Safety Engineering Series DOI 10.2478/tvsbses-2013-0003

ANALYSIS OF THE POWDERED MATERIAL PRODUCED BY PROCESSING OF DIFFERENT WOOD SAMPLES

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Research article

Abstract: Mechanical wood processing creates a large quantity of wood waste and hazardous dust. If adequate measures for their removal from the workplace are not undertaken, there is a potential danger to the health, and even lives of the workers. A research was conducted in order to determine the degree of risk to workers in such workshops. Analyzed was the powdered material with the granulometric analysis produced during the processing of solid wood spruce (*Picea abies L.*) *Karst.*, beech (*Fagus sylvatica L.*) and of agglomerated material particleboard. A comparison was made between the particle size distribution of the powdered wood materials that are produced during processing on a thickness planer surface planer, and circular saw. In order to assess the health risks, also measured was the amount of finely powdered, airborne dust particles.

The lower explosion limit of wood dust was determined in laboratory conditions, and the obtained values were compared to the relevant measurements from the workplace.

Keywords: Wood, Sawing, Spruce (*Picea abies L.*) Karst., Beech (*Fagus sylvatica L.*), Particleboard.

Introduction

Explosive atmosphere

The technological process of mechanical treatment and processing of wood produces a large quantity of wood waste. The amount of waste, as well as its dimensions and shape, depend on the type of machine, the degree of processing and the species of wood. Certain operations such as cutting, sanding, and polishing can produce large quantities of fine wood dust (Orémusová et al., 2012). Fine dust can be harmful to workers' health, and can also explode. This would not only cause significant material damages, but it would also endanger the lives of the employees, the residents in the near vicinity, and can also have a detrimental impact on the environment.

For an explosion of wood dust to occur, certain physical-chemical conditions must be satisfied at a given place and at the same time:

- a sufficient amount of oxygen or oxidant;
- a source of ignition;
- an appropriate size of the wood dust particles;
- the mixture's concentration must be within explosion limits, between the upper and lower explosion limits.

If all of these conditions are not fulfilled, the occurrence of an explosion or fire is not possible.

One of the more important factors when it comes to dust explosiveness is the size of the particles. The reduction of the particles' size significantly increases their total surface, which increases their chemical activity, i.e. their ability to oxidize. In terms of the risk of explosion, smaller particles are always more explosive and dangerous than dust particles of larger dimensions. The upper limit for particle sizes that can cause an explosion, according to Pritchard, is 0.5 mm. As soon as the dust particles are finer the maximum explosiveness of the powder is higher, and thus it requires less energy to ignite (Pritchard, 2004). In the usual technical dusts, the lower explosive limit (LEL) is between 20 and 60 $g.m^{-3}$. For most materials the LEL is approximately 50 $g.m^{-3}$, while the upper explosive limit (UEL) is between 2000 and 6 000 $g.m^{-3}$ or 2 - 6 $kg.m^{-3}$.

Particle size has a direct impact on the stability of systems, where systems with smaller particles are always more stable than systems with larger particles. Settling velocity also depends on the size of the particles. Particles that are larger than 0.025 mm settle relatively quickly, and from the aspect of industrial hygiene they are not particularly dangerous to human health, but as deposited dust,

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under certain conditions, they can pose a certain danger in terms of ignition and fire (Milanko et al., 2010). The dangers of explosion caused by deposited dust are more frequent in industrial facilities, due to:

- Heated surfaces on which the dust settles, where ignition of a dust layer can occur above smolder temperature;
- Whirling of the accumulated dust due to mechanical processes, airflow, or ventilation, can create an explosive atmosphere (secondary explosion).

Dusty environment

Exposure to dust in the workplace represents a potential health problem. Inhalation of wood dust can cause allergic symptoms of the respiratory system's mucous membrane. If large quantities of dust are present, it has an irritant effect on the eyes, nose and throat. Significant accumulations of fine particles can damage lung function, trigger asthma and have a carcinogenic effect. In order to protect the health and safety of workers, the limit values for wood dust have been prescribed (Karabasil and Jakovljević, 2007). For the inhalation fraction for hard wood species, the European Union Guidelines prescribe a limit value of 5 $mg.m^{-3}$ (Council Directive 99/38/EC). TWA is Measured or calculated in relation to a reference period of eight hours time-weighted-average.

The standard that was developed under the OSHA PEL (OSHA 3371- 08, 2009) (on permissible exposure limits), prescribes:

- TWA 15 $mg.m^{-3}$ for the total wood dust (hard and soft), and
- TWA 5 $mg.m^{-3}$ for respiratory wood dust (hard and soft).

The National Institute for Occupational Safety and Health - NIOSH prescribes a REL (recommended exposure limit) of TWA 1 $mg.m^{-3}$. The MDHS14/3 for hard and soft wood dust prescribes a TWA (workplace exposure limit) of 5 $mg.m^{-3}$ TWA for eight hours (MDHS 14/3, 2000).

Materials and methods

The research was conducted in a carpentry workshop that manufactures furniture. The carpentry workshop for cutting and processing wood and similar materials uses a combined planer surface planer, thickness planer a circular saw and mechanized hand tools.

The surface planer is used to level the solid wood and create a base plane, according to thickness and width (Hauert and Vogl, 1995). By their design, these machines represent a combination of a surface planer, (Fig. 1) and an thickness planer (Fig. 2). During research on the combined machine, the leveling of solid wood spruce (*Picea abies L.*) Karst., beech (*Fagus sylvatica L.*), was performed, where the first chosen cutting thickness was 1 mm.

Fig. 1 Surface planer

Fig. 2 Thickness planer

Fig. 3 Circular saw

Also performed during the research was longitudinal cutting of solid wood spruce (*Picea abies L.*) Karst., beech (*Fagus sylvatica L.*), and particleboard, using a circular saw machine (Fig. 3).

The machines for cutting and processing wood are not connected to special devices for vacuuming and collecting wood dust into fabric bag filters.

Size analysis of the samples

Analysis of screening is the oldest, simplest and cheapest method for detecting the particle size of solids. This method is called to a small group fractionation and separation techniques for particle size analysis. (Fig. 4) Analysis of screening is based on the use of sets of sieves of known mesh size, which is drawn in the direction of gravity transport of the analyte in the block with gradually shrinking the size of the holes. Solids can be analyzed either in dry or in suspension. After fractionation of each site remains a part of the original sample, which contains particles within specified size holes top and bottom screen. The rest of the site will be considered and the result is evaluated as the weight fractions of defined particle size range. Sieve analysis results in terms of weight of each fraction and also real samples with a defined particle size are the biggest advantages of this method (N01-ES-85421, 2000).

For granulometric analysis, samples of the fragmented wood were separated into fractions on a sieve shaker from the manufacturer Endecotts Limited, with sieve sizes of (sides of the square hole) 10, 2, 1, 0.5, and 0.315 mm. The samples were sieved for 15 minutes, and the process was repeated three times.

Fig. 4 Sets of analytical sieving machines

Determination of the amount of wood dust in the air

The measurement was performed using direct reading instrument Microdust Pro (Fig. 5). The Microdust Pro. From Casella CEL is a portable, real-time monitor for assessing the concentration of suspended particulate matter. Instrument is available with the ability to measure from 1 μg.m^{-3} to 2 500 mg.m^{-3}. The Microdust Pro measures particulate concentrations using a near forward angle light scattering technique. Infrared light of 880 nm wavelength is projected through the sensing volume where contact with particles causes the light to scatter. The amount of scatter is proportional to the mass concentration and is measured by the photo-detector (N01-ES-85421, 2000). Dust concentrations are presented in two unique ways:

- numerical values - instantaneous concentrations are displayed, as well as values for the Time Weighted Average (TWA) and maximum concentrations,
- graphical representation - the graph is able to show a continuous trace over a number of time-bases. These may be set on the x- axis at 100 seconds, 200 seconds, 15 minutes and 1 hour. The y-axis may be auto-ranging or fixed.

Fig. 5 Portable Mikrodust Pro

Assessment of the lower explosion limit (LEL) for wood dust

Explosion limits have a practical importance because they are used for assessing the danger within an environment. An assessment of the risk of explosion suggests the solution for anti-explosion protection.

Real working conditions differ from laboratory ones, thus it is important tobe aware of possible effects on explosion limits when the danger is evaluated.

The speed of flame during an explosion depends on the amount of combustible material, as well on the oxidation substance. The lower limit represents the point when the concentration of the accumulated wood dust can activate an explosion.

This method is based on the burning ability of dispersed wood dust mixture with air, after a spark by an ignition source with a sufficient amount of energy.

LEL is expressed by the value that lies between the explosion and non-explosion scale. This limit is presented in g.m^{-3}. LEL is of great importance for estimating the risk of explosion within technology systems in which this dispersed substance can be found (Mračková, 2006). Information about the LEL value can be used detection of a danger from fire or explosion of flammable industrial dust according to EN ISO 1127 - 1 (EN ISO 1127 - 1, 2001).

 DOI 10.2478/tvsbses-2013-0003

LEL assessment is performed under laboratory conditions in explosion chamber VK 100 (Fig. 6, Fig. 7, and Fig. 8). The results are then classified according to LEL evaluation criterions into explosion classes is Tab. 1.

Tab. 1 Evaluation criterions of LEL

Class	**Characteristics**	**Criterion**
1	highly explosive dust	4 $g.m^{-3}$ < LEL ≤ 40 $g.m^{-3}$
2	explosive dust	40 $g.m^{-3}$ < LEL ≤ 200 $g.m^{-3}$
3	hardly explosive dust	200 $g.m^{-3}$ < LEL ≤ 700 $g.m^{-3}$
4	explosion proof	700 $g.m^{-3}$ < LEL

In order to determine the explosion limits wood dust samples were prepared out of spruce (*Picea abies L.*) Karst., beech (*Fagus sylvatica L.*) and particleboard. They were smoothed out with a band abrasive stick. Abrasive paper Norton P 100 H 231 was used for to produce the wood dust. A sieve analysis must be done before every measurement and LEL assessment because of evaluation of the level of disintegration of the basic material. The larger particles were removed from the sample leaving only the dust consisting of 0 - 0,5 mm particles.

Fig. 6 Explosive chamber VK 100

Fig. 7 Inner space VK 100

Fig. 8 Operator control unit

Results and Discussion

Size analysis of the samples

Based on the measured individual fractions, the percentage shares of the wood waste samples from spruce (*Picea abies L.*) Karst., beech (*Fagus sylvatica L.*) and particleboard have been calculated, and the results are shown in the graphs Fig. 9, 10 and 11. The ordinate axis shows the share values of individual fractions in %, while the abscissa axis shows the particle size of the fractions in mm.

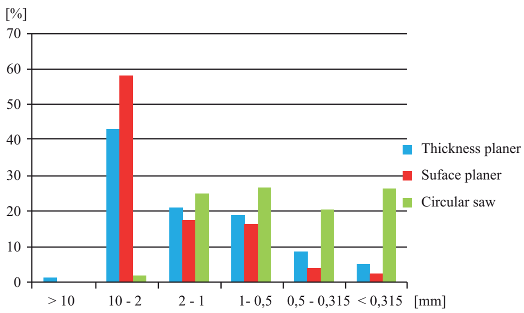

Fig. 9 Distribution of particle size of beech (*Fagus sylvatica, L.*)

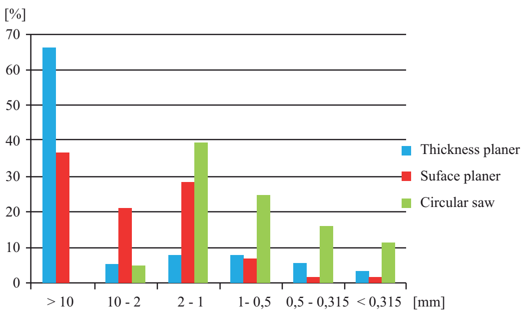

Fig. 10 Distribution of particle size of spruce (*Picea abies, L.*) *Karst.*

DOI 10.2478/tvsbses-2013-0003

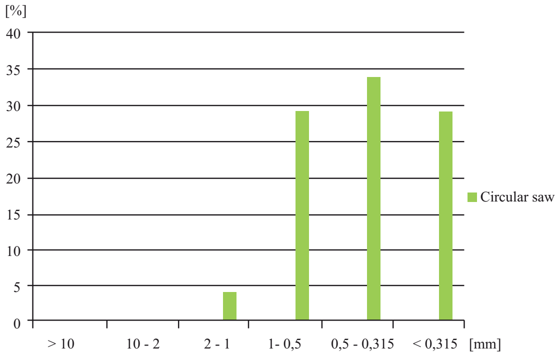

Fig. 11 Distribution of particle size of particleboard

The results indicate that the processing of spruce with a diht machine mostly creates fractions of larger dimensions, where more than 60 % are larger than 10 mm, while cutting with a circular saw produced a larger percentage of powdered material of smaller dimensions, between 0.5 and 2 mm. In the beech samples the material was generally more powdered, where only a slight amount was larger than 10 mm, while most particles range between 0.5 and 10 mm. Očkajova et al., have presented similar findings in their work (Očkajová et al., 2006).

The particleboard sample was processed only by cutting with a circular saw, and as much as over 60 % of the particles were smaller than 0.5 mm, out of which half are smaller than 0.315 mm.

Some studies found that the distribution of particles varies considerably depending on the type of wood and processing operations, where sanding produces a larger number of small particles, while sawing produces a larger number of large particles.

The measured quantity of the amount of wood dust in the air

The measured results show mentions, tabular dust data spruce (*Picea abies, L.*) *Karst.* Fig. 12 and Fig. 13 with the fundamental measured data of dust spruce (*Picea abies, L.*) *Karst.*

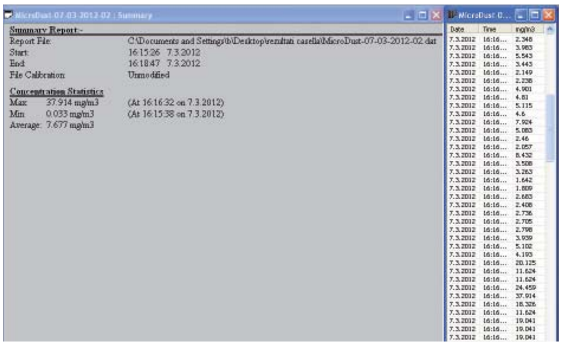

Fig. 12 Spreadsheet display with measured data of dust spruce (*Picea abies L.*) *Karst.*

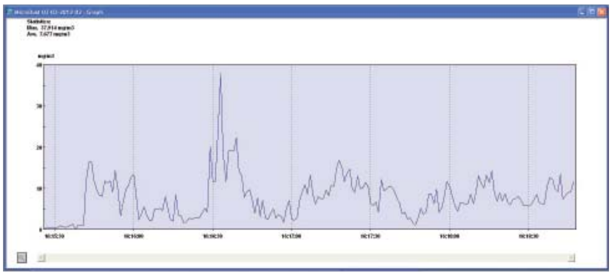

Fig. 13 The resulting graph with the fundamental measured data of dust spruce (*Picea abies L.*) *Karst.*

The results of measuring (Tab. 2) the Time Weighted Average (TWA) show different values depending on the type of wood material, as well as the type of processing. When it comes to working on a circular saw, the obtained values for all of the samples are worrisome. The particleboard samples, as expected, recorded high concentrations of 29.24 mg.m^{-3}, which can be considered very dangerous in terms of a threat to the workers' health. During the processing of solid wood with a combined machine, the values of the measured concentrations were net lower, but they exceed the values for respiratory dust (5 mg.m^{-3}) according to OSHA (OSHA 3371- 08, 2009), as well as inhalable dust according to the Guidelines of the European Union.

Tab. 2 The maximum and average concentrations of wood dust in the samples from the workplace

	Wood dust and agglomerated material						
	Beech wood (*Fagus sylvatica L.*)			Spruce wood (*Picea abies, L.*) *Karst.*			Particleboard
	Thickness planer	Surface planer	Circular saw	Thickness planer	Surface planer	Circular saw	Circular saw
Max. conc. [mg.m^{-3}]	30.91	19.14	36.13	43.61	37.91	28.65	73.66
TWA [mg.m^{-3}]	7.75	6.27	12.24	4.71	7.68	10.65	29.24

Assessment of the lower explosion limit (LEL) for wood dust

The experimental values for LEL assessment were obtained in an explosion chamber and the results are given in Tab. 3.

Tab. 3 Mutual comparison of the results of the LEL experimental assessment

Sample	LEL [g.m^{-3}]
Spruce - fraction (0 - 0.5 mm)	56.0
Beech - fraction (0 - 0.5 mm)	60.0
Particleboard - fraction (0 - 0.5 mm)	58.0

According to the LEL criterions (Tab. 1) we can say that the wood dust of spruce, beech and particleboard can be considered as explosive dust in the range between 40 $g.m^{-3}$ and 200 $g.m^{-3}$.

The data obtained in the experimental research shows that the values of dangerous explosion limit concentrations are higher than those measured in the carpentry workshop. However, when working in real conditions, it should be remembered that there can be occurrences of subsequent whirling of accumulated dust, and that there are sources of ignition which can ignite wood and lead to fire and explosion.

Conclusion

Based on the performed measurements and analyzed data, it has been determined that processing of solid wood (beech and spruce) and particleboard, without application of any protection measures on the machines, produces a considerable amount of powdered wood material and fine dust, in amounts that threaten the safety of workers and the work space. The granulometric analysis of individual fractions showed that the processing of spruce wood with a combined diht machine produces wood waste that consists predominately of fragmented particles that are mostly larger (over 10 mm) than those produced by processing beech wood. During the cutting of the samples on the circular saw, the largest amount of powdered waste material was obtained with the particleboard, where over 60 % was of dimensions below 0.5 and 0.315 mm.

The measurements of fine dust in the atmosphere around the machines showed that the produced amount of dust was within limits that threaten the health of workers. Especially large amounts were reported when working on a circular saw. The average TWA values, measured with the Microdust Pro instrument, were 29.24 $mg.m^{-3}$ for the particleboard, 12.24 $mg.m^{-3}$ for beech, and 10.65 $mg.m^{-3}$ for spruce. All of the measured values exceed the values for respiratory dust (5 $mg.m^{-3}$) according to OSHA, and inhalable dust according to the Guidelines of the European Union.

The explosion limit values that were determined in laboratory conditions amounted to 56.0 $g.m^{-3}$ and 60.0 $g.m^{-3}$. The maximum value that was measured in the workshop was 73.66 $mg.m^{-3}$, which is significantly lower than an explosively dangerous concentration. However, a large amount of dust deposited on the floors and machines was detected in the workshop, and if not removed regularly and properly, it could easily begin to whirl and create conditions that could lead to fire and an explosion. The risk of ignition sources should not be ruled out either, such as a spark of static electricity or sparks caused by friction, a heated surface, cigarettes, etc.

Making the situation worse is the fact that workers avoid using personal protective equipment, thus increasing the possibility of disease from inhaling dust and its deposition in the lungs. Therefore, in order to provide better working conditions, occupational safety and health protection of workers, it is necessary to insist on the use of personal protective equipment, for the protection of the eyes and respiratory organs (Milanko et al., 2010). The recommended measures are maintaining hygiene of the workspace, constant cleaning and removal of wood waste, ventilation, control of the safety and functioning of machinery and installations, as well as other potential sources of ignition that may cause fire and explosion.

In order to prevent the ignition and explosion of dust in the workplace, it is necessary to constantly control and remove dust, so that it does not pile up and deposit on floors, equipment, machines and other surfaces. Also avoided should be activities that lead to whirling of the deposited dust and the occurrence of dust clouds (using compressed air, brooms, brushes, etc.).

Modern facilities utilize dust collection systems. Special equipment for vacuuming and collecting dust is installed onto the woodworking machines. However, many small workshops and facilities in Serbia still operate in adverse conditions. Sometimes the cause of this is a lack of financial resources, while more often it is neglect, or a lack of awareness of the danger. This paper is based on research conducted in a carpentry workshop, with an aim of analyzing the impact of work conditions on the work environment, as well as the potential threat to the workers' health.

Acknowledgments

The authors wish to thank the financial support of the grant Project No.VEGA1/0345/12.

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