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The influence of densification time on the tensile strength and modulus of elasticity of birch veneers

ADAM SŁUPECKI[1], ANITA WRONKA[2]

[1] Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW
[2] Department of Technology and Entrepreneurship in Wood Industry, Institute of Wood Sciences and Furniture, Warsaw University of Life Sciences – SGGW

Abstract: *The influence of densification time on the tensile strength and modulus of elasticity of birch veneers*. The aim of the following study was to examine and compare tensile strength, modulus of elasticity, and thickness of birch (*Betula pendula* Roth) veneers modified by thermomechanical densification. Birch veneers were densified at the temperature of 100 °C at different times (ranges from 10 to 60 minutes). Tensile strength was tested longitudinally to the grain. As a result of this study change in tensile strength was observed for 60 minutes of densification. The rise in modulus of elasticity was also observed for 10, 20, 30, 50, and 60 minutes. The thickness of wooden veneers was changed significantly for each densification time.

Keywords: densification, birch, *Betula pendula* Roth, veneer, mechanical properties, thickness

INTRODUCTION

There are three main wood modification treatments - heat treatment, chemical modification, and enzymatic treatment. These treatments change the chemical structures of the components of the wood cell wall, i.e. lignin, cellulose, and hemicellulose, which result in the formation of covalent bonds (Kutnar and Sernek 2007, (Kollmann *et al.* 1975). Wood densification is a process, in which the density of the wood is increased for example by compressing the wood, a combination of compression and impregnation, and impregnation of the lumen of the wood cells with a liquid substance. One of the frequently used wood modification treatments is compaction. Wood densification contributes to improving the mechanical properties of the wood, which is why this treatment is most often used on wood species that have a low specific density (Sandberg *et al.* 2013). The up-to-date research confirms, that the compaction of the first few millimeters of the wood thickness contributes to increasing the mechanical properties but also increases the abrasion resistance and hardness of the compacted wood, which is very important, for example, in the production of countertops or floors (Sadatnezhad *et al.* 2017).

Densification of wood might be done with controlled moisture content in wood (thermo-hydro-mechanical densification) or without controlled moisture content (thermo-mechanical densification). Yu *et al.* (2022) proposed a new classification: non-adding steam (NAS) densification, adding steam (AS) densification, and others. The densification presented in this research can be described as NAS densification.

There are some mentions of the thermomechanical densification of wood. Most of the research was conducted on thick material rather than on thin veneers. Koubaa *et al.* (2011) in their work investigated the influence of temperature on different properties of aspen and poplar veneer during thermomechanical densification. For example, there was observed that bending strength was improved significantly, reaching its highest value at 220 °C of densification temperature. Tensile strength reaches its highest values at 160 and 180 °C. The tensile strength of densified veneer decreases as the temperature of densification rises but the modulus of elasticity rises, as well.

Pelit *et al.* (2018) tested some properties of densified and heat post-treated samples of wood. Modulus of elasticity, modulus of rupture, and compression strength were examined. Wood samples of thicknesses of 26.7 mm and 40 mm were densified by thermomechanical treatment at temperatures of 100 and 140 °C, and next, the densified samples have been stored at high temperatures to obtain dimensions stability. As a result, the mechanical properties of wood decreased with rising temperatures and increased with rising compression levels. It might be caused by the degradation of cellulose in higher temperatures.

Jakob M. *et al.* (2020) measured the tensile strength of delignified wooden veneers but also water-soaked veneers before densification. Densified veneer exhibited a tensile strength of 232.38 MPa with a standard deviation of 30.05 MPa and modulus of elasticity of 16.38 GPa with a standard deviation of 1.23 GPa. The reference veneers represent tensile strength of 90.97 MPa with a standard deviation of 14.77 MPa and modulus of elasticity of 8.66 GPa with a standard deviation at a level of 1.90 GPa. It means tensile strength was improved by a factor of 2.55 and modulus of elasticity by a factor of 1.89.

The aim of the following study was to examine and compare tensile strength, modulus of elasticity, and thickness of birch (*Betula pendula* Roth) veneers modified by thermomechanical densification in variable time of densification.

MATERIALS AND METHODS

Samples

To obtain comparable results, samples were cut only from the early wood of *Betula pendula* Roth, parallel to the grain. The rectangular shape of samples was required because of the anisotropy of wood and the fact that all raw veneers have the same thickness. The nominal dimensions of the samples were: 100 mm (along the grain) x 10 mm x 0.53 ± 0.01 mm. After densification, the samples were glued with supporting slats (Figure 1. b).

Thermomechanical densification

Before thermomechanical densification, samples were dried at a temperature of 70 °C to constant weight. Next, the samples were placed between aluminum plates and moved to a press. Densification was conducted at a temperature of 100 °C and a unit pressure of 10 MPa. Compression of samples was done at six different times: 10, 20, 30, 40, 50, and 60 minutes. After thermomechanical densification, the wooden veneers were placed in a desiccator and a climate chamber at 20 °C and 65% humidity for 24 hours.

Tensile strength and modulus of elasticity

Tensile strength and modulus of elasticity were tested at the computer-controlled universal testing machine at a loading speed of 5 mm/min. Dedicated holders to the universal testing machine were made of American walnut. Samples were installed between these holders (Figure 1. a). The initial force was 0 N, and the force was growing until the sample was broken (Figure 1. b).

The modulus of elasticity was determined based on load vs. strain data collected from a universal testing machine. A straight section in a range from 10 to 40% of the load at break was defined. Based on values of minimal and maximal load and displacement in the straight section, the modulus of elasticity was calculated, according to the formula (1):

$$\boldsymbol{MOE} = \frac{\Delta\sigma}{\Delta\varepsilon} \qquad \textbf{(1)}$$

where: MOE – modulus of elasticity; Δσ - stress increase; Δε - strain increase

The values of tensile strength have been calculated as a maximal load divided by sample crosscut dimensions (where the thickness, and width were measured in two different locations for every sample).

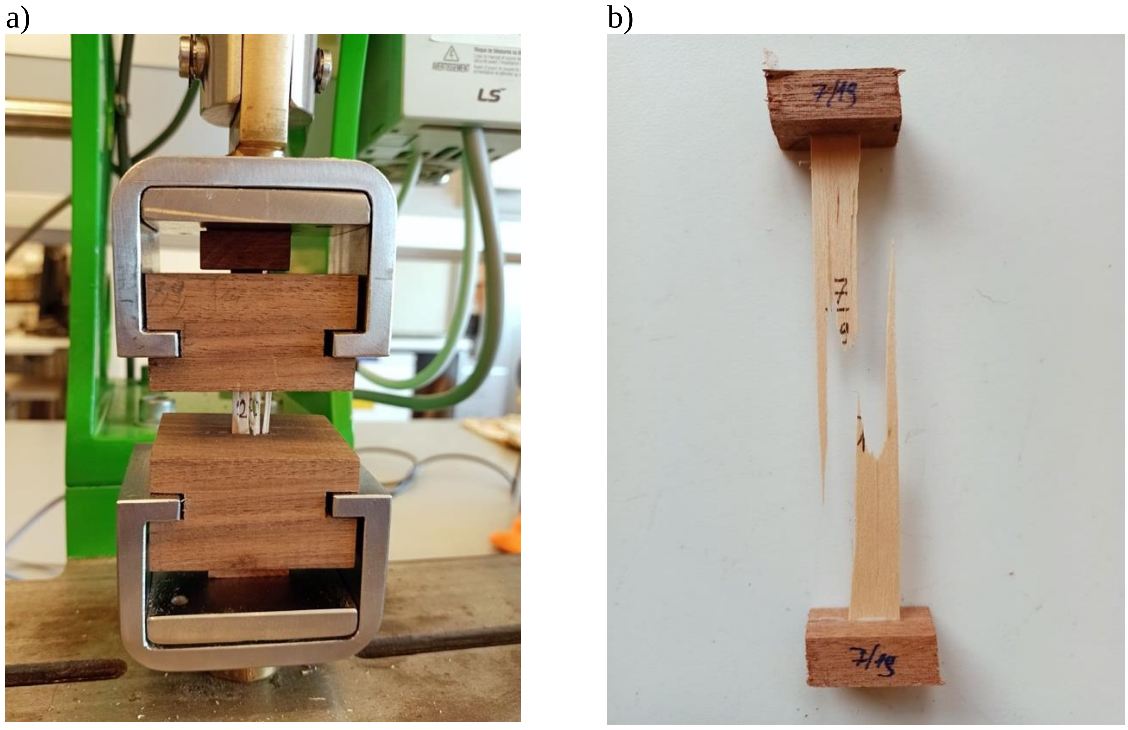

Figure 1. a) sample placed in the universal testing machine, b) broken sample

Statistical analysis

Statistical analysis was executed by analysis of variance (ANOVA) and Tukey test. The significance level of 0.05 was established to find out the differences between factors. Analysis of variances was made using the R software (Free Software under the terms of the Free Software Foundation's GNU General Public License; www.r-project.org; Vienna, Austria).

RESULTS AND DISCUSSION

As a result of this study, a statistically significant change in tensile strength was observed for thermomechanical densification at 60 minutes (Figure 2). As a reference, the native wood (not densified) tensile strength has been presented on the plot. Pramreiter *et al.* (2021) obtained much lower values for native wood. For veneers of the thickness of 0.5 mm, tensile strength totals 121.0 MPa with a standard deviation of 26 MPa. It might be caused by a different method of sample selection, whereas here in this research samples were chosen precisely from early wood. Frey *et al.* (2018) examined Norway spruce densification of native and delignified wood samples with an initial thickness of 20 mm. There was observed a significant increase in tensile strength, but these values are lower than those obtained in this research. It must be mentioned that Frey *et al.* (2018) obtained lower values of tensile strength for native wood: 80 MPa, but the increase in tensile strength was significant. Densification below 60 minutes does not show significant changes in tensile strength. The highest values of tensile strength were reached for 60 minutes of treatment: 349.3 MPa with a standard deviation of 81 MPa. It is a higher value than reached by Jakob *et al.* (2020) but if we compare it to the tensile strength of native wood, the factor by which tensile strength was improved, results are much worse.

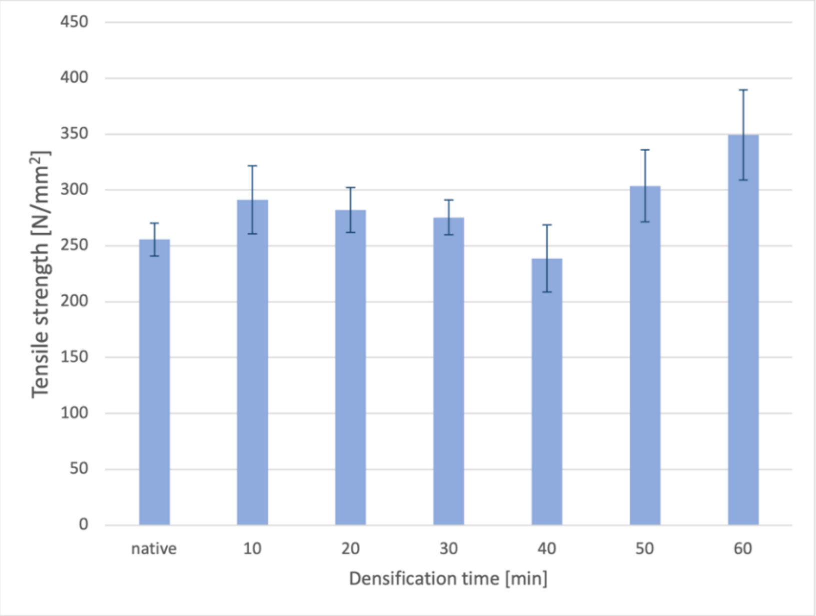

Figure 2. Tensile strength of densified samples

The changes were also observed for the modulus of elasticity (Figure 3). Densification times of 10, 20, 30, 50, and 60 minutes show significant changes in the modulus of elasticity. Obtained results show higher tensile strength and modulus of elasticity compared to native wood. Modulus of elasticity of native wood shows lower values than obtained by Pramreiter *et al.* who indicate values of 13.7 GPa with a standard deviation of 1.6 GPa for 0.5 mm veneers. The highest values of modulus were obtained for densification of 60 minutes: 17.4 GPa with a standard deviation of 4.3 GPa. These results are comparable to those achieved by Jakob *et al.* (2020), but a similar conclusion can be drawn: same as in tensile strength, if we compare the results of the factor by which MOE was improved to the modulus of elasticity of native wood, the results are worse. Frey *et al.* (2018) indicate a loss in modulus of elasticity of densified wood compared to native wood which exhibits a modulus of elasticity of 13 GPa.

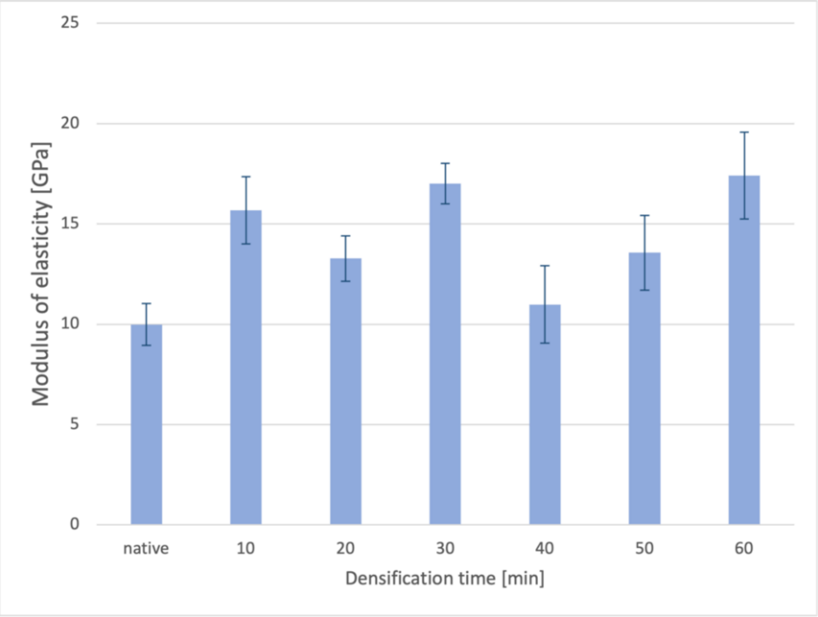

Figure 3. Modulus of elasticity of densified samples

Significant changes in the thickness of each densification time were observed (Figure *4*). The smallest thickness was observed for veneers densified for 60 minutes – 0.35 mm with a standard deviation of 0.03 mm.

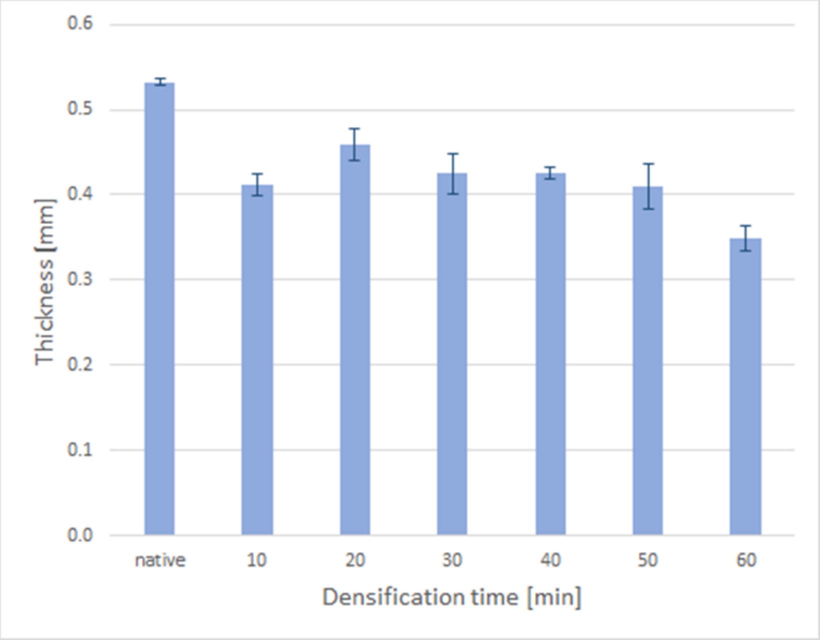

Figure 4. The thickness of densified samples

CONCLUSION

Based on the conducted research, the following conclusions can be drawn:

1. 60 minutes of densification at the temperature of 100 °C has a significant influence on the tensile strength of wood.
2. The thickness of veneers is changed significantly for each of the densification times.

3. Modulus of elasticity is changed significantly for 10, 20, 30, 50, and 60 minutes of densification.

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Streszczenie:
Wpływ czasu zagęszczania na wytrzymałość na rozciąganie i moduł sprężystości fornirów brzozowych. Celem badań było określenie wybranych właściwości mechanicznych zagęszczonych fornirów z drewna brzozowego (*Betula pendula* Roth). W ramach badań przeprowadzono badanie wytrzymałości na rozciąganie wzdłuż włókien, a także modułu sprężystości oraz analizę zmiany grubości. Wyniki wskazują, że wytrzymałość na rozciąganie wzrosła znacząco dla próbek zagęszczanych przez czas 60 minut. Zaobserwowano również wzrost wartości modułu sprężystości dla próbek zagęszczanych przez okres 10, 20, 30, 50 i 60 minut. Zaobserwowano znaczącą zmianę grubości dla wszystkich czasów zagęszczania.

Słowa kluczowe: zagęszczanie drewna, brzoza, fornir, właściwości mechaniczne

Corresponding author:

Anita Wronka
Department of Technology and Entrepreneurship in Wood Industry
Institute of Wood Sciences and Furniture
Warsaw University of Life Sciences – SGGW
Nowoursynowska Str. 159
02-787 Warsaw, Poland
email: anita_wronka@sggw.edu.pl