Analysis of Inhalable Dust Produced in Manufacturing of Wooden Furniture

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To provide an in-depth understanding of preventing occupational diseases and improving working conditions, characteristics of inhalable dust were studied. The results showed that total dust concentration (TDC) from mechanical sanding, portable planning and sanding, putty sanding, and painting sanding with inadequate exhaust ventilation were higher than occupational exposure limits (OELs). The more the furniture material was sanded and the worse the dust exhaust apparatus, the higher the TDC was. The TDC from portable planer sanding and dry sanding and putty sanding was in the range from 8.4 mg/m^3 to 8.7 mg/m^3 and from 5.3 mg/m^3 to 8.4 mg/m^3, respectively. The TDC from mechanical sanding and painting sanding was in the range from 4.4 to 6.4 mg/m^3 and from 3.4 mg/m^3 to 4.9 mg/m^3, respectively. More than 90% suspended particulate matter in their TDC had a PM_{10} in all aforementioned results. The sanding procedure produced 6.7% to 8.2% free silica in the total particulate matter, in addition to wood dust, putty dust, or painting dust. Heavy metals in dust from putty sanding and painting exceeding the OELs were lead (Pb; > 0.3 mg/m^3) and cadmium (Cd; > 0.01 mg/m^3). There was a large amount of granular grinding material, cluster putty, planar painting dust, and a small amount fibroid wood dust in the dust from putty sanding and painting sanding.

Keywords: Exposure; Inhalable dust; Characteristics; Wooden furniture

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INTRODUCTION

Wood dust particulates (WDPs) are a finely divided, air-suspended pollutant from the manufacture of wooden furniture. The WDPs can arrive at mucosae, causing rhinitis, sore throat, bronchitis, and cryptogenic fibrosing alveolitis (Hubbard *et al*. 1996; Ratnasingam *et al*. 2014). In addition, WDPs can linger on the skin, causing pruritus, pyoderma, and acne (Rekhadvi *et al*. 2009). Some WDPs may even cause nasopharyngeal carcinoma (Chen *et al*. 2004; Pérez-Escuredo *et al*. 2012). There are two major types of WDPs: cutting dust particulates and sanding dust particulates. Cutting dust particulates contain wood dust particles from cutting machines, table saws, boring machines, computer numerical controlled (CNC) woodworking machines, and portable planers. Sanding dust particulates include putty and grinding materials from putty sanding and materials from undercoat sanding processes by sanders and sand paper. The sanding dust particulates are minute and of complex composition and are more hazardous to humans in comparison to the cutting dust particulates. The dust particulates not only cause pollution in the workshop but also increase the risk of explosion and fire (Liu *et al*. 2005; Li *et al*. 2007). It is extremely important to increase global awareness of and develop effective methods for handling these dust particulates. Serious environmental problems can result when a wooden furniture manufacturer discharges dust particulates directly into the air.

Researchers pay special attention to suspended particulate matter with a diameter of 10 μm or less (PM_{10}), since such particles can be inhaled into human lungs. Fine particles of a diameter of 2.5 μm or less ($PM_{2.5}$) are most critical, for there has been found a positive correlation between $PM_{2.5}$ and death rate (Peters *et al*. 2001). These fine dust particles are found to contain a large number of heavy metals, mutagenic agents, bacteria, viruses, and other poisonous and harmful substances, causing respiratory and cardiopulmonary diseases (Ormstad 2000; Landis *et al.* 2001; Liu *et al*. 2003; Yang *et al.* 2003).

Grinding material eventually should be released from the sand paper to keep the sand tool efficiently working. In fact, it has been discovered that the main dust produced in the course of sanding processes is silica, which could cause occupational disease (Hu *et al*. 2005; Qu *et al*. 2005; Yao *et al*. 2005). The pigments, dyes, and resins used in putty and oil paint were reported to contain heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) (AQTSG 2013). According to the World Health Organization International Agency for Research on Cancer, arsenic, cadmium, and chrome are carcinogenic to humans (WHO IARC 2006). Lead is possibly carcinogenic to humans, and when absorbed may lead to symptoms of toxicity, such as cardiac disease, anemia, encephalopathy, paralysis, dizziness, amnesia, inappetence, and nausea. More seriously, lead can have a detrimental effect on embryo development and child growth (Landrigan *et al.* 2002; Lidsky 2003).

Wooden furniture manufacturing is traditionally a labor-intensive industry. The workers in a production line expose themselves to dust particles, which may lead to critical occupational health problems. There have been some advances in occupational safety in the furniture manufacture industry, and many health-related policies have been implemented by the wood industry and various levels of government. However, all previous studies have been mainly concern with the overall wood dust concentration, and exposure to the wood dust has been associated with cancers and respiratory diseases. It still has not been made clear the extent to which metals, *e.g.* Pb, Cd, Cr, and silica, are contained in the wood dust. Also the size distribution of the dust requires more study.

This study was concerned with characterization of dust particulates with respect to their diameter, free silica, and heavy metal contents, in addition to total dust concentration (TDC) in wooden furniture process. The overall purpose of the study is to generate knowledge and method in order to create an updated evidence-based platform for prevention of occupational diseases, as well as for improvement and evaluation of working conditions in the wooden furniture industry.

EXPERIMENTAL

Materials

Collection of samples

The samples were collected from two companies (designated A and B), which are located among the cluster of wooden furniture manufacturers in the west and south central areas of the Pearl River Delta, Guangdong, China. Both companies are 20 years old, and equipped with cutting machines, table saws, boring machines, CNC woodworking machines, wide band sanders, and other wood manufacturing equipment. These machines were made in Germany, USA, and Italy, and all had efficient dust collection and processing systems. In addition, Company A has a dust collection and air purification system in its sanding plant. According to GBZ 159 (2004), 4, 5, and 7, sample locations were determined, and the samples were collected. A total of 15 sampling locations were selected from all production processes and equipment such as cutting, boring, CNC machining, sanding, and workshops, such as dry sanding, putty sanding, undercoat sanding, and resurfacing sanding. Altogether for Company A there was a total of 46 samples (Table 1, a total of 45 samples, 3 samples each sampling location; Table 2, 1 sample). For Company B a total of 3 sampling locations were selected at middle part of each workshop, providing 4 samples (Table 1, 3 samples; Table 2, 1 sample) (used as a reference). A KC-120 TSP sampler (Qingdao Laoshan, Shandong, China) was used to collect the air-suspended particulate matter samples with a diameter of 10μm or less from Companies A and B over 3 to 4 h, which contained the dust of undercoat sanding (A1) and putty sanding (B1) designed for heavy metal content inspection. Explosion-proof CCZ-20A dust samplers (Jinan, Shandong, China) were used to obtain other samples.

Methods

Analysis of samples

The total dust concentration was measured according to GBZ/T 192.1 (2007). The distribution of particulates was analyzed by the microscopic method stipulated in GBZ/T 192.3 (2007). The content of free silica (crystalline) in dust was determined by the pyrophosphoric acid method in GBZ/T 192.4 (2007). The total dust concentration was calculated according to an 8-hour time-weighted average of 3 samples collected from different work periods (TWA) (GBZ 2.1 2007).

According to GB 18584 (2001), 5.2.5.1, sample A1, sample B1, and the control sample were collected. An Arian 220FS atomic absorption spectrometer and 710-ES inductively coupled plasma optical emission spectrometer (ICP-OES) (USA) was used to measure soluble Pb, Cd, Cr, As, and Hg. The soluble heavy metal content was calculated according to Eq. 1,

$$C = \frac{(a_1 - a_0) \times 25 \times F}{m} \times \mathrm{c} \tag{1}$$

where C is the soluble content of Pb, Cd, Cr, As, or Hg (mg/m^3); a_0 is 0.07 mol hydrochloric acid of control sample (mg/L); a_1 is concentration of test solution from graph of Pb, Cd, Cr, As, or Hg (mg/L); F is dilution factor (the value is 1); 25 is extractive hydrochloric acid (mL); m is sample mass of air-suspended particulate matter (mg); and c is concentration of air-suspended particulate matter (mg/m^3).

The micromorphology of sample A1 and sample B1 was analyzed using an XL-30-ESEM environmental scanning electron microscope (SEM) (FEI, the Netherlands) operating at an accelerating voltage of 20 kV. The samples were placed on an aluminum stub with copper conductive adhesive tape and metallized coating.

RESULTS AND DISCUSSION

Total Dust Concentration and Particulate Distribution

According to GBZ 2.1 (2007), the permissible concentration-time weighted average (PC-TWA) and the excursion limits (EL) for dust are 3 and 6 mg/m^3, respectively. The time weighted average (TWA) of total dust concentration (TDC) from the cutting machines, table saws, boring machines, CNC machines of Company A, and mechanical engraving workshop of Company B was in the range 1.8 to 2.7 mg/m^3, Table 1, which is below the PC-TWA. The maximal TDC of these samples was only 3.0 mg/m^3. This is because there were not the leakage in their collection interface, and the machines worked very well in the removal of dust due to an effective dust-collecting system. The TWA values of TDC from sanders 1 and 2 were 6.4 and 4.4 mg/m^3, respectively, higher than the PC-TWA. The maximal TDC of the samples from sander 1 reached as high as 6.7 mg/m^3, which may be attributed to the greater amount of leakage occurring in the collection interface, resulting in unsatisfactory removal of dust. This is in agreement with findings that the control of dust pollution is governed by the quality of a dust removal system and its effective operation (Zheng and Du 2009; Zhang 2012). It was reported that some small- and medium-scale wood companies have no efficient dust removal system, resulting in serious pollution. For example, the TDC of a cutting machine can be up to 54.3 mg/m^3 within only 15 min of operation (Ma and Tan 2012; Wang *et al*. 2012). The TWA of TDC of a portable planer without a dust removal system is 8.7 mg/m^3, with a maximal value of 9.3 mg/m^3. The TWA of TDC of a portable sander with a dust removal system can be up to 8.4 mg/m^3, with a maximal value of 8.7 mg/m^3. These values are all above the PC-TWA (by a factor of 3). Mechanization such as mechanical sander or semi-mechanization such as portable sander is usually used in rough machining of wood, which produces relatively large dust particulates in which the large size particulates are easy to sediment and easy to collect for fuel application, and the minute dust collected very difficult will cause secondary pollution to come into being air-suspended dust, which is the TDC measured here.

The manufacture of wooden furniture needs a lot of manual operation such as dry sanding, putty sanding, and undercoat sanding, which is labor-intensive, generates a huge amount of dust, and for which dust control is difficult. The dry sanding process results in wood dust with a TWA of 6.3 to 8.4 mg/m^3, which is 2 to 3 times larger than the PC-TWA. In the process of putty sanding, undercoat sanding, and resurfacing sanding, the TWA is found to be between 3.4 and 5.3 mg/m^3. Although this is much lower than the TWA of dry sanding, it may contains diverse components such as wood dust, silica, putty dust, and heavy metals (*e.g.,* Pb, Cd, and Cr) on the basis of raw materials being used to sanding and painting.

Silica, which is still employed in the manufacturing of sanding tools, since it facilitates the sanding of wooden furniture, is released when a sanding tool gets dull to come out the inner new silica to keep the tool efficiently working. Mechanical sanders and portable sanders are made from coarse particulate grinding material, while manual sanding paper is made from fine particulate grinding material. The abrasion rate of a grinding material is relevant to its quality, the hardness and roughness of an object, and the pressure applied. To increase the sanding efficiency, a sanding medium with large particulate materials is commonly used with a large amount of applied pressure, which results in a large quantity of dust, and a certain amount of free silica in the dust. It can be found from Table 1 that the dry sanding, putty sanding, and undercoat sanding produced

7.10% to 8.16% (mass concentration) of free silica in dust while the resurfacing sanding generated 6.67% free silica. The reason is the grinding material contained fine sand, which is used for sanding harder and smooth coatings. The dust produced by the cutting machine contained 4.84% of free silica. The free silica may come from airborne dust from the ground and/or virgin particleboard or MDF, which may contain sands or clay during their manufacturing process. However, the amount of silica content detected in various machines was lower than 10%, which met the requirement of GBZ 2.1 (2007).

Table 1. Total Dust Concentration and Free Silica Content in the Dust

Plant	Sample Location		Workpiece	Collection Interface	Total Dust Concentration ($mg\cdot m^{-3}$)		Silica Content (%)
					Samples	TWA	
A	1	Cutting machine	MDF	No	1.7, 2.0, 2.3	2.0	4.84
	2	Table saw	Hardwood	No	2.3, 2.7, 3.0	2.7	
	3	Boring machine	Hardwood	No	1.7, 2.0, 2.3	2.1	
	4	CNC machine	MDF	No	1.7, 1.7, 2.0	1.8	
	5	Mechanical sander	Hardwood	Leak	6.3, 6.3, 6.7	6.4	
	6	Mechanical sander	Hardwood	Leak	4.3, 4.3, 4.7	4.4	
	7	Portable planer	Hardwood	Leak	8.3, 8.7, 9.3	8.7	
	8	Portable sander	Hardwood	Leak	8.0, 8.3, 8.7	8.4	
	9	Dry sanding	Hardwood		7.7, 8.3, 8.7	8.4	8.02
	10	Dry sanding	Hardwood		6.0, 6.3, 6.7	6.3	
	11	Putty sanding	Hardwood		5.0, 5.3, 5.7	5.3	7.10
	12	Undercoat sanding	Hardwood		4.3, 4.7, 5.0	4.7	7.39
	13	Undercoat sanding	Hardwood		4.7, 5.0, 5.0	4.9	8.16
	14	Resurfacing sanding	Hardwood		3.7, 4.3, 4.7	4.4	6.67
	15	Resurfacing sanding	Hardwood		3.3, 3.3, 3.7	3.4	
B	1	Mechanical engraving workshop	Hardwood			2.0	
	2	Machining workshop	Hardwood			3.0	
	3	Manual sanding workshop	Hardwood			4.7	

The distribution of particulates is presented in Fig. 1. It was found in this study that the majority of suspended particulate matter in occupational exposure in the plant was between 2 μm and 10 μm. However, suspended particulate matter with a diameter below 2 μm from dry sanding, putty sanding, undercoat sanding, and resurfacing sanding were all more than from these machines such as cutting, table saw, sander, and so on. The distribution of particulates is closely related to the cutting method, material type, and surface roughness of a particulate. Use of a CNC machine to cut medium density fibreboard (MDF) results in more dust with a diameter below 2 μm than the solid wood. Dry sanding, putty sanding, and undercoat sanding results in more dust particles with a diameter below 2 μm than the dust particles in resurfacing sanding.

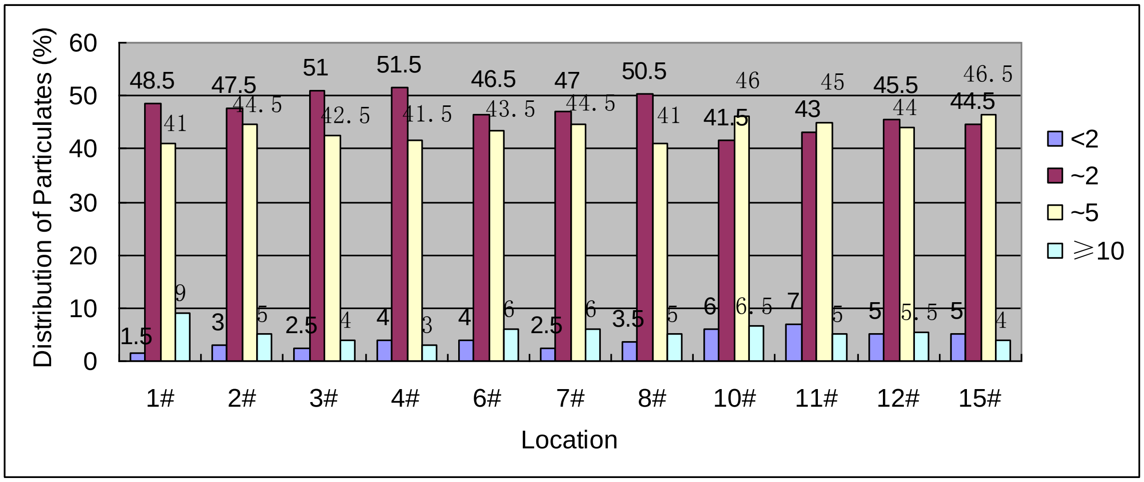

Fig. 1. Distribution of particulate matter

Heavy Metals

Standard GBZ 2.1 (2007) stipulates occupational exposure limits (OELs) of Pb, Cr, and Cd; *i.e.*, the PC-TWA of Pb and Cr is 0.05 mg/m^3 and for Cd is 0.01 mg/m^3 (GBZ 2.1 2007). In Table 2, the Pb content of samples from undercoat sanding dust (A1) and putty sanding dust (B1) obtained using FAAS and ICP-OES were 0.348 and 0.064 mg/m^3, respectively, which were higher than the PC-TWA. In sample A1, the Pb dust content was almost 7 times higher than the PC-TWA, and the Cd content was 0.010 to 0.011 mg/m^3, slightly higher than the PC-TWA. Pb and Cd content from undercoat sanding dust was 5 times, 11 times the heavy metals from putty sanding dust separately. Heavy metals in putty sanding dust were so high because lead was one of the most important raw materials to make putty.

Heavy metals such as As and Hg were not detected due to very little As and Hg in putty and painting. Thus they were far below the PC-TWA.

Table 2. Heavy Metals in Dust from Sanding Undercoat and Putty

Dust Sample	FAAS			ICP-OES				
	Pb ($mg\cdot m^{-3}$)	Cd ($mg\cdot m^{-3}$)	Cr ($mg\cdot m^{-3}$)	Pb ($mg\cdot m^{-3}$)	Cd ($mg\cdot m^{-3}$)	Cr ($mg\cdot m^{-3}$)	As ($mg\cdot m^{-3}$)	Hg ($mg\cdot m^{-3}$)
A1	0.348	0.010	*	0.309	0.011	0.004	*	*
B1	0.064	*	*	0.068	0.001	0.005	*	*

* not detected.

Microstructural Morphology of Dust

Figures 2 and 3 represent the microstructure of dust sampled from undercoat sanding and putty sanding. It is clear from Figure 2 that granular grinding materials and laminar paint dust exist on fibers of a filter membrane, but no wood dust was observed. In Fig. 3, there are some granular grinding materials, fibroid wood dust, and putty. Exterior putty or granular grinding materials adhere to the wood dust and the putty.

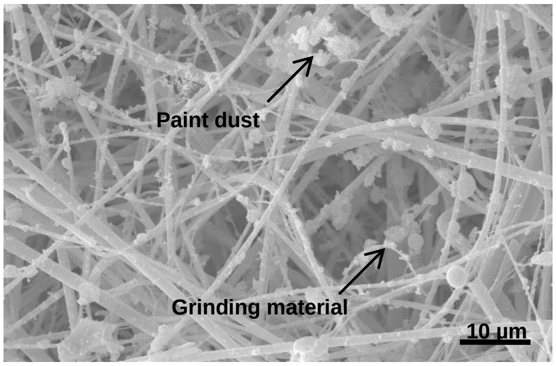

Fig. 2. Dust from sanding undercoating

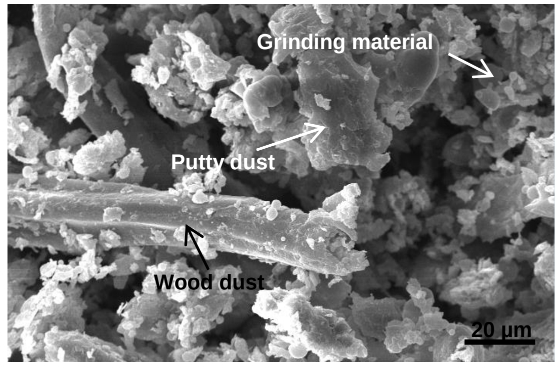

Fig. 3. Dust from sanding putty

CONCLUSIONS

The TDC from mechanical sander, portable planer, and portable sander with inadequate exhaust ventilation was far higher than cutting machines, table saws, boring machines, CNC machines with adequate exhaust ventilation, and exceeding the OELs. The reason was thought to be the dust leaking from the pipe assembling interface of the vacuum exhaust ventilation. The TDC from manual dry sanding, putty sanding, undercoat sanding, resurfacing sanding was also much more than the OELs, because dust control is difficult. Unssen *et al*. (2008) and Lazovich *et al*. (2002) found that there should be more focus on improving exhaust ventilation, professional cleaning methods, and worker training to reduce inhalable wood dust concentration.

The suspended particulate matter from putty and paint surface sanding contained diverse components: fibroid wood dust, granular silica, clustered putty dust, and heavy metals such as Pb and Cd and more fine particulate matter with diameter below 2 μm. The dust with a dimension below 2 μm more readily causes occupational diseases because these small dust containing heavy metals and other harmful substances easily float into surroundings to cause serious air, soil, water, and plant pollution (Watanabe *et al.* 1987, 1989; Hernberg 2000; Cheng *et al.* 2006).

The sanding procedure produced 6.7 to 8.2% free silica in addition to wood dust, putty dust, or painting dust. The mass concentration of free silica in dust was related to sanding tool, workpiece, and grinding technology. The increase of grinding amount would cause the increase of the mass concentration of free silica. Exposure to the wood dust containing the free silica could cause occupational disease more likely. Putty and paint surface sanding led to contents of the heavy metals of Pb, and Cd that exceeded the OELs. Pb and Cd content from undercoat sanding dust was much more than the heavy metals from putty sanding dust separately due to undercoat of pigment or dye. The authors suspect that it is also possible for silica to cause cryptogenic fibrosing alveolitis and for heavy metals such as Pb, Cd, and so on to cause cancer as a result of sanding operations.

Exhaust ventilation and professional cleaning methods should be focused to decrease the wood dust level. The effective exhaust ventilation at overall process, non-silica grinding materials, and non-heavy metal paint are critical, too. As a general approach, it is suggested to replace manual sanding by machine sanding in the wood furniture industry of China.

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