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WATER RETENTION OF BEECH SHAVINGS HEAT-TREATED AT LOWER TEMPERATURES

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ABSTRACT

Water retention after 2 hours and 24 hours of soaking in water was determined for beech shavings subjected to heat treatment at temperatures of 120°C, 140°C and 160°C for 2 hours, 4 hours, 6 hours and 8 hours in order to reduce the equilibrium moisture content (EMC) of the wood shavings for use in wood based composites. EMC was determined after 14 days of air conditioning at 23°C and 55% relative humidity. The measured values were compared with the sample dried at 103°C. Water retention was determined after 15 min of centrifugation at 1400 rev·min^{-1} for a more objective assessment of the wood's ability to retain water in the cell lumens. The results showed that heat treatment reduces the EMC of beech shavings heat-treated at 160°C for 8 hours in the given conditions from 8.7% to 6.19%. The reduction of EMC at lower temperature was not sufficient enough, especially in the shorter treatment duration of up to 6 hours. In parallel, the reduction of water retention from 65.53% to 47.79% was caused by heat treatment for 8 hours at 160°C.

KEYWORDS: Beech wood, shavings, *Fagus sylvatica*, heat treatment, water retention, equilibrium moisture content.

INTRODUCTION

Industrially important thin surface fractions of low grade wood include shavings and wood wool, which are obtained by planar milling. Wide application of thin surface fraction wood particles includes production of biocompost (Yengong et al. 2021) or can be used as bedding material for animals (Munir et al. 2019). In materials engineering, the use of thin surface fraction wood particles is mainly focused on the use in lightweight concrete and wood-cement composites (Bederina et al. 2007, 2009, da Gloria and Filho 2016, Santos et al. 2017, Khelifa et al. 2019), for biosorbents (Velić et al. 2018) and as a substitute for insulating materials (Lakrafli et al. 2017, Zavialov et al. 2022). Previous research has focused on the influence of wood particles on the physical-mechanical and thermal-technical properties of pressed panels, but the fire-resistant or soundproofing of the composites themselves has also been investigated (Tsapko et al. 2019). The material usage of lower grade wood is represented by the production of composites, where the replacement of fresh wood chips is considered (Ihnát et al. 2017, 2018). Different weights are achieved depending on the purpose of use, from thermal insulation panels 55 to 400 $kg \cdot m^{-3}$ (Pasztory et al. 2021) to structural 70-1200 $kg \cdot m^{-3}$ (Gößwald et al. 2021, Faria et al. 2020). Similar to particleboards and OSB, urea-formaldehyde and methyl diphenyl diisocyanate adhesives are used in research, but a wide range of bio-based adhesives is available (Antov et al. 2020).

The recycling potential of thin surface fractions, such as wood-wool and wood shavings, has not been described sufficiently. Different non-woody substitutes are being sought for use on composite boards (Lübke et al. 2014, Ihnát et al. 2015), and wood waste can also be used as a substitute for spruce, only in a different form of wood particles. Waste wood wool-cement composites were studied by Berger et al. (2020). Strands made from wood waste have good compatibility with cement, up to 30% of wood waste can be used in composites without decreasing the properties. However, during material recycling, it is necessary to properly monitor the chemical load contained in waste wood, from which the thin surface wood particles are produced (Ihnát et al. 2020, Lubke et al. 2020).

The purpose of this study is to determine the absorption of water into thin surface beech shavings, which were previously heat treated in order to improve the resistance of pressed composites made of these shavings. Resistance to soaking and swelling is an important property for thin surface wood fractions, as moisture generally reduces the strength properties of wood (Borůvka et al. 2018). Only a few contributions are devoted to the heat treatment of disintegrated wood, mainly wood-plastic composites (Yang et al. 2017, Hosseinihashemi et al. 2016).

The main effect of heat treatment is a decrease in equilibrium moisture content (Esteves and Pereira 2009). Reduction of equilibrium moisture content results in a consequent reduction of swelling and shrinking of the composite as a whole. The changes are at the morphological level, the variability is large, chemical composition and fiber characteristics of beech wood is different, also within species (Ihnát et al. 2021). Thermal treatments of beech wood with different temperature loads on wood also cause characteristic changes in chemical composition (Windeisen et al. 2007). Therefore, based on our preliminary tests, when higher temperatures caused brittleness of the thin surface shavings, gentle temperature regimes (120°C, 140°C and 160°C) were used. In general, higher temperatures of 160°C-210°C are used in heat treated beech wood research (Borůvka et al. 2018, Hoseinzadeh et al. 2019, Kol and Sefil 2011). Heat treatment generally causes a change in the color of wood (Mitani and Barboutis 2014). Todorović et al. (2012) even tried to determine the properties of heat treated beech based on color. With beech wood, it is generally a problem to maintain natural color of the wood even at lower drying temperatures (Dzurenda and Deliiski 2012).

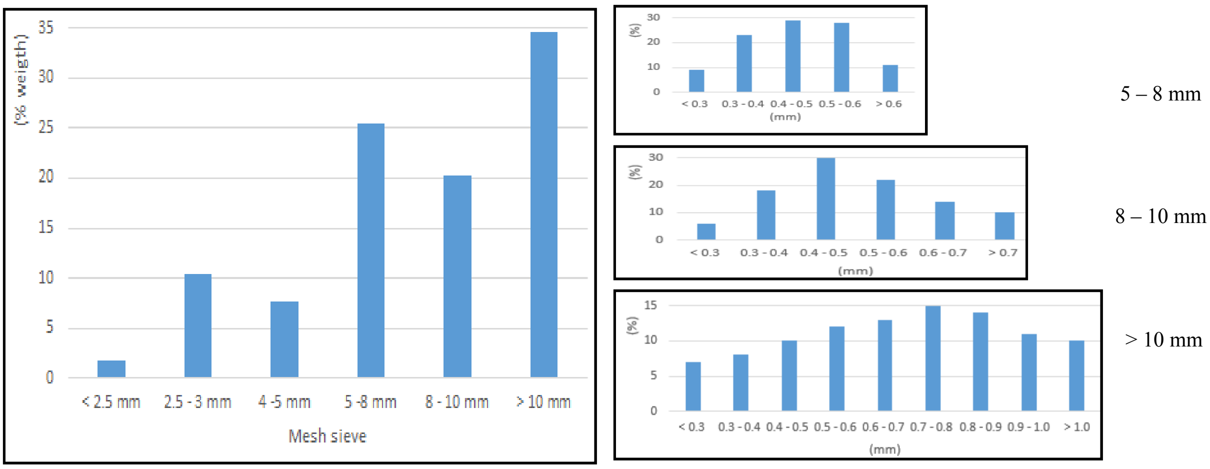
MATERIAL AND METHODS

Sample preparation

For laboratory testing, shavings produced by plane milling at a speed of 8000 rev·min^{-1} with a two-knife spindle (2.45 kW) were used. The slice thickness was set to 1 mm. Beech wood (*Fagus sylvatica*) from a tree stem was used. In the first step, shavings were sieved and smaller particles and dust were removed through a 2.5 x 2.5 mm sieve. The shavings were naturally dried for 14 days and dried for 24 hours at a temperature of 103°C.

Sample description

The mass fraction of beech shavings was determined on an average sample weighing 50.0 g (Fig. 1a). Thickness representation of fractions was determined using a Lorenton and Wettre thickness measure device (SE) on three of the largest factions (mesh above 10 mm, mesh 8-10 mm, and mesh 5-8 mm). These three fractions represent 80% of the total amount of the average sample. A representative sample of 100 particles was selected from the individual fractions. The thickness was measured for a total of 300 particles. Thickness representation of fractions is shown in Fig. 1b.



a) *b)*

Fig. 1: Fractional composition of beech shavings (Fagus sylvatica): a) mass, b) thickness representation of fractions.

Heat treatment of wood particles

A Venticell VC 222 laboratory incubator (1.9 kW) for heat treatment with extraction of excess moisture was used for the treatment. The error in maintaining the set temperature is guaranteed up to 0.4%. Three soft temperature regimes of 120°C, 140°C and 160°C were chosen. The conditioning of the heat treated samples was carried out in a specialized room at a temperature of 23°C and 55% relative humidity for 14 days. Untreated samples for comparing the effect of heat treatment were also subjected to air conditioning. The absolute humidity of the samples after conditioning was determined gravimetrically by drying at 103°C ± 1°C and calculated as:

$$w = (m_1 - m_0 / m_0) * 100 \quad (\%) \qquad (1)$$

where: m_1 - weight of the sample (g), m_0 - weight of the dry sample dried at 103°C until the weight stabilization (g).

Tests of water retention of wood particles

To determine the absorbency of water, a specific procedure was proposed by immersing 50 g of an average sample in water at 20°C for 2 hours and 24 hours. The samples were placed in air permeable plastic bags and immersed in water so that the entire volume was submerged in water. After removal, the samples were immediately placed in a centrifuge at 1400 rpm for 15 min ± 5 s. After centrifugation, the samples were immediately transferred to a plastic bag to maintain a constant environment. Absorption was determined by drying the sample at 103°C ± 1°C, according to Eq. 2. Five parallel measurements were performed for each sample. The weight was determined in grams with accuracy to three decimal places.

$$w_1 = m_{H2O} / m_{a.d.} * 100 \quad (\%) \qquad (2)$$

where: m_{H2O} – the weight of water contained in the sample after 15 min of centrifugation at 1400 rpm determined as the difference in the weight of the wet and dry sample (g), $m_{a.d.}$ – weight of absolutely dry sample (g).

RESULTS AND DISCUSSION

Equilibrium moisture content

The equilibrium moisture content of wood is an important issue, if it can be reduced, wood will be more dimensionaly stable (Bal 2015). The achieved mean values of equilibrium moisture content (EMC) determined according to Eq. 1 are contained in Tab. 1.

Temperature	Duration of heat treatment				
	0 hours	2 hours	4 hours	6 hours	8 hours
Blank 103°C	8.70 (0.59)	-	-	-	-
120°C	-	8.66 (0.28)	8.53 (0.14)	8.22 (0.28)	7.98 (0.44)
140°C	-	8.39 (0.37)	8.33 (0.25)	8.21 (0.10)	7.86 (0.45)
160°C	-	8.07 (0.51)	7.08 (0.38)	6.40 (0.29)	6.19 (0.10)

**Standard deviations are shown in parentheses. Values in (%).*

Tab. 1: The mean values of equilibrium moisture content (%) for beech shavings (Fagus sylvatica) conditioned at a temperature of 23°C and 55% relative humidity for 14 days determined according to the Eq. 1.

EMC of untreated beech shavings (blank), i.e. dried at 103°C is 8.7% (Tab. 1). Heat treatment at 160°C/8 hours causes its reduction to 6.19%, which represents a reduction to

71.1% of the original value. Another heat treatment of 140°C/8 hours causes a reduction to 7.86%, which represents a reduction to 78.8% of the original value, but the lower temperature or a shorter heat treatment time than 8 hours no longer produces the desired results. Although the values measured by us are lower than in the original sample, the practical significance is negligible. Esteves and Pereira (2009) summarized similar small value reductions in EMC for compact (not disintegrated) lumber by other authors.

Heat treatment at temperature up to 160°C, as in our case, is considered as a soft temperature regime. This is due to the use of thin surface wood particles, when partial carbonization occurs at higher temperatures above 200°C (Simsir et al. 2017). Samples of beech shavings treated at different temperatures, during different durations of heat treatment are shown in Fig. 2. Heat treatment at 120°C and 140°C is more reminiscent of a high temperature drying process (Klement and Marko 2009). Bekhta and Niemz (2003) stated that the darkening accelerated generally when treatment temperature exceeded approximately 200°C, but it is necessary to remember that it is a compact piece of wood, when the layers are gradually overheated from the surface towards the center. Thermal treatment of beech wood also results in significantly improved resistance of wood surface to wetting (Kúdela et al. 2020).

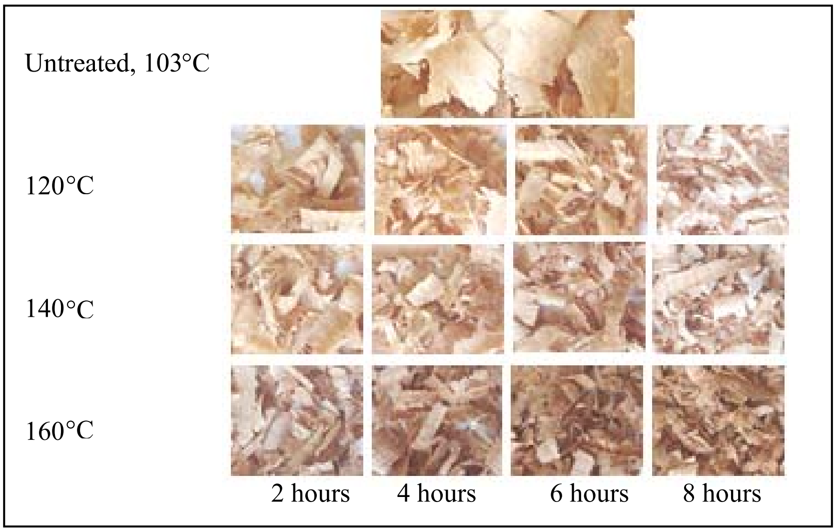


Fig. 2: Beech shavings (Fagus sylvatica) after heat treatment.

Graphical dependence of EMC on the duration of heat treatment and the applied temperature is shown in Fig. 3. The difference when using a temperature of 160°C is striking. Residence time of 8 hours and temperature above 160°C is also important in terms of durability of beech wood (Hakkou et al. 2006).

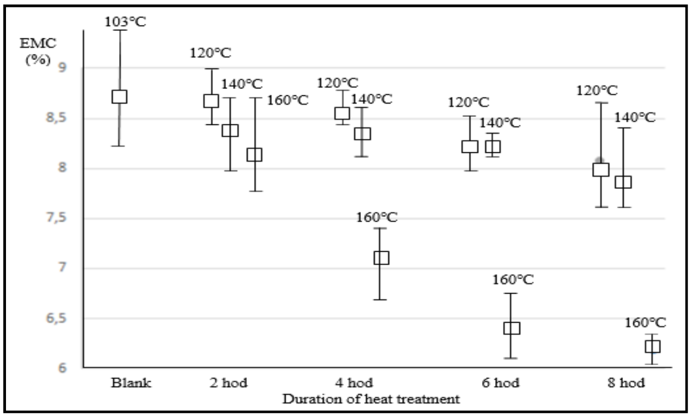


Fig. 3: Dependence of equilibrium moisture content of beech shavings on temperature and duration of heat treatment.

Water retention test results

Moisture contents of beech shavings, related to the temperature and the duration of heat treatment, calculated according to Eq. 2, are presented in Tab. 2. A centrifuge technique was applied before moisture content determination (Cheng et al. 2010). It is useful mainly for water retention value measurements of cellulosic materials, especially disintegrated. It was important to remove water from the surface of the shavings and try to record only the amount that is trapped in the lumens of wood (Boháček et al. 2022).

Tab. 2: Mean values of moisture content (%) determined after water soaking of beech shavings centrifuged at 140 rev.min^{-1} during 15 min.

	2 hours soaking in water					**24 hours soaking in water**				
Duration of thermal treatment	0 hours	2 hours	4 hours	6 hours	8 hours	0 hours	2 hours	4 hours	6 hours	8 hours
Blank 103°C	60.03 (4.62)	-	-	-	-	65.53 (4.45)	-	-	-	-
120°C	-	60.01 (3.81)	60.05 (2.86)	59.47 (3.21)	58.3 (3.89)		65.42 (2.36)	63.99 (2.28)	61.62 (1.34)	60.55 (1.84)
140°C	-	59.67 (3.35)	58.86 (2.24)	57.37 (3.47)	55.21 (3.26)		63.32 (2.07)	61.37 (1.04)	60.20 (2.08)	58.62 (1.98)
160°C	-	50.79 (3.07)	50.08 (2.18)	48.15 (3.27)	47.47 (2.77)		54.23 (2.76)	50.02 (2.72)	48.46 (1.51)	47.79 (2.4)

**Standard deviations are shown in parentheses. Values in (%).*

In general, it can be argued that soaking for 2 hours is not sufficiently long to completely saturate the cells of thin surface shavings. Blank samples were able to receive an additional amount of water, and after 24 hours the average moisture stabilized at 65.53% versus 60.01% (Tab. 2). However, there is not such difference for shavings heat treated at 160°C/8 hours. The moisture content after 2 hours of soaking (47.47%) practically did not change after 24 hours of soaking (47.79%). The absorption kinetics for compact heat treated wood shows that even if the increase in moisture is the highest in the first hours, this increase continues (Čermák et al. 2022), unlike shavings. Mean values of the moisture contents of heat treated beech shavings achieved after 2 hours and 24 hours of soaking in water are shown in Fig. 4 and Fig. 5, respectively.

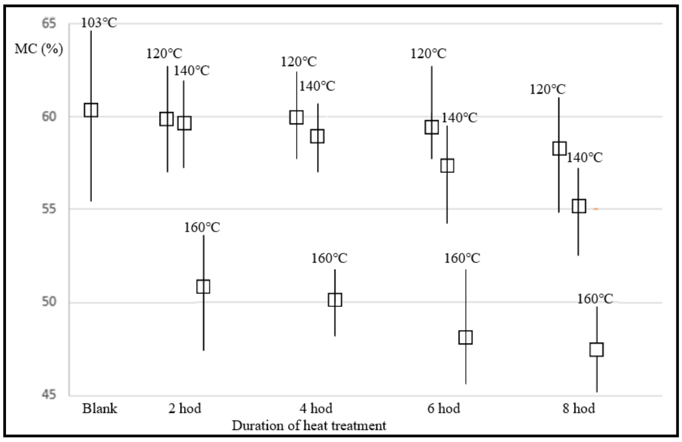


Fig. 4: Moisture contents of heat treated beech shavings achieved after 2 hours of water soaking.

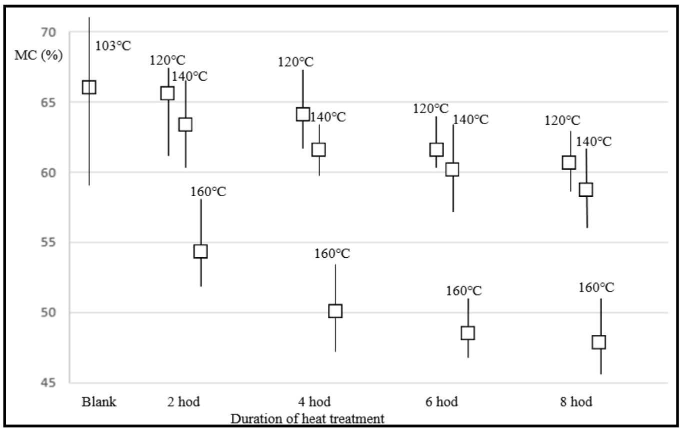


Fig. 5: Moisture contents of heat treated beech shavings achieved after 24 hours of water soaking.

Untreated samples, dried at 103°C, reach the water retention of 60.03% and 65.53% after 2 hours and 24 hours, respectively. Samples heat treated 160°C /8 hours 47.47% and 47.79% after 2 hours and 24 hours, respectively. It can be concluded that the maximum reduction in absorption reached 72.9% of the original value. At 160°C, the difference in retention is negligible for heat treatment residence times of 6 hours and 8 hours. Heat treatment at 120°C and 140°C is not very effective even after 8 hours, the achieved values represent 92.4% and 89.5% of the original value, while the variances of the measured values are relatively high (Tab. 2).

Relation between EMC and water retention

Tests have shown that heat treated beech shavings absorb less atmospheric moisture from the air. This phenomenon leads to a reduction in EMC, which depends on the heat treatment mode. At 160°C /8 hours, we achieved a reduction of 2.51% (Tab. 3). Similarly, heat treated shavings retain less water in their lumens when compared to untreated shavings. In our case, we achieved a maximum reduction of 17.74% at 160°C / 8 hours heat treatment mode.

Tab. 3: Dependence of the reduction of water retention on the change of equilibrium moisture content for heat treated beech shavings.

Heat treatment mode	∆ EMC (%)	Reduction of water retention (∆%)
120°C/ 8 hours	0.72	4.98
140°C/ 8 hours	0.84	6.91
160°C/ 8 hours	2.51	17.74

*Mean values are presented in the tab.

CONCLUSIONS

The ability to receive and maintain water after 2 hours and 24 hours of soaking was determined based on the determination of moisture content for beech shavings exposed to heat treatment at temperatures of 120°C, 140°C and 160°C for 2 hours, 4 hours, 6 hours and 8 hours. After soaking, the samples were centrifuged for 15 min at 1400 rev·min^{-1} to compare only the amount retained in the wood. The results showed that after 14 days of air conditioning at a temperature of 23°C and 55% relative humidity, a decrease in equilibrium moisture content was measured for heat treated beech shavings by 0.68%, 0.8% and 2.47% for temperatures of 120°C, 140°C and 160°C, respectively. The subsequent retention test confirmed the dependence between EMC reduction and water retention. The maximum reduction of absorbency from the original 65.53% to 47.79% (i.e., to 72.9% of the original value) was achieved by heat treatment for 8 hours at 160°C. From a practical point of view, we assume the effectiveness of heat treatment for beech shavings from 160°C and a minimum duration of 6 hours to 8 hours.

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