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THE EFFECT OF BEECH WOOD DRYING ON HARDNESS IN THE LONGITUDINAL DIRECTION FROM THE BEGINNING TO THE REAR OF THE SAMPLES

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ABSTRACT

The objective of this study was to determine the hardness of beech wood samples (*Fagus sylvatica* L.) in the longitudinal direction from the beginning to the rear of the samples versus the method of drying. The warm air-steam mixture drying process and the modified air-drying process were used in the experiment. The warm air-steam mixture drying process, in comparison to the modified air-drying process, caused a reduction of the Janka hardness by about 15.4%. Although the hardness along the length of the sample dried with a mixture of air and steam is leveled, this is not the case for the beginning and the rear of the sample, where drops in hardness are observed.

Keywords: beech wood; specific drying methods; Janka hardness.

INTRODUCTION

Most often, the re-sawing process is done for timber after drying. High quality of sawing, low material losses, and high efficiency are required for this kind of sawing process. Appropriate optimization of the sawing process allows these expectations to be met to a large extent. Accurate forecasting of cutting power allows the sawing process to be optimized and, consequently, the above-mentioned expectations of the process to be met. A precise forecast of the cutting power demand for the sawing process encourages optimally choosing the number of saw blades and their spacing, which ensures effective use of the sawing machine’s capabilities and prevents overloading of these machines. To reduce the drying time, one of the methods is drying with the warm air-steam mixture process proposed in the works by Baranski *et al.* (2017) and Baranski (2018). The proposed method can reduce the drying time. However, this process affects the granularity of dust during sawing (Orlowski *et al.*, 2019, Rogoziński *et al.*, 2021), and also the mechanical properties of dried wood, such as fracture toughness and shear yield stresses along the shear plane in the cutting zone (Baranski *et al.,* 2014, Chuchala *et al.*, 2020, Muziński, 2021) similarly as the effect of the wood provenance (Hlásková *et al.*, 2018), and colour changes (Barański *et al.*, 2020, Suchta *et al.*, 2024).

The effect of the drying treatment on the planing and moulding properties of wood has been the subject of only a few studies (Hernandez *et al.*, 2001). Sehlstedt-Persson (1995), Terziev and Daniel (2002), and Hansson and Antti (2006) have reported that no significant effect of the drying temperature was noticed in the case of softwood species, namely Scots pine and Norway spruce. The hardness, planing, and moulding properties of tamarack wood (*Larix laricina* (Du Roi) K. Koch) from natural forests were evaluated on kiln-dried specimens by Avila *et al.* (2009) following three types of drying schedules: high temperature, elevated temperature, and conventional. Machining and hardness properties appeared not to be affected differently by the drying process (Avila *et al.*, 2009). They stated that tamarack wood is suitable for the fabrication of flooring products.

While investigating the effect of the drying method of beech wood (*Fagus sylvatica* L.) on the energy effects during sawing wood on the sash gang saw, lower cutting power values were observed at the beginning of the samples and at the exit of the saws from the cut beam (Muziński, 2021). This phenomenon was not observed during the tests conducted when cutting pine wood (*Pinus sylvestris*L.) (Licow *et al.*, 2020). Cutting forces are dependent on raw material provenance and wood density (Chuchala *et al.*, 2014). Moreover, Avila *et al.* (2009) found that the hardness of tamarack wood was positively related to wood density.

The objective of this study was to determine the hardness of beech wood samples (*Fagus sylvatica* L.) in the longitudinal direction from the beginning to the rear of the samples versus the method of drying.

MATERIALS AND METHODS

Materials

The investigation was carried out for samples of beech wood (*Fagus sylvatica* L.) originating from the Baltic Natural Forest Region (PL) (the Pomeranian District, Poland). The wood specimens used in the sawing experiments were prepared as blocks in dimensions of W (Width) = 80 mm × H (Height) = 80 mm × L (Length) = 850 mm (for kiln drying) and 700 mm (for air drying) in the sawmill PHU Drew-Met, Kiełpino, Poland. Samples of beech wood were marked as BS for kiln-drying and BP for air-drying. Examined samples were dried with different modes in industrial and laboratory conditions. Both groups of analysed samples had a moisture content of about 72 % before the drying process. After drying, samples were prepared from the blocks mentioned above for hardness examination on the sash gang saw PRW15M (a prototype designed at the Department of Manufacturing Engineering and Automation. GUT, PL; manufactured by REMA-Reszel, PL) with a hybrid dynamically balanced driving system and elliptical teeth trajectory movement, as described by Wasielewski and Orlowski (2002). The oven-dry density of the air-dried samples averaged 661 kg·m^{-3} with a standard deviation SD = 31.35, while the oven-dry density of the kiln-dried samples averaged 631 kg·m^{-3} (SD = 17.1).

Warm air‒steam mixture drying process

The drying process was conducted in an experimental semi-industrial kiln designed by Gdansk University of Technology employees and manufactured by ASM Elektronik CLP, Szczaniec, Poland. The mentioned kiln is located at the Gdansk University of Technology. The methodologies of the experimental warm air-steam mixture drying process were described in detail by Baranski et al. (2017), Klement et al. (2018), and Baranski (2018). The drying process was carried out in two stages and supervised by a control system. In the first stage, the drying medium temperature in the drying kiln was increased to 65 °C and in the second stage, to 80 °C. The final moisture content was obtained at around 10%. Wood samples dried in the warm air-steam mixture drying process were additionally marked with S.

The combined air-drying process

This process was conducted outside the workshop at the Campus of the Gdansk University of Technology (Gdansk, Poland). The samples were stored under the sloped roof to keep from rain. Humidity and temperature were variable and dependent on weather conditions. The drying process was carried out in the Pomeranian Voivodeship in Poland and lasted 16 months. It started in late December and ended in April. At the end of the first process stage, the moisture content in dried material was approximately 16%. The second stage of the combined air-drying process was conditioning wood samples in a laboratory room (Gdańsk Tech laboratory), where thermal-flow conditions, such as temperature and air velocity, ensured reaching the final value of moisture content of around 10%. This modification allowed the receipt of moisture content values similar to those obtained from other analysed drying processes.

Hardness measurements

Vörös and Németh (2020) presented the history of the currently practiced static hardness test methods from 1860 till nowadays, considering the applied tool geometry and the definition and calculation of wood hardness. The most common tests for the determination of wood hardness are the Janka hardness test, Brinell hardness test, and Monnin hardness test (in France, according to Chalais – Meudon) (Riggio and Piazza, 2011, Vörös and Németh, 2020, Koczan *et al.*, 2021).

In this study, the Janka test was selected, which is currently applied to assess the suitability of wood species for use as flooring (Riggio and Piazza, 2011, Avila *et al.*, 2009). Before the hardness tests, the planks were divided into three parts: beginning B, middle M, and rear R (Fig. 1).

The hardness test was conducted by the ASTM D143 standard (ASTM, 1994), except for the dimensions of the specimens. The steel hemisphere with a diameter of 0.444 (ball 11.28 mm, projected area of 100 mm2) under the static loading is completely embedded in the wood. Hence, the hardness is always specified as the load H at the penetration of 0.222 in (5.64 mm). To ensure repeatability of penetration, the hemisphere was finished with a special collar; it should be emphasized that the particular hemisphere was CNC–machined. Indentations (Fig. 1) were made on two lines 30 mm apart on specimens with a pitch equal roughly to 28 mm.

The electromechanical Universal Testing Machine manufactured by Instron, model 1195 (capacity 100 kN) (Instron, Norwood, MA, USA), was used in the hardness tests. The hardness tool's penetration rate was equal to 7.5 mm×min-1 in each case. The test set-up allowed continuous recording of load with a sampling frequency of 10 Hz.

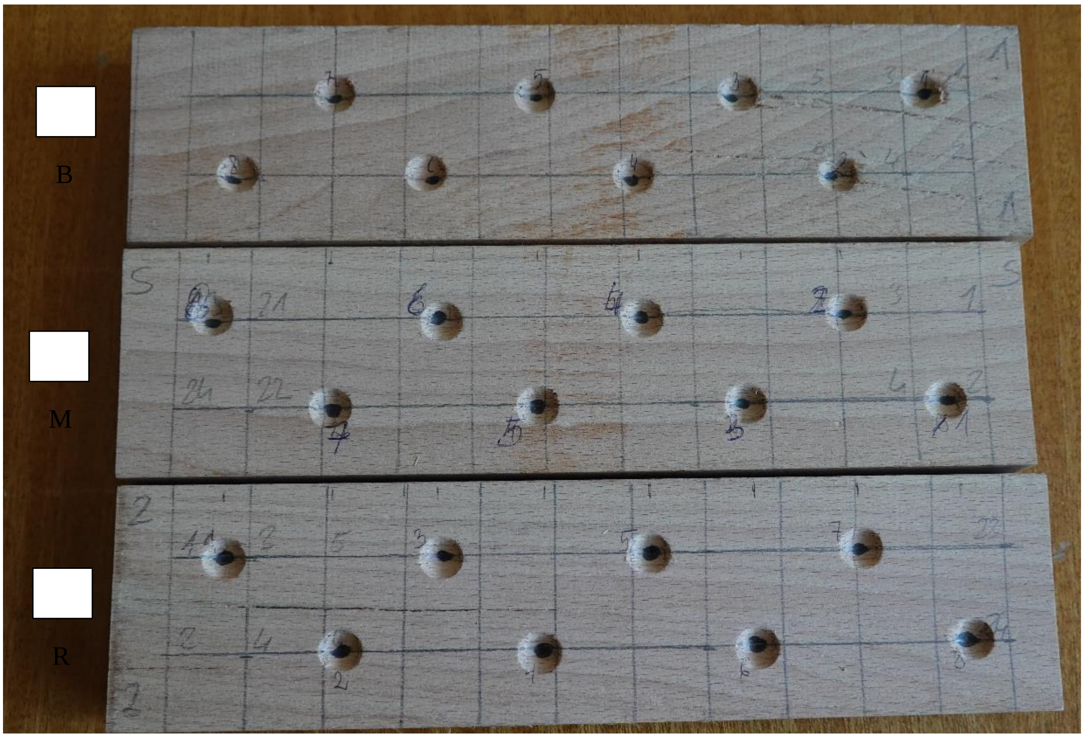

Fig. 1 Positions of indentations at the samples in the Janka hardness test, where: B – beginning part of the sample, M – middle part of the sample, R – rear part of the sample.

RESULTS AND DISCUSSION

The results of the average Janka hardness values for the modified air drying process samples as a function of relative distances from the sample beginning because of differences in sample total length are shown in Fig. 2. Each point in the graph is an average value of 3 measurements. Analysing the trend line, it can be seen that the changes in hardness are distributed parabolically, with the maximum values occurring at the mid-length of the sample. The average hardness value for the initial sample B (Fig. 1) (relative length range 0.04 - 0.32) was determined to be 7.156±0.135 kN. Confidence intervals were determined at a significance level of 0.05 according to the t-Student test (Kacew, 1978, Sachs, 1984). For the middle part M (relative length range 0.397 - 0.597), the average value was equal to 7.423 ±0.094 kN, and for the rear part, R (relative length range 0.680 - 0.960) was equal to 7.039 ±0.086 kN.

The results of the average Janka hardness values for warm air-steam mixture drying process samples as a function of relative distances from the sample beginning are presented in Fig. 3. Each point in the diagram is an average value of 8 measurements. In this case, it can be observed that in the range from 0.1 to 0.9, the trend of change is rather horizontal, not parabolical, and the hardness values are in the approximate range of 6 kN. For the latter range, an average value of the Janka hardness equals 6.053±0.16 kN. In both cases, the Janka hardnesses are approximately 0.6 kN lower at the front and rear faces of the specimen. This phenomenon could be a reason for decreasing cutting power values, which were observed at the beginning of the samples and at the exit of the saws from the cut beam while investigating the effect of the drying method of beech wood (*Fagus sylvatica* L.) on the energy effects during sawing wood on the sash gang saw (Muziński, 2021).

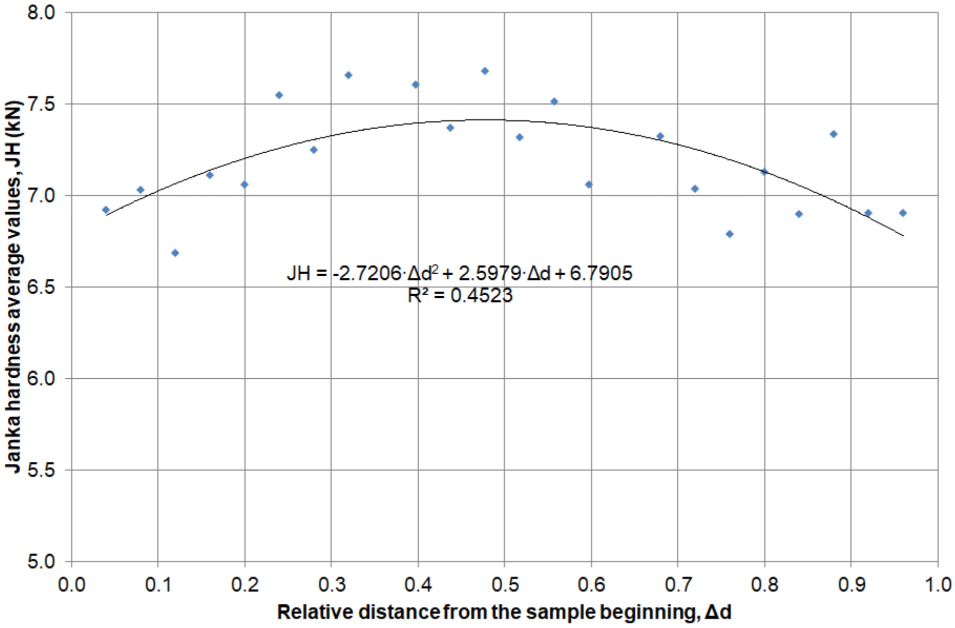

Fig. 2 Janka hardness average values for the combined air drying process of beech samples in a function of relative distances from the sample beginning.

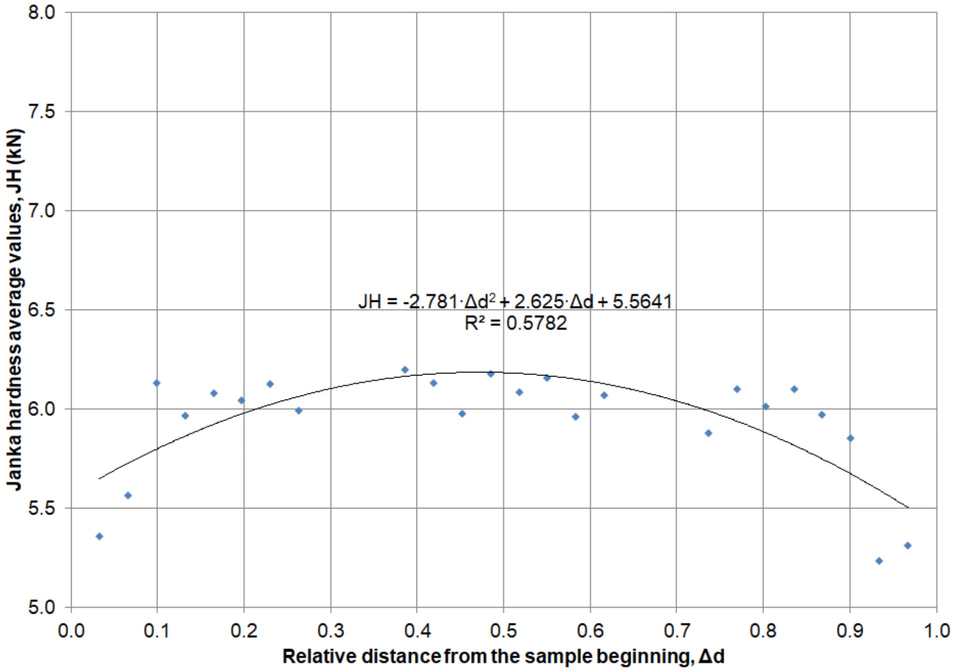

Fig. 3 Janka hardness average values for warm air-steam mixture drying process of beech samples in a function of relative distances from the sample beginning.

The drying method of beech wood (*Fagus sylvatica* L.) may reduce the Janka hardness in comparison with the hardness of wood dried with the combined air drying method. In the presented study, 15.41% of Janka hardness for the middle part of specimens decreased while the warm air-steam mixture drying process was applied.

The results obtained are difficult to compare with those of other authors, as no articles were found in which changes in wood hardness in the longitudinal direction were studied. The only research work concerned the study of the physical properties of beech wood (*Fagus* *orientalis* Lipsky) from different geographical parts of Greece, which showed that the Janka hardness values were lower than those obtained in the tests carried out (Skarvelis and Mantanis, 2013). As reported by Skarvelis and Mantanis (2013), the average hardness values were equal to 4.854 kN. The latter authors compared their findings to the values of Bektaş et al. (2002). The opposite result was obtained by Büyüksari (2013), who observed that all of the compressed veneer laminated panels with Oriental beech (*Fagus orientalis* Lipsky) veneer sheets had higher hardness values compared to non-compressed veneer laminated panel. Thermally compressed veneer laminated MDF panels can be utilized for structural purposes due to higher hardness since the Janka hardness was 8.795 kN to 9.768 kN. These values were higher than ours by approximately 1.5 kN.

CONCLUSION

Based on the carried out analyses, it can be concluded that:

- The drying method of beech wood (*Fagus sylvatica* L.) while the warm air−steam mixture drying process was applied caused a reduction in the Janka hardness of about 15.41% in the middle part of specimens in comparison with the Janka hardness of wood dried with the modified air-drying method.
- Analysing the trend line of the Janka hardness for beech wood dried with the combined air-drying method, it can be seen that the changes in hardness are distributed parabolically, with the maximum values occurring at mid-length of the sample.
- The latter phenomenon was not observed for wood dried with the warm air−steam mixture drying process, in which the Janka hardness was levelled (almost horizontal) on the whole length of the specimen, skipping the beginning and end of the sample.
- In both cases, the Janka hardnesses are approximately 0.6 kN lower at the front and rear faces of the specimen.
- Future studies should be carried out on the samples with larger cross-sections and lengths.

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