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IMPACT OF ANGLE GEOMETRY OF TOOL ON GRANULOMETRIC COMPOSITION OF PARTICLES DURING THE FLAT MILLING OF THERMALLY MODIFIED BEECH

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ABSTRACT

This paper deals with particle size analysis of beech wood, considering angular tool (mill) speed and also physical and mechanical wood properties substantially influencing wood processing technology. Particle size analysis was made by sieving the samples using a set of laboratory sieves, with subsequent determination of the individual fraction shares. The results have been compared with respect to the possibility of wood waste separation and filtration, and its subsequent utilization, above all, in production of agglomerated materials and production of wood briquettes and pellets.

By the granulometric analysis there are detected changes in granulometric composition of the particles from thermo beech. The most frequently occurring fractions in native beech samples were ranging 8 - 5 mm and 5 - 2 mm, while powder fractions below 125 μm were found less than 1 % in investigated samples. The most frequently occurring fractions in thermally modified beech wood were ranging 1 – 0.5 mm, share of powder wood particles below 125 μm was less than 4 %.

KEYWORDS: Plane milling, particle size analysis, thermally modified wood, cutting speed, feed speed, splinter size distribution.

INTRODUCTION

Wood is a naturally occurring substance and – like all natural materials – it has specific properties. Similarly, thermally modified wood has its specific properties, which are acquired in the course of thermal treatment. The thermal treatment process is aimed at suppression of wood properties that are detrimental for its use, such as water absorption, swelling, shrinkage and, above all, resistivity against biologic pest (Gaff et al. 2010, Kopecký and Rousek 2007).

Thermally modified wood has been produced almost 15 years in industrial scale. Its production has been launched in a number of West European countries as the response to changing legislation in chemical protection of timber. It was Finland that pioneered production of thermally modified wood (under ThermoWood trade mark). Later on, the production has also been opened in the Netherlands, Austria, Germany and France. Not any toxic chemicals and solely heat (combined with vapour and/or natural oils) are used for production, hence, this is an environmentally friendly method not only in terms of production but also application of this wood material, featuring longer durability compared with native wood both in interior and exterior (Kačíková and Kačík 2011).

Thermal wood modification is based on thermal and hydrodynamic wood treatment procedures at temperatures ranging 150–220–260°C. High temperatures cause decomposition of specific construction timber polymers, creating new substances that are not water-soluble, and also substances killing or repelling biologic pest agents, such as moulds and decay fungi.

Production process of ThermoWood contains the following steps (Fig. 1):

1. Growth of the drying temperature
2. Thermal modification
3. Cooling and moisture content modification

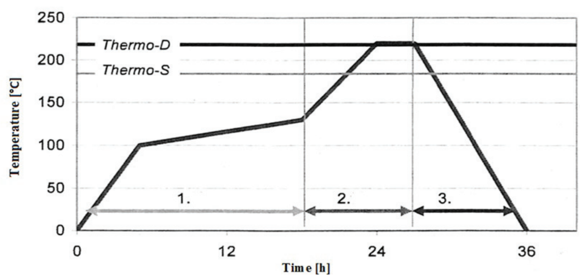

Fig. 1: Schedule of ThermoWood production (Mayes and Oksanen 2002).

Thermal wood modification is based on thermal and hydrodynamic wood treatment procedures at temperatures ranging 150–220–260°C. High temperatures cause decomposition of specific construction timber polymers, creating new substances that are not water-soluble, and also substances killing or repelling biologic pest agents, such as moulds and decay fungi. Wood strength as well as certain mechanical properties of thermally modified wood becomes reduced (Yildiz et al. 2006, Mburu et al. 2008, Esteves and Pereira 2009). The influence on mechanical parameters is substantially less dramatic if thermal treatment of wood is conducted in inert atmosphere, without oxygen, e.g. in vacuum, in presence of nitrogen and oil (Reinprecht and Vidholdová 2008, Gaff and Zemiar 2007, Kubojima et al. 2000).

Milling means the process of machining wood using rotating tools (mill, milling head, shank mill), in which nominal splinter thickness will be changed by depth of material removal, from

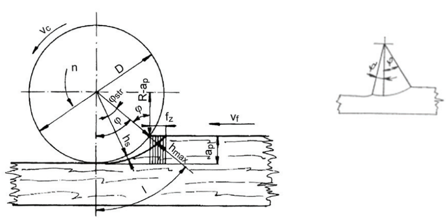

Fig. 2: Separating of splinters in a plane milling (Prokeš 1982).

minimum to maximum value in conventional (orthodox) milling process, or from maximum to minimum value in climb feed milling process. Width or shape of machined wood will also be changed. Material feed is in direction of circumferential speed vector of the rotating cutting tool (Fig. 2). In one rotation, cutting tool is engaged at arch length *l*, corresponding to central angle φ + φ´. Value φ´ is extremely small and, in most cases, it will be neglected in calculation of splinter length *l* (Lisičan 1988, 1996, Buda et al. 1983, Dzurenda 2002, Kvietková and Barcík 2011, 2012).

MATERIAL AND METHODS

The zones suitable for samples were cut from the trunk European beech trees (*Fagus sylvatica* L.) at a height of 2.5 m from the stump. The zones, which were in the middle distance between the pith and bark, were chosen for sample preparation. All the samples were air conditioned in the conditioning room (65 % / 20°C) for more than six months to achieve an equilibrium moisture content of 12 %.

Physical and mechanical wood properties have decisive impact on technological wood processing like pressing, bending, drying, cutting and other manufacturing processes. These features also affect the creation and composition of wood particles during the flat milling. Wood processing and manufacturing affects also physical properties, mainly density and moisture content of wood. Processing of wood is affected also by the following basic mechanical properties: elasticity, toughness and firmness (Požgaj et al. 1993, Šimek 2012). Physical properties were assessed according to standard ČSN 49 0103 (1979).

Beech samples for the thermal modification were put on iron grill, which was further plug into thermal box 103/6200 made by HitwoodOy, Finland, adjusted according to Fig. 3. Time of thermal modification of particular phases was the following: heating -5.5 hrs, drying – 6 hrs, thermal modification – 1 hr, cooling – 9 hrs, total time spent – 27 hrs and 30 minutes.

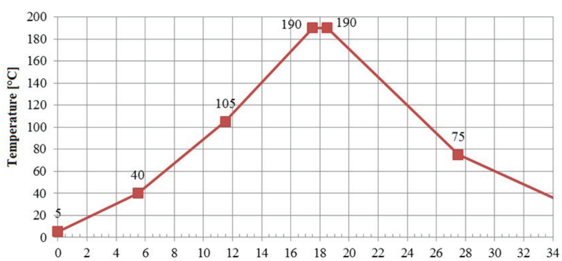

Fig. 3: Process of beech thermal modification prepared for the samples removal.

Thermally modified beech was further cut on timber with the following dimensions: 1 m length and 10 cm width. Then, all material came through align milling machine in order to reach the same thickness – 30 mm. Such modified natural and thermal adjusted material was prepared for the samples removal (Fig. 4).

Fig. 4: Material prepared for the samples removal .

The milling process was carried out using FVS spindle cutter with STEFF 2034 feeding system, produced by Maggi. Cutter parameters and also individual cutting angles are:

FVS with feed systém *STEFF 2034*-Input power 4 kW,
- RPM 3000, 4500, 6000, 9000,
- Cutting speed 20, 30, 40 $m.s^{-1}$,
- Feed speed 4, 8, 11 $m.min^{-1}$.

Cutter Head -Rake angel γ 15, 20, 25°,
- Cutting angle of wedge β 45°,
- Clearance angle α 20, 25, 30,
- Cutting angle δ 70, 75, 80.
-

Sieve analysis was carried out on a vibratory sieving machine (Retsch AS 200) with a sieving time of 5 min and breaks every 10 s. The machine was equipped with sieves with mesch sizes of 0.032, 0.080, 0.5, 1, 2, 5, 8 and bottom sieves were in accordance with ISO 3310-1 (2000).

RESULTS AND DISCUSSION

Physical and mechanical properties

Average moisture of native beech wood is 10.5 %, which corresponds to wood humidity in environmental conditions φ = 65 ± 3 %, t = 20 ± 2 %, i.e. wood moisture being approximately 12 % (Peschel 2002, Horák 1996). Average moisture of thermally modified beech is 2.6 %. Maulis (2009) and ThermoWood Handbook (2002) indicate 4 % moisture for thermally modified beech wood, at comparable conditions. In ThermoWood Handbook (2003), humidity reduction up to 50 % compared with original humidity value has been claimed. The results of our investigation are provided in Tab. No. 1.

Tab. 1: Humidity and heat-treated natural beech (190°C, 1 h).

Natural beech	
Minimum value (%)	9.9
Maximum value (%)	10.6
Median (%)	10.5
Standard deviation	0.29
Coefficient of variation (%)	2.8

Heat treated beech	
Minimum value (%)	1.6
Maximum value (%)	3.0
Median (%)	2.6
Standard deviation	0.53
Coefficient of variation (%)	20.6

Average density of native beech measured by us, is 715 $kg.m^{-3}$. This corresponds to 720 $kg.m^{-3}$, as indicated by Prokeš (1982). Average density of thermally modified beech after 1-hour exposure to temperature 190°C is 686 $kg.m^{-3}$. Hence, density of thermally modified beech wood is lower by 29 $kg.m^{-3}$, i.e. reduction amounting approximately 5 %. This is attributable, primarily, to reduction in weight. This fact has also been confirmed in ThermoWood Handbook (2002). Maulis (2009) indicates 10 % density reduction of thermally modified beech wood, however, at the temperature of 210°C.

Static bending strength (MOR) is 120.2 MPa (average value). This result is comparable with the values indicated for bending strength of beech wood at 12 % moisture. Prokeš (1982) indicates bending strength value amounting to 123 MPa. Bending strength of thermally modified beech wood increased by 32.5 MPa, thus reaching 152.7 MPa. Increase in bending strength of thermally modified beech makes approximately 25 % of that of native beech wood. This increase has been achieved owing to short period of applied temperature. According to indicated data, "ThermoWood" modification technology results in unchanged or slightly increased bending strength in case of a moderate treatment procedure (Thermo-S).

Measured and calculated results of impact toughness showed reduced value for thermally modified beech, while average impact toughness of native beech is approximately 10.8 $J.cm^{-2}$. Average impact toughness of thermally modified beech has been reduced to 8.7 $J.cm^{-2}$, i.e. approximately 20 less than original value. This value is less dramatic than that indicated by various authors, i.e. up to 50 % (Maulis 2009). Lesser reduction of impact toughness in wood samples investigated by us can be attributed to lower wood modification temperature and also shorter time of exposure.

Angular geometry

Granulometric composition of a particle has similar behaviour at the change of angle geometry of a tool within the same shift and cutting speeds. Given fractions differ only in percentual ratios. When v_c= 20 $m.s^{-1}$ and v_f= 11 $m.min^{-1}$ then it is more difference in the biggest native beech fraction.

At the cutting speed v_c= 20 $m.s^{-1}$ and shift speed v_f= 4 $m.min^{-1}$ there is evident that the highest proportion of native beech samples ranges between 5 and 2 mm in all three alternatives of angle geometry. 80-90 % is from this fraction. Shares of particular native beech fractions are comparable but they cover less than 10 %. Thermally modified beech expressed the highest amount (cca 48 %) of fraction ranged between 1 and 0.5 mm at the milling machine under 20° angle.

Under conditions of v_c = 20 $m.s^{-1}$ and v_f = 8 $m.min^{-1}$ the highest proportion of beech fraction ranged between 5 and 2 mm at the angle γ = 20°. Thermally modified wood contains mainly fraction 1 – 0.5 mm at the angle γ = 20°. Fraction of modified wood has comparable proportion (cca 30 %) in two scales of grain: 5-2 mm and 1 – 0.5 mm at all angles of the tool.

Under the speeds v_c = 20 m.s^{-1}, v_f = 11 m.min^{-1} the meaning difference in the proportion is at the fractions dimension above 8 mm native beech. 75 % of all these samples are made under γ = 25° angle. But at the angle γ = 15° this fraction covers cca 47 % and at angle γ = 20° it is only 6 %. The highest amount of thermo beech fractions are at the range 5 – 2 mm and at the angle γ = 25° but flow of the distribution curve is too similar with all angles.

Under the speeds v_c= 30 m.s^{-1}, v_f= 4 m.min^{-1} granularity of native beech has comparable results at all angles of a tool and the highest fraction is within the interval 5 –2 mm and γ = 25° angle. Thermally modified beech has highest amount of fraction within the interval 1 – 0.5 mm and γ = 20° angle.

Under the speeds v_c=30 m.s-1, v_f= 8 m.min^{-1} there is very similar granularity at native beech and the highest levels are within the interval 5-2 mm (cca 53-58 %) for all used angles. Thermally modified beech has comparable results of granularity with the different share of fractions within the interval 2-1 mm and with the highest proportion in the interval 1 – 0.5 mm for all types of angles.

Under the speeds v_c=30 m.s^{-1},v_f = 11 m.min^{-1} is the highest level of native beech fraction within the interval 8-5 mm and angle is γ = 15°. For the angles γ = 20° and γ = 25° is the highest level of fraction in the interval 5-2 mm. Thermally modified beech has highest amount of fraction within the interval 1 – 0.5 mm and γ = 15° angle.

Under the speeds v_c= 40 m.s^{-1}, v_f= 4 m.min^{-1} for the native beech is the highest level (85 %) in the interval 5-2 mm at the angle γ = 20° but other fractions have lower highest level (50 %) within the interval 8-5 mm, γ= 15° angle and interval 5-2 mm at the angle γ= 25°. Thermally modified beech has similar highest level (cca 45 %) in the interval 1 – 0.5 mm for all angles.

Under the speeds v_c = 40 m.s^{-1}, v_f = 8 m.min^{-1} for the native beech is the highest level (cca 55 %) in the interval above 8 mm at the angle γ = 15° but for angles γ = 20° and γ = 25° is the highest level (cca 47 %) comparable to intervals 8 – 5 mm and for 5 – 2 mm. Other ratios of the interval are much more below 2 %. Thermally modified beech shows highest level (cca 48 %) in the interval 1 – 0.5 mm at the angle γ = 20°, other angles have lower highest level but the behaviour of granularity is similar.

Under the speeds v_c = 40 m.s^{-1}, v_f = 11 m.min^{-1} is the highest level (cca 65 %) in the interval 8 - 5 mm at the angle γ = 25° but for angle γ = 20° and γ = 25° there is similar granularity curve. Thermally modified beech has the highest proportion of fraction (cca 43 %) in the interval 1 – 0.5 mm at the angle γ = 25° and it is the same as in the curve for the angle γ = 20°. The granularity curve for the modified beech for the angle γ = 15° has two similar maximums (cca 30 %) in the interval 5 – 2 mm and 1 – 0.5 mm.

CONCLUSIONS

As documented by the results of particle size analysis, milling of thermally modified beech causes changes in particle size distribution and also shares of individual fractions vs. native beech wood. These data are important for designing air exhaust system and, above all, for modification of design and type of cleaning systems to suit to specific shares and types of splinter fractions.

Changes in the parameters of particular fractions share resulted in the lower level of the dominant fraction at the thermally modified beech. This level was below 50 % for all milling conditions. Other nearest shares of the fractions reached 30 % share for thermally modified beech, the lowest dust fractions below 125 μm were below 4 %. For the native, not modified beech, the most frequent fractions reached 90 %. Other nearest fraction sizes has only 10 % share.

The most frequently occurring fractions in native beech samples were ranging 8-5 and 5-2 mm, while powder fractions below 125 μm were found less than 1 % in investigated samples. The most frequently occurring fractions in thermally modified beech wood were ranging 1 – 0.5 mm, share of powder wood particles below 125 μm was less than 4 %.

Based on the results obtained in this investigation, it can be said, that the difference between native and thermally modified wood splinters are comparatively small, since the smallest and the biggest splinter fractions are similar. Consequently, it is not necessary to use other type of cleaning equipment for milling thermally modified wood, as is normal with exhaustion of native wood splinters at machining.

For exhaustion of beech wood splinters during plane milling processes, fabric-filters as well as mechanic separators allowing separation of small particles (separation limit 10 micrometers) can be used in filtration and cleaning systems to comply with environmental standards of separation of disintegrated wood substance from air. The separation limit is specific parameter of the separator unit and indicates the size of the smallest "a" (μm) particles that can be separated using relevant unit.

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