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GRANULOMETRIC ANALYSIS OF CHIPS FROM BEECH, OAK AND SPRUCE WOODTURNING BLANKS PRODUCED IN THE MILLING PROCESS USING 5-AXIAL CNC MACHINING CENTER

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ABSTRACT

Granulometric composition of chips resulting from the milling process of beech, oak and spruce woodturning blanks with the thickness of 25 mm using a single milling cutter and a CNC machining center SCM TECH Z5 is presented in the paper. Granulometric composition of chips is observed in the range of commonly used technological conditions for given type of the milling cutter such as feed rate v_f = 1 to 5 m·min^{-1} and the thickness of removed layer e = 1, 3 and 5 mm. The fact that more than a half of the produced chips is a coarse fraction of fibrous chips with dimension more than 1 mm can be stated following the granulometric analysis. Isometric grains, i.e. chips with approximately the same size in all three dimensions are formed from dust fractions smaller than 500 μm. There is, on average, 2.38 % of inhalable dust with particles smaller than 125 μm. The finding that no particles in respirable dust with the size smaller than < 10 μm are formed can be stated.

Key words: CNC machining center, granulometric composition of chips, dust particles, respirable dust.

INTRODUCTION

CNC technology has become an integral part of the woodprocessing industry so far. The CNC machining centers are among the most widely used ones. The 5 axial versions of these centers are trendy. In addition to the basic movements in the X, Y and Z axes, they can also rotate in the B axis (rotational movement around the Y axis) and C (rotational movement about the Z axis). 5-axial CNC machining centers are universal machines that make possible machining of the workpiece in its five basic surfaces and their combinations (the 6th surface is determined for the attachment of a workpiece during the machining process). Because of the versatility of the 5-axial CNC machining centers, the issue of suction of formed chips from the working environment started to be study. Collection bins are used to suck the chips; the bins are pressed against the workpiece surface and suck the sawdust into the ventilation system. Collection bin in the 5-axial version of the machines can be of considerable dimensions with the volume in the range from 0.125 ÷ 0.350 m^3 (significant pressure loss is created). At the same time, collection bin outlet is axial in terms of technical feasibility (while the movement of the produced chips is mostly radial). The problem arises when the workpiece side edges are machined with the tools producing bigger chips. During the milling, a rotating air stream is formed from separated chips. The energy of a mixture of rotating air and chips is so great that its significant part is not carried by the sucked air; it hits the walls of the collection bins and

then falls into the workspace of the CNC machine. The chips cannot be removed by a ventilation system. Therefore the worker "blows" out the workpiece after the final machining by the compressed air which causes secondary pollution of the working environment around the CNC machine (BANSKI and KMINIAK 2018, KMINIAK and BANSKI 2018).

The formed chip is a polydisperse bulk mass consisting of coarse, medium coarse and dust fractions. Wood dust with a grain size ranging from 1 ÷ 500 μm (HEJMA *et al*., 1981, DZURENDA *et al*. 2010, DZURENDA and ORLOVSKI 2011, OČKAJOVÁ and BANSKI 2013, HLÁSKOVA *et al*. 2016, PAŁUBICKI and ROGOZIŃSKI 2016, MARKOVÁ *et al*. 2018,) is a hygroscopic, low abrasive, explosive bulk mass. The ratio of dust particles depends on the characteristics of the processed material, the parameters of the tool as well as the technical and technological parameters of the machining process, (PALMQVIST and GUSTAFSSON 1999, DZURENDA 2002, DZURENDA *et al*. 2006, RATNASINGAM *et al*. 2010, FUJIMOTO *et al*. 2011, OČKAJOVÁ *et al*. 2016, HLÁSKOVA *et al*. 2015).

In terms of physiology and in accordance with international standards (USA - ACGIH, EPA and Europe - ISO, CEN, BMRC) the dust fractions smaller than 100 μm are divided as follows: breathable (inhalable) mass fraction < 100 μm, thoracal 5 ÷ 10 μm, tracheobronchial (respirable mass fraction) 2.5 ÷ 5 μm, high respirable mass fraction < 2.5 μm.

Wood dust from beech and oak, as stated by OČKAJOVÁ *et al*. (2006) is considered to be toxic and is classified as group 1 carcinogen. Pursuant to the Act of the Government Regulation of the Slovak Republic No. 83/2015 Coll. amending the Act of the Government Regulation of the Slovak Republic No. 356/2006 Coll. on minimum health and safety requirements for the protection of workers against the risks relating to the exposure to carcinogenic and mutagenic factors in the workplaces, as amended by SR government in Act No. 301/2007 Coll., the dust with a carcinogenic and mutagenic effect and the concentration of the toxic component of the aerosol cannot exceed the technical values for an existing factor (5 mg.m^3) (the Act of the Government Regulation of the Slovak Republic No. 301/2007 Coll.; No. 471//2011 Coll.).

The aim of the paper is to determine a granulometric composition of the chips (produced chip – a real chip resulting from the machining process, sucked chip - a chip that can be removed from the workspace by a ventilation system) produced using the CNC machining center in the conditions associated with forming the chips with maximum size from beech, oak and spruce woodturning blanks.

METHODOLOGY

Characteristics of the used material – natural furniture woodturning blanks with following parameters: wood species – European beech (*Fagus sylvatica*), English oak (*Quercus robur*), Norway spruce (*Picea abies*), texture – tangential sawn timber, parameters – thickness of 25 mm (± 0.5 mm), width of 80 mm (± 0.5 mm), length of 500 mm (± 1 mm), moisture content of 10 % (± 2 %) were used in the experiment.

Characteristics of the used machine – the experiment is carried out using the 5-axial CNC machining centre SCM Tech Z5 (*Figure 1*) supplied by SCM-group, Rimini, Italy.

Characteristics of the used tool – in the experiment, milling cutter – single-bladed designation KARNED 4451 by the manufacturer Karned Tools Ltd., Prague, Czech Republic was used (mentioned tool was selected due to the assumption that chips of maximum sizes copying the shape of produced chips are formed). Milling cutter was equipped with the reversible blade HW 49.5 / 9 / 1.5 from sintered carbide T10MG.

Characteristics of the milling process – the workpiece was milled under following conditions: material removal rate – e = 1, 3 and 5 mm (the thickness of the removal layer is

based on the standard inputs of the processed materials), rotation speed – n = 20,000 min^{-1} (the value recommended by the tool manufacturer), feed rate – v_f = 1, 2, 3, 4 and 5 $m \cdot min^{-1}$ (maximum feed rate recommended by a manufacturer is 5 $m.min^{-1}$, but the operator adjusts / reduces the value to 1 $m.min^{-1}$ according to the local conditions of the milling process and the required quality of the formed surface). At least six samples were used in the milling process of each combination of parameters, until the chips with the dimensions of 3 × 50 g were formed.

Fig. 1 CNC machining center SCM Tech Z5.

Characteristics of the chip removal process – selected methodology of the chip removal process reflects the requirements to remove actually produced chips not only chips that can be removed by the suction unit as well as the expectation of forming the chips with maximum sizes causing the difficulties during isokinetic removal. During the experiment, the ventilation system of the machine was off and the collection bin was lifted over the working space. The ventilation system of the machine was replaced by the product see *Figure 2*. Intake vacuum of the chips from the workspace was created by a mobile suction unit OP 1500 supplied by Proma SK, Zvolen, Slovakia (with suction capacity of 1,020 $m^3.hr^{-1}$, maximum intake vacuum of 1,400 Pa and suction pipe diameter of 110 mm). Sucked chips were collected on the cloth filter Hyundai VCP 200 by Hyundai Mobis Co. Ltd. South Korea (filter class G3 - STN EN 779/1822). The chips collected on the cloth filter were dropped into the collection bin and the weight of m = 50 g was reached; further analysis were conducted. The intake port for sucking the sawdust corresponded with the resulting direction of the sawdust stream. 3 samples with the weight of 50 g were analyzed for each combination of parameters.

Fig. 2 CNC part for removing the formed chips.

Characteristics of the granulometric analysis – the process of sifting was used to detect the granulometric composition of chips. For this purpose, special set of sieves arranged one above the other (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, 0.032 mm and the bottom) placed on a vibration stand of the sifting machine Retsch AS 200c by the company Retsh GmbH, Haan, Germany was used. The parameters of sifting were as follows: frequency of sifting interruption – 20 seconds, amplitude of sieves deflection – 2 $mm.g^{-1}$, sifting time - τ = 15 minutes, weighed sample – 50 g. The granulometric composition was obtained by weighing the portions remaining on the sieves after sifting using the electric laboratory scales Radwag 510/C/2 by the company Radwag Balances and Scales, Radom, Poland, with the weighing accuracy of 0.001 g. Three samples for each combination of parameters were analyzed in the process of sifting.

In order to specify the information about size of the smallest particles of fine fraction of dry sawdust, a microscopic analysis of granules of fraction of dry sawdust with the size smaller than 125 μm was carried out. Optical method – analysis of the picture obtained from the microscope Nikon Optiphot-2 with the lens Nikon 4×, was selected to conduct the proposed analysis of sawdust. Granules of sawdust were scanned by three low-cost television CCD cameras HITACHI HV-C20 (RGB 752 × 582 pixel), with horizontal resolution 700 TV lines and evaluated by the software LUCIA-G 4.0 (Laboratory Universal Computer Image Analysis), installed on a PC with the processor Pentium 90 (RAM 32 MB) with the graphic card VGA Matrox Magic under the operation system Windows NT 4.0 Workstation. The analysis of picture LUCIA-G enables us to identify the individual particles of disintegrated wood material, quantitative determination of individual particles situated in the analyzed picture and basic information such as: width and length of particles, circularity expressing the measure of deviation of projection of a given chip shape from the projection of the shape of a circle according to the formula:

$$\psi = (4*\pi*S)/P2, \quad (1)$$

where: S – surface of particle [m2], P – perimeter of particle [m]

RESULTS AND DISCUSSION

Average values resulting from three sifting for each combination of examined parameters (wood species, feed rate and the thickness of removed layer) are summarized in *Table 1*.

Characteristics of produced mixture of chips

Fraction chips with dimensions over 2 mm belong to a category of flat chips, i.e. the length and width of the chip significantly exceed its thickness. The chip has the shape of a removed layer of milled wood. When the feed rate was lower, the chips were without breaks. When the feed rate increases, the breaks occur more often. Fraction chips with the grain ranging from 2 mm to 500 μm belong to a category of fibrous chips, i.e. chips with a significant extension in one direction. Fractions smaller than 500 μm, can be characterized as isometric chips, i.e. chips with approximately the same size in all three dimensions. The 1.4 % of inhalable dust with fraction of particles smaller than 125 μm was formed in case of beech wood, 1.95 % in case of oak wood and 3.8 % in case of spruce wood analyzed. The CNC machining centre does not produce respirable fractions smaller than 10 μm.

The gathered data were statistically analyzed and the facts that the factor associated with wood species and the factor associated with the thickness of removed layer are considered statistically significant can be stated. The statistical effect was not confirmed in case of the factor – feed rate.

Tab. 1 Average granulometric composition of chips for considered combinations of material removal rate and feed rate.

Wood species	sieves	Thickness of removed layer **e [mm]**														
		1 mm					**3 mm**					**5 mm**				
		feed rate v_f **[m.min^{-1}]**					feed rate v_f **[m.min^{-1}]**					feed rate v_f **[m.min^{-1}]**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
BEECH	**2mm**	87.60	83.27	93.77	95.43	92.23	84.93	72.39	66.94	63.46	55.87	52.97	46.06	37.70	40.48	37.50
	1mm	6.63	11.97	3.09	2.05	3.13	5.65	6.65	8.56	9.65	10.98	14.25	11.92	9.54	10.60	9.44
	500µm	1.75	2.11	1.05	0.92	2.22	3.43	9.89	10.87	11.58	15.04	11.42	13.68	16.50	18.11	22.26
	250µm	1.34	1.16	0.98	0.81	1.46	2.52	6.42	8.22	10.73	14.45	9.85	13.18	20.19	21.34	25.12
	125µm	1.41	0.92	0.66	0.47	0.50	2.04	3.62	4.66	3.79	2.43	7.46	12.08	13.91	7.60	4.04
	63µm	1.01	0.42	0.34	0.28	0.36	1.10	0.84	0.58	0.62	0.97	3.40	2.61	1.76	1.48	1.26
	32µm	0.26	0.15	0.12	0.04	0.09	0.32	0.20	0.17	0.16	0.27	0.65	0.47	0.40	0.38	0.37
	bottom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAK	**2mm**	84.01	77.90	67.88	70.84	64.72	64.95	74.10	64.77	51.72	44.83	44.01	30.85	33.03	36.10	41.76
	1mm	6.55	8.78	14.83	14.49	17.17	9.90	9.77	15.95	16.84	19.36	14.90	16.36	17.93	15.74	13.75
	500µm	1.72	5.32	7.36	6.53	7.44	9.87	7.83	9.12	12.82	15.96	14.49	17.16	16.78	17.32	16.57
	250µm	2.14	3.48	4.55	4.62	6.12	7.98	4.68	4.41	12.71	14.51	11.57	16.50	18.59	21.51	22.33
	125µm	3.20	3.36	4.08	2.83	3.24	5.10	2.75	4.36	4.75	3.84	9.17	14.42	11.34	7.81	4.67
	63µm	1.96	1.03	1.12	0.62	1.09	1.78	0.71	1.13	0.95	1.18	4.78	4.11	1.91	1.20	0.70
	32µm	0.41	0.13	0.18	0.06	0.23	0.42	0.15	0.26	0.21	0.32	1.04	0.56	0.40	0.32	0.22
	bottom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.01	0.00	0.00
SPRUCE	**2mm**	0.26	3.19	16.55	1.94	47.82	41.74	0.29	27.93	21.19	31.06	46.85	45.05	29.06	42.66	34.12
	1mm	63.86	67.60	56.85	75.26	17.28	25.56	58.92	29.17	38.27	28.63	18.31	14.26	22.98	18.25	29.21
	500µm	14.74	8.66	9.05	11.53	13.57	10.29	16.85	19.24	19.87	22.54	9.12	16.44	23.45	21.16	20.64
	250µm	9.74	10.59	9.34	6.29	11.77	10.87	9.62	12.99	11.39	10.69	13.05	12.98	14.09	10.60	10.56
	125µm	7.27	6.68	5.41	3.10	5.72	6.29	7.51	6.21	5.47	4.49	7.17	6.76	6.66	4.68	3.75
	63µm	3.37	2.88	2.47	1.64	3.05	4.05	5.75	3.33	2.74	2.15	4.16	3.57	2.79	2.06	1.37
	32µm	0.75	0.40	0.34	0.24	0.79	1.20	1.06	1.14	1.07	0.45	1.34	0.95	0.97	0.59	0.35
	bottom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The effect of wood species

Three economically most important wood species in the Slovak Republic – beech, oak and spruce were used in the experiment. Following the statistical analysis of the gathered data, the fact that statistically significant difference among the wood species is in fractions with the dimension over 500 µm (*Figure 3*) can be stated. The fractions with the dimension over 2 mm can be observed especially in chips from beech wood. It is followed by oak and the smallest portion can be seen in the chips of spruce. A lower portion of the fraction over 2 mm is compensated for a higher proportion, in particular, fractions over 1 mm and fractions over 500 µm.

The effect of the thickness of removed layer

An increase in the thickness of removed layer means the length extension of the removed layer resulting in greater friability due to longer contact with the face of tool and thinner chips. As a result of chip friability, a decrease in the portion of fraction over 2 mm and subsequent increase in remaining fractions can be observed (*Figure 4*).

The effect of feed rate

The effect of the feed rate was not proven despite the fact that an increase in feed rate means a decrease in the maximum thickness of the removed layer and an increase in the break occurrence.

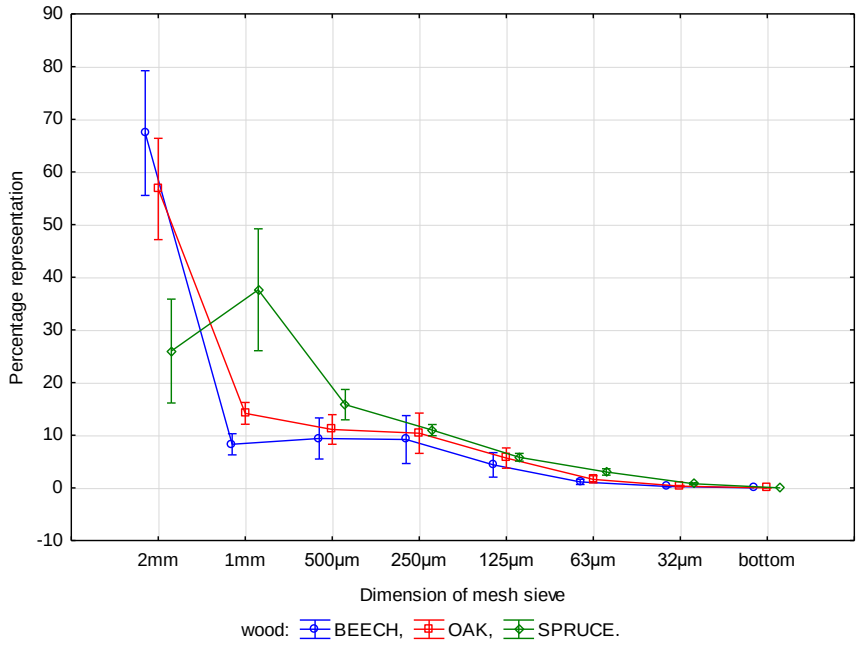

Fig. 3 The effect of wood species on the average granulometric composition of chips.

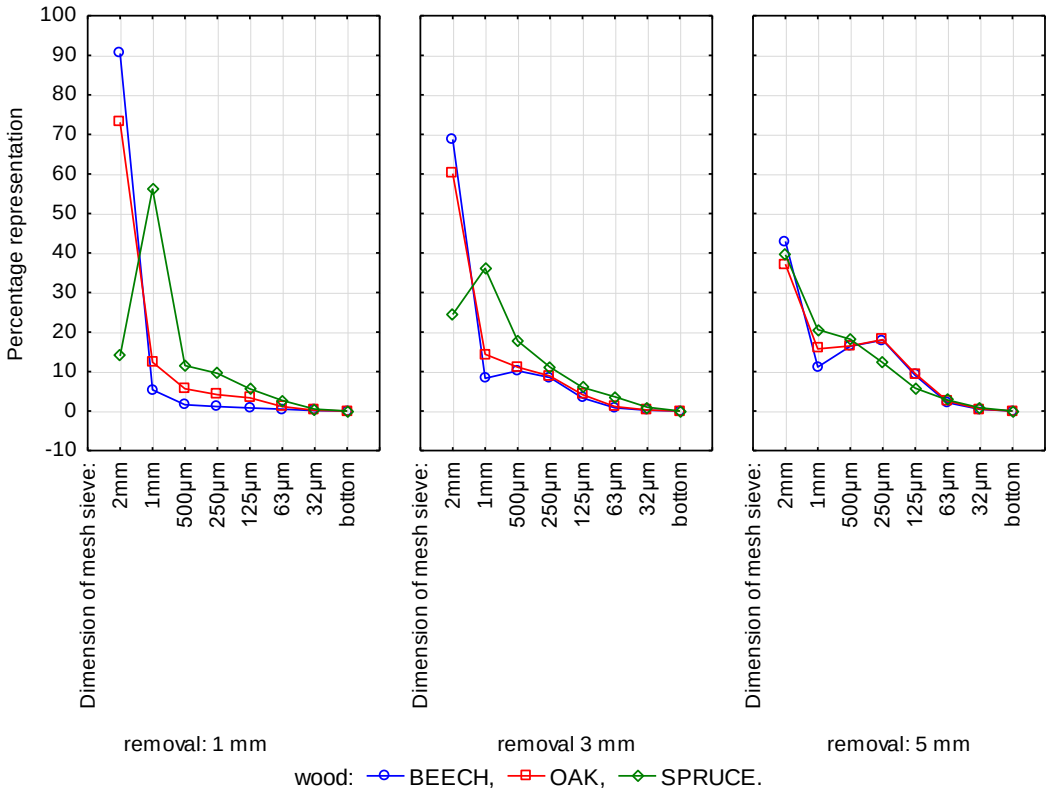

Fig. 4 The effect of wood species and the thickness of removed layer on the average granulometric composition of chips.

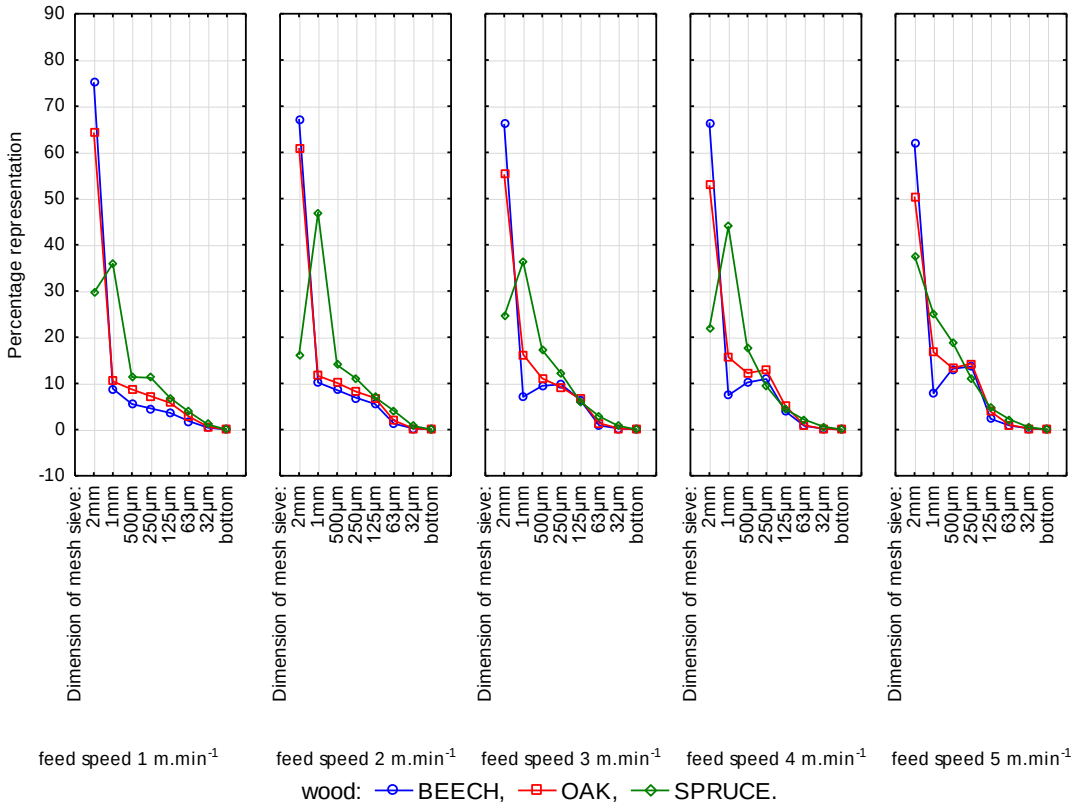

Fig. 5 The effect of wood species and feed rate on the average granulometric composition of chips

CONCLUSION

Following the experiments, we can draw the following conclusions:

- Fractions with dimension over 1 mm are considerable portion of sucked chips.
- On average, 17.85 % of the sucked chips formed during the milling process using the CNC machining centre are dust particles smaller than 500 µm.
- On average, 2.38 % of the sucked chips are inhalable dust particles smaller than 125 µm.
- The occurrence of particles smaller than 32 µm and thus, of respirable particles was not proven.

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