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GRANULOMETRIC COMPOSITION OF CHIPS AND DUST PRODUCED FROM THE PROCESS OF WORKING THERMALLY MODIFIED WOOD

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ABSTRACT

The granulometric composition of chips and dust from the longitudinal milling and sanding of thermally modified oak and spruce wood over a set of modification temperatures: 160, 180, 200 and 220 °C is determined and differences between the factors affecting the granulometry during these two woodworking processes are defined in the paper. Sieve analysis yielded percentages on individual sieves. Residual curves were used to emphasize the difference in these technologies in the granulometric composition, where a shift to the left signals smaller (finer particles) or dust particles. While the sanding dust residue curves shift to the right due to the elevated temperature of the wood treatment, i.e. towards larger fine particles and medium coarse particles, the chip residue curves from the milling process shift to the left, with a higher share of medium coarse, fine and dust fractions due as the wood modification temperature increases.

Key words: woodworking, thermally modified wood species, granulometry, residual curves.

INTRODUCTION

Thermally modified wood is a material that is coming more and more to the forefront with efforts to make use of its physical and mechanical properties in areas where it is suitable. The major advantage offered is the ability to use less valuable wood from a temperate zone, which is modified through the application of high temperatures to deliver new properties, many of which approach those of tropical wood species, which they could potentially replace. In order to make adequate use of thermally modified wood, it is necessary to know its response in all potential areas of application. Simply knowing how its properties change as a result of thermal modification or the actual technologies for processing and potential risks are insufficient on their own. For the individual technologies for working thermally modified wood, it is important to know how this wood will respond in terms of workability, emissions and the resulting surface quality, which have been the focus of numerous authors (BUDAKCI *et al.* 2013, KVIETKOVÁ *et al.* 2015, KAPLAN *et al.* 2018, SANDAK *et al.* 2017, KUBŠ *et al.* 2016, KOLEDA *et al.* 2018). A specific area within the individual methods of mechanical working of this wood is the actual chip forming process, or the granulometry of the chips or dust that form, which remains a little explored area in terms of the modification of wood by applying high temperatures and it is necessary to determine if the secondary material (chips and dust) may be used, what percentage of fine fractions are created by these individual technologies, and if these increase the health and safety risks associated therewith, especially the formation of dust particles with dimensions of ≤ 0.100 mm, which are characterized as airborne, difficult to settle in space, and are a problem for the operating staff (BARCÍK and GAŠPARÍK 2014, DZURENDA *et al.* 2010, DZURENDA and ORLOWSKI 2011, IGAZ *et al.* 2019, KMINIAK and DZURENDA 2019, KUČERKA and OČKAJOVÁ 2018, MIKUŠOVÁ *et al.* 2019, ROGOZINSKI 2016, ROGOZINSKI *et al.* 2017). The occurrence of this dust is problematic in terms of health because they can be inhaled and settle on the skin, in mucous membranes, etc. A safety risk is posed by the fire hazard or explosion hazard they pose, and the smaller the particles generated by a woodworking process and the greater the quantity, the greater the probability of such risks.

Given thermally modified wood is characterised by low strength (both bending and tensile strength) and lower toughness (REINPRECHT and VIDHOLDOVÁ 2008, KAČÍKOVÁ and KAČÍK 2011, THERMOWOOD HANDBOOK 2003, ČABALOVÁ *et al.* 2016), a higher percentage of smaller particles is expected during woodworking (REINPRECHT and VIDHOLDOVÁ 2008, KRÁL and HRÁZSKÝ 2005), as the above-specified strengths are dominant in the chip forming process (SIKLIENKA *et al.* 2017).

The objective of this paper is to compare the influence of milling and sanding technologies of thermally modified oak and spruce wood (modified at temperatures of 160°C, 180°C, 200°C and 220°C) on the granulometric composition of the formed chips and wood sanding dust with confirmation or refutation of the influence of woodworking technology, wood species and modification temperature on increases in the share of fine (particle size ≤ 0.125 mm) and dust fractions (particle size ≤ 0.08 mm).

MATERIALS AND METHODS

Sample preparation

Sessile oak (*Quercus petraea*) and Norway spruce (*Picea Abies*) for experiment were prepared by OČKAJOVÁ *et al.* (2019). The samples were dried to a residual moisture content of 8 %.

Thermally modification of oak and spruce wood is exactly described by KUČERKA and OČKAJOVÁ (2018).

Milling and sanding machines

Lower spindle milling machine ZDS-2 (Liptov machine shop, Slovakia), feeding device Frommia ZMD 252/137 (Machinenfabrik Ferdinand Fromm, Fellbach, Germany), milling head FH 45 Staton SZT (Turany, Slovakia) with diameter of 125 mm and thickness of 45 mm, rake angle $\gamma = 25$ °, cutting speed of 40 $m \cdot s^{-1}$, feed rate of 15 $m \cdot min^{-1}$, depth of cut of 1 mm.

Narrow belt sanding machine JET JSG-96 (JPW Tool AG, Fälladen, Switzerland), cutting speed of 10 $m \cdot s^{-1}$, grit size 80 of sanding belt HIOLIT XO P80 (KWH Group Ltd., Vaasa, Finland), individual pressure of wood sample on sanding belt.

Granular analysis

Granular analysis was made in accordance with the standards STN 9096 (83 4610), STN 153105/STN ISO 3310-1 and steps by OČKAJOVÁ *et al.* (2019). A standard kit of several sieves ordered vertically (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.080 mm, 0.063 mm, 0.032 mm, and bottom of the machinery – dust particles passed through all of the mesh screens) were placed on the vibrating stand of the sieving machine (Retsch AS 200c;

Retsch GmbH, Haan, Germany) with an adjustable sieving interruption frequency (20 s) and a sieve deflection amplitude (2 mm/g).

RESULTS AND DISCUSSION

Residue curves were used to evaluate the measured data, as they give a clear idea of the granulometric composition of the chips and sanding dust depending on the modification temperature as well as the mechanical woodworking technology itself, Fig. 1, 2. While the residue curves for the chips from the milling process move to the left towards fine particles as the wood modification temperature rises for both oak and spruce, the residue curves for sanding dust move to the right towards particles with a lower share of dust fractions with increasing wood modification temperature.

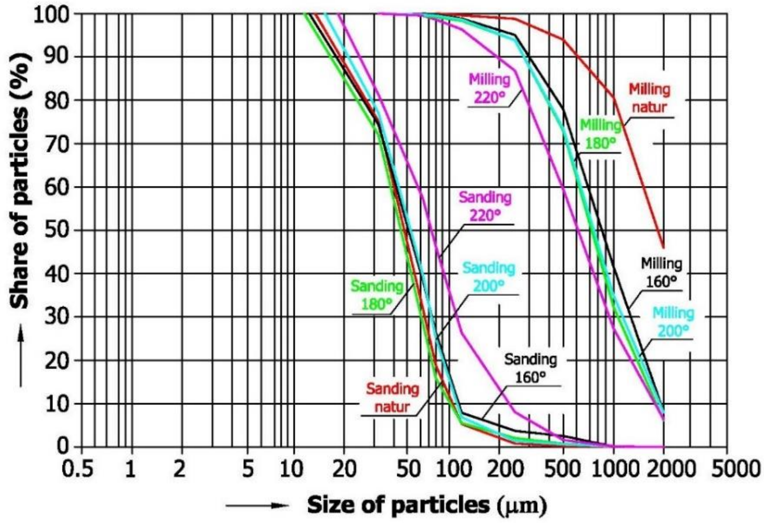

Fig. 1 Residual curves of chips and sanding dust depending on the modification temperature and the mechanical woodworking technology for oak.

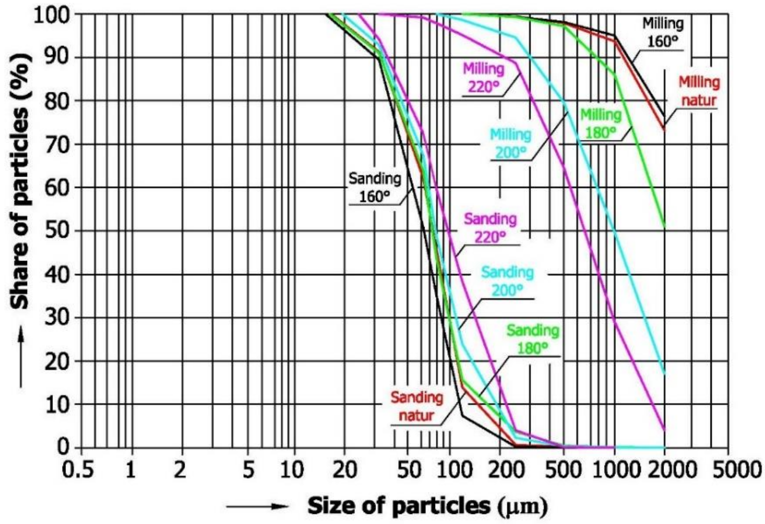

Fig. 2 Residual curves of chips and sanding dust depending on the modification temperature and the mechanical woodworking technology for spruce.

The influence of modification temperature and wood species in milling process

In the case of chips produced from the longitudinal milling of oak, an increase was primarily noted as modification temperature increased among medium chips (0.5 mm and 0.25 mm sieves) along with the share of fine chips and particles size ≤ 0.125 mm as well as dust, particles size ≤ 0.08 mm. The largest share of dust was recorded at a thermal modification temperature of 220 °C – 3.63%. In the case of natural oak, chips in the sieves were predominant (2 mm, 1 mm and 0.5 mm) and the share of fine fractions and dust is approximately 1% and therefore it can be said that the decrease in mechanical properties of the wood manifested at higher modification temperatures, as the wood itself is more fragile, which was reflected in the formation of the dust fraction (REINPRECHT and VIDHOLDOVÁ 2008, KRÁL and HRÁZSKÝ 2005). This change was immediate at a modification temperature of 160 °C.

The chips formed from the process of milling spruce, a coniferous tree species, show a different granulometric composition as compared to oak. Similar values in terms of the percentage share of chips from the milling process were obtained on the 2 mm and 1 mm sieves (i.e. the coarse fraction) for natural spruce and at modification temperatures of 160 and 180 °C, where the share of the coarse fraction was approximately 86.02 ÷ 95.03%. A significant difference was noted at a modification temperature of 200 °C, where the coarse fraction share fell to approximately half compared to natural wood and to about a third at a temperature of 220 °C. At modification temperatures of 200 and 220 °C, the percentage of medium coarse fraction on the 0.5 mm and 0.250 mm sieves increased. At a temperature of 220 °C this share was up to 59.67%, compared to a maximum share of this fraction of 13.19% (at a modification temperature of 180 °C).

The percentage share of the fine fraction**,** particles size ≤ 0.125 mm, for natural wood and wood modified at temperatures of 160 and 180 °C fluctuated in a range of 0.53% ÷ 0.70%, which rose to 5.44% for a modification temperature of 200 °C and doubled again at a modification temperature of 220 °C.

While no dust particles with size of ≤ 0.08 mm were encountered with natural spruce and at modification temperatures of 160 and 180 °C, their percentage share fluctuated from 1.36% to 4.64% at modification temperatures of 200 and 220 °C and the same conclusion may be made as in the case of chips from the oak milling process, whereby at higher modification temperatures, the share of medium chips, fine fractions and wood dust increase, but significant changes only occur at temperatures of 200 °C and above, which correlates to the authors' assertions that changes occurring as a result of increasing temperature occur later in coniferous species as compared to deciduous species due to their higher lignin content (REINPRECHT and VIDHOLDOVÁ 2008, KAČÍKOVÁ and KAČÍK 2009, 2011, GEFFERT *et al.* 2019). The decrease in hemicellulose content as a result of increased temperature is different between maple and oak too (GEFFERTOVÁ *et al.* 2018). ORLOWSKI *et al.* (2019) note that the sawing process on a frame saw produced a different granulometry in sawdust from beech wood and pine at working temperatures of around 105 °C.

The influence of modification temperature and wood species in sanding process

In the case of oak sanding dust, similar shares of particles were obtained on the individual sieves, with a significant change only appearing at a modification temperature of 220 °C. In the case of sanding dust and based on previous research, it may be said that the share of dust fractions, i.e. particles size ≤ 0.08 mm when sanding various types of wood is very high, ~ 85 ÷ 95% (MARKOVÁ *et al.* 2016, OČKAJOVÁ *et al.* 2018), which corresponds to the results from research conducted on natural oak and modification temperatures of 160, 180 and 200 °C, where shares of particles size ≤ 0.08 mm range from 92.10% to 94.72%, with a lower share of only 73.68% at a modification temperature of 220 °C (OČKAJOVÁ *et* *al.* 2019). At this temperature, the share of larger (finer – 0.125 mm sieve and medium coarse – 0.250 mm sieve) particles captured on these ones increased dramatically compared to natural wood, specifically to 18.28% compared to 4.48% and to 6.42% compared to 0.6% for natural wood.

In the case of sanding dust from the longitudinal sanding of spruce, it may be said that the percentage shares of dust fractions (particles size ≤ 0.08 mm) were very high (84.44 ÷ 92.63%) and the values were similar for natural spruce and modification temperatures of 160 and 180 °C. A significant decrease in the value of dust fractions occured at modification temperatures of 200 and 220 °C (76.09 and 61.68%). At a temperature of 220°C, the percentage share of larger particles on the 0.125 mm sieve once again increased to 34.30% compared to natural wood, where this share was only 13.25%, and also on the 0.250 mm sieve (medium coarse particles), where this percentage share of particles is 3.87%, compared to 0.35% for natural wood. Based on these results, it may be said that sanding thermally modified wood does not generate a higher percentage of dust fractions, which was confirmed in experiments conducted by HLÁSKOVÁ *et al.* (2018) on beech wood. The working of such modified wood does not represent an elevated health or safety risk in such establishments, which correlates to the results produced by MIKUŠOVÁ *et al.* (2019), where no significant differences by modification temperature were identified in inhalable and respirable fractions when sanding thermally modified meranti wood.

The influence of technologies

Granulometric analysis from the woodworking processes (milling and sanding) involving thermally modified wood showed a different stratification of chips or sanding dust on the individual sieves. Given that the effects of the thermal modification of the wood did not manifest themselves in a uniform manner in terms of granulometry, we supposed that in addition to the decrease in mechanical properties and decrease in density, a specific role plays the actual chip forming process, which varies significantly in the case of these 2 technologies.

In the case of milling, the geometry of the cutting wedge is defined precisely, and the chips that are created should have the same size, which is given by the cutting tooth feed rate (f_z) and the depth of removal (e), Fig. 3. However, we know that each cutting wedge imparts a velocity to the resulting chip during milling equal to the cutting speed and at the same time the separated chip is deformed in some way from the face of the cutting wedge and receives a certain amount of potential energy. At the moment the chip is separated, this potential energy is transformed to kinetic energy in the form of the movement of the created chip and is therefore higher than the actual cutting speed, which results in the violent collision of the chip against the wall of the exhaust equipment or with other chips and their resulting breakdown. As such, the created chips do not have the same size and in the case of thermally modified wood with degraded mechanical properties and increased wood fragility, this effect may be further enhanced, which results in a higher share of fine chips and dust.

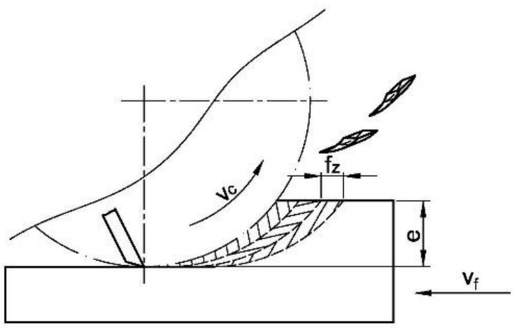

Fig. 3 Chip forming process during milling.

In the case of sanding there is the tool geometry not defined. Each grain, with its varied shape resulting from crushing, with mostly negative geometry, functions as a separate chisel that detaches wood particles, which then melt in front of it in the form of wood dust filling the space between the grains (LISIČAN 1996), Fig. 4.

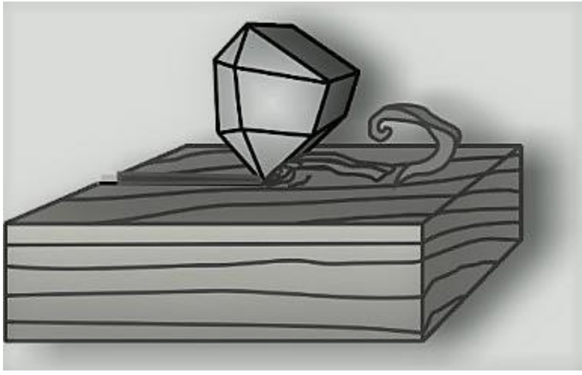

Fig. 4 Chip forming process during sanding (JOBBÁGYOVÁ 2008).

The length of a created chip was theoretically determined by the path of each cutting wedge over the workpiece; however, the cutting wedge deflected and then breaks out of the substrate differently, meaning every chip was different. Cutting speeds were fours of times lower compared to milling and therefore the same may be said of the speed of the particles that were generated. While mechanical properties, including bending strength and shear strength, were involved in the chip forming process and which were degraded by the thermal modification of wood, we supposed that the significant reduction in the density of the wood (OČKAJOVÁ *et al.* 2019) was reflected in the granulometry from the sanding process, which was indicated by previous experiments using various types of wood, with their densities and given that the individual sanding grains more easily penetrate into the wood with lower density and are able to scrape off larger particles (HAMMILÄ and USENIUS 1999, OČKAJOVÁ and BANSKI 2009).

CONCLUSION

Based on the above, the conclusion from the viewpoint of granular analysis is that coniferous and deciduous tree species react differently to temperature increases and there are also differences among deciduous species:

- when milling oak, the change in the granulometric composition of chips was immediate at a modification temperature of 160 °C, in spruce, the modification temperature was 200 °C when this change occurred,
- when sanding oak, the change in the granulometric composition of chips occurred at a modification temperature of 220 °C, in spruce, the modification temperature was 200 °C when this change occurred.

The influence of woodworking technologies manifested itself in the granulometric composition of chips and dust. While a higher share of medium coarse chips, fine chips (particle size ≤ 0.125 mm) and dust too (particle size ≤ 0.08 mm) was produced during milling at higher modification temperatures as a result of the degraded mechanical properties of the thermally modified wood a lower percentage of dust fractions (particle size ≤ 0.08 mm) was produced during sanding and the share of larger fine fractions on the 0.125 mm and 0.250 mm sieves (medium coarse fraction) increased as a result of the lower density of the thermally modified wood.

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