces of both samples were being joined for gluing, the mutual position of the post-machining structure on both surfaces being connected was focused on and recorded. The next step was to place the sample in the Zwick strength testing machine, type 1120.20, and to submit the samples to a compressive strength equal to 50, 75 or 100 N, which, in case of a gluing surface equal to 225 mm², corresponded to a compressive stress, respectively, of 0.22, 0.33 and 0.44 MPa. After the end of the test, the excessive amount of glue which had been squeezed out of the tube on its side surfaces (Fig. 4c) was wiped away and the sample was weighed again. In this way, the amount of glue necessary to make a secure joint was determined. The ambient temperature during the performance of the experiments was about 14 °C which corresponds to the temperature suitable for joining as recommended by the manufacturer of each glue (Table 2). Each of the measurements for each glue was repeated five times (Table 3), which gives a total of 60 measurements. The results were averaged for each of the five measurements, with two extreme values of measurements being rejected for the average calculation purposes. Then the weight of the glue necessary to correctly make the glued connection over an area of one square meter was recalculated.

![Fig. 1 Surface structure of a sample prepared for tests in magnification: a surface photo, b 3D surface mapping](image)
Fig. 2 Roughness graph during the test parallel to the machining structure direction

Fig. 3 Roughness graph during the test perpendicular to the machining structure direction

Table 1 Results of sample surface roughness measurements done in parallel and perpendicular to the surface structure direction

| Parameter                        | Measurement parallel to the structure (µm) | Measurement perpendicular to the structure (µm) |
|----------------------------------|-------------------------------------------|-----------------------------------------------|
| $R_z$-greatest height of the profile | 22.896                                    | 39.042                                        |
| $R_t$-total height of the profile | 41.655                                    | 49.819                                        |
| $R_a$-arithmetic mean of the profile ordinates | 3.889                                    | 6.092                                         |
| $S_{av}$-average width of grooves of the profile elements | 402.206                                  | 145.818                                       |
| $R_p$-greatest elevation of the profile | 12.070                                   | 12.290                                        |
| $R_v$-greatest depression of the profile | 10.826                                   | 26.751                                        |
Results and discussion

During the tests, the results presented in Table 4 were obtained.

Based on the results obtained (Table 4) for each glue, graphs of relation between the average glue amount and the value of tension caused during the gluing operation as well as the mutual position of the structure after the processing of the glued elements were produced (Figs. 5, 6, 7, and 8). The tests have proved that the type of glue used to make the connection had a significant effect on the test results obtained. As the graphs show, regardless of the type of glue used for the tests, the pressure force increase during the gluing resulted in the decrease of the glue amount necessary to make a correct connection. Also, a clear difference has been found in the behavior of both glues when under pressure. In the case of glue A, the differences in the amount of glue necessary to make a correct connection turned out to be more noticeable.

In an extreme case, the doubling of the pressure force for glue A in a perpendicular connection resulted in a 26.3% decrease of the amount of glue in the connection. It also turned out that the actual amount of glue necessary to make some connections in case of glue A is slightly higher than the one declared by its producer. The differences in the amount of a specific glue used to make the same connection turned out to be significant. To obtain a perpendicular connection and a compressive stress of 0.22 MPa, 20.6% more of glue A should be used than glue B.

The effect of the mutual position of surface structures during the gluing operation on the amount of glue in the connection turned out to be of small significance. In case of glue A, the difference in the amount of glue for a perpendicular connection and a parallel connection made under the same pressure varied within a range of 1.9 to 15.1% whereas for glue B it was significantly lower and ranged from 1.6 to 8.0%. This is probably due to very small deformations of the surface structure peaks during the gluing operation and the glue being held between the grooves formed as a result of the machining.

**Table 2** Properties of glues used for the tests

| Parameter                  | Glue A          | Glue B          |
|----------------------------|-----------------|-----------------|
| Base                       | PVA dispersion  | PVA dispersion  |
| Consistency                | Viscous fluid   | Liquid          |
| Curing time                | Physical drying | Physical drying |
| Viscosity (mPa*s)          | 8000–15,000     | 9000–15,000     |
| Density (g/cm³)            | 1.1             |                 |
| Dry volume content (%)     | 46 ± 1          | 50 ± 2          |
| Ph                         | 2.5–3.5         |                 |
| Temperature of application (°C) | 5–30           | > 7             |
| Max. open time at 20 °C (min.) | 8               | 8               |
| Consumption (g/m²)         | 160–180         | 150–200         |
| Minimum gluing pressure (MPa) | 0.1             | 0.2             |

**Table 3** Experiment testing plan for each glue

|                              | Pressure 0.22 MPa | Pressure 0.33 MPa | Pressure 0.44 MPa |
|------------------------------|-------------------|-------------------|-------------------|
| Perpendicular arrangement of the structure | 5                 | 5                 | 5                 |
| Parallel arrangement of the structure          | 5                 | 5                 | 5                 |

![Fig. 4](image-url) Samples photographed: a method of applying glue on glued surfaces b before the axial compression test, c after the axial compression test
Table 4 Results of tests of the required glue amount depending on the mutual position of the glued surfaces

| No | Force, (N), Tension (MPa) | Structure of fibers against one another | Amount of glue A after test (g) ± 0.0005 | Amount of glue A, (g/m²) | Amount of glue B after test (g) ± 0.0005 | Amount of glue B, (g/m²) |
|----|--------------------------|----------------------------------------|------------------------------------------|------------------------|------------------------------------------|------------------------|
| 1  |                         | Parallel                               | 0.047                                    | 229.6                  | 0.042                                    | 192.6                  |
| 2  | 50                       |                                        | 0.049                                    |                        | 0.043                                    |                        |
| 3  | /                        |                                        | 0.053                                    |                        | 0.053                                    |                        |
| 4  | 0.22                     |                                        | 0.053                                    |                        | 0.044                                    |                        |
| 5  |                          |                                        | 0.053                                    |                        | 0.045                                    |                        |
| 6  | Perpendicular            |                                        | 0.046                                    | 225.2                  | 0.037                                    | 186.7                  |
| 7  | 50                       |                                        | 0.049                                    |                        | 0.041                                    |                        |
| 8  | /                        |                                        | 0.051                                    |                        | 0.042                                    |                        |
| 9  | 0.22                     |                                        | 0.052                                    |                        | 0.043                                    |                        |
| 10 |                          |                                        | 0.053                                    |                        | 0.044                                    |                        |
| 11 | Parallel                 |                                        | 0.041                                    | 203.0                  | 0.037                                    | 186.7                  |
| 12 | 75                       |                                        | 0.045                                    |                        | 0.042                                    |                        |
| 13 | /                        |                                        | 0.046                                    |                        | 0.042                                    |                        |
| 14 | 0.33                     |                                        | 0.046                                    |                        | 0.042                                    |                        |
| 15 |                          |                                        | 0.047                                    |                        | 0.043                                    |                        |
| 16 | Perpendicular            |                                        | 0.038                                    | 176.3                  | 0.036                                    | 183.7                  |
| 17 | 75                       |                                        | 0.039                                    |                        | 0.04                                    |                        |
| 18 | /                        |                                        | 0.040                                    |                        | 0.042                                    |                        |
| 19 | 0.33                     |                                        | 0.040                                    |                        | 0.042                                    |                        |
| 20 |                          |                                        | 0.040                                    |                        | 0.044                                    |                        |
| 21 | Parallel                 |                                        | 0.038                                    | 177.8                  | 0.037                                    | 167.4                  |
| 22 | 100                      |                                        | 0.039                                    |                        | 0.037                                    |                        |
| 23 | /                        |                                        | 0.040                                    |                        | 0.038                                    |                        |
| 24 | 0.44                     |                                        | 0.041                                    |                        | 0.038                                    |                        |
| 25 |                          |                                        | 0.047                                    |                        | 0.039                                    |                        |
| 26 | Perpendicular            |                                        | 0.036                                    | 165.9                  | 0.039                                    | 180.7                  |
| 27 | 100                      |                                        | 0.036                                    |                        | 0.039                                    |                        |
| 28 | /                        |                                        | 0.038                                    |                        | 0.041                                    |                        |
| 29 | 0.44                     |                                        | 0.038                                    |                        | 0.042                                    |                        |
| 30 |                          |                                        | 0.039                                    |                        | 0.042                                    |                        |

**Fig. 5** Graph of the effect of the compressive stress on the amount of glue necessary to make a connection, glue A, parallel structure

**Fig. 6** Graph of the effect of the compressive stress on the amount of glue necessary to make a connection, glue A, perpendicular structure
Conclusions

The tests are innovative and should be considered to be pilot tests. Regardless of the type of glue used for tests, the increase of the pressure force during the gluing resulted in a decrease of the amount of glue necessary to make a correct connection. The experiments have also proved that the type of glue used to make the connection had a significant effect on its amount necessary to make a correct connection. Contrary to what was expected, the effect of the mutual position of surface structures during the gluing operation on the amount of glue in the connection turned out to be of small significance. In an extreme case, the difference of a necessary minimum amount of glue was 15.1% for the same type of connection and a different position of the glued surfaces against each other. The research should be continued with its focus being put on the effect that the surface structure has on the strength properties of connections.

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Fig. 7 Graph of the effect of the compressive stress on the amount of glue necessary to make a connection, glue B, parallel structure

Fig. 8 Graph of the effect of the compressive stress on the amount of glue necessary to make a connection, glue B, perpendicular structure
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