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FACTORS INFLUENCING PARTICLE SIZE DISTRIBUTION OF OAK AND FIR SAWDUST IN CIRCULAR SAWING

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ABSTRACT

Woodworking machines and cutting parameters, as well as processed material properties determine the particle size distribution of chipped wood and as a result also the emission of airborne wood particles at the workplace. The objective of this paper was to clarify the influence of feed speed, cutting angle and wood structure on particle size distribution of sawdust generated during sawing of solid fir-wood (*Abies Alba* Mill.) and oak-wood (*Quercus Robur* L.) with circular saw.

In sawing at lower working table position (which means cutting nearly perpendicular to grain) the share of small particles in sawdust decreases with the increase of feed speed, and oak-sawdust contains more small particles than fir-sawdust.

In sawing at higher working table position, i.e. cutting nearly along the grain, the influence of feed speed on particle size distribution is not quite clear but it seems that with increasing feed speed the share of small particles also increases. It is very interesting that there are more small chips in fir sawdust than in oak sawdust when cutting at upper working table position.

More small particles are produced during circular saw cutting of solid wood with lower feed speed at low working table position than in cutting at high working table position in spite of smaller chip thickness. It could be concluded that the influence of the cutting angle is more significant than the influence of the average chip thickness.

KEY WORDS: sawdust, fir-wood, oak-wood, particle size distribution

INTRODUCTION

Woodworking machines and cutting parameters, as well as working material properties determine the particle size distribution of chipped wood and as a result also the emission of airborne wood particles at the workplace (Kos et al. 2001, Kos and Beljo Lučić 2004). Material capability to fragment depends on dimensions and characteristics of the basic structure elements.

Workers' exposure to airborne wood dust particles in the surrounding air of the workplace may cause different allergy problems and asthma in wood industry. Also, woodworking is considered a high risk activity since it may cause the development of nose and nasal cavity cancer (Noack and Ruetze 1990, Ruetze et al. 1994, Kohler 1995, Rapp et al. 1997).

Consequently, particle size distribution of sawdust, especially the share of airborne wood particles, having origin in different mechanical working of different wood species, is frequently the object of research (Očkajová and Dzurenda 2002, Očkajová and Beljaková 2004, Dzurenda 2004).

Many authors investigate the possibility of reducing the finest (airborne) particles by the control of machining parameters and by varying the cutting speed, feed speed, tool type and tool size, cutting angles, number of blades and processed material (Fujimoto and Takano 2003, Varga et al. 2004, Hemmilä et al. 2003). Airborne dust is determined as a fraction of dust where aerodynamic particle size is 100 µm or less (Hemmilä et al. 2003).

According to the results of the mentioned researches, the average chip thickness is one of the most important parameters for the resulting particle size distribution of wood dust generated during mechanical woodworking. The influence of cutting direction and processed material is also considerable.

Thickness of chip generated in circular sawing depends on cinematic parameters of the working machine, cutting height and working table height in relation to the axes of spindle rotation. In circular sawing, chip thickness varies between minimum and maximum value (δ_{min} to δ_{max}) and the average chip thickness could be calculated according to the relation (Goglia 1994):

$$\delta_a = f_z \frac{h}{l} \tag{1}$$

where:

δ_a – average chip thickness, mm
f_z – feed rate per tooth, mm
h – cutting height, mm
l – cutting edge path, mm.

The chip surface in the plane parallel to the feed speed at every point of cutting edge path is equal to feed per tooth f_z. At circular saw rim there are z cutting edges and feed per tooth could be calculated from the ratio of feed rate per blade revolution and number of cutting edges, or as a ratio of feed speed and edges cutting frequency.

$$f_z = \frac{f_o}{z} = \frac{v_f}{z_s} = \frac{v_f}{v_c} \cdot t \tag{2}$$

where:

f_o – feed per blade revolution, mm
z – number of cutting edges
f_z – feed per tooth, mm
v_f – feed speed, m/s
z_s – edges cutting frequency, s^{-1}
v_c – cutting speed, m/s
t – distance between cutting edges, mm.

The average chip thickness decreases with the increase of the cutting angle and it could be approximately expressed as

$$\delta_a \cong f_z \cdot \cos \varphi_a \tag{3}$$

where:

δ_a – average chip thickness, mm
φ_a – middle cutting angle.

As shown by equations (1), (2) and (3), feed rate per tooth and consequently chip thickness, too, increase with the increase of feed speed but decrease with the increase of cutting speed. Under the same process conditions, chip thickness increases with the decrease of the cutting angle (Goglia et al. 2002).

In the report of experiment results Hemmilä et al. (2003) stated that the cutting speed was proportionate to the airborne dust, i.e. lower cutting speed resulted in decreased dust emission. They also stated that lowering feed speed caused decreasing of airborne dust emission or that it had no clear effect on airborne dust emission. This is quite the opposite of the conclusion made based on relations (1), (2) and (3) and the statement that increasing of chip thickness decreases airborne dust emission. Based on performed investigations, Varga et al. (2004) also stated that increasing feed rate and cutting speed resulted in a larger fine dust fraction when cutting oak-wood and particleboard.

Based on the results of their research, Palmqvist and Gustafsson (1999) came to the conclusion that the average chip thickness had the most important influence on mass concentration of airborne wood particles during machining of different materials.

The effect of cutting parameters on particle distribution of chipped wood is not quite clear because of complex and varying morphology of the processed material, which ranges from softwood through light and dense hardwoods to particleboard, and differences in fragmentation of chips generated during sawing.

The objective of this paper was to clarify the influence of feed speed, cutting direction and processed material structure on particle size distribution of sawdust generated during circular sawing of fir (*Abies Alba* Mill.) and oak (*Quercus Robur* L.) solid wood.

MATERIAL AND METHODS

Sampling of chipped wood was carried out during machining of oak-wood (hardwood) and fir-wood (softwood) with circular saw. Tab. 1 shows the data of cutting parameters and Fig. 1 shows the arrangement of experimental sawing.

The circular saw blade had alternately slanted teeth and it was usually used for wood cutting along and across grain.

Tab. 1: Data of wood material and woodworking machine

Woodworking machine	Circular saw
Power , P_{mn} (kW)	1.1
Rotation speed, n_v (min^{-1})	3824
Tool diameter, D (mm)	300
Number of cutting edges, z	24
Cutting speed, v_c (m/s)	60
Moisture content of wood material, (%)	7.7 – 12.2 %
Working table position, h_{t1} (mm)	55
Working table position, h_{t2} (mm)	106
Cutting height, h_1 (mm)	21 – 27

Granulometric analysis of chipped wood was carried out on samples weighing 40 g with five repetitions. The samples were sieved by use of a laboratory electromagnetic sieve shaker (medium power, vibration amplitude 1.5 mm; τ = 15 min), type RP 08 ϕ200-ϕ203 mm (manufactured by CISA Cedaceria Industrial, Barcelona, Spain). The samples were screened on five mash screens: 1.25; 0.8; 0.5; 0.25 and 0.1 mm (ISO 2395:1990). The mass of individual fractions of chipped material was weighted by electronic precision scales, type Acculab Vicon VIC 412 (Acculab Europe, Sartorius group, Goetingen, Germany). The results of granulometric analysis are shown in accordance with ISO 9276-1:1998.

Tab. 2 shows the fraction of particles in view of the screen mash size and the related particle size.

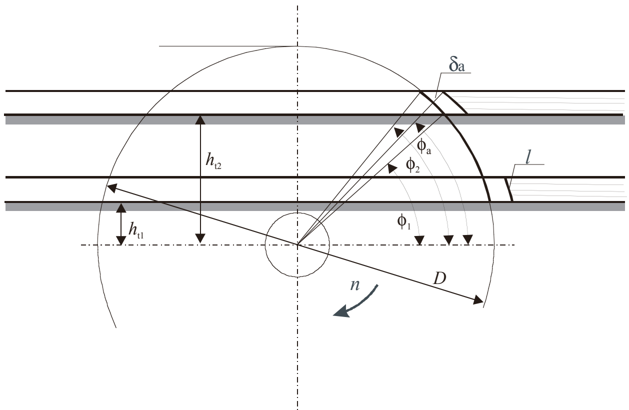

Fig. 1: Presentation of the arrangement of experimental circular sawing and chip crossection

Tab. 2: Fraction of particles and related particle size

Fraction of particles, mm	Particle size number
< 0.1	0.1
0.1 – 0.25	0.25
0.25 – 0.5	0.5
0.5 – 0.8	0.8
0.8 – 1.25	1.25
1.25 <	P1.25

Sawing along grain of oak-wood and fir-wood samples was performed with feed speeds of 33; 18.35; 9.18; 4.58 and 1.8 m/min for fir-wood and 18.35; 13.77; 9.18; 4.58 and 1.8 m/min for oak-wood and at two working table positions (see Fig. 1).

RESULTS AND DISCUSSION

Diagrams in Fig. 2 and 3 present cumulative particle size distribution of analysed fir-wood and oak-wood sawdust, respectively.

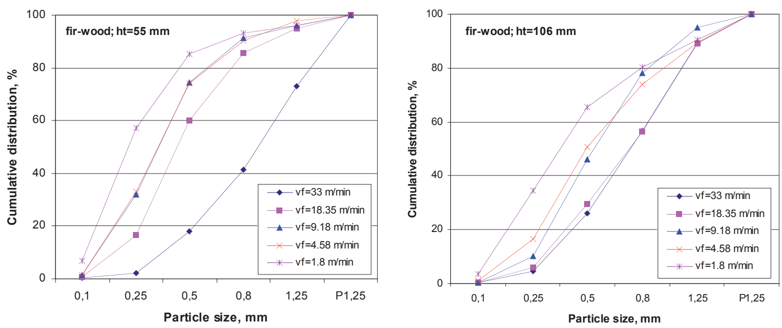

Fig. 2: Particle size distribution of fir-wood sawdust generated during circular sawing with different feed speed and at different working table position

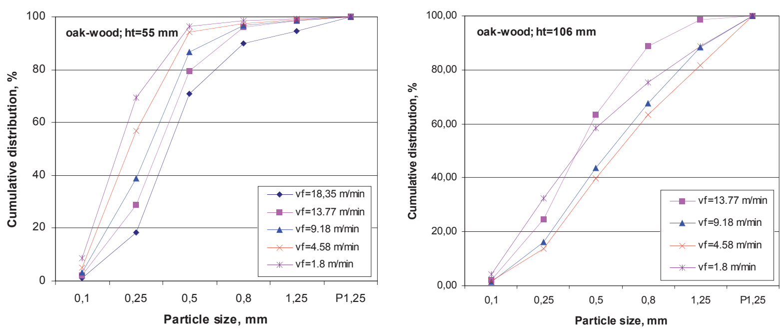

Fig. 3: Particle size distribution of oak-wood sawdust generated during circular sawing with different feed speed and at different working table position

When sawing at a lower working table position (h_{t1}=55 mm), the effect of reducing feed speed obviously results in the increase of share of smaller sawdust particles, which is quite the opposite of the conclusions reached by Hemillä et al. (2003) and Varga et al. (2004).

However, when sawing at a higher working table position (h_{t2}=106 mm) the effect of reducing feed speed on particle size distribution is not so obvious and cannot be clearly interpreted. This part of research is in accordance with the results of research reached by Hemillä et al. (2003) and Varga et al. (2004).

Cutting direction is influenced by the working table position. Lower working table position, or small cutting angle, has resulted in cutting nearly perpendicular to grain and producing shorter and thicker chips. On the other hand, upper working table position has resulted in cutting along the grain and producing longer and thinner chips.

It can be concluded from the experiment results that in sawing wood with a circular saw, when chips are generated by cut perpendicular to grain, the reduction of share of small particles in the sawdust can be achieved by the increase of feed speed. However, in sawing along the grain, the increase of feed speed results in generating sawdust with a higher share of small particles, which is especially emphasised in sawing oak-wood at a higher table working position.

If comparison is made of size distribution of particles generated in sawing fir-wood (Fig. 4) with the same feed speed at different table working positions (different cutting angle), it can be concluded that regardless of lower thickness, chips produced at a higher working table position with feed speed up to 18.35 m/min show a lower tendency to producing small particles, and compared to chips produced in cut perpendicular to grain they have a lower share of small particles.

Consequently it can be concluded that the cutting angle and the form of produced chips have a more significant influence on particle size distribution of sawdust than the chip thickness. The effect of increase of share of small particles by increase of feed speed is noticed during sawing at a higher working table position and that was the reason for higher share of small particles during sawing with feed speed of 33 m/min at a higher than at a lower working table position.

Due to higher specific cutting resistance with respect to fir-wood, it was possible to carry out sawing of oak-wood with the highest feed speed of 18.35 m/min by use of the same machine by which experimental sawing was carried out. The comparison of size distribution of particles generated in sawing oak-wood shows a considerably higher share of small particles generated at a lower working table position. However this difference is reduced with the increase of feed speed (Fig. 5). The effect of increase of the small particles share by increase of feed speed, regardless the bigger chip thickness, can be caused by higher filling of the gullet area at higher feed speed and higher fragility of the produced chips because of the form and physical properties.

Fig. 6 shows the dependence of share of small particles (particle size 0.1 and 0.25) on chip thickness calculated according to the relation (1). As shown in Fig. 6, the share of small particles increases with the reduction of average chip thickness, and this growth is significant when the thickness of chips is lower than the limit value of 0.1 mm, as shown by the research of Palmqvist and Gustafsson (1999). It should be noted that with the same chip thickness, a higher share of small particles is generated when cutting is perpendicular to the grain (sawing at a lower working table position) than in sawing along the grain (higher working table position). In other words, reduction of chip thickness has a higher impact on the increase of share of small fraction when sawing is carried out with circular saw at a lower table position (cut perpendicular to the grain) than at a upper table position (cut along the grain).

Differences in morphological structure of oak-wood and fir-wood affects easier chip fragmentation for oak-wood chips than for fir-wood chips and consequently there are more small chips in particle size distribution of oak sawdust than fir sawdust, as shown by particle size distribution in Fig. 7.

However, this is only true when the cutting direction is nearly perpendicular to grain (lower working table position). When cutting along the grain the results are quite the opposite – there are more small chips in fir sawdust than in oak sawdust (Fig. 8).

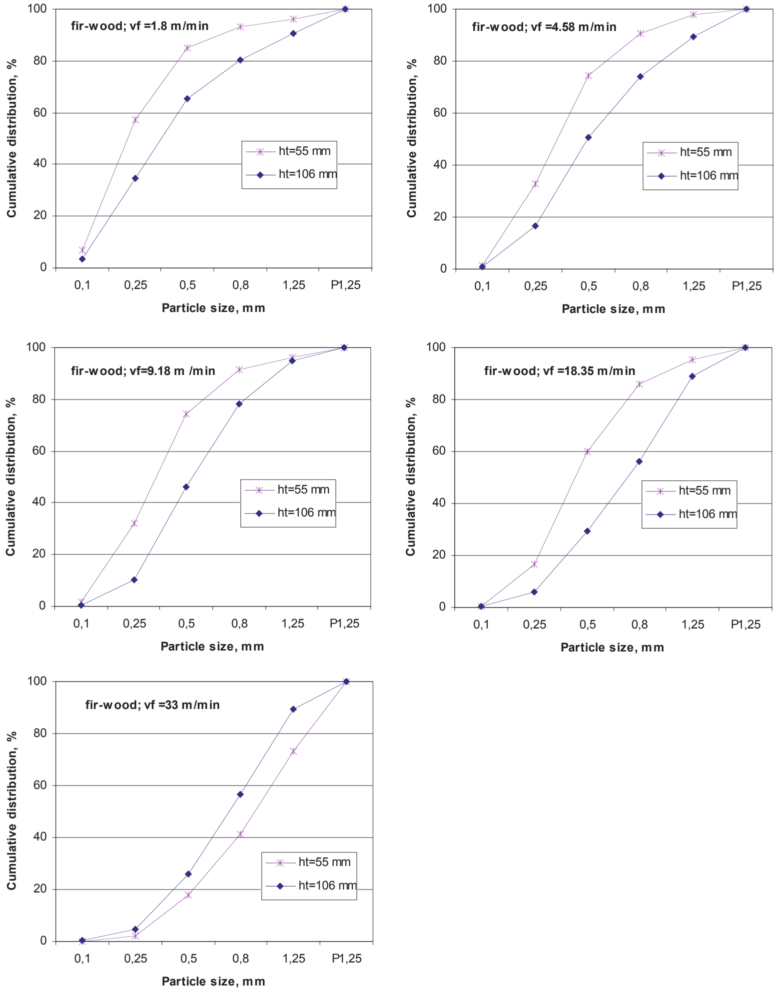

Fig. 4: Particle size distribution of fir-wood sawdust affected by working table position

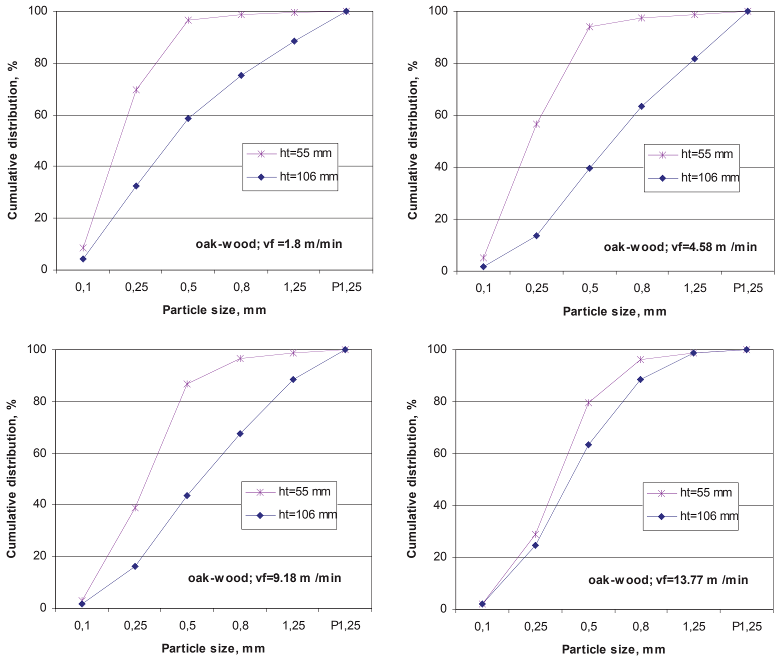

Fig. 5: Particle size distribution of oak-wood sawdust affected by working table position

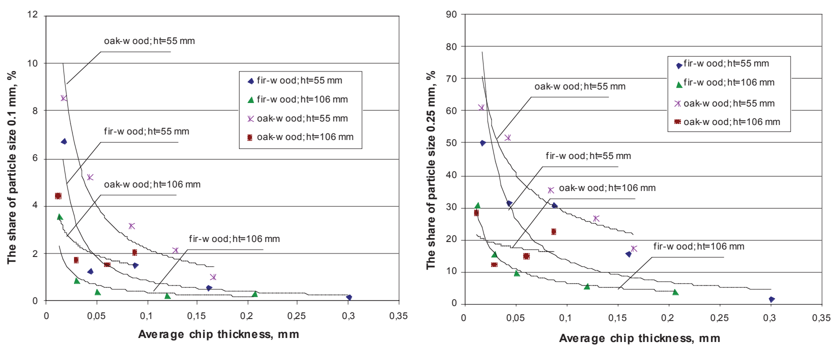

Fig. 6: The share of particle size 0.1 mm and 0.25 mm depending on average chip thickness

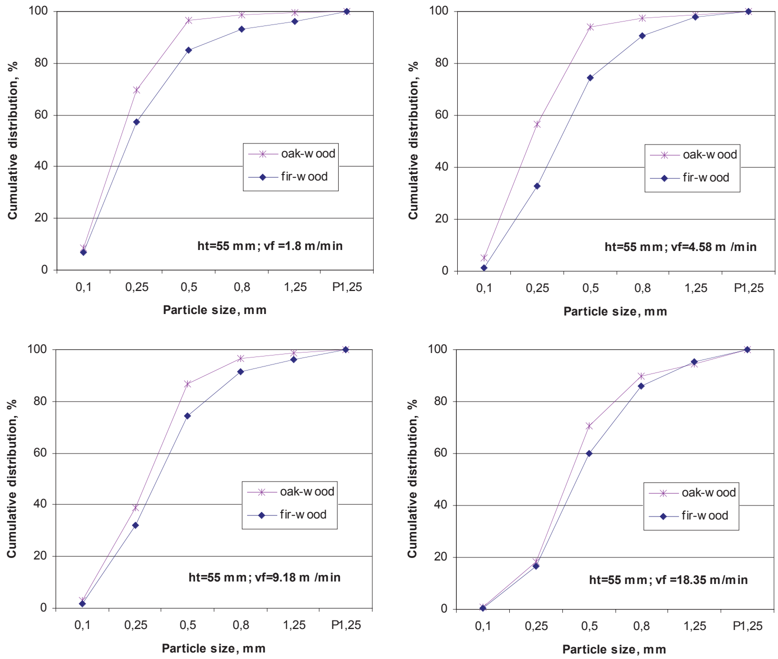

Fig. 7: Comparison of particle size distribution of oak-wood and fir-wood sawdust (working table position h_{t1}=55 mm)

CONCLUSIONS

The optimisation of machining parameters should involve the influence of machining parameters on generating airborne wood dust. One of the most important parameters is certainly average chip thickness (Palmqvist and Gustafsson 1999, Kos and Beljo Lučić 2004). However, according to the results of researches considered in this paper, in circular sawing of solid wood the most important parameters influencing particle size distribution of sawdust is cutting direction related to grain direction and form of generated chips.

It is obvious that the form of an individual particle, which is different with respect to the working table position, also defines the fragility of the produced particle, and hence also the production of even smaller particle fraction. Physical and mechanical features of wood also have a significant impact on the production of airborne wood dust, and to this respect more comprehensive research should be carried out of fragility of specific wood species and wood material.

When sawing at lower working table position (which means cutting nearly perpendicular to grain) the share of small particles in sawdust decreases with the increase of feed speed and hence there are more small particles in oak-sawdust than in fir-sawdust.

When sawing at higher working table positions, i.e. nearly along the grain, the influence of feed speed on particle size distribution is not clear but it seems that with increasing feed speed the share of small particles also increases. It is very interesting that there are more small chips in fir sawdust than in oak sawdust when cutting is performed along the grain.

When cutting solid wood, if trying to optimise machining parameters related to the production of airborne dust, low feed speed should be avoided, especially when cutting perpendicular to grain. When cutting with circular saw at a high working table position, high feed speed should be avoided because chips show a tendency to fragment and generate airborne dust.

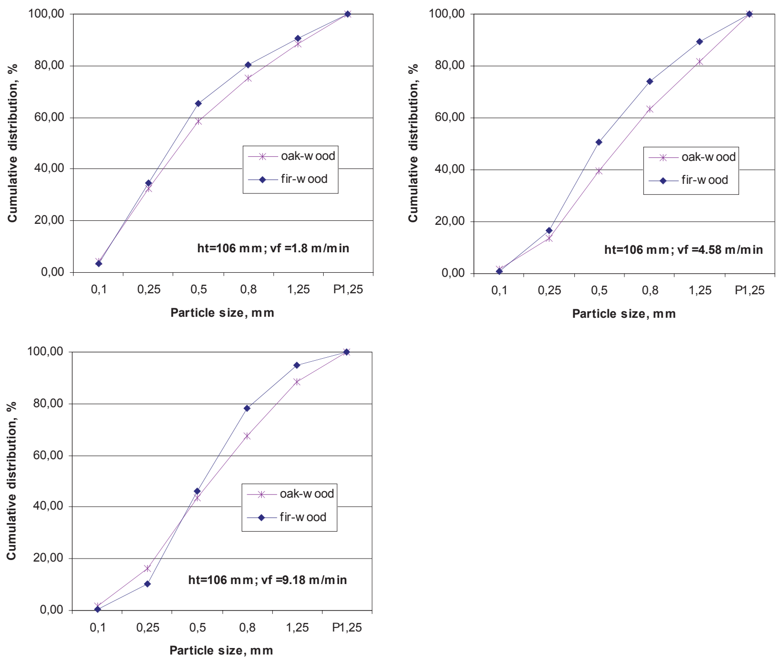

Fig. 8: Comparison of particle size distribution of oak-wood and fir-wood sawdust (working table position h_{t1}=106 mm)

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17. ***ISO 9276-1:1998: Representation of results of particle size analysis – Part 1: Grafical representation

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