



Effect of grain direction on particle size distribution during sanding of spruce, beech and oak wood

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Abstract

This paper focusses on the impact of the grain direction of the sanding of selected wood types on the particle size distribution. In the experiment, a hand-held GBS 100 AE belt sander was used, with particles obtained through two grain directions of the sanding models: at angles of 0° and 90° with respect to the wood structure. The study examined the effects of grain direction on the particle size distribution in beech, oak and spruce wood sawdust. Statistical analysis was used to characterize the particle size distribution, and a combination of grain direction was compared for each type of wood. Statistical analysis revealed significant differences in the particle size distribution between the two cutting grain directions, with p-values of 0,018 and 0,0002 for beech and spruce, respectively. On the contrary, oak did not show minimal statistically significant differences between grain directions ($p = 0,912$). The results highlight the crucial role of the wood microstructure in determining the effect of grain direction on particle morphology. Specifically, spruce showed the highest sensitivity to grain direction changes, while oak remained relatively stable in different cutting directions.

Keywords: wood sawdust, particle size distribution, grain direction, belt sanding, beech, oak, spruce, sieve analysis

Introduction

Wood is a natural material composed primarily of cell walls made of cellulose, hemicellulose, and lignin, arranged in an anisotropic structure. The main components are long cellulose fibers (tracheids in softwoods and vessels in hardwoods), which form the longitudinal (axial) direction, while other cells and pores run in the transverse (radial and tangential) directions. This anisotropy - the differing mechanical and physical properties along the grain compared to across the grain - significantly affects the behavior of wood

during machining, especially in cutting and sanding processes (Kollmann & Côté, 1968; Zimmermann et al., 2006).

During sanding, abrasive grains collide with the surface of the wood, gradually detaching or tearing fragments from the material. The mechanism of sawdust formation depends on several factors: the grit size of the sandpaper, the applied pressure, the speed of movement, and especially the grain direction of sanding. In the longitudinal direction, abrasive grains generally encounter lower resistance, resulting in longer, fibrous particles; in contrast, transverse sanding typically produces smaller, more amorphous fragments (Welling et al., 2008; Demirci, 2019).

The particle size distribution of sawdust has practical implications across various industries: in fiberboard production, it is critical for layer compaction and product strength; in the biofuel sector, it influences grinding efficiency and combustibility; and in pharmaceutical and food applications, wood dust parameters affect processing behavior and safety standards (Delviawan et al., 2019). To evaluate distribution, common techniques include laboratory sieve analysis, laser diffraction, or optical imaging, with results typically characterized by metrics such as median size (D_{50}), standard deviation (σ), and curve shape (skewness, kurtosis).

The grain direction of sanding in relation to the wood grain is a key factor influencing not only the abrasive process mechanics but also the shape and size of the removed particles. Belt sanders, such as the GBS 100 AE, require precise belt guidance, and two extreme orientations are typically used in experimental setups (Očkajová, 1999; Očkajová et al., 2003; Očkajová & Banski, 2013):

- 0° (longitudinal cut): the movement of the belt aligns with the grain direction; longer, fibrous particles are expected due to the “pulling” of material along the fibers,
- 90° (transverse cut): the movement of the belt is perpendicular to the fibers, resulting in shorter, crushed particles due to the fracturing mechanism along natural structural bonds in the wood (Nourbakhsh et al., 2010; Mu et al., 2018).

Although there are existing studies addressing changes in particle shape and size at grain directions (Dzurenda, 2000; Dzurenda et al., 2008; Dzurenda & Očkajová, 2003; Rogoziński et al., 2021), comparisons between individual wood species and their statistical validation remain partially unexplored. Previous research suggests that differences in particle morphology affect not only material handling and flow during further processing, but also the wear rate of the sanding belt and the associated economic costs of the machining process. These knowledge gaps serve as the motivation for the present study, which focuses on quantitatively evaluating the effect of grain direction on the particle size distribution of three common wood species: beech, oak, and spruce.

Materials and Methods

Selection of Sawdust Test Samples and Description of the Sampling Site

Research was carried out on wood dust obtained from an experimental sanding process using a Bosch GBS 100 AE handheld belt sander, with dust extraction provided by a Rowenta vacuum cleaner. For analysis, dust was produced from three species of wood: beech, spruce, and oak. The samples were sanded along the grain and across the grain, primarily in the radial plane of the wood. Cubic samples with dimensions of 50×50×50 mm were used for sanding. These samples were dried and conditioned to a moisture content of 12%. The average density of individual wood samples was as follows: spruce 395 kg·m⁻³, beech 692 kg·m⁻³, and oak 748 kg·m⁻³. The dust generated during the sanding was transferred from the disposable vacuum cleaner paper filter bag into plastic bags and sealed to prevent changes in the moisture content of the test samples.

Cutting Parameters of the Sanding Process

Machine

Belt sander Bosch GBS 100 AE:

- Sanding was performed at a cutting speed of 7,8 m.s-1
- Rated power: 1200 W

Tool

Abrasive belts LS 309 XH from Klingspor (Germany):

- Belt length: 610 mm
- Belt width: 100 mm
- Grit size: 80

Specific pressure

The sanded sample was pressed against the abrasive belt with a constant contact force using a roller mechanism. The specific pressure was 1,04 N.cm⁻².

For the preparation of wood dust, a new sanding paper was used for each wood species and each grain direction, and the sander was thoroughly cleaned after each sanding process.

Sample Collection

The wood dust was collected using a Rowenta vacuum cleaner in disposable paper bags, from which it was transferred to plastic bags. A new paper filter was used for each wood species and each direction to maintain the conditions specified in the STN 834501 standard, which defines a sample as a representative part of the whole, in which a given substance is determined with the aim of obtaining information about the whole from which it was taken.

Particle Size Measurement

The sieve analysis was performed using an automatic vibratory sieve shaker RETSCH AS 200 with a set of control sieves according to STN ISO 3310-1. The mass of residues on individual sieves was determined using BOSCH digital laboratory scales with a weighing accuracy of 0,001 g. The measurements were carried out at an average sanding dust moisture content of 12%, as higher moisture is not suitable for dust sieving. The methodological procedure is described in detail in the article Kučerka, 2008.

The above procedure was repeated three times for each measured sample to eliminate measurement errors.

To refine the information about the shape and dimensions of the largest particles in the coarse fraction, as well as the shape and dimensions of the smallest particles in the very fine fraction of wood dust, a separate analysis of particle grains was carried out.

The analysis of the dimensions of the smallest particles in the very fine fraction was performed using an optical method - through microscopic image analysis. The images were acquired using a Nikon Optiphot-2 microscope with a Nikon 4x objective in the biometric laboratory of FLD MZLU Brno. The wood dust particles were recorded with a 3-chip TV CCD camera Hitachi HV-C20 (RGB 752×582 pixels), with a horizontal resolution of 700 TV lines, and evaluated using the software LUCIA-G 4.0 (Laboratory Universal Computer Image Analysis). This procedure is described in detail in the article Mračková et al., 2016.

Statistical Analysis

Statistical analysis was employed to characterize the particle size distribution and to evaluate the impact of grain direction (0° and 90°) on particle morphology. The ANOVA analysis was used to identify significant differences between the selected wood species (beech, oak, and spruce) across various sieve sizes. To further determine the significance of differences between the two grain directions for each wood species and sieve fraction, t-tests were performed.

The results were considered statistically significant at a threshold of $p < 0,05$. Data variability was quantified using the weighted average particle size, standard deviation, and standard error of measurement, the latter of which is represented in the graphical outputs as error bars. In the figures, levels of statistical significance are indicated by asterisks (e.g., *, **, ***).

Results and Discussion

As part of the experimental research, samples of three wood species (beech, oak, and spruce) were analyzed. Samples were obtained by sanding with a handheld belt sander (GBS 100 AE) under two grain directions, at angles of 0° and 90° relative to the wood grain. The results of the sieve analysis were processed and visualized using graphs, providing a comprehensive overview of the particle size distribution.

Comparison of Weighted Average Particle Sizes with Error Bars

The following set of graphs (Figure 1) presents the weighted average particle sizes for each wood species at both grain directions (0° and 90°) across all sieve sizes. The error bars represent the standard error of measurement, allowing for a statistical evaluation of the significance of the observed differences. The graphs clearly show that the grain direction has a significant impact on the resulting particle size; however, this effect varies depending on the wood species. The asterisks (*) in the following graphs (Figure 1) represent the level of statistical significance of the differences between the individual grain directions (0° and 90°) based on the size of the particles. (*) Asterisks indicate statistical significance: *p < 0,05, **p < 0,01, ***p < 0,001. These symbols in Figure 1 confirm that the differences in particle distribution (e.g., for spruce on the 0,125 mm sieve) are not accidental but are directly influenced by the grain direction.

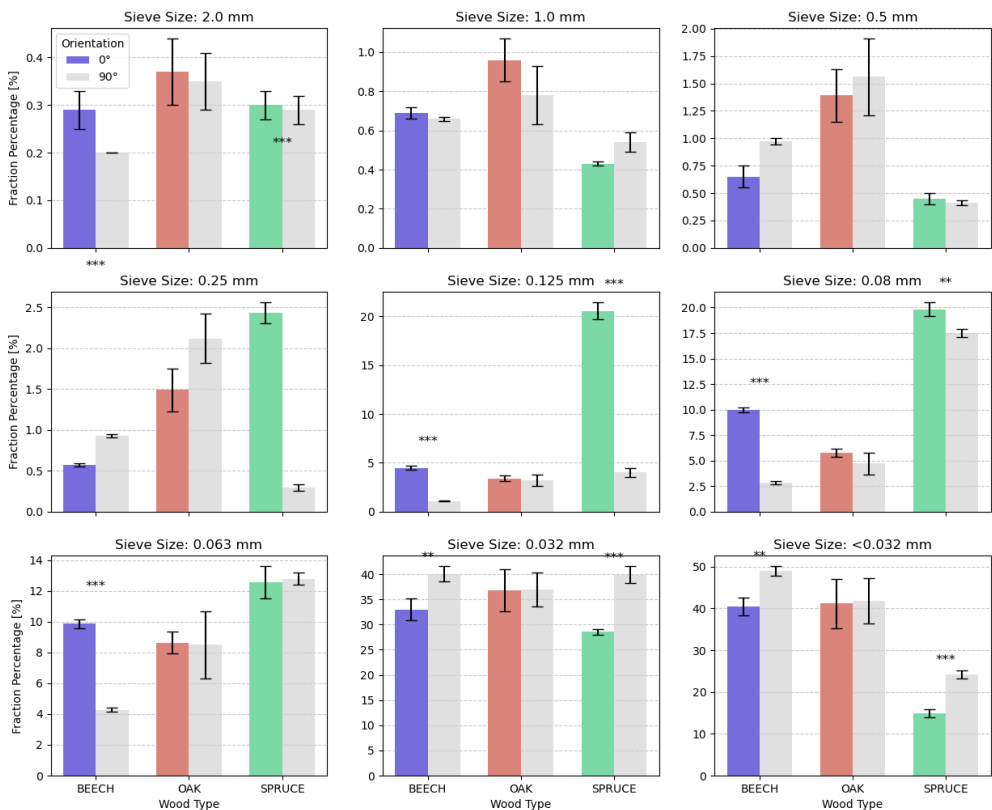


Fig. 1. Mean fraction percentage with standard deviation by wood type and grain direction

In the case of beech (Tab. 1), a statistically significant difference (p = 0,018) was observed between the grain directions. Grain direction at 0° produced particles with a weighted average size of 0,0803 mm, while the 90° grain direction resulted in finer

particles with an average size of 0,0723 mm, representing a 9,86% difference. This difference is large enough to have practical implications for the processing of beech wood.

The most pronounced difference was recorded for spruce, where grain direction at 0° produced particles with an average size of 0,0909 mm, while the 90° grain direction yielded significantly finer particles with an average size of 0,0710 mm. This 21,87% difference is highly statistically significant ($p = 0,0002$) and indicates that grain direction has a substantial effect on the particle morphology of spruce wood.

In contrast, oak exhibited only a minimal difference between grain directions (just 0,72%), which was not statistically significant ($p = 0,912$). The average particle size was 0,0914 mm at 0° and 0,0907 mm at 90°, suggesting that oak wood demonstrates high stability in particle size distribution regardless of grain direction.

Table 1. Statistical Differences Between Wood Species

Wood type	Mean_0°	Mean_90°	Percent Difference	p_value	Significant
Beech	0,0803	0,0723	9,86	0,018	***
Oak	0,0914	0,0907	0,72	0,912	ns
Spruce	0,0909	0,0710	21,87	0,0002	***

The ANOVA analysis revealed significant differences between the wood species for most sieve sizes ($p < 0,05$). T-tests identified significant differences between the grain direction of 0° and 90° for many combinations of wood species and sieve sizes, particularly for beech and spruce. The beech shows a higher percentage of smaller particles (< 0,032 mm) when sanded at 90°. Oak generally produces larger particles compared to other wood species. Spruce exhibits the most pronounced differences between grain direction.

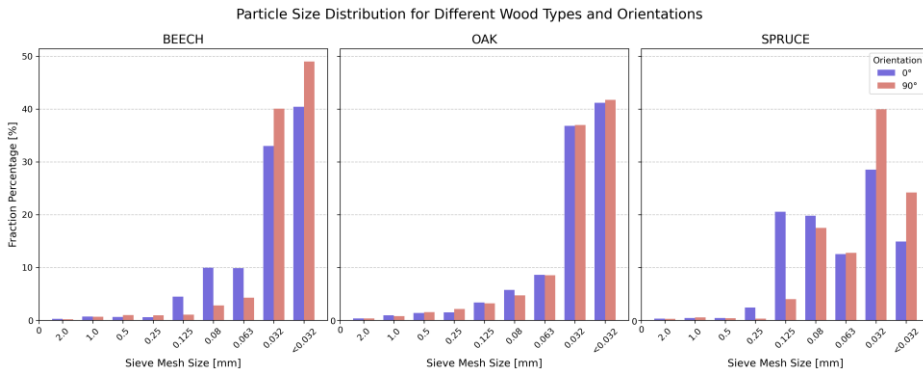


Fig. 2. Particle size distribution for different wood types and grain directions

Evaluation of Particle Sizes

The grain direction has a statistically significant effect on particle size only in the case of beech, where grain direction at 0° produces larger particles. For oak and spruce, no statistically significant difference was observed between the grain directions.

Table 2. Analysis of particle sizes during sanding of beech, oak, and spruce parallel and perpendicular to the grain

Wood type	Grain direction	Average Size (μm)	Statistical Significance
Beech	0° vs 90°	2,30 vs 2,09	yes (p = 0,0218)
Oak	0° vs 90°	1,81 vs 1,90	no (p = 0,4560)
Spruce	0° vs 90°	2,03 vs 2,75	yes (p = 0,0021)

The next graph illustrates the average particle sizes along with their standard deviations. It was found that beech, when sanded longitudinally, has the highest average particle size compared to other species. This may indicate that the grain direction or the wood species results in larger particles.

In contrast, oak sanded longitudinally has the lowest average particle size. This means that the average particle size in this group is smaller than in the others, suggesting that the sanding process or the wood type leads to finer particles.

Spruce, when sanded transversely (90°), shows significantly larger error bars, indicating high variability in particle size. This suggests that the particles obtained from the sanding of spruce wood are inconsistent and more fibrous, which is also supported by findings from other studies (Očkajová, 2002; Očkajová et al., 2006; Marková et al., 2016; Očkajová & Marková, 2016; Očkajová et al., 2018, 2019, 2021).

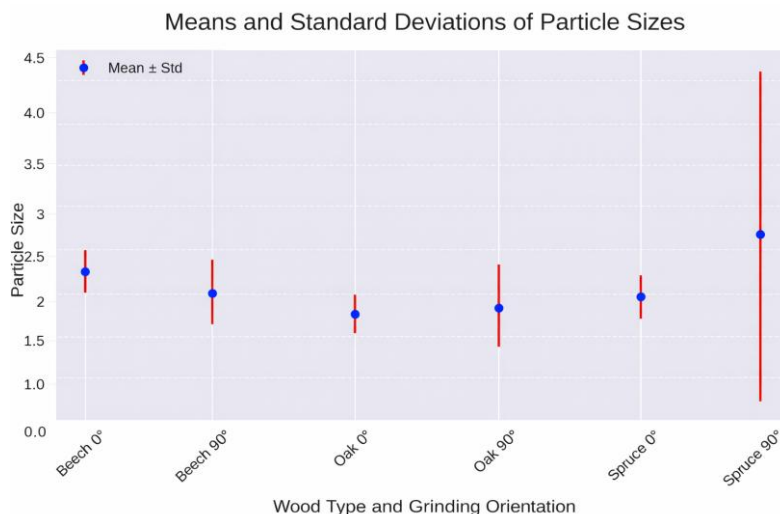


Fig. 3. Means and standard deviations of particle sizes

The analysis revealed several interesting findings:

- Fine fractions (particles smaller than 0,032 mm) dominate in all wood species.
- Hardwoods (oak, beech) tend to produce finer particles compared to spruce.
- Transverse grain direction (90°) tends to produce finer particles than longitudinal grain direction (0°).
- Remarkable variability is observed among the samples.

Conclusions

The experimental research demonstrated that the grain direction of the sanding has a significant impact on the size distribution of the particles in different wood species. The results of the sieve analysis revealed statistically significant differences between longitudinal (0°) and transverse (90°) grain direction, particularly for beech and spruce. In the case of beech, longitudinal grain direction produced larger particles, while transverse grain direction resulted in finer fractions, with a difference of nearly 10% ($p = 0,018$). An even more pronounced effect was observed for spruce, where transverse grain direction produced particles that were 21,87% smaller ($p = 0,0002$).

In contrast, oak exhibited high particle size stability regardless of grain direction - the difference was minimal and statistically insignificant ($p = 0,912$).

Analysis confirmed that fine fractions (particles $< 0,032$ mm) dominate in all wood species examined. Hardwoods (beech and oak) tended to produce finer particles than softwood (spruce). Furthermore, transverse grain direction (90°) generally led to the production of finer and less fibrous particles compared to longitudinal grain direction (0°).

From a practical standpoint, these findings can help optimize the sanding parameters according to the desired size and shape of the wood dust, for example, to produce fiberboards, biofuels, or other processing. The results also highlight the importance of the microstructure of wood in determining the characteristics of the sanding waste.

Acknowledgments

This research was supported by the grant agency VEGA under project No. 1/0323/23.

References

- Delviawan, A., Kojima, Y., Kobori, H., Suzuki, S., Aoki, K., & Ogoe, S. (2019). The effect of wood particle size distribution on the mechanical properties of wood-plastic composite. *Journal of Wood Science*, 65(1), 67. <https://doi.org/10.1186/s10086-019-1846-9>
- Demirci, S. (2019). Determination of the Effect of Cutting Direction and Grit Sizes of the Abrasive on Surface Roughness of Scotch Pine (*Pinus sylvestris* L.) and Oriental Beech (*Fagus orientalis* L.) Woods. *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, 19(2), 164-172. <https://doi.org/10.17475/kastorman.626270>
- Dzurenda, L. (2000). Analýza rozmerov a tvaru mokrej smrekovej piliny. *Acta Facultatis Xylogologiae Zvolen*, 129-137.

Dzurenda, L., Kučerka, M., & Banski, A. (2008). Vplyv techniky na kvalitu deleného a obrábaného dreva (1. vyd.). Technická univerzita vo Zvolene.

Dzurenda, L., & Očkajová, A. (2003). Rozmerová analýza drevného prachu smreka, borovice a duba z procesu rovinného brúsenia. *Obrábanie a spájanie dreva*, 53-57.

Kollmann, F. F. P., & Côté, W. A. (1968). *Principles of Wood Science and Technology: I Solid Wood*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-642-87928-9>

Kučerka, M. (2008). Metodika pre sitovú analýzu piliny z procesov pílenia dreva. *Trieskové a beztrieskové obrábanie dreva*, 155-159.

Marková, I., Očkajová, A., & Mračková, E. (2016). Granulometry of selected wooddust species of dust from orbital sanders. *Wood Research*, 61(6), 983-992.

Mračková, E., Krišťák, L., Kučerka, M., Gaff, M., & Gajtanska, M. (2016). Creation of Wood Dust during Wood Processing: Size Analysis, Dust Separation, and Occupational Health. *BioResources*, 11(1), 209-222. <https://doi.org/10.15376/biores.11.1.209-222>

Mu, B., Wang, H., Hao, X., & Wang, Q. (2018). Morphology, Mechanical Properties and Dimensional Stability of Biomass Particles/High Density Polyethylene Composites: Effect of Species and Composition. *Polymers*, 10(3), 308. <https://doi.org/10.3390/polym10030308>

Nourbakhsh, A., Karegarfard, A., Ashori, A., & Nourbakhsh, A. (2010). Effects of Particle Size and Coupling Agent Concentration on Mechanical Properties of Particulate-filled Polymer Composites. *Journal of Thermoplastic Composite Materials*, 23(2), 169-174. <https://doi.org/10.1177/0892705709340962>

Očkajová, A. (1999). Sand belt running time and its wear. *Acta Facultatis Xylogologiae Zvolen*, 9-13.

Očkajová, A. (2002). Analýza faktorov v procese plošného brúsenia dreva (1.). Technická univerzita vo Zvolene.

Očkajová, A., & Banski, A. (2013). Granulometria drevného brúsneho prachu z úzkopásovej brúsky. *Acta Facultatis Xylogologiae*, 55, 85-89.

Očkajová, A., Banski, A., & Rončka, J. (Ed.). (2006). Dust in Woodworking Plants and Possibilities of its Reducing. V *Manufacturing Engineering in Time of Information Society* (s. 255-260). Gdansk University of Technology.

Očkajová, A., Barčík, Š., Kučerka, M., Koleda, P., Korčok, M., & Vyhňáliková, Z. (2019). Wood dust granular analysis in the sanding process of thermally modified wood versus its density. *BioResources*, 14(4), 8559-8572. <https://doi.org/10.15376/biores.14.4.8559-8572>

Očkajová, A., Kučerka, M., Kminiak, R., & Banski, A. (2021). Sustainable Manufacturing Process in the Context of Wood Processing by Sanding. *Coatings*, 11(12), 1463. <https://doi.org/10.3390/coatings11121463>

Očkajová, A., Kučerka, M., Krišťák, L., & Igaz, R. (2018). Granulometric Analysis of Sanding Dust from Selected Wood Species. *BioResources*, 13(4), 7481-7495. <https://doi.org/10.15376/biores.13.4.7481-7495>

Očkajová, A., & Marková, I. (2016). Particular size analysis of selected wood dust species particles generated in the wood working environment. 2(XVIII), 24-31.

Očkajová, A., Siklienka, M., & Barčík, Š. (2003). Sand belt wear in the dependence on sanding direction for beech, alder, oak and pine samples. 539-545.

Rogoziński, T., Chuchala, D., Peździk, M., Orłowski, K. A., Dzurenda, L., & Muzinski, T. (2021). Influence of drying mode and feed per tooth rate on the fine dust creation in pine and beech sawing on a mini sash gang saw. *European Journal of Wood and Wood Products*, 79(1), 91-99. <https://doi.org/10.1007/s00107-020-01608-8>

Welling, I., Lehtimäki, M., Rautio, S., Lähde, T., Enbom, S., Hynynen, P., & Hämeri, K. (2008). Wood Dust Particle and Mass Concentrations and Filtration Efficiency in Sanding of Wood Materials. *Journal of Occupational and Environmental Hygiene*, 6(2), 90-98. <https://doi.org/10.1080/15459620802623073>

Zimmermann, T., Thommen, V., Reimann, P., & Hug, H. J. (2006). Ultrastructural appearance of embedded and polished wood cell walls as revealed by Atomic Force Microscopy. *Journal of Structural Biology*, 156(2), 363-369. <https://doi.org/10.1016/j.jsb.2006.06.007>

List of standards

STN ISO 3310-1 (2016). Technické požiadavky a skúšobné metódy pre skúšobné sitá z kovovej drôtenej tkaniny s veľkosťou otvorov od 125 mm do 20 µm.

STN 834501 (1997). Ochrana ovzdušia. Základné termíny a definície., 28.

Reviewed paper / Artykuł recenzowany

Submitted / Zgłoszony: 30.05.2025

Published online / Opublikowany online: 22.12.2025