Kastamonu Uni., Orman Fakültesi Dergisi, 2020, 20(3): 266-271 Research Article
Kastamonu Univ., Journal of Forestry Faculty
Doi:

# Water Resistance of Welded Birch Wood Produced by Linear Friction

Mustafa ZOR[1*], Mojgan VAZIRI[2], Dick SANDBERG[2]

[1]Zonguldak Bülent Ecevit University, Department of Design, Zonguldak, TURKEY
[2]Lulea University of Technology, Wood Science and Engineering, Skelleftea, Lulea, SWEDEN
[*]Corresponding Author: mstfzor@gmail.com

Received Date: 02.05.2020 Accepted Date: 20.11.2020

**Abstract**

*Aim of study:* In this study, it was aimed to determine the shear strength after water immersion and observe bond-line density of the welded birch wood.

*Material and methods*: 24 welded samples of dimensions 200x20x20 mm$^3$ (LxTxR) were prepared from sapwood of birch wood (*Betula pendula*). Shear strength of welded birch at 24h and 48h water soaking were investigated.X-Ray CT-scanning was used to monitor the density profile of welded bond-line.

*Main results:* The results showed that shear strength decreased slightly with increasing water immersion time. The decreasing of the average shear strength, caused by immersion for 24h and 48h were 60.25% and 78.9%, respectively, compared to control sample. With the welding process, a significant change in density was observed in the welding bond-line. As a result, the X-Ray CT scanner shows that it works effectively on wood material.

*Highlights:* The results of this research revealed the applicability of a new method alternative to traditional mechanical fasteners (nail, screw etc.) or gluing. The availability of welding combining method in the field of wood engineering should be explored widely and more studies are recommended for appropriate parameters.

**Keywords:** Birch Wood, X-Ray CT Scanner, Linear Welding, Water Resistance

# Doğrusal Sürtünme İle Üretilen Kaynaklanmış Huş Odunun Su Dayanımı

**Öz**

*Çalışmanın amacı:* Bu çalışmada, kaynaklanmış huş odunun su daldırma sonrası makaslama dayanımının belirlenmesi ve kaynak birleşim hattı yoğunluğunun gözlemlenmesi amaçlanmaktadır.

*Materyal ve yöntem:* Huş odunun diri odunlarından 200x20x20 mm$^3$(boyuna x radyal x teğet boyutlarında 24 örnek hazırlanmıştır. 24 saatlik ve 48 saatlik suya daldırma sonrası kaynaklanmış huş odunun makaslama dayanımları incelenmiştir. Odun kaynak birleşim hattının yoğunluk değişimi için X-Ray bilgisayarlı tomografi tarayıcısı kullanıldı.

*Temel sonuçlar:* Sonuçlara göre, suya daldırma süresi arttıkça makaslama dayanımı azda olsa azalma göstermiştir. Kontrol örneğine göre, makaslama dayanımındaki azalış, 24 saatte ortalama %60.25, 48 saatte ortalama %78,9 oranındadır. Kaynak işlemi ile kaynak hattında yoğunlukta önemli derecede değişiklik gözlenmiştir. Sonuç olarak, kullanılan X-Ray CT tarayıcısı, ahşap malzeme üzerinde etkili bir şekilde çalıştığını göstermektedir.

*Araştırma vurguları:* Bu araştırmanın sonuçları, geleneksel ahşap mekanik bağlantı elemanlarına (çivi, vida vb.)ya da yapıştırmaya alternatif yeni bir yöntemin uygulanabilirliği ortaya çıkmıştır. Ahşap mühendisliği alanında kaynak birleştirme yönteminin kullanılabilirliği geniş çapta irdelenmeli ve uygun parametreler için daha çok çalışmalar yapılması önerilmektedir.

**Anahtar Kelimeler:** Huş Odunu, X-Ray CT Tarayıcı, Doğrusal Kaynaklama, Su Dayanımı.

## Introduction

In all industrial applications where wood is used as a construction material, it is necessary to bond different wood components together using more or less environmentally friendly adhesives, and the adhesive used may affect the life cycle analysis (LCA). It is a challenge for scientists to produce more eco-friendly wood products, e.g. glue-less joints, using the friction welding technique, which is a new way to combine mechanically induced wood welding with two pieces of wood (Martins et al., 2013). Some studies on the behavior of welded wood in interior and exterior uses have been ongoing for the past two decades (Vaziri, 2011).

One of the disadvantages of welded wood is its low water resistance in the bond-line, which limits its applications to indoor use only. In order to increase the application of welded wood, it seems necessary to improve the water resistance to withstand the outdoor climate. Previously studies investigated by varying parameters such as welding time and pressure, amplitude of vibration and surface quality by tensile-shear strength test under water immersion and results have been showed that after 4 hours of immersion the strength strongly decreased (Mansouri et al., 2009; Omrani et al., 2009; Ganne-Chédeville et al., 2005). Some disadvantages can be improved with the use of non-synthetic waterproof chemicals. However, these additives seriously affect the environmental friendliness of wood at some points.

Some researchers have been made to increase the water resistance in the wooden welding combination and it is not seen that the permeability of the water is prevented (Omrani et al., 2009; Mansouri et al., 2009; Vaziri et al., 2010; Mansouri, et al., 2011; Pizzi et al., 2011; Mansouri et al., 2011; Pizzi et al., 2013; Amirou et al., 2017) and to carry out the review paper on the applicability of welded joint on wood material (Zor, 2019). Therefore, research to reduce water permeability is still ongoing.

Birch (*Betula pendula*) is often used in construction, transportation, interior surfaces of products.

However, high quality birch veneers are used on the surfaces visible on furniture, interior decoration panels, handicrafts and various special places (Heräjärvi, 2002). Birch wood has a permeable structure (Verkasalo & Heräjärvi, 2009), generally there is a compatibility between summer wood and spring wood. It has bright wood and has an average full dry density of 480-520 kg/m$^3$. The average air dry density of birch wood (at a level of 12-15% humidity) is 630 kg/m$^3$ (Wagenführ, 1996). Ruponen et al., (2015a) have conducted studies to reduce the water resistance of heat treated birch wood by linear friction welding. As a result, they revealed that the water resistance in the heat treated material is effective on the obtained mechanical resistances. In another study by Ruponen et al. (2015b), they conducted a study to determine the optimal weld time of the mechanical properties of birch wood combined with linear friction. As a result, they obtained 7.9 MPa tensile strength with optimum welding time (3.5 s).

In this study, the influence of water resistance of welded birch wood was studied. The objectives were (1) to determine the tension-shear strength after water immersion for welded birch wood, and (2) to observe bond-line density changes of the welded wood.

## Material and Methods

*Wood Materials*

48 straight-grained specimens of dimensions 200×20×20 mm (Longitudinal × Tangential × Radial) were prepared from sapwood of birch wood. The samples were conditioned for one week to reach 20 °C and relative humidity 65% prior to testing.

*Wood Welding Processing*

The specimens welded together two by two in a linear vibration-welding machine (LVW 2061 Mecasonic) as shown in Figure 1. and in the study, the welding parameters that Vaziri (2011) developed were preferred and are shown in Table 1. Experiments were carried out on samples from 24 samples totally.

Figure 1. Linear vibration-welding machine

Table 1. Welding machine settings for test samples

| Parameter | Unit | Value |
|---|---|---|
| Welding pressure (WP1 and WP2) | (MPa) | 1.3-1.8 |
| Welding time (WT1 and WT2) | (s) | 2.5-3 |
| Welding displacement (WD) | (mm) | 2 |
| Frequency | (Hz) | 150 |
| Holding pressure (H.P) | (MPa) | 2 |
| Holding time (H.T) | (s) | 10 |

*Shear Strength and Water Immersion*

Samples for shear strength test were cut according to EN 205. Two cuts were made in the middle of the samples perpendicular to the welding line and the distance between them was adjusted to be 10 mm. The test equipment detailed is showed in Figure 2 (Vaziri, 2011). The shear strength of the welded wood was obtained along the wood fiber direction by a tensile-shear test machine at 2 mm / min. After the experiment, the average and standard deviations of the bond strength and the average wood failure were calculated for each set of samples (Vaziri et al., 2020).

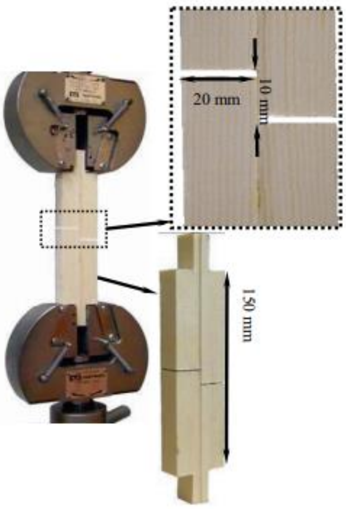


Figure 2. Shear strength of the welded birch wood

The water resistance of welded joint woods was made by using water immersion method. In addition, the immersion in water may not give a definitive conclusion in terms of fully examining the changes in welded joints during absorption and desorption in outdoor conditions (Vaziri, 2011). In this study, specimens were immersed horizontally in water bath with a temperature of 20°±1°C. Shear strength performance of the samples were determined either after 24 hours and 48 hours water immersion period (Figure 3).

Figure 3. Water immersion

*CT-scanning Studies and Image Processing*

To study welded wood was studies by X-Ray CT scanning in a medical CT scanner (SIEMENS Emotion Duo medical X-ray CT-scanner). With the assistance of image-processing software (Image J) from the National Institutes of Health (NIH), density was measured for three different sections that include welded zone, left side zone of material, and right side zone of material then eventually differences were identified.

The right and left side represent the edges of the material close to the surface, and called welding zone. At these parts, how the current density changes after heat and vibration (welding process) was examined. The near part of the welding zone is defined as densification zone.

## Results and Discussion

*Shear Result and Water Immersion*

The shear strength provided supportive understanding to bond-line characterization. Table 2 show the shear strength, and, a strong bonding was noted with average shear strength value of about 10 MPa before water soaking. After water immersion the average of shear strength decreased to 4.05 MPa and 2.14 MPa for 24h and 48h immersion, respectively.

Table 2. Mean value of average shear strength and wood failure for birch samples

| Specimen Type | Average Shear Strength (MPa) | Maximum Shear Strength (MPa) | Wood failure (%) |
|---|---|---|---|
| Control | 10.19(±0.07) | 14.34 | 20 |
| 24h | 4.05(±0.09) | 7.52 | 10 |
| 48h | 2.14(±0.11) | 5.71 | 10 |

Parenthesis is standard deviation.

Although the average shear strengths of the welded joints were acceptable, the percentage of wood failures was relatively.

Ganne-Chedéville (2008) investigated that an immersion experiment on linear welded samples of beech and rubber tree (*Hevea brasiliensis*). After three hours, the tensile-shear strength in the water immersion test was 62% for rubber wood and 98% for beech wood. Pizzi et al., (2006) and Mansouri et al., (2009) reported that if the welding conditions were changed, welded beech samples could withstand only 25 hours of cold water. It was stated that as a result of immersion in water, it can be preferred only for indoor use due to the weak resistance of the connection against water. Vaziri et al., (2010) investigated that the moisture sensitivity of scotch pine samples produced by linear friction welding was investigated. According to the results, it showed the highest water resistance value with 1.3 MPa welding pressure and 1.5 sec welding time with the use of heartwood.

*CT-scanning Studies*

Density of three different sections (welded zone, left side and right side) were compared. With the assistance of image-processing software (Image J) from the National Institutes of Health (NIH) X-ray absorption was measured as a profile which is shown in Figure 4.

The average wood density of the birch samples was about 510 kg/m$^3$ while the maximum wood density in the bond was much higher at about 620kg/m$^3$. After welding process, the wood component of the birch wood appears to strengthen the welded intermediate phase to ensure the weld line is always higher value than that of the surrounding wood.

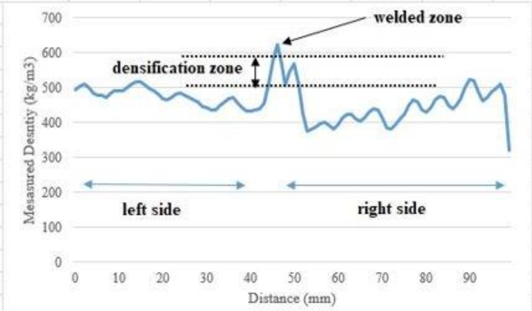

Figure 4. Measured density value of the welded birch wood

In the study carried out by Zhang et al., (2014), the welding pressure that affects the homogeneity of the weld line is more than 2 MPa, reveals that the connection mechanical performance is related to the weld density profile. As a result, they stated that narrower and more homogeneous density profile improved the adhesion performance.

The chemical formation that occurs in the welding process actually occurs in the brief pressure-holding phase immediately after the welding process. Despite the indication that some self-condensation and / or cross-linking reactions involving lignin and furfural are clearly occurring, their limited extent does not seem to justify joint bond strengths in excess of 10 MPa as achieved in wood fusion welding (Gfeller et al., 2003). Both ionic type formation and radical reactions occur at last (Wieland et al., 2005).

Adhesion of wooden surfaces with vibration welding is accompanied by a significant increase in the density of wood in the connected interface (Leban et al., 2004). In conclusion, X-ray micro tomography imaging appears to be a good method to investigate and characterize the bond line properties as a non-destructive test method.

## Conclusions

The shear strength change of the welded birch wood in water at different time and density changes in different weld line zone were observed. The following conclusions could be drawn from the results of the present study:

-After 48 hours soaking, the linear friction-welded birch wood had very poor shear strength with approximately 80% loss of resistance.

-X-Ray Computed Tomography (CT scan) preserves the integrity of the sample non-destructively, so it can be said that it can be used to investigate moisture content in wood and provide information about structural analysis. This method is also important to further investigate and characterize bond line properties.

-This study made it possible to characterize water absorption property of welded joining.

**Acknowledgements**

The authors thank Birger Marklund for the sample preparations, and Dr. Jose Couceiro for CT analysis. We gratefully acknowledge the Scientific and Technological Research Council of Turkey (TUBITAK- 2219/BIDEB, 2019) for the scholarship of the visiting researcher Dr. Mustafa ZOR to do the post-doc study at the Luleå University of Technology, Skellefteå, SWEDEN. This study was presented as a conference paper at the III. International Mediterranean Forest and Environment Symposium (IMFES-2019).

**References**

Amiroua, S., Pizzi, A., Belleville, B. & Delmotted, L. (2017). Water resistance of natural joint of spruce produced by linear friction welding without any treatment, *International Wood Products Journal*, 8(4), 201-207.

EN 205. Adhesives – wood adhesives for non-structural applications – determination of tensile shear strength of lap joints. Brussels: European Committee for Standardization.

Ganne-Chedeville, C. (2008). Soudage linéaire du bois étude et compréhension des modifications physico-chimiques et développement d’une technologie d’assemblage innovante, PhD thesis, Université Henri Poincaré – Nancy.

Ganne-Chedeville, C., Pizzi, A., Thomas, A., Leban, J-F., Bocquet, J-F., Despres, A. & Mansouri, H. R. (2005). Parameter interactions in two-block welding and the wood nail concept in wood dowel welding. *Journal of Adhesion Science and Technology*, 19, 1157-1174.

Gfeller, B., Zanetti, M., Properzi, M., Pizzi, A., Pichelin, F., Lehmann, M. & Delmotte, L. (2003). Wood bonding by vibrational welding, *Journal of Adhesion Science Technology*, 17(11), 1573-1589.

Heräjärvi, H. (2002). Properties of birch (*Betula pendula*, *B. pubescens*) for sawmilling and further processing in Finland. The finnish *Forest Research Institute*, Research Papers, 35(4), 469-485

Leban, J.-M., Pizzi, A., Wieland, S., Zanetti, M., Properzi, M. & Pichelin, F. (2004). X-Ray microdensitometry analysis of vibration welded wood. *Journal of Adhesion Science Technology*, (18), 673-685.

Mansouri, H. R., Omrani, P. & Pizzi, A. (2009). Improving the water resistance of linear vibration-welded wood joints. *Journal of Adhesion Science Technology*, 23, 63-70.

Mansouri, H. R., Pizzi, A., Leban, J. M., Delmotte, L., Lindgren, O. & Vaziri, M. (2011). Causes for the Improved Water Resistance in Pine Wood Linear Welded Joints. *Journal of Adhesion Science and Technology*, 25,1987-1995.

Mansouri, H. R., Pizzi, A., Leban, J. M., Delmotte, L. O. & Vaziri, M. (2011). Causes for the improved water resistance in pine wood linear welded joints. *Journal of Adhesion Science and Technology*, 26(19) 1987-1995.

Martins, S. S., Ganier, T., Pizzi, A. & Del Menezzi, C. H. S. (2013). Parameter scanning for linear welding of Brazilian Eucalyptus benthamii wood. *European Journal of Wood Production*, 71, 525-527.

Omrani, P., Pizzi, A., Mansouri, H. R., Leban, J. M. & Delmotte, L. (2009). Physico-chemical Causes of the Extent of Water Resistance of Linearly Welded Wood Joints, *Journal of Adhesion Science and Technology*, 23, 827-837.

Pizzi, A., Despres, A., Mansouri, H. R., Leban, J-M. & Rigolet, S. (2006). Wood joints by through-dowel rotation welding Microstructure, 13CNMR and water resistance, *Journal of Adhesion Science and Technology*, 20, 427-436.

Pizzi, A., Mansouri, H. R., Leban, J. M., Delmotte, L. & Pichelin, F. (2011). Enhancing the exterior performance of wood joined by linear and rotational welding. *Journal of Adhesion Science and Technology*, 25(19), 2717-2730.

Pizzi, A., Zhou, X., Navarrete, P., Segovia, C., Mansouri, H. R., Placentia Pena, M.I. & Pichelin, F., (2013). Enhancing water resistance of welded dowel wood joints by acetylated lignin, *Journal of Adhesion Science and Technology*, 27(3), 252-262.

Ruponen, J., Čermák, P., Rhême, M., Miettinen, A., Rohumaa, A. & Rautkari, L. (2015b). Influence of Welding Time on Tensile-Shear Strength of Linear Friction Welded Birch (*Betula pendula* L.) Wood. *BioResources*, 10(2), 3481-3491.

Ruponen, J., Čermák, P., Rhême, M. & Rautkari, L. (2015a). Reducing the moisture sensitivity of linear friction-welded birch (*Betula pendula* L.) wood through thermal modification. *Journal of Adhesion Science and Technology*, 29(22), 2461-2474.

Vaziri, M. (2011). Water resistance of Scots pine joints produced by linear friction welding. PhD thesis, Luleå University of Technology, SWEDEN.

Vaziri, M., Abrahamsson, L., Hagman, O. & Sandberg, D. (2020). Welding of Wood in the Presence of Wollastonite, *BioResources*, 15(1), 1617-1628.

Vaziri, M., Lindgren, O. & Pizzi, A. (2011). Influence of Welding Parameters and Wood Properties on the Water Absorption in Scots Pine Joints Induced by Linear Welding, *Journal of Adhesion Science and Technology*, 25, 1839-1847.

Vaziri, M., Lindgren, O. & Pizzi, A., (2010). Moisture Sensitivity of Scots Pine Joints Produced by Linear Frictional Welding. *Journal of Adhesion Science and Technology*, 24(8-10), 1515-1527.

Verkasalo, E. & Heräjärvi, H. (2009). Potential of Europen Birch Species for Product Development of Veneer and Plywood-Recovery, Grades and Mechanical Properties and Future Market Requirements. *Forest Product Industry*, 52, 40-51.

Wagenführ, R. (1996). *Holzatlas*. [Wood Atlas]. VEB Fachbuchverlag Leipzig. 4th ed. 688p. (In German).

Wieland, S., Bozhang, S., Pizzi, A., Properzi, M., Stampanoni, M., Abela, R Lu, X. & Pichelin, F. (2005). Vibration welding of wood X-ray tomography, additives, radical concentration. *Forest Products Journal*, 55(1), 84-87.

Zhang, H., Pizzi, A. & Xiaoning, L. (2014). Palmyra palm bonding by vibrational welding. *European Journal of Wood Production*, 72, 693-695.

Zor, M. (2019). Investigation of the Use of Wood Based Materials in Friction Welding Method Applications. *Journal of Bartın Forestry Faculty*, 21(3), 927-937.