ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 60(2): 43−51, 2018
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2018.60.2.04

# THERMOWOOD AND GRANULARITY OF ABRASIVE WOOD DUST

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## ABSTRACT

The granular composition of the abrasive dust of heat-treated wood from spruce and oak depending on the treatment at the temperature of 160 °C, 180 °C, 200 °C and 220 °C is presented in the paper. The proportion of dust fractions with a dimension of ≤ 0.08 mm was determined by a sieve analysis. The percentage of these proportions is similar for natural wood and wood treated at the temperature of 160 °C, 180 °C and 200 °C. Significantly lower proportion of dust fractions with dimensions of ≤ 0.08 mm occurred at a temperature of 220 °C in all examined samples. The fact that the main factor causing the drop of the dust fraction with a dimension of ≤ 0.08 mm at 220 °C is the reduction in wood density is assumed.

**Key words:** thermowood, grinding, wood dust, granular analysis.

## INTRODUCTION

Thermowood is heat-, steam- and water-treated wood, it is free of harmful chemicals with new physical-mechanical properties. This method of wood treatment has been known for several thousand years and originates from China, also used by the Vikings, who modified wood for shipbuilding. This knowledge was later endorsed by the Finnish Association of Wood Manufacturers and Processors in order to present material in the form of Thermowood. Wood with these properties is similar to tropical wood, which in many cases can be replaced by temperate woods, which are less economically significant (Thermowood 2016). Thermowood has two forms of treatment, the Thermo-S class is an increase in wood stability and the Thermo-D class is an increase in wood durability (ThermoWood Handbook 2003). The advantages of Thermowood particularly include the reduction of moisture absorption, dimensional stability, biological resistance, the attractive appearance of heat-treated wood, the application of material without surface treatment, the high durability of heat-treated wood, the displacement of resin from the material, as it causes a problem with cutting tools as well as with the use of natural wood without surface treatment, the reduction of thermal conductivity, the increase of wood surface hardness (for weathered areas), the increase of resistance against cracks. Heat-treated wood has lower dynamic strength, mainly bendability and toughness, in terms of mechanical properties, which results in a more brittle wood, not excluding its versatile use in the exterior and interior of a very humid environment (Tepelně upravené dřevo Thermo Wood 2013).

The change of physical-mechanical properties mainly results from the change of the chemical properties of the wood. At high temperatures, some original building polymers of the wood are decomposed and new water-insoluble substances are formed, as well as toxic or repulsive effect substances. Such treated wood is more resistant to biological pests and its hygroscopicity decreases (REINPRECHT, VIDHOLDOVÁ 2008). The least chemically stable component is hemicellulose, since various depolymeridation and dehydrating reactions occur at 150 °C, resulting in various monomers that enter condensation reactions to form more hydrophobic substances, resulting in a decrease in wood hygroscopicity and increased dimensional stability. In depolymerizing cellulose from 150 °C, nanocraks and microcracks in the cell walls are formed in individual layers, resulting in more brittle cell walls, which reduce the strength of the wood (especially tensile and flexural) and toughness (REINPRECHT, VIDHOLDOVÁ 2008, KAČÍKOVÁ, KAČÍK 2011, ThermoWood Handbook 2003, ČABALOVÁ *et al*. 2016). The chemical reactions of lignin occur at temperatures of 180 to 260° C, resulting in the degradation of products condensing in the wood again and creating new structures with a biocidal effect, which results in the increased durability of the wood.

In general, we can say that the higher the temperature and the longer the duration of the action, the more intense the reactions and the changes in the wood. Leafy wood species with a lower proportion of lignin are thermally modified more intensely than coniferous wood species. Each type of wood can be heat-treated, but each wood has its own characteristics, so the heat treatment parameters are modified for each type of wood (or for similar types), for Thermo-S and Thermo-D treatment, in terms of optimizing the final quality (ThermoWood Handbook 2003, Terasové dosky 2013).

Thermowood is the subject of many researches. The research examines the changes in the physical-mechanical properties (GUNDUZ *et al*. 2009), the chemical properties (REINPRECHT, VIDHOLDOVÁ 2008, KAČÍKOVÁ, KAČÍK 2011, ThermoWood Handbook 2003, ČABALOVÁ *et al*. 2016), the quality of the surface obtained (BUDAKCI *et al*. 2013, KVIETKOVÁ *et al*. 2015, VANČO *et al*. 2017, KAPLAN *et al*. 2018) the color of the wood, the woodworking (SANDAK *et al*. 2017, REINPRECHT, VIDHOLDOVÁ 2008, KRÁL, HRÁZSKÝ 2005), the workability in the context of energy consumption (KUBŠ, GAFF, BARCÍK 2016), the stability against the impact of weather (PANAYOT, JIVKO 2008, YILDIZ *et al*. 2011), the granulometry of the chips (BARCÍK, GAŠPARÍK 2014), or sawdust (DZURENDA *et al*. 2010, DZURENDA, ORLOWSKI 2011).

The aim of the present paper is to determine the granular composition of the wooden abrasive dust obtained from the longitudinal grinding of heat-treated wood, called “thermowood”, on a vertical belt grinder with a manual pressure on the grinding belt, depending on the wood (spruce, oak) and heat treatment conditions (of 160 °C, 180 °C, 200 °C and 220 °C), focusing in particular on the proportion of dust fraction measuring ≤ 0.08 mm, which does not settle or sediment in the working environment, and is a source of both health and safety risks. The granular composition of any dust is their input characteristic, whether in terms of suction quality or deposition in the body (MRAČKOVÁ *et al.* 2016, OČKAJOVÁ *et al.* 2016).

## MATERIAL AND METHODS

**Experimental samples:** two kinds of wood, Sessile oak *(Quercus petraea*), Norway spruce (*Picea abies*). The Sessile oak and Norway spruce were taken in the location of Vlčí jarok (Budča) at 440 m above sea level. Radial boards were sawed from the oak and spruce trunks and processed in test samples measuring 20 × 100 mm with a length of approximately 700 mm. The samples were then dried to a residual moisture of 8 %. The entire process was performed in the Research and Development Workshops of the Technical University in Zvolen.

### Heat treatment and sample processing methods

The processed samples, measuring 20 × 100 × 700 mm, were heat-modified in the Arborétum FLD (ČZU Praha) in the city of Kostelec nad Černými lesy. The S400/03 (LAC Ltd., Czech Republic) chamber was used for thermal modification, Fig. 1, designed to heat the wood with ThermoWood technology, with the parameters listed in Tab. 1. Five samples were prepared for each treatment.


**Fig. 1 Chamber S400/03.**

**Tab. 1 Chamber parameters S400/3.**

| | |
|---|---|
| Maximal temperature (°C) | 300 |
| Volume (l) | 380 |
| External dimensions - w×h×d (mm) | 1400 × 1850 × 1200 |
| Internal dimensions - w×h×d (mm) | 800 × 800 × 600 |
| Weight(kg) | 350 |
| Fan | 1 |
| Input (kW) | 6,0 |

The heat treatment procedure for the individual temperatures was as follows: the application of temperature sensors and a humidity sensor for the sensors, the storage of samples in the chamber, the closure and locking of the chamber door, the setting of the heat treatment parameters with a computer program – target temperature, steepness [°C /hr.] for heating and cooling, heat treatment of samples, sample collection from the chamber.

The thermal modification was conducted at 160, 180, 200 and 220 °C in six phases: 1st phase – increase of temperature to 40 °C, 2nd phase – increase of temperature to 130 °C, drying, 3rd phase – heat treatment – heating to working temperature, 4th phase – heat treatment – working temperature of 3 hours, 5th phase – cooling to 130 °C and humidity treatment, 6th phase – cooling to 60 °C with humidity treatment at the level of 4–7%. The process is complete when the temperature reaches 60 °C.

Due to the space in which the samples were stored, they were placed in the dryer at approximately 10 °C. The samples taken from the dryer after completing the heat treatment process had a temperature of about 40 °C. The heating, conditioning and cooling phases of the individual wood samples and the action intervals are shown in Tab. 2.

### Machinery

JET JSG-96 narrow belt sander, cutting speed of 10 $m \cdot s^{-1}$, HIOLIT XO P 80 grinding belt with a grain grinding belt of 80, individual pressure of wood sample on grinding belt, laboratory experiments. A sharp grinding belt was used for each heat treatment variant.

**Tab. 2 Time intervals of the thermal modification of the wood.**

| Working temperature (°C)/ samples | phase | | | | | | ∑ (h) |
|---|---|---|---|---|---|---|---|
| | I. (h) | II. (h) | III. (h) | IV. (h) | V. (h) | VI. (h) | |
| 160 °C | | | | | | | |
| oak | 0.8 | 8.2 | 3.0 | 3.0 | 1.2 | 1.8 | 18.0 |
| spruce | 1.0 | 6.9 | 3.0 | 3.0 | 1.2 | 1.8 | 16.9 |
| 180 °C | | | | | | | |
| oak | 0.8 | 8.2 | 5.0 | 3.0 | 2.0 | 1.8 | 20.8 |
| spruce | 1.0 | 7.5 | 4.5 | 3.0 | 2.0 | 1.8 | 19.8 |
| 200 °C | | | | | | | |
| oak | 0.8 | 8.2 | 7.0 | 3.0 | 2.8 | 1.8 | 23.6 |
| spruce | 1.0 | 6.9 | 6.4 | 3.0 | 2.8 | 1.8 | 21.9 |
| 220 °C | | | | | | | |
| oak | 0.8 | 8.2 | 9.0 | 3.0 | 4.1 | 1.8 | 26.9 |
| spruce | 1.0 | 7.5 | 8.2 | 3.0 | 3.6 | 1.8 | 25.1 |

## Granular analysis

Samples for the granular wood dust analysis were taken isokinetically from the suction pipe of the grinders in accordance with STN 9096 (83 4610): “The manual determination of the mass concentration of solid pollutants” during the grinding of individual heat-treated wood samples.

The granular composition of the wooden abrasive dust was found by sieving. For this purpose, a special set of superimposed sieves (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.080 mm, 0.063 mm, 0.032 mm and the bottom) was used on the vibrating stand of the sieving machine (Retsch AS 200c) with an adjustable sieving interruption frequency (20 seconds) and a sieve deflection amplitude (2mm/g), in accordance with STN 153105/STN ISO 3310-1.

The granular composition was obtained by weighing the percentages remaining on the sieves after sieving on a Radwag WPS 510/C/2 electronic weighing scale, with a capacity of 510 g and an accuracy of weighing at 0.001 g. For each variant, three sievings were performed and the results are given as their mean value.

## RESULTS AND DISCUSSION

The results of the experiment are presented in the form of graphs, Fig. 2–3.

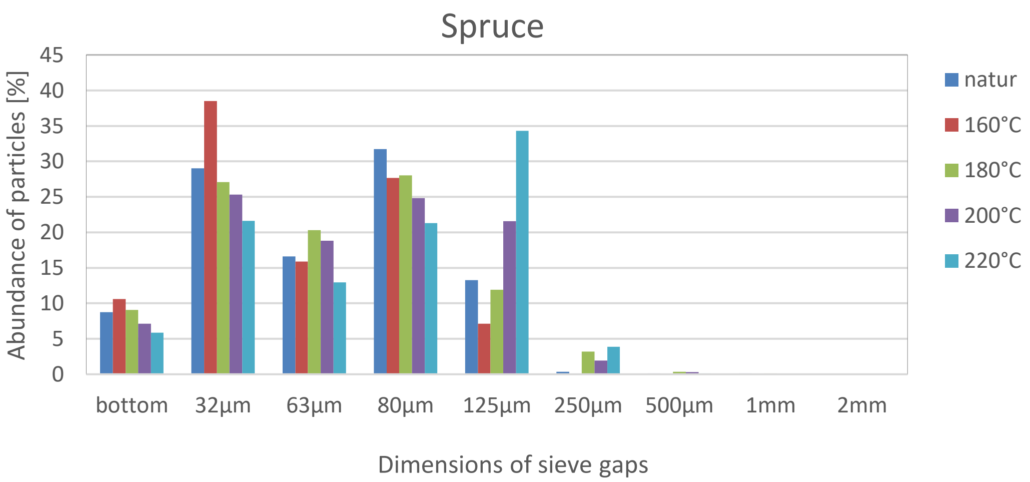


**Fig. 2 Granular analysis of spruce dust.**

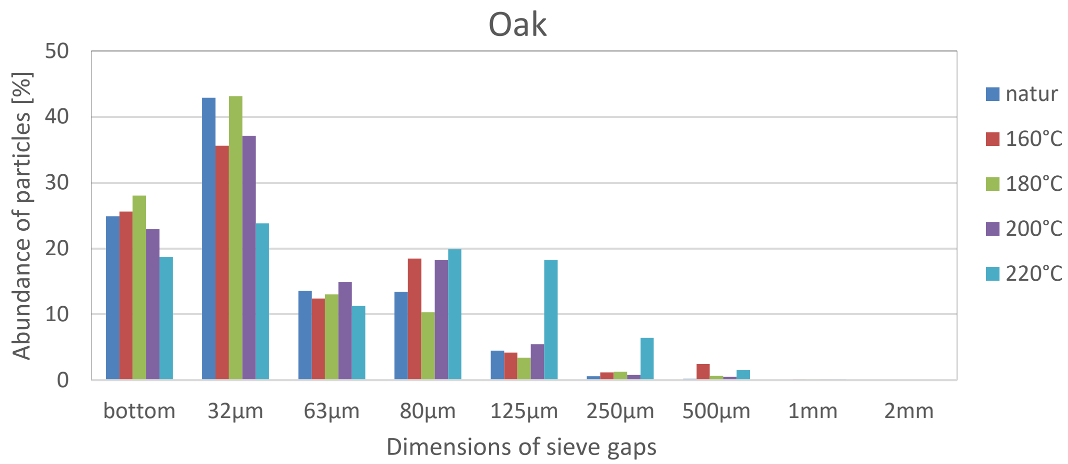


**Fig. 3 Granular analysis of oak dust.**

Based on the results of the granular analysis of spruce dust, 2 peaks can be observed in the graphs, which correspond to the formation of 2 kinds of particles. Such a course is typical for spruce and may be justified by the different physical mechanical properties of spring and summer wood, mainly by its different density (OČKAJOVÁ *et al*. 2008). The highest percentages of particles were recorded on a 0.08 mm sieve and a 0.032 mm sieve, representing about 40 % (220 °C) to 60 % (natural wood) in all fractions. A similar process was obtained with natural wood and at temperatures of 160 °C, 180 °C and 200 °C. At the treatment temperature of 220 °C, the highest percentage of particles was recorded on a 0.125 mm sieve, and this value was 34.30 %.

The highest percentage of dust fractions measuring ≤ 0.08 mm was recorded at a treatment temperature of 160 °C, up to 92.63 %. The proportion of dust fraction measuring ≤ 0.08 mm is similar for natural wood (86.11 %) and the treatment temperature of 180 °C (84.44 %). With the increase of temperature, the proportion of dust fraction measuring ≤ 0.08 mm decreases to 76.09 % for 200 °C and 61.68 % for 220 °C, where in both cases there was recorded an increased proportion of particles in the sieve measuring 0.125 mm, with a proportion of 21.59 % (200 °C) and 34.30 % (220 °C). When comparing the natural wood and heat-treated wood at 220 °C, we observe the drop of dust fraction measuring ≤ 0.08 mm by 28.37 %.

Oak, as a typical circular-porous wood, behaved a little differently within the granular analysis, producing particles of one type with the highest proportion of the 0.032 mm sieve. It can be stated that the proportion of dust fractions measuring ≤ 0.08 mm is similar for natural wood (94.72 %) as well as in temperatures of 160 °C (92.10 %), 180 °C (94.53 %) and 200 °C (93.17 %). A significant difference in the granular composition occurred at the temperature of 220 °C, when the percentage of dust fraction measuring ≤ 0.08 mm dropped to 73.68 %, with a markedly varying percentage proportion of dust particles in individual sieves. A very high proportion of particles already appeared in the 0.125 mm sieve, up to 18.28 % compared to values of approx. 4 % at other temperatures and a reduced percentage of the 0.032 mm sieve and on the bottom. The drop in the dust fraction measuring ≤ 0.08 mm is 22.22 % at 220°C, compared to natural wood.

The proportion of dust fraction measuring ≤ 0.08 mm obtained in these experiments is comparable to the results of other authors for natural wood (oak and spruce). OČKAJOVÁ, KUČERKA (2017) presented the proportion of the dust fractions of oak measuring ≤ 0.08 mm, achieved in the narrow belt sander and a handheld grinding belt at a range from 91.99 % to 94.72 %, which corresponds to the results of the authors DZURENDA, OČKAJOVÁ (2003), where the dust particles of oak are classified as fine and very fine fractions, with grain sizes from 4.1 µm to 355 µm, with a percentage up to 97.5 %. MARKOVÁ *et al.* (2016) obtained similar results for oak wood dust from the grinding process on handheld vibrating grinder, particle proportion measuring < 100 µm is 86.4 %. The percentage proportions of the dust fraction measuring < 100 µm are 87.13 % for spruce. OČKAJOVÁ, BANSKI (2013) presents percentage proportions of dust fractions measuring ≤ 0.08 mm for beech at 91.95 % and for pine at 85.07 %.

During the grinding it was basically the work of a number of cutting wedges (grinding grains), which work in a groove. The basic strength properties of the wood, involved in the formation of chips, include bending strength (bending of the chips in front of the cutting wedge), the traction along the fibres (on the inside of the chip – oriented toward the face of the cutting wedge) and the pressure along the fibres (on the outside of the chips), traction perpendicular to the fibres in front of the cutting edge in the case of longitudinal cutting (grinding) and shear strength also manifests itself in a determined way SIKLIENKA *et al.* (2017), PORANKIEWICZ *et al.* (2010).

Based on the experiments performed so far, we can state that most of the mechanical properties are reduced by heat treatment (microcracks and nanocracks in the cell walls) and the wood becomes more brittle, the bending strength decreasing by approx. 50% at a treatment temperature of 200–220 °C (BEMGTSOON *et al.* 2002, BEKHTA, NIEMZ 2003), REINPRECHT, VIDHOLDOVÁ (2008), ThermoWood Handbook (2003) state the decrease in bending strength of 5 to 30%, as well as ANONYMUS (2002) , but only at a treatment temperature of 240 °C, since at a treatment temperature of 100 to 180 °C it indicates an increase in bending strength for pine.

The pressure strength along the fibers of the heat-treated wood at temperatures above 180 °C increased by approx. 30 % (MAULIS 2009, ThermoWood Handbook, 2003, REINPRECHT, VIDHOLDOVÁ 2008). The shear strength at 230 °C decreased in a radial direction by approx. 25 %, in a tangential direction by approx. 40 %, at 190 °C by approx. 20 % in both directions (ThermoWood Handbook, 2003). Taking these facts into account in the machining process of the heat treated wood, the problem can be the formation of fine fraction to dust, what is caused by increasing brittleness and decreasing some mechanical properties REINPRECHT, VIDHOLDOVÁ 2008, KRÁL, HRÁZSKÝ 2005), which results in a higher percentage representation of dust fractions at higher temperatures than declared DZURENDA *et al.* (2010) during sawing and BARCÍK, GAŠPARÍK (2014) during milling, although a statistically significant difference is not reported. Most changes in the mechanical properties of heat-treated wood, which may be encountered in the chip-forming process, have a tendency to decrease, but the pressure strength increases and the bending strength is questionable.

In the case of grinding, however, it is necessary to mention the change in physical properties of heat-treated wood, mainly the decrease in weight and density. The density of the heat-treated spruce through the Platowood method decreased by 10 %, (ThermoWood Hhandbook, 2003, www.platowood.nl), similar result is for beech MAULIS (2009), GUNDUZ *et al*. (2009) reporting a decrease in the density of common alder at a treatment temperature of 210 °C for 12 hours by 16.12 %. According to preliminary results (so far not published), the density of our samples decreased approx. by 18 % for spruce and 21.5 % for oak at a temperature of 220 °C.

Based on many granular analyses of various wood abrasive dusts, from the longitudinal grinding in previous research, we found that the granularity of wood abrasive dust significantly changes in density, because when grinding low-density wood, the individual chips are easier to separate than for higher density wood (HAMMILÄ, USENIUS 1999, OČKAJOVÁ, BANSKI 2009). With increasing of wood density (cca 42 %) in the tested interval from 450 kg.m$^{-3}$ ÷ 774 kg·m$^{-3}$ (spruce 450 kg·m$^{-3}$, poplar 487 kg·m$^{-3}$, alder 527 kg·m$^{-3}$, pine 551 kg·m$^{-3}$, maple 619 kg·m$^{-3}$, beech 624 kg·m$^{-3}$, oak 774 kg·m$^{-3}$) for sanding process (hand belt sander GBS 100 AE), there is increased the percentage share of small fractions (particle size < 100 μm) from 4.2 % to 53.06 % (OČKAJOVÁ, BANSKI 2009). So we assume that our granular analysis results are substantially influenced by the decreasing density of heat-treated wood.

In terms of sawdust from a universal table saw, the density in the tested interval from 336 kg·m$^{-3}$ to 685 kg·m$^{-3}$ (spruce 336 kg·m$^{-3}$, meranti 496 kg·m$^{-3}$, beech 685 kg·m$^{-3}$) had no influence on the granular composition (OČKAJOVÁ *et al*. 2006), mainly due to the different chip-forming process, where in grinding process is no singularly defined geometry of the cutting wedge and so the shape and the size of the individual dust particles is varied, and it is known that there are no two totally identical particles in the grinding process, while sawing and milling is precisely defined angular geometry and thus the size of the generated chips is defined as well. In these processes, where chips of precisely defined larger dimensions occur, like wood abrasive dust, can be used to alter the mechanical properties of heat-treated wood, mainly the increased brittleness of wood, because at the moment of the chips' generation, there is a change in the potential energy that the cutting tool gives to chip to kinetically, moving the chips into the suction system (hitting the walls of the pipe, hitting each other), which can lead to an increased proportion of the finer fractions.

## CONCLUSION

The results of the experimental measurements can be summarized as follows:

- the proportions of the of dust fraction measuring ≤ 0.08 mm are highest for oak wood for all treatment temperatures,
- the assumption has not been confirmed that with the increasing temperature of the treatment the proportion of dust fractions increases,
- the lowest values of dust fractions measuring ≤ 0.08 mm were obtained with all woods at treatment temperatures of 220 °C; for the spruce there was a decrease of this fraction by 28.37 % and for oak by 22.22 %,
- we assume that the main factor contributing to the granular analysis of heat-treated wood in the grinding process is the decreasing density of heat-treated wood.

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## ACKNOWLEDGEMENT

This work was supported by the grant agency KEGA under the project No. 009TUZ-4/2017 and by the grant agency VEGA under the project No. 1/0315/17.

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