OPTIMIZATION OF FRICTION PARAMETERS IN THE PROCESS OF WOOD WELDING WITHOUT ADDITIONAL ADHESIVES

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Abstract

Wood welding technologies have been developed as a new way of timber bonding without any adhesives. Welding of wood is a process where chemical and physical reactions take place. During the process of welding, the surface layers of wood (lignin) melt, due to high pressure and temperature, which is usually generated by mechanical friction of the elements being in contact. Friction can be induced by vibration or by rotation.

This paper presents the results of our own research of the influence of the injection direction of wood dowel into surface by observing the dowel embedded force. In the experimental investigation the differences between the direction of penetration changing the profile of the pre-drilled hole, the impact of consumption of the dowel cap and the impact of the bond strength in relation to the angle between axes of penetration and the line of tree rings are observed.

Keywords: welding of solid wood; rotational welding; wooden joints; joint strenght; wood welding

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1. Introduction

One of the most commonly used technologies in wood processing is wood joining. This technology is applied in order to increase the size and to adjust the shape of the workpiece (for example lamination), or in order to increase the dimensional stability and isotropy (veneered panel). Bonding is the most commonly used technology in the wood industry for joining elements. The application of the adhesive itself must carry out carefully at the process of applying the adhesive as well as during the drying process, which also requires time and space. Industrial adhesives are often based on products from the oil industry and as such they have a negative impact on the service life of wood products and negative impact on the environment.

Welding of wood provides an interesting alternative to bonding, because the removal of the adhesive can reduce production costs and environmental impact generated throughout the product life cycle.

Welding technology involves the joining of two or more similar or dissimilar materials, melting or pressing, with or without the addition of supplementary materials, in a manner to obtain a homogeneous joint, free from defects and with required mechanical and other properties. Technology of welding is widespread in plastic and automotive industries while welding of wood is relatively young technology and still at the stage of development. These processes of joining are fast and have a high resistance. Its great advantage is that the process takes place very quickly and that this process does not require the use of additional materials for connection (mechanical elements or synthetic adhesives).

Welding technology can be successfully brought together as solid wood and wood-based panels (plywood, OSB, MDF ...) and realized joints provide satisfactory results for constructive use. [1]

Studies have shown that the technology is easily applicable in a porous wood such as adaptive material and to realize joints in a very efficient manner. [2]

Previous research and development of welding technology of wood took place through consideration of mechanically induced friction caused by vibration (vibration welding) and through rotation (rotational welding).[3]

Welding method with help of vibration occurs in a way so that wooden elements are vibrating. Welding occurs as a result of creating a mechanically-induced friction between the surfaces in contact with the linear movement of the plane (axis) and welding under pressure. The process shown in Figure 1.(a) can be divided into two operations; welding and clamping.

Fig. 1. (a) Vibratory welding; (b) rotational welding

Where; PZ - welding pressure, VZ – welding time, Fr - friction force, a - amplitude of vibratory movement and p – displacement.

Rotational welding method of wood is characterized by injecting dowels to the wood substrate, in order to join the elements of wood. This method is somewhat simpler way to connect two or more elements or solid wood panels, unlike vibratory welding. It is realized in a way that holes are pierced in to the elements. The holes are of smaller diameter than those of dowels. Then the dowel is inserted by means of torque, while the elements stick tightly to be banded.

Both forms of welding wood result from the friction between the surfaces in contact, whereby the heat that develops "soften and melt" cell structure of wood (hemicelluloses and lignin), and the wood fibres are woven together. [4]

1.1. Advantages of wood welding technology

For wood welding technology all energy is focused on an area that should be attached, especially to the thermoplastic components. This binding method results as solid join in a wood, without use of glue or any other supplement. Welding technology of wood is characterized by short process within a few seconds or a short time in the clamping tools. The process is repeatable and a pure assembly is obtained (use only "dry" materials). Welds require less work of moulds, presses or clamps. Welded dowels also show good weather resistance due to the density of the thermoplastic bond with the wood surface. The joints made in this way are environmentally friendly because they are made up entirely from wood.

These joints are economically justified for two reasons:

1. Elimination of synthetic glue from furniture and joinery, actually removal of harmful PVAc with the ultimate goal of their complete removal,
2. Thus obtained joints are achieved very quickly having the same mechanical properties of the assembly with those obtained using the synthetic adhesive.

On the other hand, wood is not a homogeneous material, so the aim of achieving better permanent quality requires adjustments of various influential parameters during the welding process [5]. The influence of moisture has negative effects on welded joint, where the rise in humidity leads to decrease the joint solidity.

2. Materials and models

In order to select optimal models of welding, testing modes and type of woods, 13 samples are made and tested from Larch (*Larix*), Douglas-fir (*Pseudotsuga*) and exotics "Marblewood" (*Marmaroxylon racemosum*), using the dowel of beech (*Fagus sylvatica*). The final selection of the wood of Douglas fir is taken, due to its physical and mechanical similarities with wood fir/spruce, which is widespread in Bosnia and Herzegovina market. In this study, the special reception head is designed and manufactured for montage of samples on a universal testing machine.

Specimens have been made joining two elements of above-mentioned woods, having dimensions 200X35X21 mm, with four rotationally welded beech dowels. Cylindrical beech dowels are commercially procured, having following features; material beech class 1, diameter 10 mm, length 100 mm, grain direction parallel to the length.

To test the strength of the weld, three models of test samples are made:

- Model M1, having pre-drilled holes with a diameter of 8 mm and injecting dowels only from one side (Fig. 2. (a)),
- Model M2, having pre-drilled holes with a diameter of 8 mm on the first transmission element and 6.7 mm at the second coupling means, with one-sided embossing of the dowel (Fig. 2. (b)),
- Model M3, having pre-drilled holes with a diameter of 8 mm and with two-sided embossing of the dowel, two on each side of the sample (alternately) (Fig. 2. (c)).

Fig. 2. (a) Model M1, (b) model M2 and (c) model M3

Preparation of the hole of 8 mm diameter to impress the dowel of 10 mm diameter is considered optimal, with tightness of 2mm because. In the second element of the scaled models M2, the hole is made of 6.7 mm diameter.

From a total of 120 welded samples (480 dowels), 90 of them are included in this research, in addition the two samples, with the maximum and minimum values of embedded force to each of the models, are exempted from further consideration.

Welding tightness of dowel is one of the very important factors of welding and has a considerable influence on the strength of the joint. It is the difference in diameter between the dowel and the prepared holes. When tightness increase or decrease compared to the optimal, the embedded force and bond strength significantly reduce. [6]

Before testing, measurement of moisture content in wood was performed for each sample, using digital hygrometer. Results of measurement of moisture content for all samples have ranged from 9.0 to 13.7%. Since this is a small difference in moisture content, in further processing of the data of moisture it is not considered regarding to the bonding strength.

For model fixture in the receiving head according to EN 319:1996, it was necessary to develop special metal plates to replace the test blocks. Special backing head was designed and manufactured to place the test specimens in the receiving head Fig. 3.

Fig. 3. Backing head with the test sample

Measurements of force and displacement were carried out with the help of computers and all values were accurately checked (Fig. 4.). Testing was performed under displacement of 5 mm/min.

Fig. 4. Measurement of embedded force and displacement

3. Results of tests

3.1. Embedded force

As extreme values regarding to maximum or minimum values of the embedded force, certain test samples are excluded from the further analysis of the results.

The measurements showed that the maximum embedded force is generated in the juncture over the thickness within the model M2, applying the stepped profile of the bore for insertion of the dowel.

Model	EMBEDDED FORCE (kN)	RELATION VS M2
M1	3,8098	27,27 % < M2
M2	5,2385	-
M3	4,3024	17,88 % < M2

Table 1. Comparison of embedded force results for the M1, M2 and M3 models

Fig. 5. Diagram of embedded force analysis

3.2. The direction of the dowel penetration with respect to the orientation of wood fibers

Wood is orthotropic material. It means that in this case the strength in one direction is much higher than strength in other directions. Tensile strength is largest parallel to fibres, but in this direction the shear strength is less than shear strength perpendicular to the fibres. Tensile strength perpendicular to the fibre is significantly lower than that parallel to the fibres.

Differences in anatomy and physical structure of the wood certainly affect the welding process, so it can be assumed that the chemical, anatomical and physical properties of the same species of wood have an impact on the strength of welded joints [7]. Within the same width of the tree rings, there are variations in the proportion of early and late wood. The same ring width and a higher proportion of late wood are prerequisite for increasing the density of the wood and it can influence the strength of welded joints. According to the investigations [8], increasing the density of wood the embedded force is increased.

In this research, beech dowels are welded in the wood of Douglas fir perpendicularly to the wood fibers (radial-tangential texture) and at different penetration angles to the fiber lines.

The area with most part of the early wood theoretically achieves weaker weld than with the larger proportion of the late wood with higher density.

Table 2 shows mean values of embedded force for test models in relation to the penetration angle respecting the tree lines.

MODEL	Number of samples			Embedded force		
	0°	45°	90°	0°	45°	90°
M1	6	9	15	3,488	3,969	3,843
M2	8	10	12	4,626	5,326	5,574
M3	8	10	12	3,323	4,537	4,761
				17,52%	0,53%	

Table 2. Ratio of embedded force for test models in relation to the penetration angle respecting the tree lines

The results have showed that the strongest juncture in relation to the embedded force is achieved at the angle of 90° to the cross direction of tree lines.

- comparing the embedded force for penetration angle of 90°, it is 0,53% higher than for the angle of 45° and 17,52% higher than for angle of 0°, where the penetration is parallel to the tree lines.
- the strength of the breakup for the angle 90o is 0,12% higher than for the angle of 45 ° and 14,46% higher than for the angle 0o (Table 3).

MODEL	Number of samples			Strength of breakup (MPa)		
	0°	45°	90°	0°	45°	90°
M1	6	9	15	0,842	0,921	0,894
M2	8	10	12	1,205	1,369	1,412
M3	8	10	12	0,785	1,030	1,093
				14,46%	0,12%	

Table 3. Ratio of strength of breakup for test models in relation to the angle of penetration to the tree lines

For results of embedded force and strain, analysis of variance (ANOVA) is applied, to analyze their results regarding to the penetration angle respecting the tree fibers (Fig.6.).

Fig. 6. Diagram of (a) embedded force; (b) strain respecting the angle

The results of analysis for the embedded forces and the strain showed that there are statistically significant differences between 3 groups of samples which are analyzed respecting the dowel's angle penetration to the tree lines. In fact, most solid juncture can be at angle of 90° to tree lines, followed by an angle of 45°, while the minimum strength is obtained for the angle of 0° respecting the tree lines.

3.3. Wear of dowels

When welding, the dowels are inserted through the entire length of the thickness of the elements in contact. Reason of diameter measurement of the dowel at the exit of the test sample is due to the appearance of elastic deformation in a wood. With increasing the density of the material, the wear of dowels increases too. The results show that the wear of the dowels are greatest for exotics Marblewood and smallest for Douglas-fir (Table 4.).

WOOD	DENSITY (kg/m ³)	WEAR (%)
DOUGLAS-FIR	510	19,54
LARCH	575	20,98
MARBLEWOOD	1005	24,15

Table 4. Measurement results of dowel wear for samples of three different types of wood

4. Conclusion

Welding of dowel in wooden surface can be achieved under sufficient pressure on wooden dowels during the insertion stage. After welding it is required to hold it shortly at the cooling phase in order to obtain a better weld.

In rotational welding special role, on the strength of welded joints, have: size of the gap between the dowel and the hole in which it is welded, the coherence of the speed with the shift, welding time, injection pressure, moisture content, type of wood, direction of penetration compared to the orientation of tree lines and wood anatomy.

This study confirm the fact that there is a significant difference in results of embedded force respecting the different rotation directions of welding dowels as well as the change of the hole diameter.

The angle of penetration of the dowel by rotational welding in relation to the tree lines is also one of the influencing factors on the final strength. We show that the greatest strength of breakup for wood plates is obtained for perpendicular insertion of the dowel to the wood fibres. Strength of breakup and embedded force are high and varies slightly when the angle of the dowel insertions to the tree lines varies between 45 and 90 and decrease significantly when the insertion direction approaches to the tree lines.

Due to of wear of the dowel by passing through the elements in contact, its geometry is changed with the transition from the cylinder to the final shape of a truncated cone. The greatest wear of dowel is obtained for hardest wood and for model with narrowing the diameter, where the strength of breakup is largest.

Finally, using the techniques of wood welding and choosing special design of pierced holes, orientation of dowel insertion related to the tree lines and type of wood it is possible to have satisfying mechanical characteristics of joint parts compared to the conventional techniques of gluing.

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