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ORIGINAL ARTICLE

Fine dust after sanding untreated and thermally modified spruce, oak, and meranti wood

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Abstract
Airborne wood dust poses health and safety risks in the construction and furniture industry. The study verified whether the thermal modification affects the share of fine wood dust particles (< 10 μm) generated during spruce, oak, and meranti wood sanding. The experimental research involved nine material variants, including three wood species in three states: untreated, thermally modified at 160 °C, and thermally modified at 220 °C). To collect at least 200 g of each dust sample, a belt sander with P80 sandpaper and a belt speed of 10 m/s was used, along with a dust collector. The collected dust was then separated into fractions using a set of sieves with aperture sizes of 2000, 1000, 500, 250, and 125 μm. A laser particle sizer was employed to measure the sizes of dust particles in the under-sieve fraction (dust with particle sizes smaller than 125 μm). The under-sieve fraction was decomposed into three subfractions, with particle sizes: <2.5, 2.5-4.0, and 4.0–10 μm. Surprisingly the results indicate that sanding dust from thermally modified wood generates a lower average mass share of potentially harmful fine particle fractions than dust from untreated wood. Oak dust contained a higher mass share of fine particles compared to the spruce and meranti dust samples. Dust from thermally modified oak and meranti wood had a lower content of harmful particle fractions than dust from untreated wood. The average mass shares of these dust fractions for modified wood at 160 and 220 °C showed no statictically significant differences ($p < 0.05$). Conversely, spruce dust had a low content of fine fractions because spruce particles exhibit a more irregular elongated shape. The study considered the extreme temperatures of 160 and 220 °C used in the thermal modification of wood. Therefore, the above statements are assumed to be valid for all intermediate thermo-modification temperatures.

1 Introduction

Woodworking generates wood dust particles of various sizes and shapes. In industrial production, these particles are collected by local exhaust ventilation and transported through piping systems from the generation space to waste disposal units that collect this organic material as energetic by-products and raw material for furniture boards. Regrettably, the finest wood particles are not always fully collected and tend to become airborne particulate matter, harming human health during inhalation or contact with the skin or eyes. A legal limit in the United States for an employee's exposure to wood dust in the workplace is 15 mg/m^3 total exposure and 5 mg/m^3 exposure over an 8-hour workday. The National Institute for Occupational Safety and Health

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(NIOSH) has set a recommended maximum exposure level of 1 mg/m^3 of exposure to total dust. Long-term exposure to wood dust is a mucous membrane irritant and may cause dermatitis, allergic respiratory effects, mucosal and nonallergic respiratory effects, and cancer (Wood Dust and Formaldehyde, (WHO 1995)). The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a 0.5 mg/m^3 limit for wood species not suspected of carcinogens. The ACGIH lists oak and beech as confirmed carcinogenic species and highlights birch, mahogany, teak, and walnut as suspected carcinogenic species. The value is below the 2 mg/m^3 permissible limit (BOELV) for the inhalable fraction of hardwood dust, introduced by the European Commission (2017/2398/UE), which are valid in the EU countries as of 18 January 2023. When hardwood dust is mixed with other dust types, the concentration limit value applies to the entirety of the wood dust present in the mixture.

The fractional composition and the amount of dust suspended in the air are not constant. Large particles are usually heavier and sink faster to the ground; therefore, dust containing the smallest particles in size is most dangerous to humans because it tends to float in the air after a long time. The wood dust, which is spread into the air during woodworking, contains inhalable, thoracic, and respirable fractions. An inhalable fraction consists of all particles that can enter the human respiratory tract during breathing. Inhaled airborne dust particles that are not stopped in the nose, penetrate the pharynx and larynx, forming the thoracic dust fraction (≥ 10 µm, according to WHO definition), while the finest respirable fraction (≥ 4 µm) can penetrate the lower respiratory tract (trachea, bronchus, and lungs). The sizes and shapes of wood particles spread into the air depend on the type of woodworking, the technology parameters used, the type of processed wood material, and relative air humidity (Nasir and Cool 2020; Kminiak et al. 2020, 2021). For example, in sanding, the mean particle size of the dust created with P60 sanding paper was 1.4 times larger than that of the dust obtained with P180 sanding paper (Pędzik et al. 2020). The blunt level of the sanding paper is another factor that affects the particle size distribution (Sydor et al. 2021). The type of wood (hardwood or softwood) also significantly influences the particle size and content of the dust fraction with the finest particle sizes (Pędzik et al. 2020).

Wood dust also causes other hazards. Airborne sawdust is highly explosive. The dust of the finest particles dispersed in the air at a sufficient concentration in a confined area may explode if affected by any ignition source (Callé et al. 2005; Santamaría-Herrera et al. 2023). Wood dust adversely affects the complex mechanisms of modern industrial devices. It can pollute the lubrication systems, hinders the movement of feed devices, and disables optical systems of surveillance over industrial processes (Sydor et al. 2021).

The wood dust collected during woodworking can be as a raw material for industrial production. It can be admixture in making particleboard, fiberboard, and other wood-based engineering materials (Lee et al. 2022; Sydor et al. 2022). Wood dust can also be used as a fuel source in energy production (Nhuchhen et al. 2021).

The heat treatment of wood influences the particle size distribution of wood dust. Heat is used in many wood technologies, for example, in the steam kiln drying of lumber, in steam wood aging, in hot air drying of veneer, in hot-press gluing, in wood densification, in solid wood steam bending, and modification of solid wood properties. An industrial-scale wood modification process by temperature was developed in 1993 in Finland (Pertti et al. 1997). In this hydrothermal processing, wood is heated for several hours at high temperatures (up to 250°C) with aqueous vapor to change its physical properties. These changes result in a reduced volumetric mass density, improved dimensional stability, and increased resistance against biological factors (Stamm and Hansen 1937). Thermal modification can lead to a deterioration of strength properties, making the wood more fragile (van Blokland et al. 2020). Dust particles created during thermally modified wood processing are generally finer than particles from natural wood (Majka et al. 2022). The smaller particle size of the wood dust from the wood after thermo-modification makes them more susceptible to dispersion in the air.

All these reasons: protection of employees' health, safety against fire, reliability of industrial equipment, the willingness to collect the entire valuable wood by-product, and changed wood properties by heat treatment, justify research and analysis of the finest wood dust fractions created during woodworking of thermally modified woods. The research described in the article aims to characterize the fine dust particles that can form a thoracic fraction when dispersed in the air, with sizes < 10 µm, generated untreated and thermally modified meranti, oak, and spruce wood during sanding. We hypothesized that the temperature of thermal modification affects the mass share of the fine dust particles generated during wood sanding.

2 Materials and methods

2.1 Test samples

The research program included three types of wood: Norway spruce (*Picea abies* (L.) H. Karst) and Sessile oak (*Quercus petraea* (Matt.) Liebl.) were collected from Vlčí jarok (Budča, Slovakia) at an altitude of 440 meters above sea level, while meranti (*Shorea acuminata* Dyer) was purchased from a sub-provider (Wood Store, Prague,

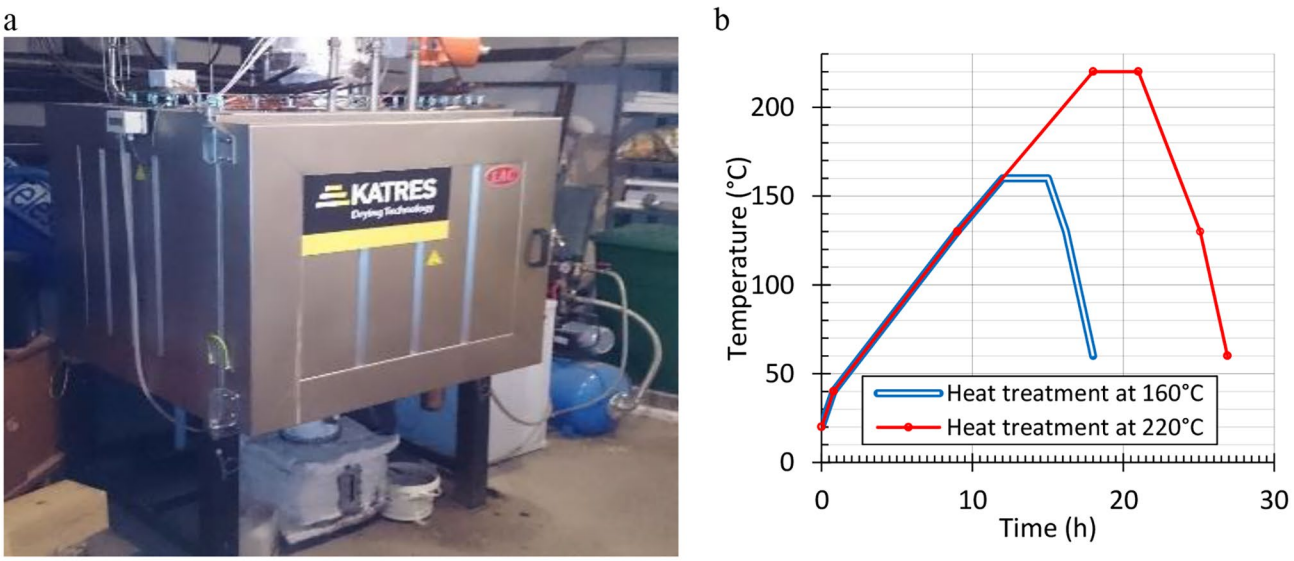

Fig. 1 Heat treatment: **a** – chamber, **b** – schedule

Table 1 Chamber parameters S400/3

Parameter	Value
Maximal temperature (°C)	300
Volume (l)	380
External dimensions, W×D×H (mm)	1400×1850×1200
Internal dimensions, W×D×H (mm)	800×800×600
Chamber weight (kg)	350
No. of fans	1
Power input (kW)	6.0

Czech Republic) and originated from Malaysia. Three test samples were obtained from each type of wood by cutting radial 20×100×700 mm boards from the logs, which were then dried to a residual moisture content of 8%. The entire process was carried out in the Research and Development Workshops of the Technical University in Zvolen (Zvolen, Slovakia).

2.2 Thermal modification of tested wood species

The tested wood species were thermally modified in the Arboretum FLD (Czech University of Life Sciences, Prague, Czech Republic) in the town Kostelec nad Černými lesy. The chamber (S400/03, LAC Ltd., Rajhrad, Czech Republic), used for thermal modification (Fig. 1a), was designed to process the wood with ThermoWood technology. Table 1 summarizes the main parameters of the chamber used in the heat treatment of test samples.

The thermal modification included two variants of temperatures, 160 and 220°C; the procedure was as follows:

1. Placing a humidity sensor, putting the samples in the chamber, setting off the thermal modification temperatures and times (values and steepness in °C/h for heating and cooling phases);
2. Thermal modification of samples in six phases: first phase – an increase in temperature to 40 °C for 48 min., second phase – an increase in temperature to 130 °C for 8 h and 12 min., third phase – heating to working temperature (160 or 220 °C) for 3 h, fourth phase – heat treatment at working temperature for 3 h, fifth phase – cooling to 130 °C and humidity treatment for 1 h and 12 min., sixth phase – cooling to 60 °C with humidity treatment at the level of 4–7% for 1 h and 48 min. The process was completed when the temperature reached 60 °C. Figure 1b shows the used heat treatment schedule;
3. Samples extraction from the chamber.

The thermal modification methodology used in this study has been previously described in published documents (Kučerka and Očkajová 2018; Očkajová et al. 2018a).

2.3 Dust generation by sanding

A laboratory narrow belt sander (JET JSG-96, JPW Tool AG, Fällanden, Switzerland), with a belt speed of 10 m/s, and a sanding belt (HIOLIT XO P 80, KWH Group Ltd., Vaasa, Finland) was used to generate the wood dust tested in this study. Every time a new sharp sanding belt was used for each of the nine sample variants (3 tested wood species × 3 variants of treatment used). Figure 2 presents the laboratory sander used.

All wood dust created was captured using a Rowenta vacuum cleaner (Erbach im Odenwald, Germany) into a Rowenta Original ZR 814 in disposable paper bags. A new

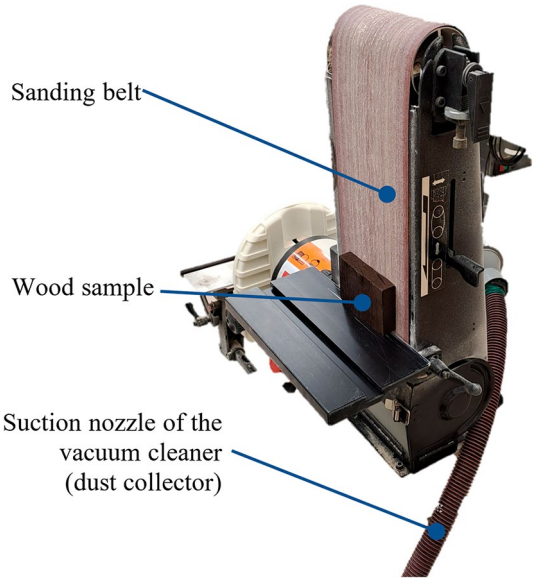

Fig. 2 Narrow belt sander used in the study

paper bag was used for each of the nine sample variants. At the end of each sanding, the dust sample from a paper bag was poured into a plastic bag and hermetically closed to avoid any change in the dust parameters. Approximately 200 g of each dust sample was collected.

The particle size distribution of wood dust was tested by sieving. We used a Retsch AS 200c sieving machine (Retsch GmbH, Haan, Germany) to separate the dust particles into different size fractions according to the STN 153105/STN ISO 3310-1 (2000) standard. The testing machine was equipped with a set of vertically ordered sieves, including mesh screens with pore sizes of 2000, 1000, 500, 250, 125 µm and a bottom collector for particles passing through all sieves. The sieving process was carried out with an adjustable frequency of 20 Hz and a sieve deflection amplitude of 2 mm/g. As much as 30 g of material was analyzed in each sieving process. Each dust sample was exposed to six sieving processes.

The mass particle-size distribution was obtained by weighing the wood dust remaining on the sieves after sieving on the Radwag WPS 510/C/2 electronic weighing scale (Radwag Balances and Scales, Radom, Poland), with a capacity of 510 g and an accuracy of a scale with the resolution of 0.001 g. The weight figures for each sieve were recorded in MS Excel (Microsoft Corporation, Redmond, WA, USA), and the results were statistically evaluated using STATISTICA 13 software (TIBCO Software Inc., Palo Alto, CA, USA).

2.4 Laser particle size analysis

The sieve analysis only provides information on the masses of individual fractions without any information on the particle size distribution in these dust fractions. The laboratory laser particle sizer (Analysette 22 Microtec Plus, Fritsch, Idar-Oberstein, Germany) was used to specify details regarding the dust with the size of particles smaller than 125 µm (collected in the bottom collector). The laser particle sizer automatically measures a particle size according to a predetermined Standard Operating Procedure and theoretical assumptions. The results obtained were processed by MaScontrol software (Fritsch, Idar-Oberstein, Germany). It gives two quantities: the sum of the Q(x) distribution and the $q(x)$ density distribution.

According to $dQ_r(x) = q_r(X)\,dx$, $q_r(x)$ is a component of $dQ_r(X)$, which is contained in the interval dx for particles from x and $x + dx$. The result is a random variable r (when $r = 3$, it means volume distribution; assuming a constant density of tested material, it is also mass distribution), where:

$$q_r(x) = \frac{x^r \times q_0(x)}{\sum_{i=1}^{n} x_i^r \times q_{0i}(x_i)} = \frac{dQ_r(x)}{dx}$$

This distribution determines the mass share of the particles in the assumed size ranges (CLi) of the dust collected in the bottom collector (CS125) by MaScontrol software. The most critical particle size ranges from the point of view of human respiratory tract penetration ability (< 2.5 µm, 2.5-4.0 µm, 4.0–10 µm) were used to calculate the mass share of fine particles in the total dust mass.

2.5 Calculation of the fine particles content

The calculation of the mass share of particles < 2.5 µm, 2.5-4.0 µm, 4.0–10 µm in the whole mass of dust created was performed as follows:

$c_i = c_{S125} \cdot c_{Li}$

where c_i – mass share of dust particles in the assumed size range of the entire mass of dust, c_{S125} – mass share of dust collected during the sieve analysis in the bottom collector, and c_{Li} – mass shares of the dust in the assumed ranges determined using laser diffraction analysis in the c_{S125} share.

This calculation was based on physically performed particle size distribution tests using two complementary methods. Sieve analysis gave the directly weighted mass share of dust fraction. Then the fraction of the finest dust collected in the bottom collector was tested by laser diffraction, which gave the volume shares of dust fractions of sizes that cannot be tested by sieving. The volume shares are equal to the mass shares because the dust density is constant. Therefore, the product of these mass shares is the mass share of the

Table 2 Particle size distribution of dust variants by the sieving method

Sieve aperture size (µm)	Percentage share of dust fractions								
	Spruce			Oak			Meranti		
	untreated	modified at 160 °C	modified at 220 °C	untreated	modified at 160 °C	modified at 220 °C	untreated	modified at 160 °C	modified at 220 °C
Bottom	86.11	92.63	61.68	94.72	92.1	73.68	84.17	87.18	74.48
125	13.25	7.14	34.3	4.48	4.18	18.28	14.95	11.18	24.12
250	0.35	0.1	3.87	0.6	1.18	6.42	0.71	0.45	1.41
500	0.15	0.1	0.15	0.2	2.44	1.52	0.2	0.1	0
1000	0.15	0.05	0	0	0.1	0.1	0	0.1	0
2000	0	0	0	0	0	0	0	0	0

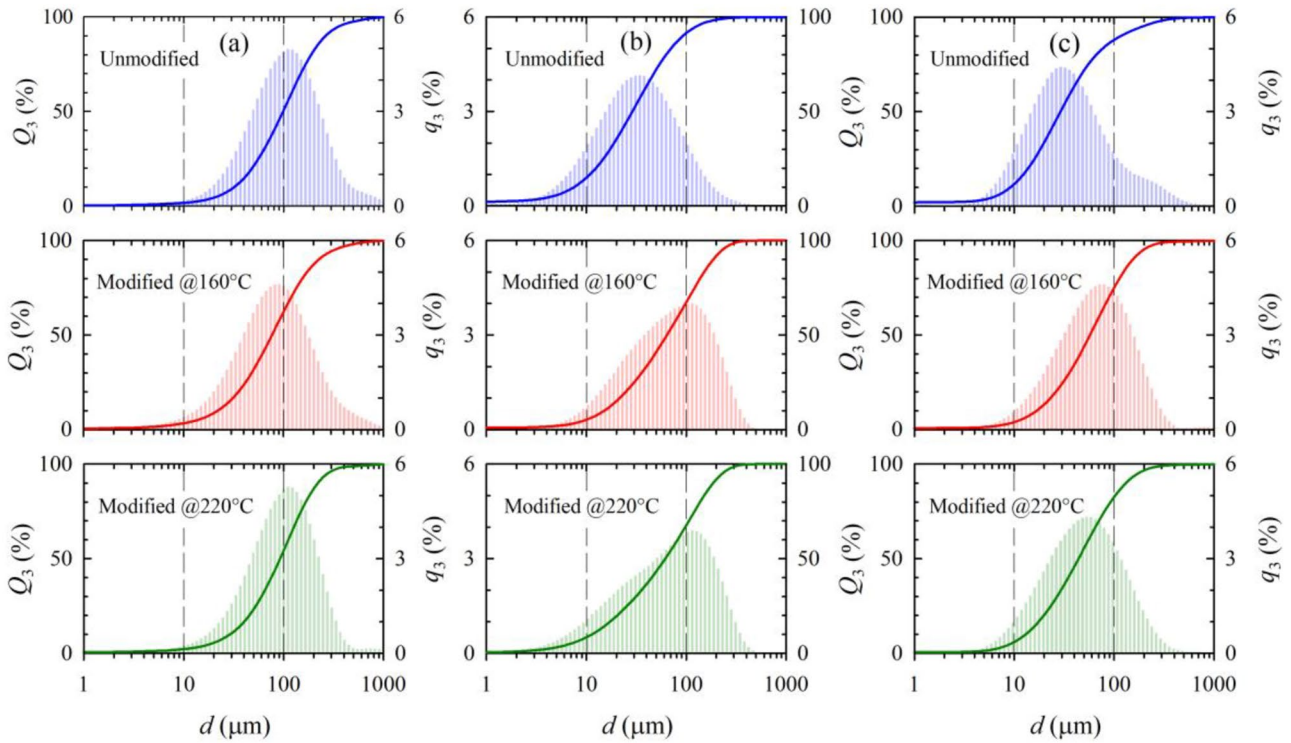

Fig. 3 Averaged cumulative distribution (Q_3) and density distribution (q_3) of untreated and thermally modified wood dust: (a) spruce, (b) oak, (c) meranti ($n = 9$ for each variant)

dust particles in the assumed size range of the whole mass of dust created in the experiments. This calculation method has already been used to determine the finest dust shares in earlier studies (Rogoziński et al. 2021; Pędzik et al. 2021).

2.6 The statistical analysis

The two-way analysis of variance (ANOVA) was used to assess the particle size distribution for the nine dust variants (dust of untreated wood, dust of thermally modified wood dust at 160°C, and thermally modified wood dust at 220°C originating from spruce, oak, and meranti). A post hoc Tukey's range test was used to find means that are significantly different from each other.

3 Results

The results of the sieve analysis are shown in Table 2.

The results of the particle size distribution by a laser diffraction method are shown in Fig. 3. The distributions depicted on the graphs were used to determine the dust particle share in the assumed size ranges (c_{Li}) of dust collected in the bottom collector (c_{S125}).

Figure 3 shows that the under-sieve fraction consistently contained the highest mass share of dust (below the 125 µm sieve). While there were some differences in the value of this share between the tested samples, the lowest percentage was consistently measured in the dust generated during modified sanding of the wood at 220°C, suggesting that the

Table 3 Analysis of Variance (ANOVA) table for the mass share of finest particles in untreated and thermally modified spruce, oak, and meranti wood dust, considering the effects of heat treatment and particle size

	Effect	SS	df	MS	*F*-value	*p*-value
Spruce	Intercept	80.20411	1	80.20411	92.74634	0.000000
	Heat treatment (factor a)	16.12952	2	8.06476	9.32592	0.000260
	Particle size (factor b)	20.80817	2	10.40408	12.03106	0.000033
	a × b	6.66957	4	1.66739	1.92814	0.115497
	Error	59.66902	69	0.86477		
Oak	Intercept	1208.43	1	1208.43	668.787	0.000000
	Heat treatment (factor a)	236.822	2	118.411	65.5327	0.000000
	Particle size (factor b)	627.237	2	313.618	173.5674	0.000000
	a × b	128.393	4	32.098	17.7642	0.000000
	Error	124.676	69	1.807		
Meranti	Intercept	478.7123	1	478.7123	642.0294	0.000000
	Heat treatment (factor a)	137.7533	2	68.8766	92.3745	0.000000
	Particle size (factor b)	287.0063	2	143.5032	192.4606	0.000000
	a × b	68.85080	4	17.2127	23.085	0.000000
	Error	49.2112	66	0.7456		

SS – the sum of squares, df – degrees of freedom, MS – mean squares, *F* – Fisher's *F*-test

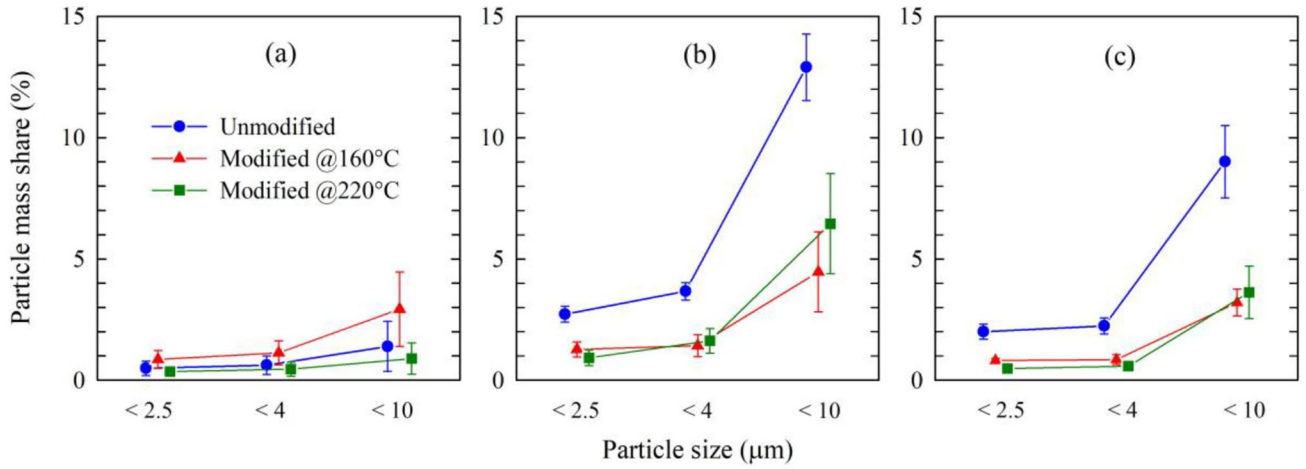

Fig. 4 Comparison of the average values of the finest fractions of untreated and thermally modified wood dust: **(a)** spruce, **(b)** oak, **(c)** meranti, error bars depict ± 95% confidence limits

modification temperature can influence the dust particle size after sanding. The statistical analysis results and a direct comparison of these mass shares are presented in Table 3.

The two-way analysis of variance results presented in Table 3 confirms the significant importance of the influence of the prior thermal modification (factor a) on the dimensional characteristics of the dust generated during wood sanding and the share of the finest particles fractions of the dust (factor b), which, when dispersed in the air, may constitute thoracic and respirable dust. Furthermore, the interaction between factors (a) and (b) was confirmed in the case of oak and meranti wood dust. There is no such interaction in the case of spruce wood dust (marked gray row in Table 3).

However, the sieve analysis provided only a general particle size distribution, and the detailed particle size distribution should be determined using a complementary measurement method. The results of the laser measurement presented in Fig. 4 allow the calculation of the mass share of particles in the ranges: <2.5, 2.5-4.0, and 4.0–10 µm in the total dust mass tested.

Among the cases examined, oak wood dust has the highest average share of the finest particles in all size ranges (<2.5 µm, 2.5-4.0 µm, 4.0–10 µm). This characteristic holds for both untreated and thermally modified wood dust. These results suggest that sanding dust from thermally modified wood exhibits a lower average proportion of potentially harmful particles, which, when airborne, can contribute to the formation of thoracic and respirable dust, compared to sanding dust from untreated wood. However, this trend does not apply to the dust samples obtained from spruce wood. Table 4 presents the statistical analysis results

Table 4 Statistical analysis of fine particle mass share of untreated and thermally modified spruce, oak, and meranti wood dust

	Treatment option	Particle mass share (%)		
		< 2.5 µm	< 4 µm	< 10 µm
Spruce	Untreated	0.49 ^{ab} ±0.39	0.62 ^{ab} ±0.49	1.40 ^{ab} ±1.55
	Thermally modified at 160 °C	0.86 ^{b} ±0.48	1.13 ^{b} ±0.64	2.93 ^{b} ±1.99
	Thermally modified at 220 °C	0.36 ^{a} ±0.22	0.46 ^{a} ±0.35	0.90 ^{a} ±0.76
Oak	Untreated	2.72 ^{b} ±0.39	3.67 ^{b} ±0.43	12.90 ^{b} ±1.64
	Thermally modified at 160 °C	1.28 ^{a} ±0.41	1.43 ^{a} ±0.58	4.47 ^{a} ±2.14
	Thermally modified at 220 °C	0.98 ^{a} ±0.42	1.63 ^{a} ±0.65	6.46 ^{a} ±2.69
Meranti	Untreated	2.00 ^{b} ±0.40	2.24 ^{b} ±0.43	9.01 ^{b} ±1.94
	Thermally modified at 160 °C	0.82 ^{a} ±0.09	0.85 ^{a} ±0.24	3.21 ^{a} ±0.72
	Thermally modified at 220 °C	0.49 ^{a} ±0.06	0.58 ^{a} ±0.12	3.62 ^{a} ±1.29

Mean value ($n=9$) ± standard deviation; identical superscripts (a, b, c) indicate a non-significant difference ($p<0.05$) between mean values according to post hoc Tukey's test

for the fine particle mass share of untreated and thermally modified spruce, oak, and meranti wood dust.

The statistical analysis results show that the average mass share of the finest dust fractions isolated from the dust generated during the sanding of oak and meranti wood does not depend on the parameters of the previous thermal modification process. In the cases discussed, the average mass shares of these dust fractions (for all levels of discrimination – size ranges) generated during the sanding of modified wood at 160 and 220 ° C do not differ significantly ($p<0.05$).

4 Discussion

The obtained results align with the earlier studies on dust from modified wood. There is a general opinion that the thermal modification of wood does not influence the sizes of dust particles generated during wood sanding. Other factors, such as wood species, density, and processing parameters, are more crucial in generating wood dust. However, some studies report an increased mass fraction of fine wood dust when processing thermally modified wood. Kučerka and Očkajová (2018) studied the dust of Sessile oak (*Quercus petraea*) and Norway spruce (*Picea abies*) wood. After thermal modification at four different temperatures (160, 180, 200, and 220°C) for 3 hours, the wood samples were sanded with P80 sandpaper using a vertical belt sander. The set of sieves with aperture sizes 2000, 1000, 500, 250, 125, 80, 63, and 32 µm was used to separate the dust into sieve fractions. The fine particle size fraction (≤32 µm) of oak dust showed the highest mass share for all treatment temperatures; simultaneously, the lowest values of the dust fraction with a size of ≤32 µm were obtained at the processing temperature of 220°C for both wood species studied. The authors pointed out that the increase in treatment temperature in the range of 160–200°C does not significantly affect the amount of fine dust generated and indicated oak dust as having an unfavorable tendency to contain a large amount of fine particles. While thermal modification at 220°C reduces the share of the finest fraction in the dust created during sanding. The cited authors stated that in the sieve range up to 80 µm, thermal modification at temperatures of 160–200°C does not significantly change the mass proportions of the sieve fractions of oak and pine dust generated during sanding. The lowest values of dust fractions measuring ≤80 µm were obtained with all tested woods after thermal modification at temperatures of 220°C. Our results partially confirm this trend in the smallest grain size fractions (up to 10 µm). Figure 4 shows that in the case of pine dust, the thermal modification does not change the amount of the finest dust, while in the case of oak dust and meranti dust, thermo-modification favorably reduces the dust with the smallest grains in the total amount of tested dust. Additionally, oak dust contains significantly more fine particles.

The studies carried out by Očkajová et al. (2020b, a) compared the granulometric composition of chips and dust from longitudinal milling and sanding of thermally modified oak and spruce wood at different modification temperatures. As it is known, the residue curve shifted to the left means a large proportion of fine particles in the dust, while the residue curve shifted to the right - a large proportion of particles with large grain sizes. In sanding, the dust residue curves shift to the right, whereas the milling dust residue curves shift to the left under the influence of thermal modification. Kminiak and Dzurenda (2019) investigated the changes in the particle size distribution of wood chips due to thermal wood treatment and found that thermally modified maple wood does not form the finest dust particles. This observation is confirmed by earlier reports on oak sanding dust (Marková et al. 2016; Očkajová et al. 2018b). Our study and all these cited studies suggest that woodworking technology and wood treatment temperature impact the particle size distribution of wood dust, which is vital for wood processing and worker safety.

Očkajová et al. (2019) studied the wood dust created after sanding untreated wood and wood after thermal modifications at temperatures of 160, 180, 200, and 220°C. The cited authors used a belt sander, P80 sanding paper, and processed three species of wood: Sessile oak (*Quercus petraea*), Norway spruce (*Picea abies*), and meranti (*Shorea acuminata*). A set of sieves, 2000, 1000, 500, 250, 125,

80, 63, and 32 µm, was used to assess the dust particle size distribution. The fraction of fine particles (≤ 80 µm) in thermally modified oak dust was similar to that of untreated wood's fine dust. The mass of this fraction was 92–95%. A significant decrease in the mass share of this fraction was observed in the dust originating from wood modified at 220° C. The highest mass share of dust with a particle size of ≤ 80 µm for the other wood species was measured in dust from wood modified at 160°C (87% – meranti, 93% – spruce). This share decreased with the increasing temperature of wood modification. A similar influence of temperature was observed in the 32–63 µm sieve fraction and the under-sieve fraction (with the finest particle sizes < 32 µm). It is convenient to analyze the study results using residue curves. The residue curves presented by the cited authors confirm our research results presented in Fig. 3. In the case of pine wood, the dust from wood modified at 160°C has a fractional composition similar to that of unmodified wood, while the dust from wood modified at 220°C contains a slightly larger proportion of coarser particles (the residue curve is slightly shifted to the right). The impact of thermo-modification on reducing the share of fine particles in dust is much more visible in oak and meranti wood. For these species, both low-temperature modification (160°C) and high-temperature modification (220°C) shift the residue curves to the right. Očkajová et al. (2019) explained the sieve analysis results with the reduced density of thermally modified wood.

The above-cited research results suggest that the thermal modification reduces the dust fraction with a particle size ≤ 80 µm. An example is the study of dust from sawing oak and pinewood (Dzurenda et al. 2010), milling and sanding oak, and spruce wood (Očkajová et al. 2020b, a). Furthermore, in scientific publications on the dust generated from thermally modified wood (oak, spruce, meranti), based on the sieve analysis performed, a lower particle content of particles with the smallest size was found in the modified dust from the wood at the highest temperature (220°C) (Kučerka and Očkajová 2018; Očkajová et al. 2019). The absence of the finest particles, i.e. < 32 µm, was also found. Kminiak and Dzurenda (2019) proposed a similar conclusion based on their research on dust from milling maple wood. The authors also stated no significant differences in particle sizes for modified and untreated wood dust.

Furthermore, Mikušová et al. (2019) investigated the influence of various temperatures of thermal modification on the size distribution of meranti (*Shorea accuminata*) wood dust created by a hand-held belt sander. The untreated samples were compared to the thermally modified samples at temperatures of 160, 180, 200, and 220°C using optical and gravimetric methods. The mass share of the finest particles in tested wood dust was highest after the treatment at 160°C. However, the authors stated that thermal treatment did not have a significant influence on mass proportion.

The occurrence of the finest particles (≤ 10 µm) in the dust created by untreated and thermally modified wood of five species (aspen, fir, maple, ash, and poplar), was also investigated. Thermal modification of wood did not affect the amount of these particles in the air (Aro et al. 2019). Majka et al. (2022) compared the dust from untreated beechwood to the dust from thermally modified beechwood (200°C, 3 h). The dust variants tested were separated into four sieve fractions with grain sizes < 25 µm, 25–80 µm, 80–250 µm, and > 250 µm. The authors studied whether the thermal modification changes the particle size distributions and whether all four dust sieve fractions contain the finest particles. The wood materials were sanded with P120 paper. Both types of tested dust had similar particle size distributions and measurements using a laser particle sizer found the presence of particles < 10 µm in each of the four fractions.

Such statements contradict the research results described by other authors. An example of such research is the work of Hlásková et al. (2018). On the basis of the sieve analysis results, these authors found that the increased modification temperature of beech wood resulted in a reduced mass share of the smallest particles in the dust created in sanding. However, in the dust of wood modified at higher temperatures, the microscopic image analysis showed a higher content of the finest particles. The use of the laser diffraction analysis method to assess the mass share of the finest particles in the undersieve fraction (containing the smallest particles) also led to the conclusion that the modification temperature influences the higher mass share of the finest particles in the resulting dust when milling modified pine wood (Piernik et al. 2019).

Therefore, there is still uncertainty as to whether and to what extent, depending on the type of wood and the processing method, thermal modification affects the increase in the mass share of fine dust. This is a reason for further research in this area to ensure that the knowledge base is extensive enough to clearly assess this impact.

5 Conclusion

The experimental setup included three types of wood (European softwood, European hardwood, and Asian hardwood). We analyzed dust originating from unmodified wood and modified wood in two extreme temperatures of modification (low and high). Test samples were processed with the most dust-generating technology (sanding). Combined sieve and laser analysis methods were used to analyze dust fractions. Among the examined cases, oak wood dust is characterized by the highest average mass share of the finest particles (of

all assumed ranges, i.e. <2.5, 2.5-4, and 4–10 µm), which, when dispersed in the air, may pose a health risk to workers in the surroundings of workstations. This statement applies to both the dust of untreated and thermally modified wood.

In general, sanding dust from thermally modified wood tends to have a lower average mass share of potentially harmful particle fractions than sanding dust from untreated wood. However, as mentioned in the Results section, this trend does not hold for the dust samples obtained from spruce wood. This discrepancy may be attributed to the inherently low average mass share of these fractions in spruce wood dust and the relatively large variation in the results, possibly caused by the irregular shape of spruce wood dust particles. The irregular shapes of the particles can negatively affect the accuracy of the measurement methods used to determine the size of the wood dust particles.

Extreme temperatures, a low (160 °C) and the highest (220 °C), were used in the thermal modification of wood. It should be assumed that the above two statements, about the generally lower mass share of potentially harmful particle fractions compared to the dust generated when sanding untreated wood, as well as there are no statistically significant differences in the average mass share of the finest fractions, are valid at all intermediate temperature variants used in the thermal modification of spruce, oak and meranti wood.

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