Thermal Treatment's Effect on Dust Emission During Sanding of Meranti Wood

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The aim of this research was to investigate the effects of various temperatures of thermal treatment of red meranti (*Shorea accuminata*) wood on mass concentration and size distribution of wood dust produced by a hand-held belt sander. The experiment was conducted during the sanding of the meranti wood in the natural state and using specimens that were heat-treated *via* the ThermoWood® technology at the temperatures of 160 °C, 180 °C, 200 °C, and 220 °C. An analysis of variance was used to measure the significance of the effects. Average values of the inhalable and respirable fractions of wood dust mass concentration determined *via* the optical and gravimetric method was highest at the treatment temperature of 160 °C. The results showed that mass concentration was not significantly influenced by thermal treatment.

Keywords: Thermowood; Meranti; Sanding; Wood dust; Mass concentration

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INTRODUCTION

Various types of sanders (belt sander, disc sander, and special sander) used for refining the surface of individual parts before the surface finish treatment are some of the most important devices in both furniture manufacturing and joinery. However, their operation is associated with dust production, which is seen as a negative effect. Although every sander is equipped with suction, most hand-held band sanders do not have the whole part of the sanding belt covered. Thus, fine dust (dust particles < 100 μm) is released into the working environment and poses a risk to safety as well as to human health.

High concentration and long-term exposure to any type of dust in the air causes deposition of dust particles in the eyes, nose, and mouth, and on the skin; it stresses the lungs' self-cleaning system and decreases overall human immunity, which can eventually lead to chronic bronchitis (Schwarz *et al.* 2009). The highest risk to the human respiration system is posed by the respirable fraction with particle sizes lower than 10 μm. Following several research studies (Marková *et al.* 2016; Mračková *et al.* 2016; Očkajová *et al.* 2016) of several dust types, including wood dust, it is important to consider also other fractions, mainly the fine dust that is hardly deposited in the working environment with a particle size < 100 μm. These fractions are harmful for humans, and the wood dust of some hardwoods (beech, oak) and their inhaled particles cause mostly paranasal sinus cancer (WHO 1999). From the viewpoint of evaluating the potential health risks according to the

Slovak legislation (Regulation of the Government of the SR No. 471/2011 Coll.), meranti wood dust is classified as a solid aerosol of a mostly irritating character. The permissible exposure limit (PEL) for solid aerosols (dust) is determined as the time-weighted average of exposure of the overall (inhalable) concentration of the solid aerosol (TWE), and its value for exotic wood species is 1 mg.m^3. The PEL for solid aerosols does not consider the possible allergic effects or presence of microorganisms in the dust.

Thermally treated wood is currently being researched in many studies. The primary aim of thermally treated wood is to prepare a material that brings the following benefits: a lower hygroscopicity, higher dimensional stability, higher resistance to wood-decaying and discolouring fungi, moulds, and ligniperdous insects, maintaining or improving the aesthetics (colour, minimal cracks, gloss, texture, *etc*.), and preservation or improvement of the mechanical properties (strength hardness, stiffness, *etc*.) (Požgaj *et al.* 1997; Bengtsoon *et al.* 2003; Niemz *et al.* 2010; Barcík and Gašparík 2014). Thermally treated wood is designed for various applications both in exterior and in extremely humid indoor environments because it has a reduced moisture absorption capacity, with decreases in the range 30 to 50% (*e.g.* terrace and pool tiles, garden furniture production, sauna furniture production etc.). The thermal process results in an equilibrium moisture content of 5 to 7%, although it is found in a significantly higher humidity environment. Another benefit of this material is the fact that it is treated using heat, steam, and water without the use of any chemicals. Thermally treated wood has been studied regarding various aspects: physical and mechanical properties (Gunduz *et al.* 2009; Dzurenda and Orlowski 2011), chemical properties (Kačíková and Kačík 2011; Čabalová *et al.* 2016; Miklečić and Jirouš-Rajković 2016), quality of the modified surface (Budacki *et al.* 2013; Kvietková *et al.* 2015; Pinkowski *et al.* 2016; Vančo *et al.* 2017; Korčok *et al.* 2018), wood color and machinability (Sandak *et al.* 2017; Hrčková *et al.* 2018), the energy consumption in the milling process (Kubš *et al.* 2016), stability against weather conditions (Panayot 2008; Yildiz *et al.* 2011), the granulometry of the created chips (Barcík and Gašparík 2014; Očkajová *et al.* 2014), and the granulometry of the sawdust (Dzurenda *et al.* 2010).

In general, thermally treated wood has increased fragility and brittleness, which results in the production of smaller dust particles than unmodified wood (Očkajová *et al.* 2016). There is minimal quantitative data describing the mass concentration and particle size of airborne wood dust produced when sanding thermally treated wood. The majority of previous studies (Rogoziński *et al.* 2015; Kučerka and Očkajová 2018; Očkajová *et al.* 2018) analyzed dust that was captured by exhaust piping/dust extraction systems attached to the sander. However, there are no known studies analyzing airborne thermally treated wood dust during sanding that was not captured by exhaust systems, as described in this paper.

The aim of this study is to investigate the effects of various temperatures of red meranti wood heat treatment on the mass concentration and size distribution of wood dust produced by a hand-held belt sander.

EXPERIMENTAL

Materials

All experimental wood pieces were in the form of planks with dimensions of 20 × 100 × 700 mm. Specimens were obtained from a commercial supplier (Wood Store, Prague, Czech Republic). The specimens were subsequently dried to the residual moisture content of 8%. The entire process was completed in the Development Workshops and Laboratories of the Technical University in Zvolen (Slovakia).

The test specimens were heat-treated in the Arboretum of the Faculty of Forestry and Wood Sciences (Czech University of Life Sciences, Prague, Czech Republic) in Kostelec nad Černými lesy. The S400/03 chamber (LAC Ltd., Rajhrad, Czech Republic), designed for thermal wood treatment using the technology ThermoWood®, was used for the heat treatment of the specimens. Four specimens were prepared for each variant of the heat treatment (160 °C, 180 °C, 200 °C, and 220 °C). The process of the heat treatment is described in detail in the study by Očkajová *et al.* (2018).

Experimental Set-up

The experimental measurements were taken in a room according to requirements of the standard STN EN 50632-1 (2016). The temperature and humidity in the room during the experiment reached a relatively constant level of values in the range of 20 to 21 °C and 36 to 37%, respectively. The average speed of air circulation in the place of dust sampling was determined using a Thermo-Anemometer Testo 480 (Testo Ltd., Alton, United Kingdom) and ranged from 0.21 m.s^{-1} to 0.28 m.s^{-1}.

The meranti wood moisture was evaluated by the gravimetric method and reached 8% at sanding time. Sanding was performed using a commercial hand-held belt sander PBS 75A (Robert Bosch Power Tools GmbH, Stuttgart, Germany) without a microfilter system. The belt sander was adjusted to the maximum speed (350 m.min^{-1}). The abrasive belt LS309XH (Klingspor Schleifsysteme GmbH & Co. KG, Haiger, Germany) with dimensions 75 mm × 533 mm was used for sanding, and it was replaced after each test cycle. The grain size of the sanding papers was p80. The mobile workbench PWB 600 (Robert Bosch Power Tools GmbH, Stuttgart, Germany) was used for clamping the samples. The experimental set-up is illustrated in Fig. 1.

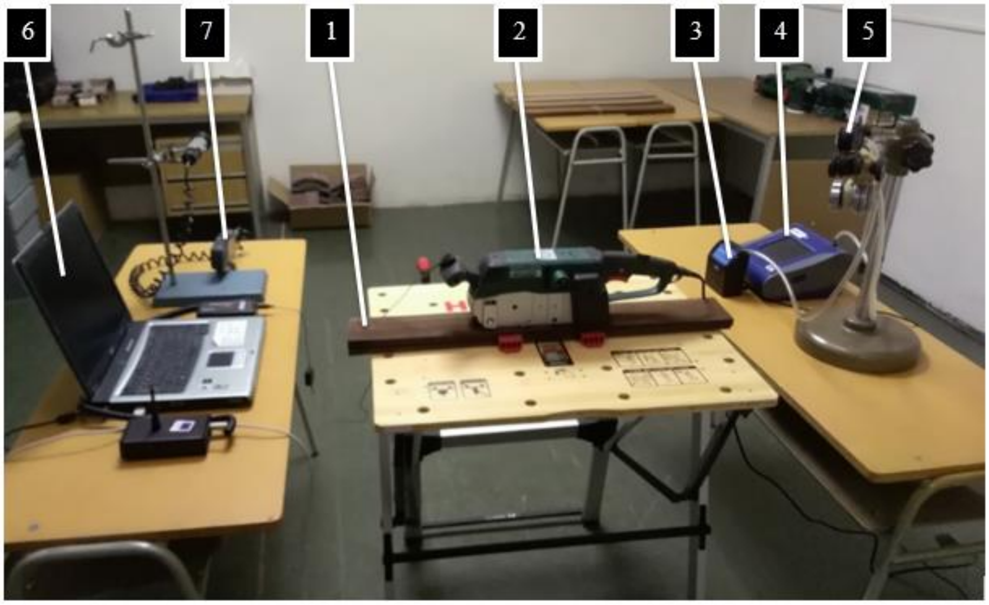

Fig. 1. Experimental set-up: 1 - Test sample, 2 - Belt sander, 3 - Flow pump, 4 - Aerosol monitor, 5 – Multi-fraction sampler, 6 – Notebook with software for monitoring pressure force, and 7 - Photometer

To ensure consistent sanding operation, monitoring the pressure force was performed by the load cell capacity ergoPAK™ FSR Senzor (Hoggan Scientific LLC, Salt Lake City, UT, USA). Figure 2 illustrates the detail of the component set-up for monitoring the pressure force during the sanding process. The pressure force was constant during sanding of all samples and reached 50N ± 5N. This pressure force was applied according to STN EN 50632-2-4 (2016).

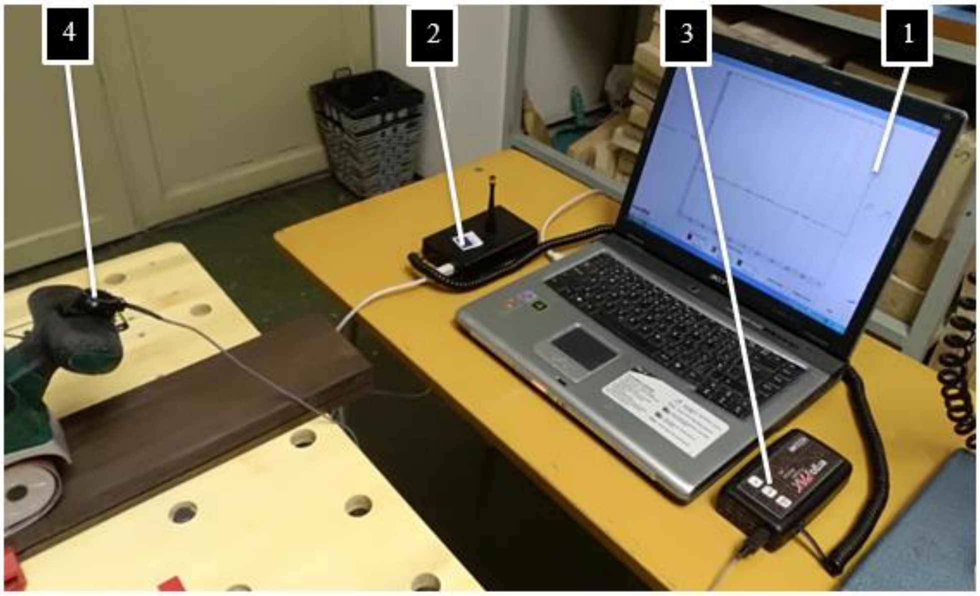

Fig. 2. Detailed set-up of components for measuring the pressure force: 1 - Data acquisition software, 2 - Wireless receiver with antenna, 3 - Device hub, and 4 - Load cell

To verify adequate cleaning and ventilation after each sampling event, the background concentration in test room was monitored using a photometer (MicroDust Pro CEL-712, Casella CEL Inc., Buffalo, NY, USA).

Methods

Measurement of dust concentration

The airborne wood dust was sampled in the breathing zone of the belt sander operator. The wood dust sampling period (3 min) was determined following the time required for sanding one test specimen. The aerosol monitor DustTrak DRX 8533 (TSI Incorporated, Shoreview, MN, USA) was used for measuring the inhalable (particle size < 100 μm) and respirable (particle size < 5 μm) fractions of wood dust. An aerosol monitor combines a light scattering photometer and an optical particle counter for mass concentration measurements between 0.001 mg.m^{-3} and 150 mg.m^{-3}. Zero-point calibration of the device was completed prior to each sampling event, as recommended by the manufacturer. To improve the accuracy of the mass concentration measurement, the aerosol monitor was compared with reference gravimetric samplers in two ways. First, the aerosol monitor was fitted with a 37-mm filter cassette in-line with the aerosol flow, which allowed for a gravimetric analysis of the same aerosol as optically measured. Glass fiber filters with a diameter of 37 mm (GF 50 037; Hahnemühle, Dassel, Germany) were used for the gravimetric sampling of the inhalable fractions. Second, gravimetric samples were obtained using an external pump Libra L-4 (A. P. Buck Inc., Orlando, FL, USA) and a multi-fraction sampler (IOM Multidust sampler; SKC Inc., Eighty Four, PA, USA). The IOM sampler was equipped with a 25-mm glass fiber filter (GF 50 025; Hahnemühle, Dassel, Germany) and a polyurethane foam insert (IOM MultiDust respirable foam disc; SKC Inc., Eighty Four, PA, USA). Figure 3 illustrates the set-up of the IOM samplers.

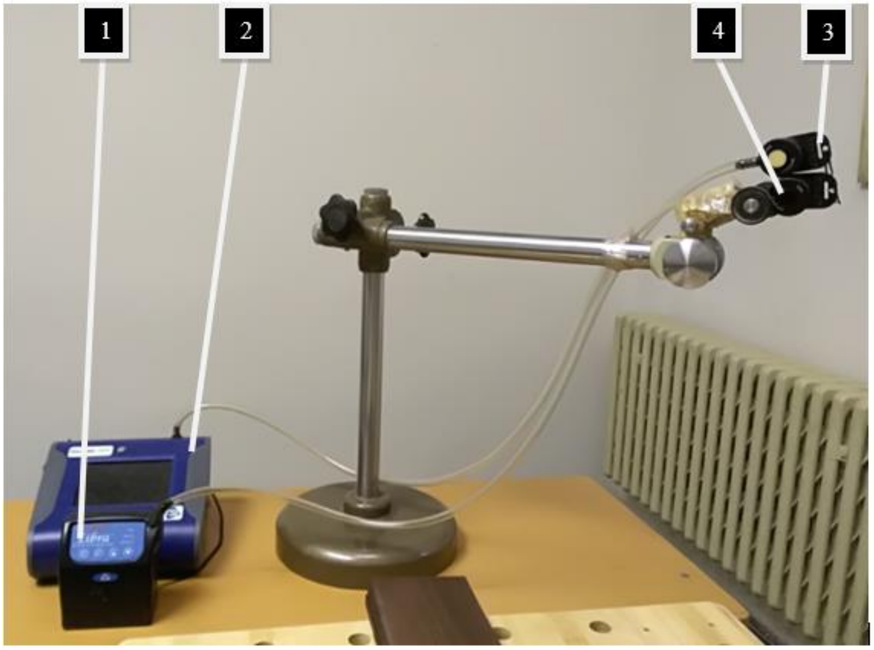

Fig. 3. IOM samplers position: 1 - Flow pump, 2 - DustTrak DRX aerosol monitor, 3 – Reference gravimetric sampler, and 4 - IOM sampler connected to DustTrak DRX

Prior to the sampling event, the multi-fraction sampler was connected to a pump that was set to operate at 2 L.min^{-1} using a BIOS DryCal primary flow meter (Bios International Corporation, Butler, NJ, USA). Pump flow rates were measured again after sampling to confirm the constant airflow rate. All collection substrates were conditioned before and after the sampling for at least 12 h in a desiccator. Gravimetric analysis was performed using an analytical balance (XA 110; RADWAG USA LLC, Radom, Poland).

Evaluation of wood removal

The total amount of airborne wood dust produced is a function of the total mass of wood removed during the abrasive sanding process (Thorpe and Brown 1995). Therefore, the quantity of dust removed from the planks during the 3 min of sanding was determined by weighing the planks before and after the sanding operation. The weighing procedure was performed using an analytical balance (BP 3100 P; Sartorius AG, Goettingen, Germany).

Statistical Analysis

An analysis of variance (ANOVA) was used to determine the influence of thermal treatment on the magnitude of the generated wood dust mass concentration. The significance level was set at $p = 0.05$. The data analysis was performed using the statistical software Statistica v.10 (StatSoft Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Effect of Thermal Treatment on Wood Removal

The amount of removed wood dust depending on the heat treatment is illustrated in Fig. 4. The measured values of wood removal are in the form of the arithmetic mean of four measurements. Compared to the untreated wood, approximately 1.2 to 3 times more dust was generated when the thermally treated wood was sanded. There was a statistically significant difference between the groups as determined by the one-way ANOVA (F(4,15) = 62.553, p = .000).

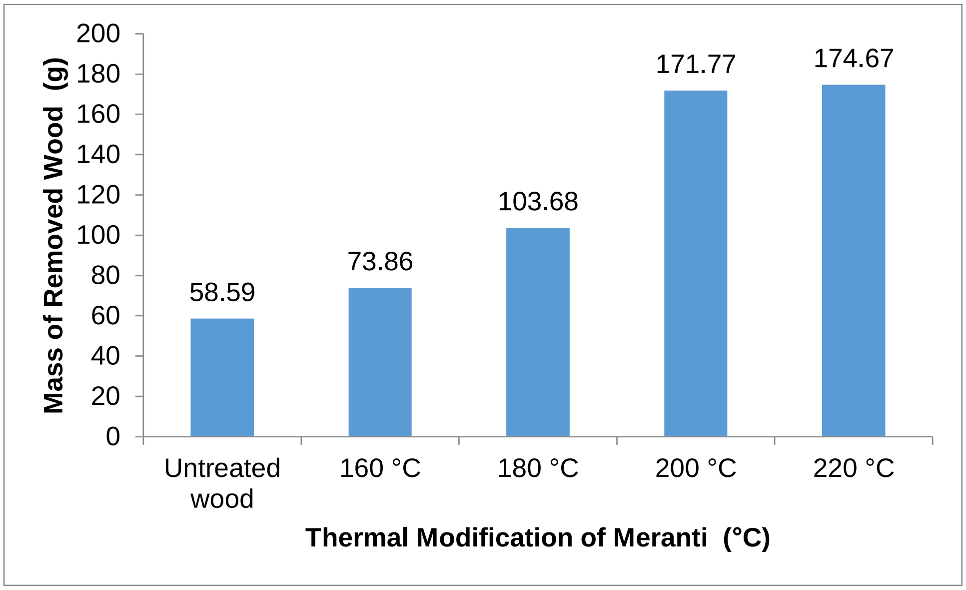

Fig. 4. Effect of thermal treatment on wood removal during sanding

The processed data indicated that the wood removal increased with increased treatment temperature, which corresponded to the results of decreasing density of the heat-treated meranti wood by 14.11% (treatment temperature of 220 °C) when compared to untreated wood. The data generated by this study were consistent with previous research that tested the material removal mechanism during sanding for meranti (Ratnasingam *et al.* 2011), oak and treated beech wood (Očkajová *et al.* 2016), beech and cypress wood (Ojima 2016), and oil palm wood and rubberwood (Ratnasingam *et al.* 2019).

Inhalable and Respirable Fractions

The effect of thermal treatment on the inhalable and respirable fractions of the wood dust mass concentration is presented in Figs. 5 and 6. All data are given as the arithmetic mean of four repeated tests.

For the inhalable fractions, there were no statistically significant differences between group means as determined by a one-way ANOVA (F(4,15) = 1.818, p = .177). The average values of the inhalable fraction determined using optical and gravimetric methods are the highest at the treatment temperature of 160 °C. These results also correspond to the granulometry reported by Očkajová *et al.* (2018) because at these temperatures the highest ratio of dust fractions with the dimensions of $\leq$ 0.08 mm (87.18% - treatment temperature of 160 °C) was recorded.

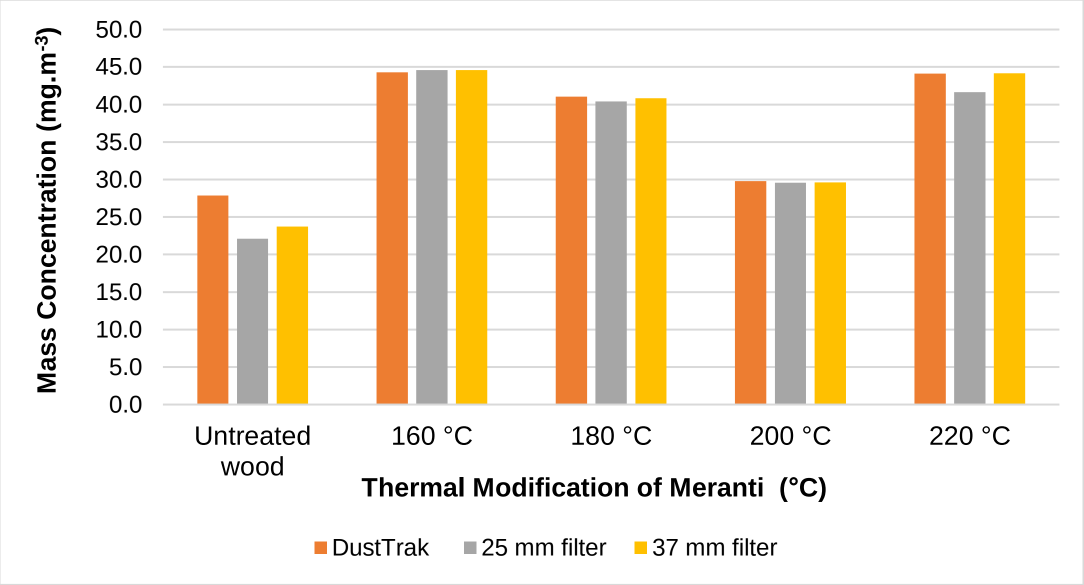

Fig. 5. Effect of thermal treatment on inhalable fraction of the wood dust mass concentration

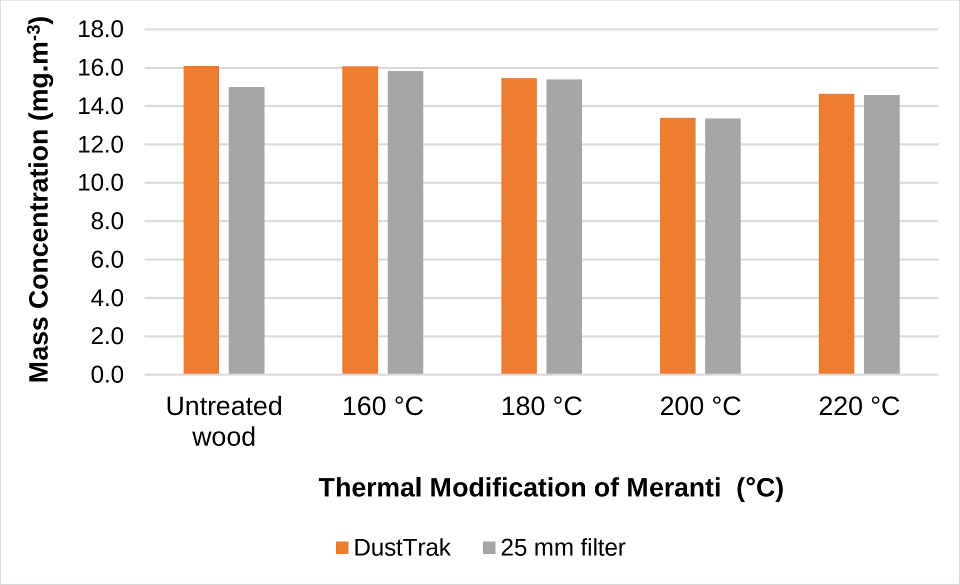

Fig. 6. Effect of thermal treatment on respirable fraction of the wood dust mass concentration

A noticeable decrease in the amount of inhalable fraction was recorded at the treatment temperatures of 200 °C and 220 °C, corresponding to the increase in the percentage of particles caught on a 0.125-mm sieve from approximately 6% for the treatment temperature of 200 °C to approximately 12% for the treatment temperature of 220 °C.

For the respirable fractions, there were no statistically significant differences between group means as determined by the one-way ANOVA (F(4,15) = .204, p = .932). The average values of the respirable fraction determined through optical and gravimetric methods decreased in the case of sanding wood treated at the temperatures of 200 °C and

220 °C, which corresponded to the granulometry point of view to the lowest percentage representation of dust particles at the bottom of the sieving machine.

Meranti is a typical broad-leaved diffuse porous wood species with physical and mechanical properties similar to beech. The percentage ratio of dust fractions for beech with the dimensions < 100 µm are 87.23% (Marková *et al.* 2016). Očkajová and Banski (2013) mention the percentage ratio of dust fractions with the dimensions ≤ 0.08 mm for beech at 91.95% and for pine 85.07%.

Nevertheless, when sanding the wood, the change in the physical properties of heat-treated wood has to be mentioned as well, mainly the decrease in weight and density. The density of spruce heat-treated *via* the Platowood method decreased 10%; a similar decrease is mentioned by Maulis (2009) for beech. Gunduz *et al.* (2009) mention a density decrease of 16.12% for black alder treated at the temperature of 210 °C for a period of 12 h. According to the preliminary results (not published so far), the density of the authors' specimens decreased approximately 14.11% when treated at the temperature of 220 °C.

According to the measured values, there were no statistically significant discrepancies between the meranti wood and heat-treated meranti wood. Thus, it can be stated that sanding the heat-treated wood does not increase the health or safety risk. Similar results were also achieved by Aro *et al.* (2019) and Kminiak and Dzurenda (2019).

CONCLUSIONS

1. The processed data indicated that the wood removal increased with increased treatment temperature, which corresponded to the results of decreasing density of the heat-treated meranti wood by 14.11% (treatment temperature of 220 °C) when compared to untreated wood.
2. Thermal treatment affects the creation of wood dust but does not significantly affect to amount of airborne dust. However, a noticeable increase of the average values of the inhalable fraction was observed at the treatment temperature of 160 °C.

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REFERENCES CITED

Aro, M. D., Geerts, S. M., French, S., and Cai, M. (2019). "Particle size analysis of airborne wood dust produced from sawing thermally modified wood," *Eur. J. Wood Wood Prod.* 77(2), 211-218. DOI: 10.1007/s00107-019-01385-z

Barcík, Š., and Gašparík, M. (2014). "Effect of tool and milling parameters on the size distribution of splinters of planed native and thermally modified beech wood," *BioResources* 9(1), 1346-1360. DOI: 10.15376/biores.9.1.1346-1360

Bengtsoon, C., Jermer, J., Clang, A., and Ek-Olausson, B. (2003). *Investigation of Some Technical Properties of Heat-treated Wood* (IRG/WP 03-40266), International Research Group on Wood Protection, Brisbane, Australia.

Budacki, M., Ilce, A. C., Gurleyen, T., Utar, M. (2013). "Determination of the surface roughness of heat-treated wood materials planed by the cutters of a horizontal milling machine," *BioResources* 8(3), 3189-3199. DOI: 10.15376/biores.8.3.3189-3199

Čabalová, I., Kačík, F., Zachar, M., and Dúbravský, R. (2016). "Chemical changes of hardwoods at thermal loading by radiant heating," *Acta Facultatis Xylologiae, Zvolen* 58(1), 43-50.

Dzurenda, L., Orlowski, K., and Grzeskiewicz, M. (2010). "Effect of thermal modification of oak wood on sawdust granularity," *Drvna Industrija* 61(2), 89-94.

Dzurenda, L., and Orlowski, K. (2011). "The effect of thermal modification of ash wood on granularity and homogeneity of sawdust in the sawing process on a sash gang saw prw 15-M in view of its technological usefulness," *Drewno: Prace Naukowe, Doniesienia, Komunikaty* 54, 27-37.

Gunduz, G., Korkut, S., Aydemir, D., and Bekar, I. (2009). "The density, compression strength and surface hardness of heat-treated hornbeam (*Carpinus betulus* L.) wood," *Maderas. Ciencia y Tecnología* 11(1), 61-70.

Hrčková, M., Koleda, P., Koleda, P., Barcík, Š., and Štefková, J. (2018). "Color change of selected wood species affected by thermal treatment and sanding," *BioResources* 13(4), 8956-8975. DOI: 10.15376/biores.13.4.8956-8975

Kačíková, D., and Kačík, F. (2011). *Chemické a Mechanické Zmeny Dreva Pri Termickej Úprave [Chemical and Mechanical Changes During Thermal Treatment of Wood],* Technical University of Zvolen, Zvolen, Slovakia.

Kminiak, R., and Dzurenda, L. (2019). "Impact of sycamore maple thermal treatment on a granulometric composition of chips obtained due to processing on a CNC machining mentre," *Sustainability* 11(3), 718-727. DOI: 10.3390/su11030718

Korčok, M., Koleda, P., Barcík, Š., and Vančo, M. (2018). "Effects of technical and technological parameters on the surface quality when milling thermally modified European oak wood," *BioResources* 13(4), 8569-8577. DOI: 10.15376/biores.13.4.8569-8577

Kubš, J., Gaff, M., and Barcík, Š. (2016). "Factors affecting the consumption of energy during the milling of thermally modified and unmodified beech wood," *BioResources* 11(1), 736-747. DOI: 10.15376/biores.11.1.736-747

Kučerka, M., and Očkajová, A. (2018). "Thermowood and granularity of abrasive wood dust," *Acta Facultatis Xylologiae Zvolen* 60(2), 43-51.

Kvietková, M., Gaff, M., Gašparík, M., Kaplan, L., and Barcík, Š. (2015). "Surface quality of milled birch wood after thermal treatment at various temperatures," *BioResources* 10(4), 6512-6521. DOI: 10.15376/biores.10.4.6512-6521

Marková, I., Mračková, I., Očkajová, A., and Ladomerský, J. (2016). "Granulometry of selected wood dust species of dust from orbital sanders," *Wood Research* 61(6), 983-992.

Maulis, V. (2009). *Technologie a Zhodnocení Vybraných Vlastností Dřeva Modifikovaného Teplem [Production Technology and Evaluation of Thermal Modified Wood]*, Master's Thesis, Czech University of Life Sciences, Prague, Czech Republic.

Miklečić, J., and Jirouš-Rajković, V. (2016). "Influence of thermal modification on surface properties and chemical composition of beech wood (*Fagus sylvatica* L.)," *Drvna Industrija* 67(1), 65-71.

Mračková, E., Krišťák, Ľ., Kučerka, M., Gaff, M., and Gajtanska, M. (2016). "Creation of wood dust during wood processing: Size analysis, dust separation, and occupational health," *BioResources* 11(1), 209-222. DOI: 10.15376/biores.11.1.209-222

Nariadenie vlády SR č. 471/2011 Z.z., ktorým sa mení a dopĺňa NV SR č. 355/2006 Z.z. o ochrane zamestnancov pre rizikami súvisiacimi s expozíciou chemickým faktorom pri práci v znení NV SR č. 300/2007 Z.z. [Ordinance of the Government of the Slovak Republic No. 471/2011 Coll., amending and supplementing the Ordinance of the Government of the Slovak Republic No. 355/2006 Coll. on protection of employees against risks due to exposure to chemical factors at work in the version of the Act No. 300/2007 Coll.]

Niemz, P., Hofmann, T., and Rétfalvi, T. (2010). "Investigation of chemical changes in the structure of thermally modified wood," *Maderas-Cienc. Tecnol.* 12(2), 69-78. DOI: 10.4067/S0718-221×2010000200002

Očkajová, A., and Banski, A. (2013). "Granulometria drevného brúsneho prachu z úzko-pásovej brúsky [Granularity of sand wood dust from narrow belt sanding machine]," *Acta Facultatis Xylologiae* 55(1), 85–90.

Očkajová, A., Kučerka, M., and Banski, A. (2018). "The influence of heat treatment on granularity of sand wood dust," *Chip and Chipless Woodworking Processes* 11(1), 123-130.

Očkajová, A., Kučerka, M., Banski, A., and Rogoziński, T. (2016). "Factors affecting the granularity of wood dust particles," *Chip and Chipless Woodworking Processes* 10(1), 137-144.

Očkajová, A., Stebila, J., Rybakowski, M., Rogozinski, T., Krišták, L., and Ľuptáková, J. (2014). "The granularity of dust particles when sanding wood and wood-based materials," *Advanced Materials Research* 1001, 432-437. DOI: 10.4028/www.scientific.net/AMR.1001.432

Ojima, J. (2016). "Generation rate and particle size distribution of wood dust by handheld sanding operation," *Journal of Occupational Health* 58(6), 640-643. DOI: 10.1539/joh.16-0136-BR

Panayot, A., and Jivko, V. G. (2008). "Weathering of Polymer Coatings, Formed on Thermally Modified Wood," in: *Trieskové a Beztrieskové Obrábanie Dreva 2014: Zborník Prednášok* [*Chip and Chipless Woodworking Processes 2014: Conference Proceedings*], Zvolen, Slovakia, pp. 363-368.

Pinkowski, G., Krauss, A., Piernik, M., and Szymański, W. (2016). "Effect of thermal treatment on the surface roughness of scots pine (*Pinus sylvestris* L.) wood after plane milling," *BioResources* 11(2), 5181-5189. DOI: 10.15376/biores.11.2.5181-5189

Požgaj, A., Chovanec, D., Kurjatko, S., and Babiak, M. (1997). *Štruktúra a Vlastnosti Dreva [Structure and Properties of Wood]*, Príroda A. S., Bratislava, Slovakia.

Ratnasingam, J., Liat, L. C., and Latib, H. A. (2019). "A comparison of the abrasive sanding dust emission characteristics of oil palm wood and rubberwood," *BioResources* 14(1), 1708-1717. DOI: 10.15376/biores.14.1.1708-1717

Ratnasingam, J., Scholz, F., Natthondan, V., and Graham, M. (2011). "Dust-generation characteristics of hardwoods during sanding processes," *European Journal of Wood and Wood Products* 69(1), 127-131. DOI: 10.1007/s00107-009-0409-y

Rogozinski, T., Wilkowski, J., Górski, J., Czarniak, P., Podziewski, P., and Szymanowski, K. (2015). "Dust creation in CNC drilling of wood composites," *BioResources* 10(2), 3657-3665. DOI: 10.15376/biores.10.2.3657-3665

Sandak, J., Goli, G., Cetera, P., Sandak, A., Cavalli, A., and Todaro, L. (2017). "Machinability of minor wooden species before and after modification with thermo-vacuum technology," *Materials* 10(2), 121-132. DOI: 10.3390/ma10020121

STN EN 50632-1 (2016). "Elektrické náradie. Postupy na meranie prachu. Časť 1: Všeobecné požiadavky [Electric motor-operated tools. Dust measurement procedure. Part 1: General requirements]" Slovak Office of Standards Metrology and Testing, Bratislava, Slovakia.

STN EN 50632-2-4 (2017). "Elektrické náradie. Postupy na meranie prachu. Časť 2-4: Osobitné požiadavky na brúsky iné ako kotúčové [Electric motor-operated tools. Dust measurement procedure. Part 2-4: Particular requirements for sanders other than disk type]" Slovak Office of Standards Metrology and Testing, Bratislava, Slovakia.

Schwarz, M., Dado, M., and Hnilica, R. (2009). *Pracovné Prostredie a Technika Prostredia. 1. Časť* [*Working Environment and Environment Technique. 1. Part*], Technical University of Zvolen, Zvolen, Slovakia.

Thorpe, A., and Brown, R. (1995). "Factors influencing the production of dust during the hand sanding of wood," *American Industrial Hygiene Association Journal* 56(3), 236-242. DOI: 10.1080/15428119591017060

Vančo, M., Mazán, A., Barcík, Š., Rajko, Ľ., Koleda, P., Vyhnáliková, Z., and Safin, R. F. (2017). "Impact of selected technological, technical, and material factors on the quality of machined surface at face milling of thermally modified pine wood," *BioResources* 12(3), 5140-5154. DOI: 10.15376/biores.12.3.5140-5154

World Health Organization (WHO) (1999). *Hazard Prevention and Control in the Work Environment: Airborne Dust* (WHO/SDE/OEH/99.14), World Health Organization, Geneva. Switzerland.

Yildiz, S., Yildiz, U. C., and Tomak, E. D. (2011). "The effects of natural weathering on the properties of heat-treated alder wood," *BioResources* 6(3), 2504-2521. DOI: 10.15376/biores.6.3.2504-2521

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