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Design and comparison of a suitable dust separation technique during the machining process in a CNC machining center

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Abstract: *Design and comparison of a suitable separation technique during the machining process in a CNC machining center.* The paper deals with the issue of chip extraction from the milling process in a CNC machining center. The paper aimed to compare the particle size distribution of dust generated in the milling process of natural wood (beech, oak, and spruce) and MDF on a 5-axis CNC machining center. The particle size distribution was evaluated using sieve analysis of samples from the total weight of the captured dust. The results showed that the processing of natural wood is mainly characterized by the formation of coarse dust fractions (2 mm - 1 mm sieves), while the processing of MDF was associated with the formation of fine dust fractions with a size below 100 μm. Another of the objectives was to compare the separation values on the fractional separation curves of selected mechanical separators and filters with the size distribution of dust particles and to propose a suitable separation technique that meets the criteria of "best available technique" (BAT) in the processing of natural wood and MDF, as well as to point out the creation of and the production of harmful dust fractions, which arise mainly during the processing of MDF. We intended to assess whether the introduction of the given technology with the given material mix will also require modifications on the side of the extraction device.

Keywords: wood processing, medium density fiberboard, CNC machining center

INTRODUCTION

The processing of natural wood as well as wood-based materials is almost always associated with the formation of different size fractions of chips, which are often scattered in the air and thus cause health problems for workers who perform their work in such an environment (Simon et al. 2014). Working with wood and exposure to wood dust mainly causes respiratory problems such as cough, upper respiratory tract cancer, chest pain, asthma, shortness of breath, etc. among workers in the woodworking industry. (Mohan et al. 2013, Hlásková et al. 2015, Tureková et al. 2019).

The separation of sawdust from the transport air is carried out using separation techniques such as mechanical separators of the SEA type series with T3/1000 cells, SEB type separators with T4/630 cells, and various fabric filters with dust particle permeability with dimensions below 3,5 μm (Dzurenda et al. 2008). Separators SEA and SEB are used to separate coarse and medium coarse particles such as sawdust, shavings, chips, etc. (Dzurenda 2002). Fabric filters with filter fabrics made of FINET-PES materials are more suitable for extracting finer and fibrous chip fractions. The optimal technical solution of the air-conditioning system and the conditions of the separation of sawdust from the transport air is conditioned, among other things, by considering the knowledge about the physical properties, grain size, and geometric shapes of the chips of the extracted loose wood mass (Mračková et al. 2016, Očkajová et al. 2010, Drevko et al. 2005).

For computer numerical control (CNC) machines, a significant proportion of accumulated wood particles that are not displaced by suction are a problem and pose a health risk to workers (Dünisch & Bauch, 1994).
Machining of MDF panels is characterized by the formation of high amounts of fine dust and a potential risk of exposure to formaldehyde or other adhesive chemicals. It is well known, but it is seldom possible to observe it that it is best to cut MDF outdoors, as it creates a lot of dust. It is also smart to wear respiratory protection when cutting or sanding MDF, to avoid exposure to fine dust and to the resins used in manufacture (Rogoziński, 2016, 2018).
The material separation mechanism creates cracks on the surface (cutting surface) which naturally divides the whole particle into smaller particles before the process of its separation. The mentioned causes are also directly related to the change of the real particle size distribution due to the change of the material (wood) and technical-technological parameters (sliding speed and removal size).
This study aimed to compare the particle size distribution of dust generated during the machining of natural wood (beech, oak, and spruce) and MDF by a 5-axis CNC machine. Another goal was to compare the separation limits on the fractional separation efficiency curves of selected separators with particle-size distributions of dust and to design a suitable separation technique that meets the criteria of "best available technique" (BAT) in the machining of natural wood and MDF, as well as pointing out the formation and production of harmful dust fractions which arise mainly during MDF machining (Rogoziński et al. 2021).

MATERIALS AND METHODS

CNC machine

The experiments were carried out on a 5-axis CNC machining center SCM Tech Z5 manufactured by the company SCM Group, Headquarters Via Emilia 77, 47921 Rimini (RN), Italy. The basic technical parameters of the machining center given by the manufacturer are provided in Table 1.

Table 1. Technical and technological parameters of CNC Machining Centre SCM Tech Z5 used in this work.

Useful desktop	x = 3050 mm, y = 1300 mm, z = 300 mm
Speed X axis	0 ÷ 70 $m \cdot min^{-1}$
Speed Y axis	0 ÷ 40 $m \cdot min^{-1}$
Speed Z axis	0 ÷ 15 $m \cdot min^{-1}$
Vector rate	0 ÷ 83 $m \cdot min^{-1}$
Parameters of the Main Spindle Electric Spindle with HSK F63 Connection	
Rotation axis C	640°
Rotation axis B	320°
Revolutions	600 ÷ 24 000 rpm
Power	11 kW 24 000 rpm
	7.5 kW 10 000 rpm
Maximum tool diameter	D = 160 mm
	L = 180 mm

Figure 1. CNC machining center SCM Tech Z5

Tool parameters

The characteristics of the tool used were as follows: a shank cutter with one reversible razor blade with the designation KARNED 4451, manufactured by Karned Tools, s.r.o., Praha, Czech Republic (Figure 2), was used in this experiment. Reversible razor blades HW 49.5/9/1.5 made of the sintered carbide material T10MG were mounted in end mills from the company BOTO, s.r.o., Nové Zámky, Slovakia.

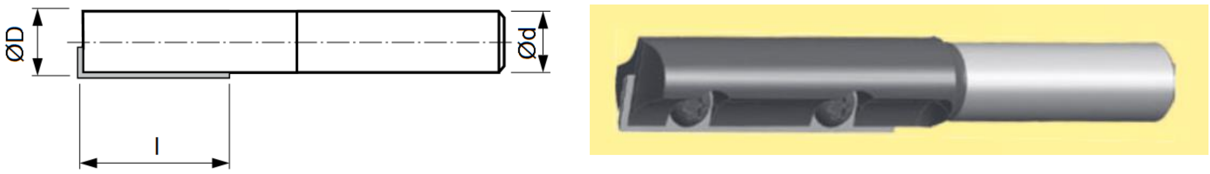

Figure 2. End mill used in the experiment - KARNED 4451 (ØD - working average, l - working length, Ød - clamping diameter).

A milling cutter tool with reversible razor blades was selected for conducting the experiments because it is a frequently used tool in small woodworking companies, due to low operational costs (the tool does not need to be reground; in case of dullness, only reversible razor blades will be turned or replaced). In addition, this tool has zero inclination to the main cutting edge (the cutting edge is parallel to the tool axis) and thus there is mainly axial removal of particles.

The production of furniture blanks was chosen for the experiments. Roughly formatted blanks are finished to nominal size by milling on a CNC machining center (created either by sawing on a formatting circular saw or by nesting milling directly on the CNC machining center) with subsequent technological operations to create technological holes (holes for fittings and fasteners). This represents the so-called finishing technological operation (milling in which the final part is created from the workpiece, where the machining allowances from the side edges of furniture blanks are removed.

This allowance can range from 1 mm (usual machining allowance) to 5 mm (limiting thickness of residual material in nesting milling) depending on the type of previous technological operation. An accompanying phenomenon of milling is that a considerable number of particles formed is not sucked out (production variability requires universal suction baskets typical of their large dimensions and axial outlet for suction pipes). The particle leaves the tool due to the centrifugal force in the radial direction and the individual particles have considerable kinetic energy it falls on the workpiece, on the clamping beams, or into the so-called collecting trough under the workpiece and it remains in the working space of the CNC machine.

Workpiece

Tangential furniture blanks with a maximum deviation of the annual rings from the loading area of the blank of 15°, with moisture content w = 8% ± 1% from two commonly used hardwood species (common beech and sessile oak), and one softwood species (Norway spruce) were used to experiment. Characteristics of the wood raw material used follows.

The dimensions of the furniture blanks used were as follows: thickness h = 20 ± 0.25 mm, width š = 80 ± 0.25 mm and length l = 500 ± 1 mm. The blank surfaces were machined by face milling. Each sample blank was manipulated from a different pillar cutout within a given combination of the technical and technological parameters (sliding speed/removal).

Raw MDF panels, manufactured by the company Kronospan Polska sp. z o.o., ul. Waryńskiego 1, PL-78-400 Szczecinek, Poland, was used for conducting the experiments. The processed MDF blanks had a thickness h = 20 mm, width = 500 mm, and length l = 500 mm.

Milling parameters

The workpiece was milled with an end mill under the following conditions: removal e = 1.3 and 5 mm, cutter speed n = 20 000 min^{-1}, feed speed v_f = 1.3 and 5 $m.min^{-1}$. For each combination of parameters, 6 samples were milled.

Samples for particle size analysis of wood dust were taken isokinetically from the exhaust pipe of the CNC woodworking center by the STN 9096 (83 4610) standard (STN 9096, 2021). The particle size distribution was determined by sieving. A special set of stacked sieves was used for this purpose (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, 0.032 mm, and bottom) placed on the vibrating stand of the screening machine Retsch AS 200c (Retsh GmbH, Haan, Germany). The sieving parameters were by ISO 3310-1 (ISO 3310-1, 2016), sieve interruption frequency 20 seconds, network deflection amplitude 2 $mm.g^{-1}$, screening time τ = 15 minutes, weight 50 g. The particle size distribution was obtained by weighing the proportions remaining on the sieves after sieving on an electric laboratory balance Radwag 510/C/2 (Radwag Balances and Scales, Radom, Poland), with a weighing accuracy of 0.001 g. Screening was performed on three samples for each combination of parameters. Multi-factor statistical analysis of variance (ANOVA) was carried out to discern significant differences at a 95% level of confidence, using a specialized SAS software program (version 9.2, 2010) (SAS, Cary, NC, USA, 2010).

RESULTS

The efficient separation of the individual particle samples was characterized based on the comparison of the separation limits of selected separators with the size of the smallest particle a_{min} (defined by the manufacturer of separation equipment) the dust to be separated assumed as the lower limit of particle-size distribution. It can be stated that the SEB mechanical separator meets best the BAT criteria with cells T4/630 s, with a separation limit of 12 µm and also fabric filters FINET PES 1 with a separation limit of 8 µm on the fractional separation curves of mechanical separators of the SEA type series with cells T3/1000, separators of the SEB type series with cells T4/630 and fabric filters FINET PES 1 with the permeability of dust particles with dimensions below 8 µm with the curves of beech particles (Figure 3). The lower limit of granularity of beech dust particles was already below the limit of separation of mechanical separators, i.e., 40 µm SEA type series with cell T3/1000. These devices are commonly used in woodworking processes.

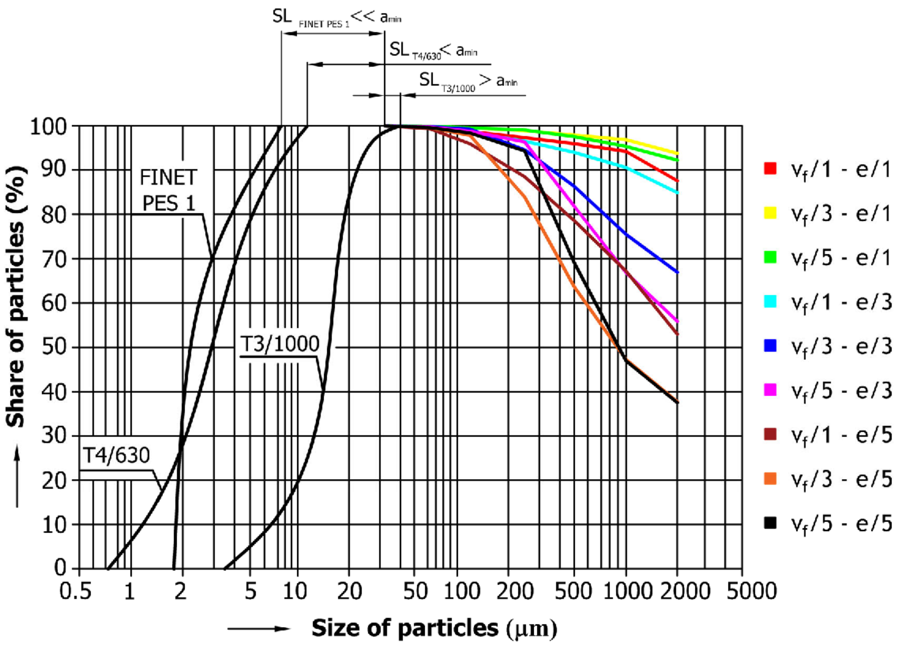

Figure 3. Efficiency assessment of beech particle separation in the individual types of separation techniques

A graphical representation of the curves of the air-transported oak and spruce particles is presented in Figures 4 and 5, respectively. Based on the results, it could be stated that the trends are similar to the ones obtained for machining beech wood. In addition, similar results on the process of dry beech, oak, and spruce wood sawing were reported in the literature (Mračková et al. 2016, Dzurenda et al. 2006, Igaz et al. 2019).

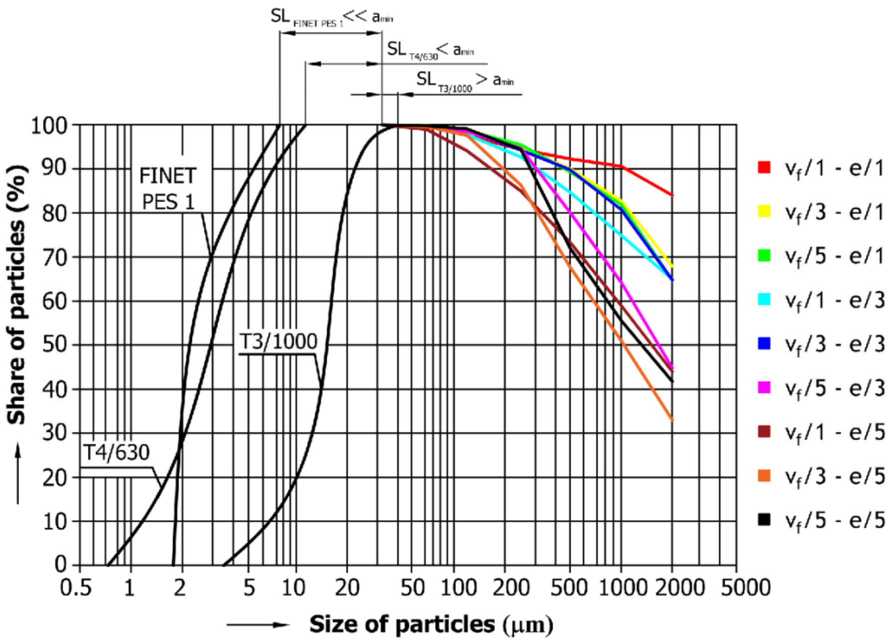

Figure 4. Efficiency assessment of oak particle separation in the individual types of separation techniques

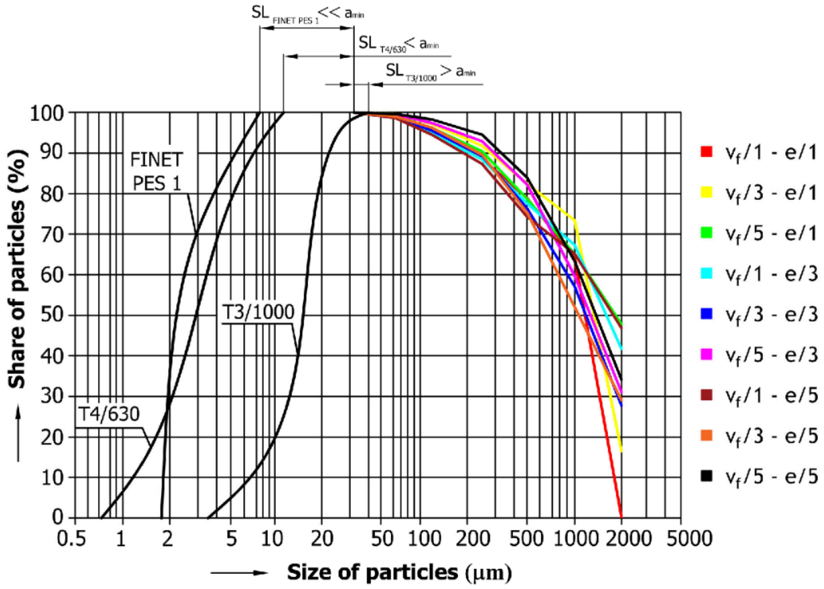

Figure 5. Efficiency assessment of spruce particle separation in the individual types of separation techniques

Noticeably, there was a change in the higher proportion of fine dust particles with dimensions below 32 μm when comparing the curves of residues from natural wood and MDF (Figure 6) and it was significantly below the separation limit of mechanical separators SL = 40 μm type series SEA with cells T3/1000. As there is the greatest presumption of the formation of even finer particles from the point of view of the production program variability, as grinders producing wood dust are usually connected to the air-conditioning system, the concentration of dust fractions of fluffy wood mass is higher than the permissible amount of dust in the recirculated air TZL ≤ 1 mg.m^{-3}. We do not recommend the use of this series mechanical separators because, as mentioned above, these devices will not be sufficient in the case of diverse production. From the point of view of dry particle extraction and its environmental effects it can be stated that vacuum ventilation systems with separators with a separation limit SL ≤ 20 μm are suitable optimal technical solutions meeting the criteria BAT. Mechanical separators with cells T4/630 and fabric filters with filter cloths FINET PES 1 meet the required criterion (Dzurenda et al. 2006, Igaz et al. 2019, Očkajová & Kučerka, 2009, Kopecký & Rousek, 2007).

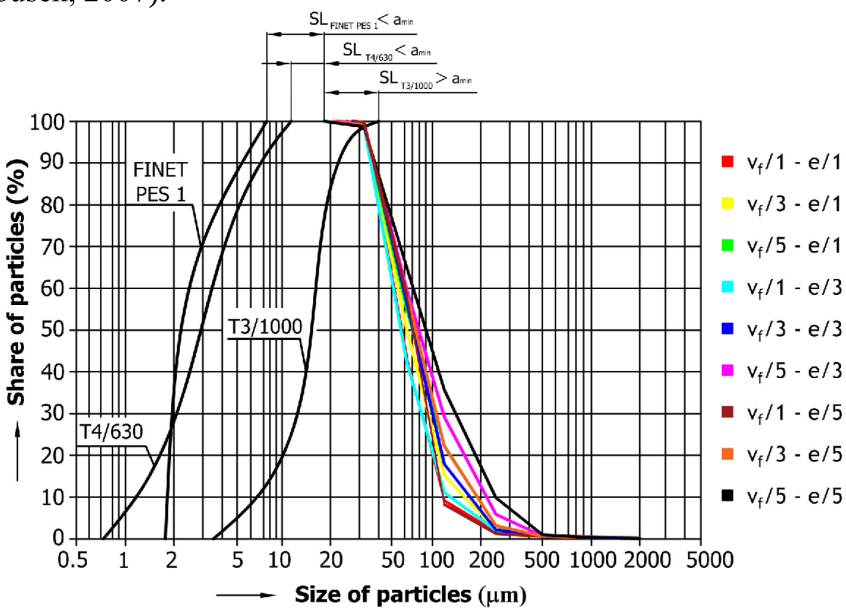

Figure 6. The efficiency assessment of MDF particles separation in the individual types of separation techniques

CNC machine tools are included in the existing extraction units in case of introduction of new CNC technologies or they are connected to additional functioning production units in the working space with installed extraction devices in case of their unsatisfactory absorbency.
Here it is necessary to point out another risk, associated with the usual methodology for assessing the suitability of the extraction type for specific technological equipment. The methodology is usually based on proving the fact that the technological equipment does not form particles with a size below the limit. In real practice this means that it is taken a sample of sawdust/wood dust from the technological equipment, which is subjected to particle size analysis, the usual composition of the nets set is 2 mm, 1 mm, 500 μm, 250 μm, 125 μm, 63 μm, 32 μm, bottom (finer sieve than 32 μm is not chosen based on the nature of the wood dust). Unless particles under 32 μm have not been proved by particle size analysis, it was considered that such particles are not formed in the process and for such technological equipment a suction device with a sufficient separation limit was used, in the case of secondary wood processing with fabric filters with a separation limit at 10 μm.

CONCLUSIONS

This research demonstrated that during the machining of furniture blanks on CNC machining centers, a significant percentage of dust particles with a size below 100 μm is created. The comparison of the particle size distributions of dust generated during machining of natural wood (beech, oak, and spruce) and medium density fiberboard (MDF) by a 5-axis CNC machine in terms of occupational hygiene shown that:
The finest dust is generated during MDF machining. In the case of natural wood, the weight rate of the fine particles is significantly lower than in MDF. There is no clear influence of the feed rate of the fine dust creation, but the removal increasing effects in decreasing of dust particle size.
The comparison of the separation limits of the fractional separation efficiency curves of selected separators with particle-size distributions of dust shows that separator SEA with cells T3/1000 may be not enough efficient for the separation of dust created during MDF machining. All considered separators have sufficient efficiency for dust from natural wood processing.

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Streszczenie: Zaprojektowanie i porównanie odpowiedniej techniki separacji podczas procesu obróbki w centrum obróbkowym CNC. W artykule poruszono zagadnienie odsysania wiórów z procesu frezowania w centrum obróbczym CNC. Celem pracy było porównanie rozkładu wielkości cząstek pyłu powstającego w procesie frezowania drewna naturalnego (buk, dąb i świerk) oraz płyt MDF na 5-osiowym centrum obróbczym CNC. Rozkład wielkości cząstek oceniono za pomocą analizy sitowej próbek z całkowitej masy wychwyconego pyłu. Wyniki wykazały, że obróbka naturalnego drewna charakteryzuje się głównie tworzeniem grubych frakcji pyłu (sita 2 mm - 1 mm), podczas gdy obróbka MDF wiązała się z tworzeniem drobnych frakcji pyłu o wielkości poniżej 100 µm. Kolejnym celem było porównanie wartości separacji na krzywych separacji frakcyjnej wybranych separatorów mechanicznych i filtrów z rozkładem wielkości cząstek pyłu oraz zaproponowanie odpowiedniej techniki separacji spełniającej kryteria "najlepszej dostępnej techniki" (BAT) w

obróbce drewna naturalnego i płyt MDF, a także wskazanie na powstawanie i wytwarzanie szkodliwych frakcji pyłu, które powstają głównie podczas obróbki płyt MDF. Naszym zamiarem była ocena, czy wprowadzenie danej technologii przy danej mieszance materiałowej będzie wymagało również modyfikacji po stronie urządzenia odciągowego.

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