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FACTORS AFFECTING THE GRANULARITY OF WOOD DUST PARTICLES

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Abstract
The results of this contribution are focused on the amount of dust particles with the dimension of < 100 µm in diameter (airborne dust particles) that are produced by individual woodworking machines and they might present a potential risk to service personnel if they are not suitably eliminated from this environment. The results of the experimental measurements relating to the factors that affect the granularity of created chip in the wood and wood-based materials processing. Variables for obtaining individual characteristics of dust particles were: a kind of the processed material – coniferous, deciduous tree species, wood-based materials (mainly MDF), its physical properties – density, wood moisture, thermal wood treatment, the tool (type, diameter, angle geometry), cutting speed and feeding speed, model of cutting and chip thickness.

Key words: *airborne dust particles, granularity, wood, wood-based materials*

INTRODUCTION

Wood machining can be classified as a machining with creation of chip and without creation of chip (Lisičan et al. 1996). In many technologies a chip, a sawdust, a splinter and dust (as a bulk material, Dzurenda, 2007) is only by-products, but there are the technologies, where these ones are the main products e.g. chipboard and fibreboard production, pulp and paper industry, production of dimensionally and energetically homogenised fuel – briquettes or pellets (Dzurenda and Kučerka, 2009).
Wood dust as a by-product in woodworking industry is a problem from the viewpoint of their physico-mechanical and chemical properties. Dust according to the ISO 4225, 1994 is defined as *"Dust: small solid particles, conventionally taken as those particles below 75 µm in diameter, which settle out under their own weight but which may remain suspended for some time"*. Wood dust in the working environment can be as airborne or settled dust. In the settled form, it is flammable (spontaneous combustion in contact with hot surface) and in the swirling form, it is explosive in some concentration with air. Dust particles increase the wear of frictional and moving parts of mechanism, affecting safety at work and working environment. Wood dust can affect a woodworker by means of irritants, sensitizers, toxins and carcinogens (Meier, 2008). Individual approach should be taken to each of the exotic woods from the viewpoint of processing technology, toxicity of aerosol and sedimented particles and from the viewpoint of fire and explosion prevention (Klouda et al. 2014).

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For the possibility of utilization of a chip, sawdust, a splinter and a dust not only as a main product but as a by-product, it is very important to know the physical and mechanical properties mainly the size and shape, the amount, some granularity and homogeneity of these wood particles. These characteristics are very important for pulp and paper industry, for uniform chip impregnation, they are the first requirements for the high quality of particleboards and fibreboards etc., (Očkajová, 1996; Medved and Resnik, 2007).
The size and shape, amount, granularity and homogeneity of wood particles determined also conveyer system, exhaust system (Dolny, Potok and Rogozinski, 2013), storage of bulk material, projecting of production shop (from the viewpoint of dust settling) (Očkajová, Beljaková and Luptáková, 2008) and design of an exhaust and filtering/ventilation system (Kopecký and Rousek, 2007).
In wood processing by tool with exactly defined geometry, tool movement, and by model of cutting we can define quite exactly shape and size of created chip and so it is possible to affect its size and shape with accurate choice of kinematics parameters (Dzurenda, 2007; Beljo Lučič et al. 2006; Očkajová et al. 2006), but created splinter or particle is despite the fact smaller in real time because of high speed obtained in the moment of cut (as a consequence of received kinetic and potential energy) with the results of strong impact to walls of exhaust system and impact to each other (Očkajová, 1996). Other condition for chip creation is by using tool with complicated cutter head (a lot of cutting wedges and wedge angles) that resulting in bulk material with no similar particles but with two, three or more types (size and shape) of particles (Dzurenda, 2007; Očkajová a Kučerka, 2011). In wood processing by tool without exactly defined geometry and tool movement (wood sanding), there is no possible to define size and shape of created particle. In wood machining a chip creation is influenced by material itself – native wood (kind of wood with its physical and mechanical properties, moisture content and cutting direction) or agglomerated material (MDF as a homogenous material, or particleboards with various particles in each layers, etc.).
The aim of the proposed contribution is to summarize experimental results which monitor the influence of chosen factors (workpiece, way of machining, tool, kinematic parameters) on granularity of wood particles and wood dust particles (particle size < 100 μm) from the processing of wood and wood-based materials directly at the source.

MATERIAL AND METHODS

The most frequent ways of expressing the grain composition of substances in presented results were the distribution curve or the distribution histogram and the cumulative curve. There were used the fractionating methods of the particle size analysis (sifting).
Samples for the granular analysis of wood dust were taken out isokinetically from the exhaust piping of individual machines (Gravimetric equipment, type MU 5-OT).
Granular analysis was done according to IMP-AS 200 (Methodics for determination of granularity of bulk wood material on the sifting device AS 200, by Retch).
In the experimental measurements, they regarded and assessed the parameters shown in the following Table 1.

Tab. 1 Assessed parameters

workpiece	tool	machine	kinematic parameters
softwood, hardwood, wood-based materials – MDF, plywood	shape and geometry of wedge	type of technological operation	cutting speed
physical properties – density, moisture	diameter of the tool		feeding speed
wood treatment	tool revolutions		chip diameter
			cutting model

RESULTS AND DISCUSSION

The influence of material density, moisture content and treatment on granularity

Material density

The higher density is, the more dust with smaller parameters are produced (Hammilä and Usenius, 1999). In milling process (NC router) of wood material (pine, MDF, plywood), the percentage shares of dust (particle size < 100 μm) are 75 % for pine, 89 % for MDF and 95 % for plywood.

With increasing of wood density in the tested interval from 450 $kg.m^{-3}$ ÷ 774 $kg.m^{-3}$ (spruce 450 $kg.m^{-3}$, poplar 487 $kg.m^{-3}$, alder 527 $kg.m^{-3}$, pine 551 $kg.m^{-3}$, maple 619 $kg.m^{-3}$, beech 624 $kg.m^{-3}$, oak 774 $kg.m^{-3}$) for sanding process (hand belt sander GBS 100 AE), there is increased the percentage share of small fractions (particle size < 100 μm) from 4.2 % to 53.06 %. The share of dust (particle size < 100 μm) for hard wood species is approximately 10-times higher than those for coniferous and broadleaf soft wood species. In sawing process, (universal circular saw), the density of wood species in the tested interval from 336 $kg.m^{-3}$ to 685 $kg.m^{-3}$ (spruce 336 $kg.m^{-3}$, meranti 496 $kg.m^{-3}$, beech 685 $kg.m^{-3}$) does not have a significant influence on particle size distribution of created particles. The share of dust (particle size < 100 μm) is in the interval from 0.59 % to 3.32 % (Očkajová and Banski, 2009).

We can rank the density of wood and wood-based materials among the basic factors affecting the granular composition as well as bulk properties of dust particles obtained in the process of wood machining. Moreover, a higher density value of the processed material also corresponds to a higher proportion of smaller dust particles. However, there also co-operates the particular wood species with its microscopic structure, mechanical properties and also the technology by means of which the dust is formed (exactly defined tool geometry, undefined tool geometry). Machining of hardwood species produces more small dust particles than softwood coniferous species or soft broadleaved species, which is given by their structure. Hardwood broadleaved species have to do with their good mechanical and strength properties, higher density and hardness, which is manifested also by more difficult separating chips. Softwoods are characterised by a simple structure, lower density, lower values of mechanical properties, a cutting tool overcomes lower resistance of wood, there is an easier way of chip formation and chips can be obtained with larger dimensions.

Moisture content

Wood with higher moisture content will create less dust when machined (Heisel and Weiss, 1989; Palmqvist and Gustafsson, 1999). The similar results are obtained by Dzurenda (2004) in sawing process (frame saw RZ-71, log band saw Mini Profi 900, log circular saw UPH 35/850) of wet spruce samples with moisture content of 80 %. The percentage share of airborne dust particles (particle size < 70 µm) was very low, for Mini Profi 900 approx. 2.5 %, for frame saw RZ-71 approx. 2 %, and for log circular saw UPH 35/850 there was not found.

Material treatment

The particle size distribution obtained in planning (WEINIG Powermat 400) of thermally modified beech wood and steamed beech wood is different. The content of particles (thermally modified wood) smaller than 0.25 mm is up to 7 times higher than in particles of steamed beech wood. These results are the consequences of reduced cutting strength and increased of fragility of thermally modified wood. The percentage share of airborne dust particles (particle size < 90 µm) is up to 1.26 % in chips of thermally modified wood (Beljo-Lučic et al. 2009).

The similar results confirmed Dzurenda, Orlowski and Grzekiewic (2010) for sawing of oak wood and Hlásková et al. (2015) for sawing of beech. Thermally modified oak and beech sawdust is finer than unmodified oak and beech sawdust.

By milling of thermally modified beech wood and native beech wood using FVS spindle cutter with STEFF 2034 (altered RPM = 3000, 4500, 6000, 9000; v_c = 20, 30, 40 m.s^{-1}; v_f = 4, 8, 11 m.min^{-1}; tool geometry) the cumulative curves are shifted to the left for thermally modified beech wood (Kvietková, Barcík and Aláč, 2015). Powder fractions below 125 µm were for native beech samples less than 1 % and for thermally modified beech samples less than 4 %. From the viewpoint of wood treatment, there is an interesting result by Martinka et al. (2014). The results obtained by Duncan´s test show that dust particles size (dust with particle size less than 71 µm, from 71 to 150 µm and from 150 to 200 µm) has a significant influence while the thermal modification of spruce (according to ThermoWood – Thermo-S programme) has only negligible influence on dust cloud ignition temperature.

The moisture of machined material or thermal wood treatment affects also strength and elastic properties of wood. Decreasing of wood moisture within bound water or thermal wood treatment increase the strength properties but on the other hand, decrease the elastic properties of wood whereas by processing, the proportion of dust particles increases. The thermal wood treatment increases wood fragility and breaking which also results into the production of smaller dust particles comparing to classic natural wood.

The influence of tool and kinematic parameters on granularity

Tool diameter, tool type and tool geometry

Tool geometry affects the size distribution of dust and chip through the shape of the created chips when processing (CNC processing machinery) oak, when processing beech, whether using the small or large diameter of tool (16 or 60 mm tool diameter), small particles are dominant. This is caused by the difference in material characteristics (Varga et al. 2004).

The tool with a profile disc (profiling MDF on UNIMAT 23EL – 8000 rpm) produced about 16.5 % more dust (particle size < 100 µm) than the tool with a cutter head with four cutters (POWERMAT 1000 – 12000 rpm), (Očkajová and Kučerka, 2009).

Wood sanding by tool with large abrasive grains produces lager dust particles because of its deeper penetration of abrasive grains in wood than small abrasive grains so they produce a lower percentage of particles with the dimension < 100 µm in diameter. Dust proportion (particle size < 100 µm) is in the interval from 6.43 % (grit size 40) to 86.47 % (grit size 120) for wide-belt sander, (Rončka and Očkajová, 2007).

When using a tool with the exactly defined angle geometry and equally set kinematic conditions of machining – there should be regularly formed and created single chips when machining any material. However, just the structure and physical and mechanical properties of wood cause different proportions of single fractions of dust at the same technology because the tree species respond to the interaction with the tool differently. When using a tool with not exactly defined angle geometry, e.g. grinding grains, unified chips, which are not formed and co-acting of tree species with its various structure, thus the different physical and mechanical properties causes a large variability in size, shape, and in granular composition of dust particles. A higher production of dust particles is contributed to a certain degree also by a new generation of tools with a lot of cutting wedges and variable angle geometry.

Chip thickness

In order to reduce the amount of dust, cutting data should be chosen so that the average chip thickness is greater than 0.1 mm. It is of no importance how the average chip thickness is obtained (feed speed, rotational speed, etc.) the dust emitted will be the same (Palmqvist and Gustafsson, 1999). Očkajová et al. (2006) confirmed these results in the sawing process of native wood by the universal circular saw. When the mean chip thickness was 0.105 mm (saw blade with tipped swaged teeth), the amount of dust (particle size < 100 µm) was twice lower than with the mean chip thickness of 0.045 mm (saw blade with triangular asymmetric spring set teeth). All actions leading to some increase of average chip thickness decrease the amount of specific dust (Gottlöber and Hammilä, 2003). In high-speed milling of hardwood (beech) there were confirmed the theoretical hypothesis that the amount of dust particles decreases with increasing the mean chip thickness (Kopecký and Rousek, 2006). For trimming to the size of agglomerated material the percentage share of particles smaller than 100 µm is from 20 to 30 % depending on the chip thickness (0.023 mm, 0.017 mm, and 0.011 mm) (Kopecký et al. 2009).

Beljo Lučic, Čavlovič and Dukič (2007) by comparing feed speed, cutting angle (lower working table position – cutting nearly perpendicular to grain and higher working table position, i.e. cutting nearly along the grain), and wood structure on particle size distribution of sawdust generated during sawing of solid fir-wood and oak-wood with circular saw conclude that the influence of the cutting angle is more significant than the influence of the average chip thickness.

Cutting direction

By comparing the model of sanding (hand belt sander GBS 100 AE) along the wood fibres and perpendicular to wood fibres in sanding process of native wood, the less difference of dust (particle size < 100 µm) is for broadleaf woods (beech and oak) than for coniferous wood (spruce). For spruce there is the difference of 20.43 %, for beech is 10.0 % and for oak only 0.61 % (Očkajová and Banski, 2009).

Cutting and feeding speed, feed per tooth

Feeding speed did not have any clear effect on airborne dust emissions in the process of peripheral milling on standard NC-machines (Hammilä, Gottlöber and Welling, 2003). The same conclusions are in experimental results by Beljo-Lučič et al. (2006).

The increase of feed speed with open cuts (planning, milling) affects the decrease of share of particles up to 100 µm in size. However, with closed cut, the effect of increasing feed speed does not always mean the decrease of smaller particles and it may even have a contrary effect (Beljo-Lučič et al. 2007).

The increased cutting speed is interesting from the viewpoint of increased production but on the other hand, it does not always correspond to some increased production quality. The amount of dust particles increases also with increasing cutting speed. When contacting the tool and workpiece, kinetic energy is given to the particle which equals the cutting speed. The cut off part of wood is deformed, to a higher or lower degree, from the front surface of the knife, i.e. it receives also a certain amount of potential energy which, at the moment of separating of the part of wood (chips) changes into kinetic energy of movement, a result of which can be its following breaking in the exhaust system – the impact on the walls, a mutual impact of particles, etc.

CONCLUSION

To sum up, there is given in this paper the view of the experimental results related to factors that influenced the granularity, especially the dust particles (particle size < 100 μm) created in machining process of wood and wood based materials.

The share of dust particles (particle size < 100 μm) is influenced and increased by:

- density – it has significant impact with decreasing of dust particles (co-operate with material, wood machining, tool type),
- decreasing moisture content and thermal treatment of wood, with changed strength and elastic properties of wood as well, resulting in some increase of wood fragility,
- used tool – proportionally with its diameter, with using the tool with a lot of cutting wedges and the wedge angles, with tool without exactly defined geometry (connected with way of machining),
- kinematic parameters – when the average chip thickness is decreased, revolutions per minute are increased, when cutting direction is perpendicular to the fibres.

There are a lot of altered factors that can be taken into consideration with the aim to decrease wood dust emission in wood machining.

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