Investigation of Welded Joints with Linear Turned Beech Elements

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Abstract – Welding of wood is a process where chemical and physical reactions take place, heat is formed during the friction, which melts and softens the structure of wood, and a firm joint is formed by cooling of the melt.

The paper discusses the present knowledge about wood welding and the results of wood welding research obtained in the Faculty of Forestry, University of Zagreb. The results were obtained on samples (solid beech wood) with tapered entrance holes 9 mm in diameter, the bottom of the hole 7 mm in diameter and dowel lengths of 20 mm and 30 mm, as well as samples with 8 mm hole diameters and dowel lengths of 20 mm and 30 mm. The tensile strength of welded joints was analysed. The analysis results show that there is a big difference in tensile strength between the samples with 20 and 30 mm long dowels and profile holes. 30 mm long dowels give better results than the 20 mm dowels.

wood welding / tensile strength / beech / longitudinal bonding of turned elements

1 INTRODUCTION

The wood welding technique is a newer way of connecting wooden parts without using glue, using high temperature which is generated by the friction of elements that are being connected. During the welding process, due to the influence of pressure and temperature, the lignin and hemicellulose in the layers that are in mutual contact, is melted.

Welding of metals, metal alloys and plastics with friction has been developed nearly 50 years ago, while the use of similar processes in wood was shown and patented only when Suthoff and others (1996) patented their research conducted in Germany. This patent (Suthoff – Kutzer 1997) demonstrated and showed that wood can be welded with friction heat resulting from rotation or linear movement. They suggested the possibility of joining wood with dowels. In the welding zone, the density of wood is significantly increased, because the cells are completely destroyed. Cell walls are destroyed due to thermal effects, pressure and chemical reactions during the cooling of wood.

The results of recent studies have shown that the welding of wooden dowels into the substrate with mechanical friction at a certain rotation frequency (without adhesive), gives connections with satisfactory strength. This technology is environmentally friendly, using natural materials only. Recycling or burning welded products does not lead to the release of

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toxic components, and the combustion of products which are connected this way is safe for human health (Stamm and others, 2005).

The results of previous studies have shown that by using the rotation and insertion of the dowel or plug in the hole, friction develops the temperature that causes welding. Pizzi and others (2008) showed in their studies that the welding of wooden dowels with a certain rotation frequency gives a connection of fairly high strength. The quality of the connection is affected by factors such as: species of wood, the difference in diameter between the dowel and the hole, welding duration, the frequency of the wooden dowels' rotation (very important for the bonding strength), the use of hot dowels, cross-incised dowel tops, the use of ethylene glycol, etc.

Pizzi and others (2004, 2006), Kanazawa and others (2005) and Ganne-Chedeville and others (2005.) have shown in their studies that the welding of wooden dowels with a high rotation frequency without glue provides high-strength connections. Best results were obtained in the frequency range of 1200 - 1600 rpm, especially between 1500 and 1600 rpm. The frequency was dependent on mechanical limitations of the drill that was used for welding.

Leban and others (2008) explored the dependence of dowel welding on rotation frequency and welding depth. The results showed that if the dowel is welded deep enough, in their case 46 mm, the bond strength is greater than the tensile strength of the dowels. When the depth of the welding was 22 mm, the tensile strength of the dowels was greater than the bond strength.

Besides the depth of welding and the diameter difference between the dowel and the hole, the shape of the hole into which the dowel is welded is also important. When welding dowels deeper (over 30 mm), it is necessary to drill stepwise to increase the strength of welded joint (Župčić and others, 2008), because it comes to detrition at the top of the dowel, as difference in diameter between the dowel and the hole is reduced too much and welding is not achieved.

The shape of the hole (cylindrical or tapered) at longitudinal bonding of turned elements using plugs or dowels (smooth and grooved) affects the magnitude of applied force (Župčić 2010). The average tensile force for samples joined by welding 20 mm long dowels in cylindrical holes is 5726 N, and for 30 mm dowels, also welded into cylindrical holes, is 6603 N. If welding is applied with grooved dowels cylindrical holes result in less tensile force compared to tapered holes, while using smooth dowels, the difference is statistically significant.

The aim of this study was to determine the effect of welding depth and of the shape of the hole on the strength of the linearly connected turned beech elements. Such connected components could be used for manufacturing furniture and furniture parts.

2 MATERIALS AND METHODS

2.1 Welding of samples

Research on welding dowels in holes was carried out at the Faculty of Forestry, University of Zagreb. The samples were made of beech wood with tapered holes, 9 mm and 7 mm in diameter at the entrance and at the bottom, respectively, with dowel lengths of 20 mm and 30 mm. Another set of samples with cylindrical holes of 8 mm diameter, and dowel lenghts of 20 mm and 30 mm were also prepared. The average diameter of the dowel was 10.2 mm, so the diameter difference between the dowel and the hole was 2.2 mm. The samples were connected longitudinaly by rotation welding. Welding of the dowel into the hole was carried out with a constant rotation frequency of 1520 rpm. Sketches of test samples are shown in *Figures 1 to 4.*

Table 1. List of notations

Sample code	Description
2_8	Dowel length 20 mm, hole diameter 8 mm
3_8	Dowel length 30 mm, hole diameter 8 mm
2_9/7	Dowel length 20 mm, tapered hole 9/7 mm
3_9/7	Dowel length 30 mm, tapered hole 9/7 mm

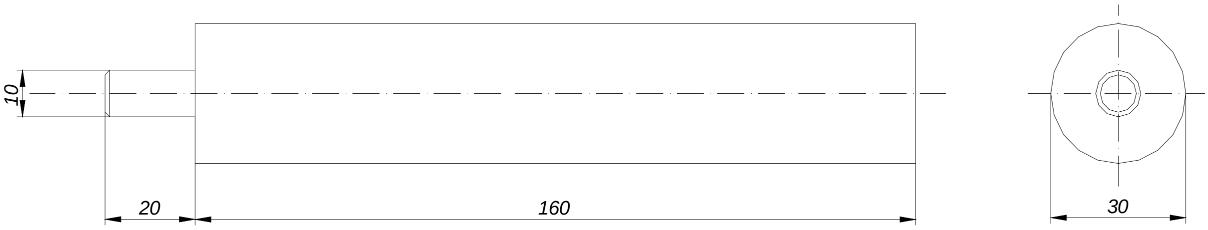

Figure 1. Turned test sample with 20 mm dowel length

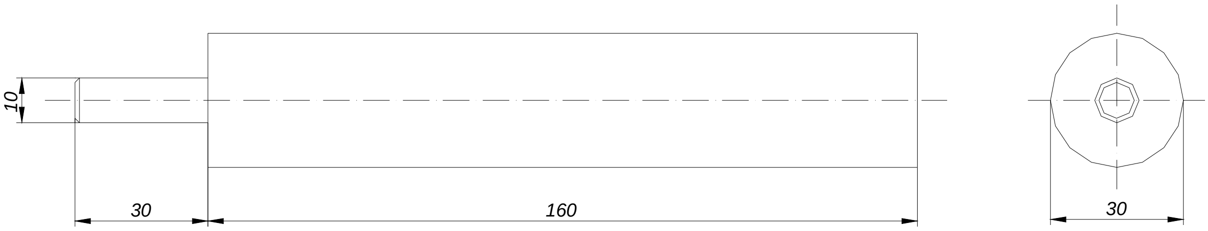

Figure 2. Turned test sample with 30 mm dowel length

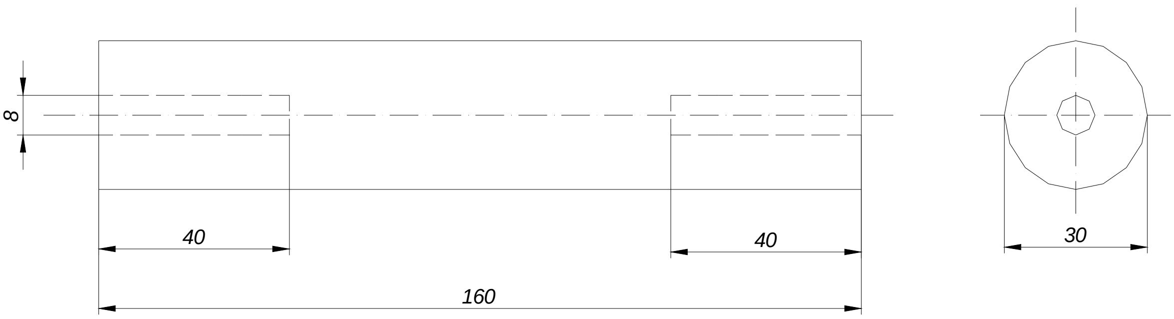

Figure 3. Turned test sample with 8 mm hole diameter

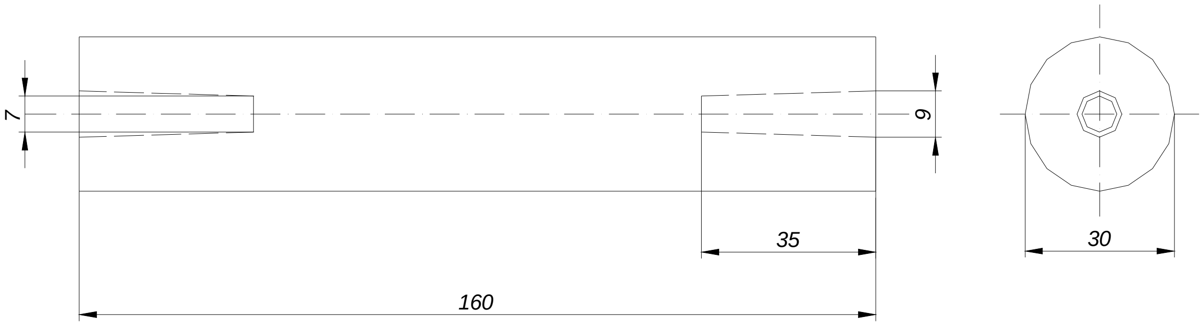

Figure 4. Turned test sample with 9/7 mm tapered hole diameter

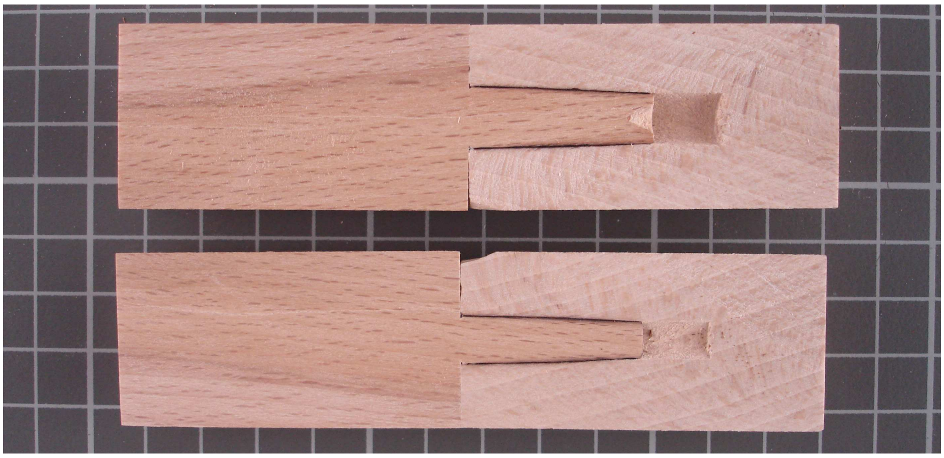

Figure 5. The longitudinal cross section of turned beech elements with 30 mm dowel length (Župčić, 2010.)

2.2 The determination of moisture content and density

Before welding, the samples had been kept in climatised conditions (temperature 23 °C, relative humidity 50%) for approximately three months, but the moisture content of the wood was not measured. After testing the tensile force for each sample, the moisture content was determined. All samples were dried to 0% water content (at 103 ± 2 °C) to constant mass. Moisture content was determined according to HRN ISO 3130:1999. (Croatian standard for determining the moisture content for physical and mechanical tests of wood). The average moisture content was 8.3% (min. 8.1% and max. 9.0%).

After determining of the moisture content, wood density was determined on the same samples according to HRN ISO 3131:1999. (Croatian standard for determining the density of wood for testing physical and mechanical tests of wood). The average density (ρ_0) was 0,69 g/cm³ (min. 0,59 g/cm³ and max. 0,78 g/cm³).

2.3 Test method

After welding, the samples were again conditioned (temperature 23 °C, relative humidity 50%) for eight days, and then tensile force was examined on a universal testing machine. The loading rate of the test was 5 mm/min. From the total of 60 welded samples, 57 were used in the test, as 3 samples cracked during welding.

3 RESULTS AND DISCUSSION

The research results are presented in *Table 2* and *Figure 6*. Linear turned elements can be successfully bonded with the dowel welded into a cylindrical or tapered hole. Research results show that by increasing the depth of welding, tensile force, respectively bond strength generally increases both for cylindrical and tapered holes. It would be logical to assume that with increasing depth of welding bond strength increases, but it is not always the case. With increasing depth of welding, bond strength is gradually increasing until the depth of 30 mm (Župčić 2010.). At this depth, however, it is visible even to a naked eye that the top of the dowel is not properly welded (the weld line is much thinner than in the middle of the hole, or is missing), which certainly affects the bond strength.

In this test series, drilling tapered holes did not lead to a statistically significant increase in tensile force, but the tapered hole reduces the sample's cracking during welding and is therefore certainly justified. When welding in cylindrical holes, in the first few millimeters rapid wearing of the top of the dowel and expansion of the hole occurs. As a result, there is extra load on the wall of the hole which leads to the cracking of the samples. In addition, to prevent the cracking of the sample during welding samples with tapered holes, the force required for pressing the dowels during welding is lower (Župčić 2010).

Table 2. Descriptive statistics of results of tensile force depending on the depth of welding and the shape of the hole

N=57

Sample code	Tensile force (N) Mean	Number of samples (n)	Tensile force (N) Std. Dev.	Tensile force (N) Minimum	Tensile force (N) Maximum
2_8	4527,692	13	982,905	2780,000	6220,000
3_8	5384, 000	15	1019,915	3450,000	6850,000
2_9/7	4760,714	14	628,704	3880,000	5800,000
3_9/7	5366,000	15	803,108	4220,000	6900,000
All groups	5030,877	57	927,680	2780,000	6900,000

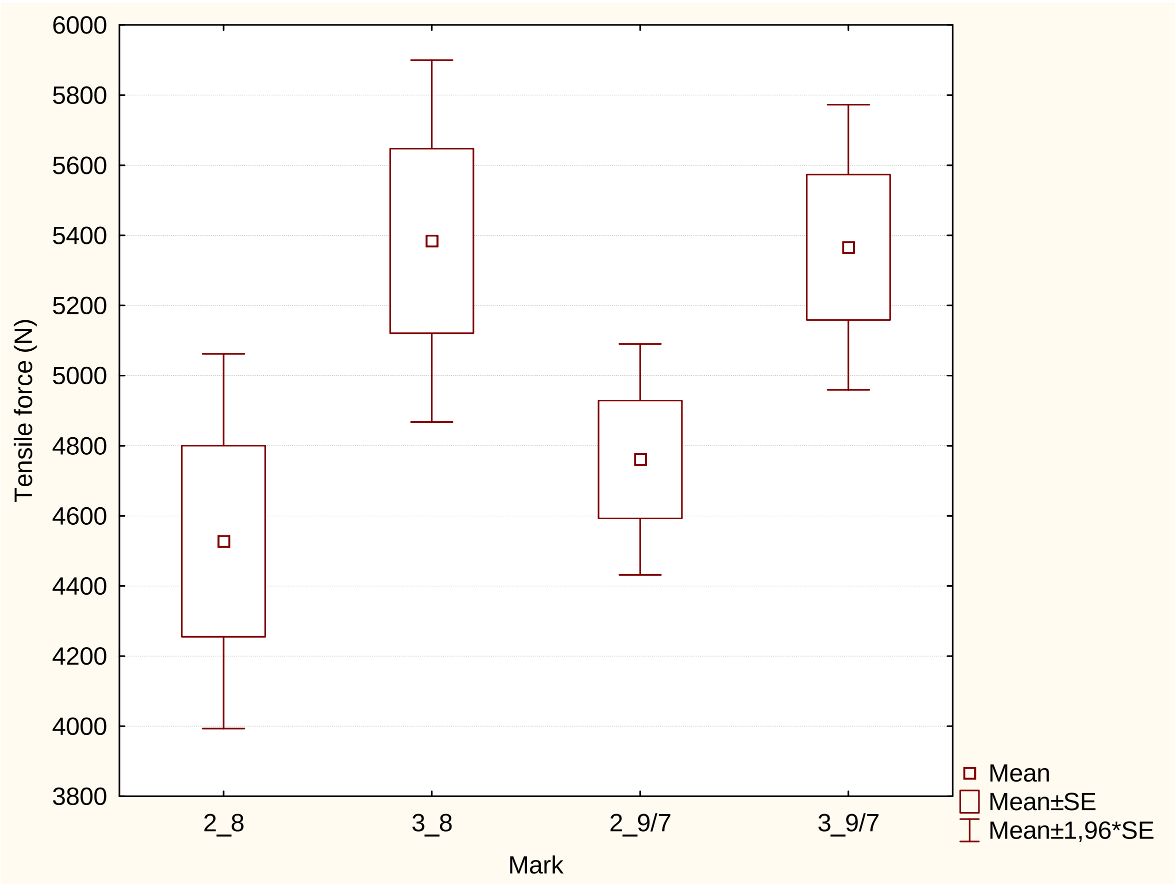

Figure 6. Dependence of tensile force on the depth of welding and the shape of the hole

4 CONCLUSIONS

- According to the results of the investigation, turned elements can be successfully connected longitudinally with dowels by the rotational welding technique. The use of rotational welding is possible for connecting turning elements longitudinally to create rods of unlimited length that can be used to manufacture furniture and furniture parts.
- Results obtained in this study show that the depth of welding of the dowel has an impact on the tensile force, respectively on bond strength.
- Between the samples with identical dowel lengths, but with either cylindrical or tapered holes (samples 2_8 and 2_9/7 and samples 3_8 and 3_9/7) there is no statistically significant difference in the values of tensile force, but the application of tapered holes is justified because it reduces weld defects (cracking of the dowels).

REFERENCES

GANNE-CHEDEVILLE, C. – PIZZI, A. – THOMAS, A. – LEBAN, J. M. – BOCQUET, J. F. – DESPRES, A. – MANSOURI, H. (2005): Parameter interactions in two-block welding and the wood nail concept in wood dowel welding. J Adhesion Sci. Technol., 19 (13–14): 1157–1174.

KANAZAWA, F. – PIZZI, A. – PROPERZI, M. – DELMOTTE, L. – PICHELIN, F. (2005): Parameters influencing wood-dowel welding by high-speed rotation. J. Adhesion Sci. Technol., 19 (12): 1025–1038.

LEBAN, J.-M. – MANSOURI, H. R. – OMRANI, P. – PIZZI, A. (2008): Dependence of dowel welding on rotation rate. Holz Roh Werkst, (66): 241–242.

MUCIĆ, M. (2007): Basics and application of friction welding. University of Tuzla, Faculty of Mechanical Engineering, 71-80.

PIZZI, A. – DESPRES, A. – MANSOURI, H. R. – LEBAN, J. M. – RIGOLET, S. (2006): Wood joints by through-dowel totation welding: microstrukture, ^{13}C-NHR and water resistante. J. Adhesion Sci. Technol., 20 (5): 427–436.

PIZZI. A. – LEBAN, J.-M. – KANAZAWA, F. – PROPERZI, M. – PICHELIN, F. (2004): Wood dowel bonding by high-speed rotation welding. J. Adhesion Sci. Technol., 18 (11): 1263–1278.

STAMM, B. – NATTERER, J. – NAVI, P. (2005): Joining of of wood layers by friction welding. J. Adhesion Sci. Technol., 19 (13–14): 1129–1139.

SUTHOFF, B. – SCHAAF, A. – HENTSCHEL, H. – FRANZ, U.(1996): German Patent DE 196 20 273.

SUTHOFF, B. – KUTZER, H. J. (1997): German Patent DE 197 46 782 A.

ŽUPČIĆ, I. – MIHULJA, G. – BOGNER, A. – GRBAC, I. – HROVAT, B. (2008): Welding of solid wood, Wood Industry, 59 (3): 113–119.

ŽUPČIĆ, I. (2010): Factors influencing the bonding of turning beech elements by virtue of a welding technique. Doctoral scientific thesis, University of Zagreb, Faculty of Forestry, 237 p.

HRN ISO 3130 : 1999. (Croatian standard for determining the moisture content for physical and mechanical properties of wood).

HRN ISO 3131 : 1999. (Croatian standard for determining the density of wood for testing physical and mechanical properties of wood).

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