Granulometric Analysis of Sanding Dust from Selected Wood Species

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Different types of sanders are used in every furniture factory and carpentry plant. The wood dust generated during sanding is considered to be one of the main health and safety hazards. Based on many studies, the whole inhaled fraction of particles less than 100 µm is harmful to health. Thus, it is important to know the specific particle size fractions of wood dust. This study compared the granulometric compositions of sanding wood dusts of selected wood species (beech and oak) and determined the statistical significance of individual factors (type of sander, wood species, grain size of sander, sanding direction) that affect the percentage of fractions ≤ 0.08 mm. The results confirmed that the use of narrow band and handheld (belt and disc) sanders caused high percentages of fractions ≤ 0.08 mm, above 90% in all cases. In these types of sanders, the working part of the sander is not completely covered, and the operator is in direct contact with the machine. Despite the use of a suction device, a certain amount of dust remains suspended in the air, or it settles on surfaces. In both cases, this dust poses a health and safety hazard.

Keywords: Wood dust; Sanding of beech and oak; Various sanders; Granularity

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INTRODUCTION

Sanders are a part of every furniture and building-joinery plant, including wide belt, cylindrical, narrow band, handheld, and special types, depending on the sizes and types of parts produced in the given plant. Wood dust is generated during the sanding of wood, causing problems for the operator, other machinery, or the entire plant. Wood dust (along with noise and vibration) is a major health and safety hazard (Potkany and Hitka 2009; Vetráková et al. 2013; Gaff 2014; Mračková *et al*. 2016; Health and Safety Executive 2017a, b; Němec *et al*. 2017; Vlčková *et al*. 2017). Although many different sanders include a suction device, most handheld belt sanders are not completely covered, enabling dust to enter the work environment.

In 1995, the International Agency for Research on Cancer (IARC) categorized dust from hardwood as carcinogenic for humans (Group 1) (IARC 1995). Seven years later, dust from softwood was also included in the same category. This was preceded by growing epidemiological studies describing the adenocarcinogenicity with respect to the noses and sinuses of employees working in the wood processing industry as a typical occupational carcinogenic disease (Hernberg *et al*. 1983; Brinton *et al*. 1984; Hubbard *et al*. 1996; Andersen *et al*. 1999; Yu and Yuan 2002; Kvasnová *et al*. 2016; Lorincová *et al*. 2016). Studies have shown an increased risk of cancer in work environments where certain types of hardwoods are processed. Oak and beech wood dust have been confirmed as carcinogenic substances in workplaces (Hadfield 1970). Softwood and hardwood particles can be distinguished by their tannin contents (Bianco and Savolainen 1994; Bianco *et al*. 1998; Mammela 2001; Gori *et al*. 2009), as hardwoods such as oak or mahogany have higher tannin concentrations than softwoods (*e.g.*, pine, spruce, or fir) (Jiménez *et al*. 2011).

The inhalation of wood dust may cause allergic reactions in the respiratory tract mucous membrane. In large amounts, dust acts as an irritant to the eyes, nose, and throat. Significant accumulations of fine particles can result in damage to lung function, cause asthma, and be carcinogenic (Nylander and Dement 1993; Ameille *et al*. 2003; Schwarz *et al*. 2009; Hnilica *et al.* 2017). The probability of particle inhalation depends on their aerodynamic diameter, the movement of air around the body, and respiratory rate (WHO 1999). Dust particle sizes of < 100 µm do not settle well; they remain suspended in the air and settle in the eyes, nose, or mouth, as well as on the skin. In the past, the criterion for assessing exposure to wood dust in the work environment was the total amount of wood dust. Today, the evaluation has shifted to the measurement of the health related fraction size of airborne dust; it is therefore important to know the specific particle fraction size.

The size distribution of wood dust particles in the workroom air varies with the distance from the source, processing method, and wood species (Porankiewicz *et al*. 2010; Gašparík and Gaff 2015; Kminiak and Gaff 2015; Gaff *et al*. 2017a, b; Mikušová and Dado 2017). The greatest danger to respiratory organs in the case of wood dust is a respirable (alveolar) component with a particle size of less than 10 µm (Dolny and Rogozinski 2014; Rogozinski 2015; Rogozinski 2016), but the entire inhaled fraction has a negative effect on health. The inhalable dust fraction has been defined by the BS EN 481 (1993) and ISO 7708 (1995) standards. These particles enter the lung alveoli, where they settle or react with bodily fluids and cause irreversible damage to the body. However, it must be stressed that not only the alveolar fraction but the entire inhalable fraction is very damaging to human health.

Table 1. Numbers of Workers Exposed to Inhalable Wood Dust and Distribution of Exposed Workers (%) according to Country and Level of Exposure in 4 States in Central Europe from 2000 to 2003 (Kauppinen *et al*. 2006)

Country	Employed (thousand)	Exposed (thousand)	Exposed (% of employed)	Occupational exposure				
				<0.5-1 mg·m^{-3}	0.5-1 mg·m^{-3}	1-2 mg·m^{-3}	2-5 mg·m^{-3}	>5 mg·m^{-3}
Slovakia	2129	42	2	14	6	8	9	5
Czech Republic	4751	148	3.1	40	25	30	33	20
Hungary	3847	62	1.6	15	10	13	15	9
Poland	13709	310	2.3	79	52	63	72	44

For occupational safety and health, maximum permissible values of wood dust in the work environment are prescribed, with EU Directive 2004/37/EC (2004) setting the limit of 5 mg/m^3 for the inhalation of hardwood fractions. The European Commission is exploring the possibility of reducing the occupational exposure limit (OEL) for hardwood dust from 5 mg/m^3 to either 3 mg/m^3 or 1 mg/m^3. The Scientific Committee for

Occupational Exposure Limits (SCOEL) of the EU has declared that exposure to wood dust above 0.5 mg/m^3 induces pulmonary effects and should be avoided. In 2003, SCOEL proposed a factor for the conversion of total dust into inhalable dust (2 to 3), which resulted in the proposal of an OEL of 1 mg/m^3 to 1.5 mg/m^3 (inhalable fraction) (SCOEL 2003). Measurements of exposure to wood dust have been carried out in a number of studies. The highest exposure levels have generally been seen in construction. The Woodex study (Kauppinen *et al*. 2006, Table 1) estimated that 84% of exposure concentrations to hardwood dust in Europe were below 5 mg/m^3 and that 34% were below 1 mg/m^3 (for the years 2000 to 2003) (Jiménez *et al*. 2011). Dust with a carcinogenic and mutagenic effect is assessed in Slovakia (GD SR no. 83/2015) and the concentration of the toxic component of the aerosol must not exceed the technical guidelines for the given factor (5 mg/m^3). In exotic wood species and other wood species (solid aerosols with predominantly irritant effects), the values are 1 mg/m^3 for exotic wood species and 8 mg/m^3 for other wood species (GD SR no. 471/2011).

It is also important to know wood dust and the size of its particles in terms of security risks, such as fire or explosion (Dudarski *et al*. 2015), because wood dust settles on machines, walls, floors, *etc*. As the particle size decreases, the specific surface area increases, resulting in faster thermal decomposition and faster burning in comparison with one piece of the same total weight (Tureková 2012). Tureková (2008), Kasalová and Balog (2010), and Martinka and Rantuch (2013) have shown that particle size has a significant effect on the ignition temperature of suspended dust when monitoring particles with dimensions < 100 µm. Settled dust presents a latent danger of explosion at a layer of only 1 mm when there is a sudden raising of the dust and the presence of an ignition source (Orlíková and Štroch 1999; Cheremisinoff 2000; Marková *et al.* 2007; Tureková et al. 2009; Gaff *et al*. 2015; Gaff *et al*. 2016; Kaplan *et al.* 2018a, 2018b).

The main objective of this paper is to compare the granulometric compositions of sanding wood dusts of selected wood species (beech and oak) typical in the Slovak furniture industry, obtained from different types of sanders, from laboratory experiments, pilot experiments, and directly from furniture plants. Another objective is to determine the statistical significance of individual factors (type of sander, wood species, grain size of sander, sanding direction) affecting the percentage of fractions ≤ 0.08 mm that do not settle at all or hardly settle in the work environment and pose a health and safety hazard.

EXPERIMENTAL

Materials and Methods

Sanded material

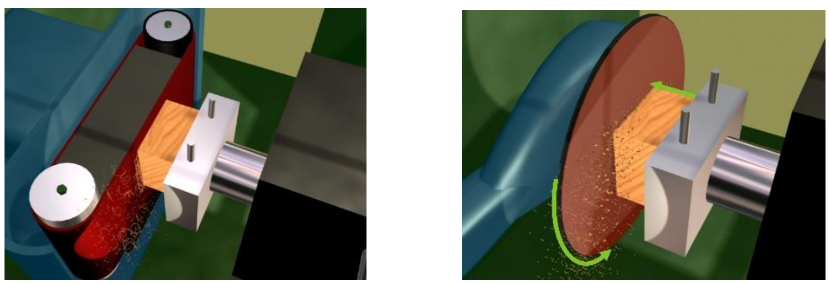
Oak is a ring-porous, heartwood, deciduous hardwood with good strength properties and an average density of 673 kg·m^{-3}. Beech is a diffuse-porous wood with a high density, good strength properties, and an average density of 687 kg·m^{-3}.The material for laboratory experiments was provided by Bučina Zvolen, a.s. (Zvolen, Slovakia), in the form of radially sawn timber with a thickness of 55 mm and length of 2,500 mm. Individual machines were used (leveling, thicknessing, sawing) to make samples with the dimensions of 50 mm × 50 mm × 50 mm (approximately 50 pieces per wood species) for handheld sanders and 20 mm × 100 mm × 200 mm (approximately 10 pieces per wood species) for the narrow belt sander JET. The prepared samples were conditioned at a temperature of 20 °C and a relative humidity of 65% to a moisture content of 12%. The basis of the moisture content was dry. To obtain sanding dust directly from a furniture plant, specific parts that had just been sanded in the plant were used: oak and beech with dimensions of 20 mm × 100 mm × 1000 mm. There was no possibility of obtaining samples to determine the density.

Machinery

The machinery used in the experiments is listed below.

Handheld belt sander (HBS) Bosch GBS 100 AE (Zvolen, Slovakia), cutting speed 7.8 m·s^{-1}, sanding belt LS 309 XH, dimensions of 100 mm × 610 mm, sanding belt grain size 80, constant pressure, laboratory experiments, sanding along the grain, and sanding perpendicular to the grain.

Handheld disc sander (HDS) Bosch GWS-14-125 CE (Zvolen, Slovakia), cutting speed 7.8 m·s^{-1}, sanding belt SIAFAST, diameter of 150 mm, sanding belt grain size 80, constant pressure, laboratory experiments, mixed (cross) sanding.



a) *b)*

Fig. 1. Handheld belt sanders: hand belt sander GBS 100 AE; b) hand disk sander GWS 14-125 CE

Narrow belt sander (NBS) JET JSG-96 (Zvolen, Slovakia), cutting speed 10 m·s^{-1}, sanding belt HIOLIT XO P 80, sanding belt grain size 80, individual pressure of wood sample against the vertical sanding belt, pilot experiments, sanding along the grain.

Narrow belt sander SAFO OZJA (Zvolen, Slovakia), cutting speed 18 m·s^{-1}, sanding belt Antistatic BMA, sanding belt grain size 80, individual pressure of the sanding belt by means of a presser foot on the wood samples, furniture plant, sanding along the grain.

Wide belt sander (WBS) COSTA (Zvolen, Slovakia), engine speed for grain size 60/80 - 1480 .min^{-1}, feed rate 10 m·min^{-1}, engine speed for grain size 120/180 - 2945 .min^{-1}, feed rate 14 m·min^{-1}, sanding belt 83146 NAXOMAX/F, sanding belt grain size 60, 120, constant pressure, furniture plant, sanding along the grain, oscillation of the sanding device.

Sanding belts for laboratory experiments and pilot experiments were conditioned at 20 °C and a relative humidity of 65% before being fitted to the machinery; 24 h before the experiment, the test belts were stored in the room where the experiment was performed.

Sample extraction

Wood dust (laboratory and pilot experiment) was captured using a Rowenta vacuum cleaner (Banská Bystrica, Slovakia) into Rowenta Original ZR 814 disposable paper bags. A new paper bag was used for each wood species and direction. At the end of each sanding, the sample from the paper bag was poured into a plastic bag, which was closed with a flexible wire to avoid changing the parameters. Approximately 200 g of each sample was collected, and 30 grams was the weight for each test.

Samples of sanding wood dust (pilot experiment) were isokinetically removed from the suction pipe of individual sanders in accordance with STN ISO 9096 (83 4610) (2004) during the sanding of individual selected samples. The moisture content of the dust samples was determined prior to the sieving by means of a resistance meter (GMH 3830, Banská Bystrica, Slovakia) with sensor-needle gauges and GMS 300/91 probes mounted on a GSG 91 electrode. The moisture content of the dust samples was within the range of 6% to 8 %.

Granulometric analysis

The granulometric composition of sanding wood dust was determined by sieving. For this purpose, a special set of stacked sieves was used (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.080 mm, 0.063 mm, 0.032 mm, and bottom), placed on the vibrating stand of the sieving machine (Retsch AS 200c), with adjustable sieving interruption frequency (20 sec) and sieve vibration amplitude (2 mm/g) in accordance with STN 1531 05 / STN ISO 3310-1 (2000).

The granulometric composition was obtained by weighing the percentages remaining in the sieves after sieving on an electronic laboratory scale with a capacity of 510 g and a weighing accuracy of 0.001 g. Five different sandings were performed for each variant and the subsequent sievings; the results are given as their average values.

RESULTS AND DISCUSSION

Narrow Belt Sanders

The highest amount of fractions was consistently recorded for both beech and oak in a 0.032 mm sieve and at the bottom for the narrow belt sander SAFO OZJA (furniture plant, with individual manual pressure of the foot on the workpiece) using a sander with a grain size of 80. The experiment was repeated with the narrow belt sander JET JSG-96 (pilot experiment, with individual pressure of the workpiece on the sanding belt), with which these results were confirmed. The results of the granulometric analysis are shown in Table 2.

To compare fraction values ≤ 0.08 mm for narrow belt sander SAFO OZJA as well as narrow belt sander JET JSG-96 for beech and oak wood, with the grain size of the sander being 80, the obtained results were statistically analyzed. In the first step, the fraction percentages ≤ 0.08 mm were added for each sieving. Subsequently, the normal distribution of the results was verified using the Kolmogorov–Smirnov test, and the F-test was used for the equality of variances, as shown in Table 3.

The results showed that the variances of fractions that were ≤ 0.08 mm were the same in both wood species. Student’s t-test was then used for the equality of variances (Table 4). There were no statistically significant differences between the values of fractions ≤ 0.08 mm for beech and oak using the narrow belt sander SAFO OZJA with a grain size of 80. This result was subsequently confirmed for repeated sanding with the narrow belt sander JET JSG-96. These results corroborate those of Očkajová and Banski (2013), who studied the quantity of particles under 100 μm in wood dust samples of beech, pine, and spruce obtained from a narrow belt sander in a plant.

Table 2. Average Granulometric Composition (%) of Sanding Dust for NBS Sanders

Dimension of Sieve Mesh (mm)	Beech	Oak
	80	80
2.000	0.44	0.1
1.000	0.74	0.7
0.500	0.62	0.68
0.250	0.68	1.09
0.125	5.55	5.4
0.080	18.27	13.41
0.063	17.55	13.55
0.032	30.92	40.18
<0.032	25.22	24.89
Σ(≤0.08)	91.96	92.03

Table 3. F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	91.964	92.03
Variance	0.04773	0.06645
Observations	5	5
Df	4	4
F	0.718284424	
P(F≤f) One-tail	0.37813802	
F Critical One-tail	0.156537812	

Table 4. t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	91.964	92.03
Variance	0.04773	0.06645
Observations	5	5
Pooled Variance	0,05709	
Hypothesized Mean Difference	0	
Df	8	
t Stat	-0.43675	
P(T≤t) One-tail	0.33692	
t Critical One-tail	1.859548	
P(T≤t) Two-tail	0.67384	
t Critical Two-tail	2.306004	

Handheld Belt Sanders

The average results of the granulometric analysis are shown in Table 5. The highest percentage of fractions in the sanding of beech and oak with the handheld belt sander was obtained with a 0.032 mm sieve at the bottom; in sanding along the grain and perpendicular to the grain, the values were slightly higher than in narrow belt sanders, as sanding with a handheld sander is one of the processes liable to cause highest exposure to wood dust.

Table 5. Granulometric Composition (%) of Sanding Dust for HBS and HDS Sanders

Dimension of Sieve Mesh (mm)	Beech^a	Beech^p	Beech^d	Oak^a	Oak^p	Oak^d
	80	80	80	80	80	80
2.000	0.29	0.2	0.23	0.37	0.35	0.33
1.000	0.69	0.66	0.45	0.96	0.78	0.84
0.500	0.65	0.97	0.65	1.39	1.56	1.29
0.250	0.57	0.93	0.5	1.49	2.12	2.32
0.125	4.49	4.29	4.22	3.39	3.2	3.31
0.080	9.97	5.82	5.67	5.75	4.73	4.92
0.063	9.87	4.28	6.99	8.62	8.51	8.54
0.032	33.02	36.03	34.52	36.82	37	38
<0.032	40.45	46.82	46.77	41.21	41.75	40.45
Σ(≤0.08)	93.31	92.95	93.95	92.4	91.99	91.91

a – along the grain HBS; p – perpendicular to the grain HBS; d – HDS

For sanding with the handheld disc sander, the granulometric analysis of beech and oak dust was analogous to that of handheld belt sanders, with the highest percentage of particles in a 0.032 mm sieve at the bottom. The percentage of fractions ≤ 0.08 mm for beech (oak) and a handheld sander was 94.0% (91.9% for oak), in comparison with 93.0% (92.0% for oak) with a handheld belt sander and sanding perpendicular to the grain. This similarity can be explained by the direction of grinding being not clearly given in a portable disc sander, with cross sanding (mixed sanding) being prevalent. These results can be compared with those of Marková *et al*. (2016), in which a portable vibrating sander was used.

Table 6. Correlation Matrix for Handheld Belt Sander (HBS)

	Beech^a	Beech^p	Beech^d	Oak^a	Oak^p	Oak^d
Beech^a	1					
Beech^p	0.987374	1				
Beech^d	0.991591	0.998081	1			
Oak^a	0.992271	0.992023	0.992959	1		
Oak^p	0.989383	0.992059	0.992858	0.999615	1	
Oak^d	0.987498	0.988591	0.98858	0.999194	0.999343	1

a – along the grain HBS; p – perpendicular to the grain HBS; d – HDS

In the assessment of significant differences among all the measured percentages of fractions in individual sieves with a portable belt and portable disc sander, a correlation matrix was determined (Table 6). The correlations between the measured values of the fraction percentages for the examined wood species (beech, oak) and the sanding directions (along the grain, perpendicular to the grain, mixed sanding - disc sanding) were very high. To determine whether there were statistically significant differences between percentages of fractions ≤ 0.08 mm for selected wood species (beech, oak) and sanding directions (along the grain and perpendicular to the grain for a handheld belt sander and mixed sanding for a disc sander), the obtained results were statistically analyzed. Using the F-test and then the t-test, no statistically significant difference was found between sanding along the grain and perpendicular to the grain in sanding with an HBS for both beech and oak. There also was no statistically significant difference between sanding with an HBS and HDS for beech wood or oak. The only small difference that was found was between the sanding of beech and oak, in which the beech values were slightly higher than the oak values. This is attributable to the anatomical structures of the sanded woods, as well as oak being a wood species that is difficult to sand (Očkajová *et al*. 2014, 2016). These results are different from those obtained in the sanding of spruce, in which the percentages of fractions ≤ 0.08 mm were lower, and there was a significant difference between the percentages of fractions ≤ 0.08 mm in sanding along the grain (56.01%) and sanding perpendicular to the grain (76.9%) (Očkajová *et al*. 2008). The significant difference in fractions ≤ 0.08 mm between sanding along the grain and perpendicular to the grain in spruce wood is due to the structure of coniferous wood, in which the bulk of the cellular elements is oriented in the longitudinal direction. The alternation of springwood and summerwood also has a significant effect here (radial samples). There was a higher proportion of springwood with a significantly lower density than that of the summerwood, resulting in the predominant fiber particles being sanded along the grain, in comparison with isometric particles when sanding perpendicular to the grain. The significant difference in the proportions of individual fractions is due to the different wood density (Hemmilä and Usenius 1999), which closely correlates with the mechanical properties of wood. Wood species with higher density (also summerwood of coniferous wood species) produce more small dust particles, because their separation is more difficult than in wood species with lower density (springwood of coniferous wood species), which produce larger particles that are often fibrous in nature (Očkajová *et al*. 2014).

Wide Belt Sander

The average results of the granulometric analysis are shown in Table 7. The results of the granulometric analysis with a wide belt sander were different from those found in narrow belt sanders and handheld sanders. The grain sizes of the sander in a wide belt sander were 60 and 120 (commonly used production grain sizes), compared to the monitored grain size of 80 in narrow belt and handheld sanders. The percentages of particles in individual sieves of a wide belt sander were stratified differently than in narrow belt and handheld sanders: At a sanding belt grain size of 60, it was from a 0.500 mm sieve, and at a sanding belt grain size of 120, it was from a 0.125 mm sieve. The highest percentages at a sanding belt grain size of 60 were in 0.250 mm and 0.125 mm sieves; at a grain size of 120, the highest percentages were in a 0.032 mm sieve. For all narrow belt sanders, the highest percentages were recorded in a 0.032 mm sieve at the bottom of the sieving machine.

Table 7. Average Granulometric Composition (%) of Sanding Dust for a Wide Belt Sander (WBS)

Dimension of Sieve Mesh (mm)	$Beech_{60}$	$Beech_{120}$	Oak_{60}	Oak_{120}
2.000	0.25	0.38	0.4	0.29
1.000	0.38	0.27	0.91	0.35
0.500	7.19	0.38	12.16	0.67
0.250	18.59	1.61	20.35	4.54
0.125	22.08	10.9	18.92	18.77
0.080	16.66	15.14	12.48	15.32
0.063	10.57	12.8	7.65	11
0.032	19.97	34.28	15.81	37.21
<0.032	4.3	24.25	11.33	11.85
Σ(≤0.08)	51.5	86.47	47.27	75.38

The results were statistical analyzed again. In the first step, it was determined whether there was a statistically significant difference between fractions smaller than 0.08 mm in beech and oak wood in sanding with a WBS with a grain size of 60.

Table 8. F-Test: Two-Sample for Variances

	Oak 60	Beech 60
Mean	47.268	51.492
Variance	2.51397	0.16802
Observations	5	5
Df	4	4
F	14.96233	
P(F<=f) One-tail	0.011282	
F Critical One-tail	6.388233	

First, the normal distribution of results was verified with the Kolmogorov–Smirnov test, and then the F-test was used for the equality of variances (null hypothesis: $\sigma_1^2 = \sigma_2^2$ *vs*. H_1: $\sigma_1^2 \neq \sigma_2^2$) (Table 8). The F-test results showed that the variances of fractions that were ≤ 0.08 mm differed in both wood species. Student's t-test was then used for unequal variances (Table 9). There were small but statistically significant differences between beech and oak wood results in sanding with a WBS with a grain size of 60, which can be attributed to the anatomical structures of the sanded woods, as well as oak being a wood that is difficult to sand. Subsequently, differences between beech and oak wood in sanding with a WBS sander with a grain size of 120 were analogously statistically compared, and a statistically significant difference was also found, with oak reaching 75.4% and beech reaching 86.5%. Finally, the results of different grain sizes were statistically compared, and it was clearly confirmed that, in sanding with a grain size of 120, the amount of small fractions was far greater than when sanding with a grain size of 60. These results were confirmed for both oak and beech wood. The last result also corresponds with the results of previous research, in which sanding with larger grain sizes (smaller grain size) that penetrate deeper into the material separates larger particles than smaller sanding grain sizes (Matsumoto and Murase 1999).

Table 9. t-Test: Two-Sample Assuming Unequal Variances

	Oak 60	Beech 60
Mean	47.268	51.492
Variance	2.51397	0.16802
Observations	5	5
Hypothesized Mean Difference	0	
Df	5	
t Stat	-5.7674	
P(T<=t) One-tail	0.001101	
t Critical One-tail	2.015048	
P(T<=t) Two-tail	0.002202	
t Critical Two-tail	2.570582	

Comparison of the Amount of Fractions ≤ 0.08 mm for Different Sanders and Grain Sizes

Table 10 shows the average amount of fractions ≤ 0.08 mm for different sanders. The results confirmed that sanding with a handheld sander is liable to cause the highest exposure to wood dust, and it is one of the greatest dust problems in the working environment. However, the results also showed that a large amount of fractions ≤ 0.08 mm were generated with NBS sanders as well. The least amount of fractions ≤ 0.08 mm were generated by wide belt sanders. Even at a grain size of 120, their quantity was significantly less than for NBS and HBS at a grain size of 80.

Table 10. Average Amount (%) of Fractions ≤ 0.08 mm for Different Sanders

Sander	NBS 80	HBS[a] 80	HBS[p] 80	HDS 80	WBS 60	WBS 120
Average for Beech	91.95	93.31	92.95	93.95	51.5	86.47
Average for Oak	92.72	92.4	91.99	91.91	47.27	75.38

a – along the grain HBS; p – perpendicular to the grain HBS; d – HDS

CONCLUSIONS

1. For narrow belt sanders (NBS), either with individual pressure of the foot on the workpiece (furniture plant) or with individual pressure of the workpiece on the sander (pilot experiment), with the same sanding belt grain size of 80, there was no statistically significant difference in the percentage of fractions ≤ 0.08 mm in individual sieves between oak and beech wood. No difference was found even with the use of different sanders.
2. For handheld belt sanders (HBS) and handheld disc sanders (HDS), there was no statistically significant difference between sanding along the grain and perpendicular to the grain for both beech and oak wood. There was also no statistically significant difference between sanding with an HBS or HDS for beech wood or oak. A small but

statistically significant difference was found between the sanding of beech and oak, in which the total amount of fractions ≤ 0.08 mm for beech is greater than for oak (with both HBS and HDS), which is attributable to the anatomical structures of the sanded woods and oak being a wood that is difficult to sand.

3. For a wide belt sander, when sanding beech and oak with different sander grain sizes ($beech_{60}$ and $beech_{120}$, oak_{60} and oak_{120}), there were small but statistically significant differences between the results in beech and oak when sanding with a WBS with a grain size of 60. Again, this difference is attributable to the anatomical structures of the sanded woods, as well as oak being a wood that is difficult to sand. For the wide belt sander, the percentage of fractions ≤ 0.08 mm was far smaller than in narrow belt and handheld belt sanders. With the use of wide belt sanders, the entire sanding part is covered, and there is no immediate contact between the operator and the sanded workpiece. With good suction and cleaning of the workplace, there is no similar danger as in the previous cases.
4. The results confirmed that, when sanding hardwoods using narrow belt sanders, handheld sanders, and disc sanders, there was a large percentage of fractions ≤ 0.08 mm, over 90% in all cases, presenting a health and safety hazard: In these types of sanders, the working arm of the sander is not fully covered, and the operator is in direct contact with the machine. Despite the use of a suction device, a certain amount of dust remains suspended in the air, or it settles on surfaces. In both cases, this dust poses a health and safety risk.

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