WATER-RESISTANCE STUDY OF LINEAR FRICTION-WELDED THERMO-TREATED BEECH USING TOMOGRAPHY

P. Lu[1]*, E. Baldenberger[2], P. Perré[1,3]

[1] LGPM, CentraleSupélec, SFR Condorcet FR CNRS 3417, Université Paris-Saclay, Centre Européen de Biotechnologie et de Bioéconomie (CEBB), Pomacle, France

[2] Centre Régional d'Innovation et de Transferts Technologiques des industries du bois, Epinal, France

[3] LGPM, CentraleSupélec, Université Paris-Saclay, Gif-sur-Yvette, France

*Corresponding author; e-mail: pin.lu@centralesupelec.fr

Abstract

Water resistant property of linear friction-welded beech and thermo-treated beech samples were compared. X-ray tomographic anatomy illustrated that the interface of welded thermo-treated beech was narrow and compact due to removal of less thermo-stable components. A profound crack was noticed for welded beech after the first dry. For both samples, cracks started from the edge of the interface not the defects inside the joint and the latewood absorbed more water than the earlywood did. There was no evident deformation of cell wall and the joint during immersion and dry process. The welded beech finally split after two immersion-dry cycles which indicated the sample easily got affected and deteriorated in the presence of water, while application of thermal treatment helped to stabilize the welded joint against it.

Keywords:

Linear friction-welding; beech; thermo-treatment; tomography; water resistance

1 INTRODUCTION

Wood welding is a promising technology offering fast, inexpensive, adhesive-free features. High-strength joints produced are strong enough for structural applications. However, due to poor water-resistant property, welded wood product is limited to interior joinery and furniture.

Thermal treatment as a wood modification is performed by heating wood in the absence of oxygen or with air deficiency to an extent intensity. It improves the resistance of wood to humidity and ensures better dimensional stability. It has been revealed that thermal treatment can enhance the moisture stability of welded birch wood [Ruponen 2012, 2015].

In recent years, great attention has been paid to use non-destructive technology of X-ray computed tomography to study the densitometry of the welding bondline with particular interest in the relation between the line density and the behaviour of the welded wood. [Leban 2004; Vaziri 2015; Wieland 2005]. Since the mechanism of water resistance of welded wood are not fully understood and reported, examination of the morphology of wood cells and the welding interface may shed light on the moisture-related property of the welded wood.

For this purpose, water-resistant behaviours of linear friction-welded thermo-treated beech as well as untreated beech samples were compared using tomography at cell-level spatial resolution which enables us to study *in situ* the effect of the humidity on the welded sample.

2 MATERIALS AND METHODS

2.1 Materials

Wood samples, including beech *(Fagus sylvatica)* and thermo-treated beech came from BURGER company (Lièpvre, France). The thermo-treated one has been heated between 160 and 245°C.

Tab. 1: Welding parameters

	Beech	Thermo-treated beech
Welding displacement (mm)	2	2
Welding time (s)	1+1.5	1+1.5
Welding pressure (kN)	3+7	3+7
Holding time after welding (s)	10	10
Holding pressure after welding (kN)	10	10

20 test pieces of each specimen were randomly selected for welding, which was carried out by a KLN

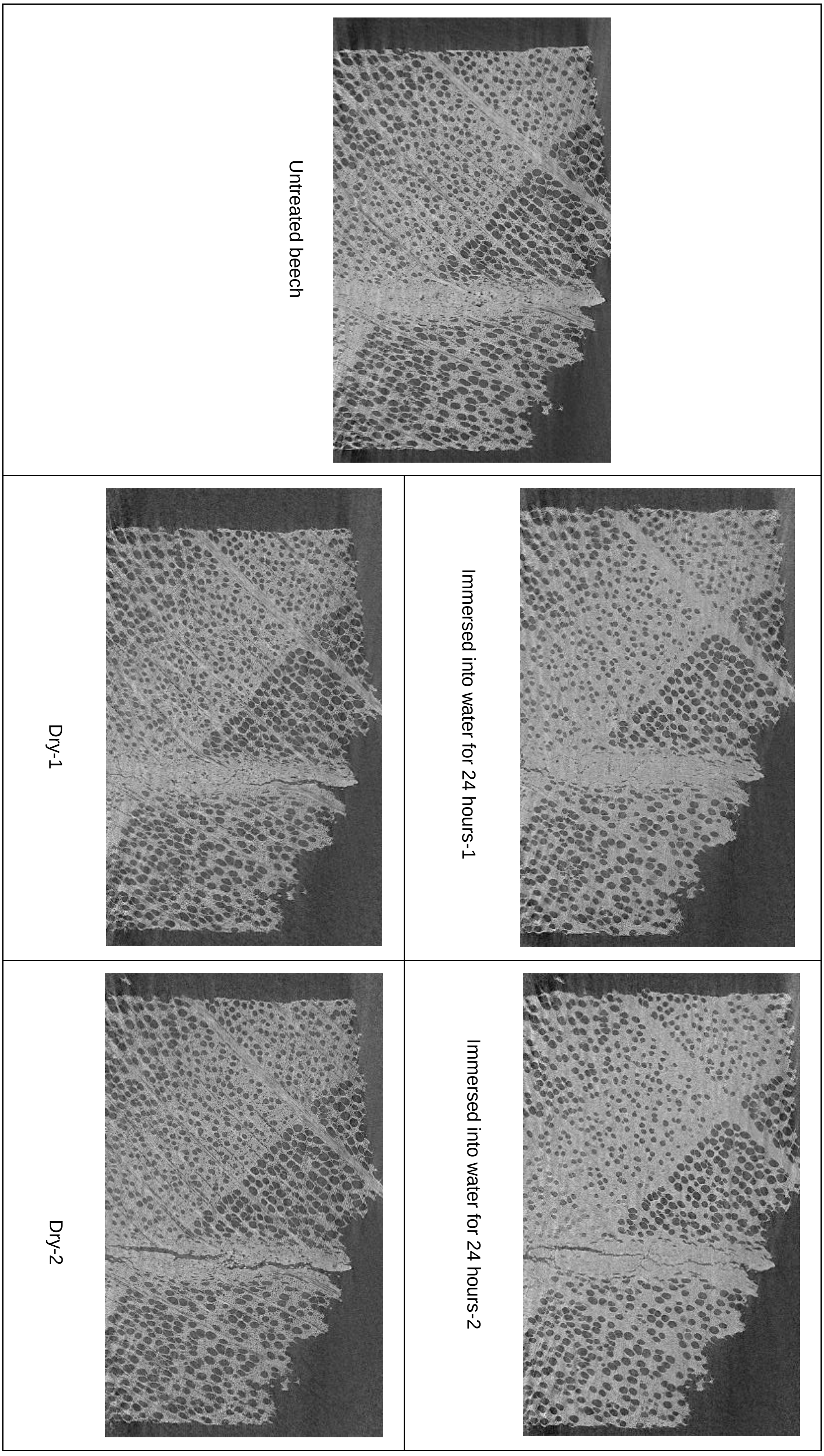

Fig. 1 Tomography anatomy of welded beech subjected to water treatment.

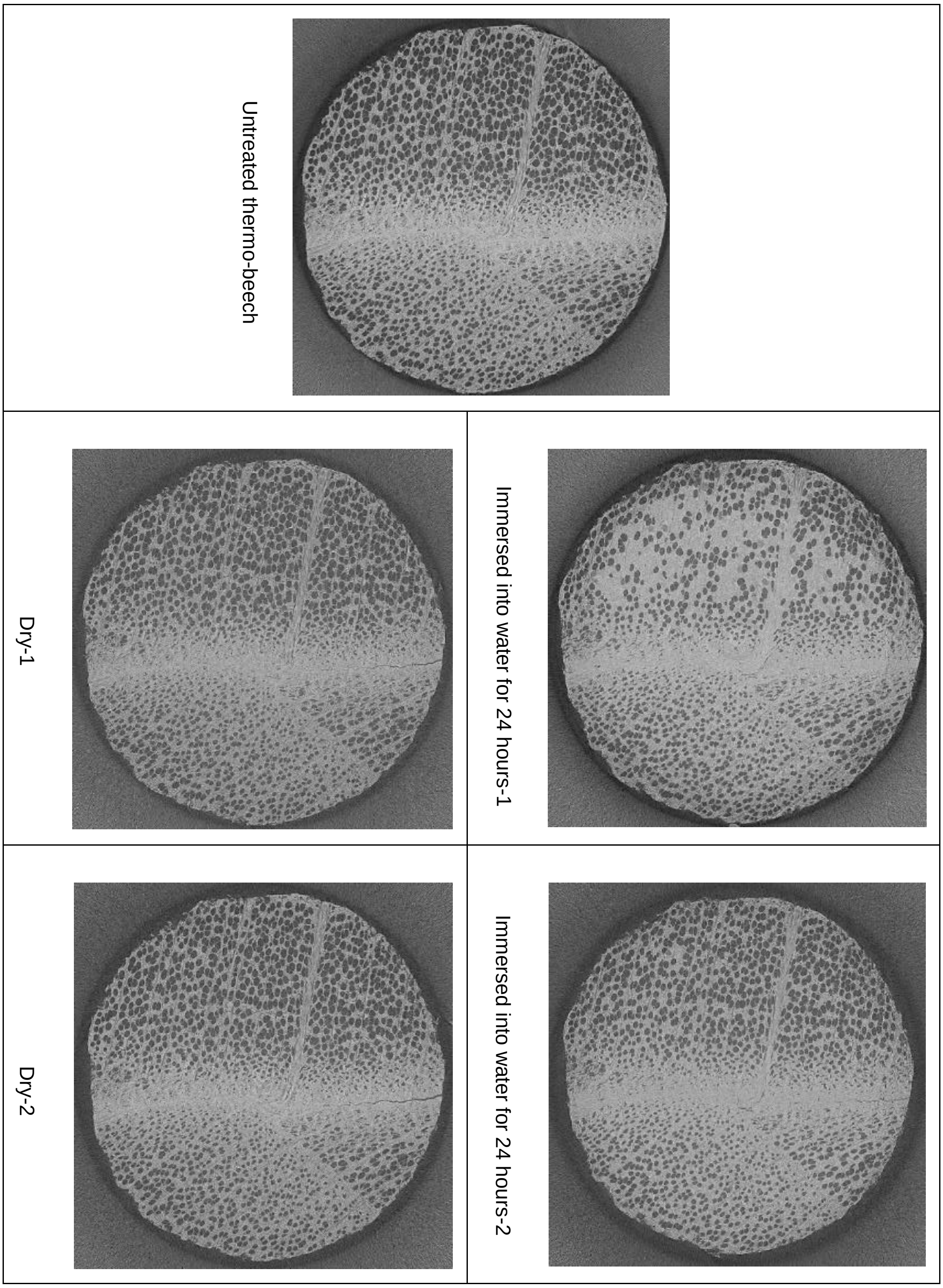

Fig. 2 Tomography anatomy of welded thermo-treated beech subjected to water treatment.

Ultraschall linear welding machine (LVW 2061 Mecasonic, France) at a frequency of 150 Hz. The welding parameters used were listed in Tab. 1.

All welded samples were conditioned in an environmental chamber at 20°C with 65% relative humidity for 5 days. Then they were cut in cylindrical form (3mm×30mm) using Charlyrobot (CHARLY4U MECANUMERIC co., France) for water resistance and tomography tests.

2.2 Water resistance test

Both beech and thermo-treated beech samples were immersed into distilled water for a period of time and then was mildly dried in a conditioned chamber at 15°C and 45% relative humidity. This immersion-dry cycle (as shown in Tab. 2) was performed several times until the welded interface completely split.

Tab. 2: Water resistance test

	Immersion time (h)	Dry time (h)
Cycle 0*	/	/
Cycle 1	24	24
Cycle 2	24	24

**Cycle 0 represents the original sample.*

2.3 Tomography test

X-ray tomograph EasyTom XL 150/160 (RX-solutions, France) was used with a nano-tube (tungsten filament) at a working voltage of 66 kV and a working current of 200 µA.

Samples were exposed to tomography test immediately after each immersion and dry process. The voxel size varied from 2 µm to 2.3 µm due to the swell of the sample. A CCD detector of 2004 × 1336 pixels was used and 1100 radiographs were obtained.

3 RESULTS AND DISCUSSIONS

It can be seen from Figure 1 that the welded interface of beech is wide and there are some defects inside the joint. When immersed into water, the latewood absorbed more water than the earlywood did. A remarkable crack in the joint was found after the first dry. It developed and extended all along the sample during the second immersion, resulting in separating two welded pieces apart afterwards. Because of thermal pre-treatment that changes the chemical structure of the sample and eliminates less thermo-stable components, thermo-treated beech, as a result, is much more thermo-homogenized than the beech sample. Thus, the welded interface is narrow and compact with less defects (Figure 2). A lot of water entered cells and lumens of the earlywood in the first immersion. This could be attributed to the degradation of thermal pre-treatment and the degraded fragments abounded of hydroxyl groups initiate the easy access to water. At the end of the first dry, a fissure developed in the joint. Probably all degraded fragments have been rinsed into water, and thus there is no obvious incursion of water during the second immersion. Unlike what happened to the untreated beech sample, the fissure in the thermo-treated beech didn't get worsened throughout the second immersion and dry.

4 SUMMARY

Thanks to high-resolution tomography, the morphology of cell wall and lumen of welded wood samples can be observed under water conditions. For both beech and thermo-treated beech samples, the latewood absorbed more water than the earlywood did and there was no evident deformation of cell wall and the joint during immersion and dry process. Cracks appeared after the first dry and it started from the edge of the interface not the defects inside the joint. Comparing to thermo-treated beech, a profound crack was noticed for beech sample and it developed and extended over the second immersion and dry processes, leading finally to the split of the joint. Therefore, untreated beech easily gets affected and deteriorated by water, while the application of thermal treatment helps to stabilize the welded joint against it.

The present study has been focused on the water resistance in longitudinal direction. A comprehensive study is in progress.

5 ACKNOWLEDGMENTS

The authors would like to thank Région Grand Est, Département de la Marne, Grand Reims and the European Union for supporting the Centre Européen de Biotechnologie et de Bioéconomie (CEBB 51110 Pomacle, France), where this study was carried out. For a three-year period (from 01/05/2016 to 30/04/2019) and with a total budget of 965,000€, 3D-BioMat is co-financed by the Grand Reims (31%) and the European Union by 48.7% (i.e. 50% of eligible expenditure). Europe is committed to the Grand Est with the European Regional Development Fund.

6 REFERENCES

[Leban 2004] Leban J.M.; Pizzi A.; Wieland S.; Zanetti M. et al.; X-ray microdensitometry analysis of vibration-welded wood. Journal of Adhesion Science and Technology, January 2004,18, 6, 673-685.

[Ruponen 2012] Ruponen J.; Rautkari L.; Hughes M.; Influence of Vacuum Atmosphere Thermal Modification on the Bond Stability of Vibrational Welded Wood in Moist Conditions. In: COST Action FP0802 workshop “Micro Characterisation of Wood Material and Properties”, 24-26 October 2012, Edinburgh, Scotland, UK; 65.

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

[Vaziri 2015] Vaziri M.; Plessis A. D.; Sandberg D.; Berg S.; Nano X-ray tomography analysis of the cell-wall density of welded beech joints. Wood Material Science & Engineering, August 2015, 10, 4, 368-372.

[Wieland 2005] Wieland S.; Shi B.Z.; Pizzi A; Properzi M. et al.; Vibration welding of wood: x-ray tomography, additives, radical concentration. Forest Products Journal, January 2005, 55, 1, 84-87