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Respiratory Effects in Woodworkers Exposed to Wood and Wood Coatings Dust: A Regional Evaluation of South East Asian Countries

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Abstract: This study investigated the dust emission characteristics of different wood coatings and wood substrates and its effects on the lung function of woodworkers in the South East Asian region. The study revealed that harder coating films produced a greater proportion of finer dust particles compared to softer coatings films, although the latter resulted in higher dust concentrations. Medium density fibreboard produced higher proportion of respirable dust and amount of total dust compared to particleboard and solid wood during the sanding operations. The study also revealed that wood dust is more prone to cause irritant respiratory symptoms, while wood coatings dust is a potent cause of chronic respiratory diseases among woodworkers. Further, the application of a single dust exposure standard for all woodworking operations is not sufficient to mitigate the effects of dust from the various woodworking processes. It is apparent that woodworkers' safety and health was compromised in most South East Asian countries and the main factor that contributed to the prevailing safety climate was the lack of management involvement and the poor enforcement of occupational safety and health regulations within the industry. Inevitably, the prevailing poor safety climate within the industry encourages the employment of foreign contract workers, who appear to be less safety and health conscious compared to their local counterparts. In this context, a concerted effort must be undertaken within the woodworking industry in the region to ensure the safety and health of the workers, if the workers' productivity and welfare are to be improved.

Key words: Wood coatings, dust particles, wood substrate, respiratory function, chronic diseases, exposure level

INTRODUCTION

Many industrial activities are associated with some kind of occupational hazard that can cause injury in an insidious manner. The adverse effects of exposure to wood dust include nasal carcinoma, allergic and irritant cutaneous and respiratory reactions and chronic respiratory impairment. Exposure to wood dust may cause various diseases, including extrinsic allergic alveolitis, the organic dust toxic syndrome, occupational asthma, non-asthmatic chronic airflow obstruction and simple chronic bronchitis (mucus hyper-secretion). Of these, simple chronic bronchitis and non-asthmatic chronic airflow obstruction occur most often. The level and pattern of disease varies with the type of wood dust, climatic conditions and the manner in which it is handled, being particularly influenced by the use of chemicals commonly found in wood coating operations (Whitehead, 1982).

In the manufacture of value-added wood products, such as furniture, the application of wood coating is an integral manufacturing process, which provides the necessary aesthetic appeal as well as protection to the wood product (Ratnasingam and Ioras, 2003). Although, studies on the properties of different types of wood coatings are ample (Donaldson *et al*., 2000), the sanding and dust emission characteristics of the common wood coatings have not been well researched (Vorbau *et al*., 2009; Bulian and Graystone, 2009; Ratnasingam *et al*., 2009a, 2010b). These aspects are important as it has far reaching manufacturing cost implications and affect workers' productivity, in terms of their health and safety (Baron and Willeke, 2001). Previous studies have shown that lung function of the woodworkers is severely affected after long-term exposure to wood dust but reports on the effects of coatings dust has not been well documented (Scheeper *et al*.,

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1995; Mandryk *et al*., 1999; Ratnasingam and McIllroy, 2011). Therefore, a study was undertaken to evaluate the dust emission characteristics of the common wood coatings and wood substrates used in the South East Asian furniture industry and its effects on the lung function of workers.

MATERIALS AND METHODS

In the first part of the study, 100 pieces of kiln dried Rubberwood (*Hevea brasiliensis*) sawn timber of 25 mm (T)×100 mm (W)×200 mm (L) in dimensions, obtained from a local supplier were used in this experiment. In a parallel experiment, 100 pieces of Medium Density Fibreboard (MDF) and Particle Board (PB) of similar dimensions were obtained from a commercial supplier to carry out comparative experiments. All the samples were pre-sanded to a grit size of 150 and had an average moisture content of 12±2%. The samples were stored in a conditioning room at 20±2°C and 65% relative humidity, until testing commenced. Three different types of sealer or undercoat of wood coatings, namely; Nitro-Cellulose (NC), urea-based Acid Curing (AC) and Poly-Urethane (PU) were obtained from a commercial wood coating supplier for this study. The volume solid content of the different coatings was 35, 45 and 55% respectively. The coatings were prepared for application by adhering strictly to the supplier's specifications using the necessary solvents to ensure the desirable application viscosity at all times. The coatings were applied on the sample boards using an experimental roller coater to achieve a final coating film thickness of 400 μm. The samples were then placed on a conveyor which passed through a drying oven at a temperature of 40°C for 30 min and were left aside to conditioning for a period of seven day before further testing. A total of 20 samples were prepared for each type of coating used in the study. Ten of the coated samples from each wood coating type were used for the sanding test carried out using a wide-belt sander (TIMESAVER C-106). The sander had a single head with rubber roller of 70° shore in hardness. Aluminium oxide abrasive belts with sanding grits of the size 180 were used in this study. The feed speed, sanding belt speed and depth of cut were maintained at 3 and 1000 m min^{-1} and 0.5 mm, respectively. The power consumed during the sanding operation was determined directly through a watt meter attached to the drive-spindle of the machine. The average surface roughness (R_a) of the sanded surfaces was evaluated using a Mitutoyo Surftest SJ-301 roughness recorder over a measurement length of 50 mm. A further test on dust emission during the sanding process of the remaining 5 uncoated and 5 coated samples was conducted using a 3 M orbital sander attached with a 180 grit aluminium oxide sand paper. The dust concentration was measured using gravimetric isokinetic air sampler, while the dust particle size distribution was ascertained using an aerodynamic particle sizer (APS 3300), as described in the report by Ratnasingam *et al*. (2011b).

The second part of the study evaluated the lung function of workers subjected to different levels and duration of exposure to wood and coatings dust. A total of 2500 woodworkers from 25 furniture factories with similar working conditions (i.e., processing Rubberwood (*Hevea brasiliensis*) and using urea formaldehyde type wood coatings) were invited to participate in the study. Five factories of comparable size and production conditions were selected from the major furniture-producing countries in the region, namely; Malaysia, Indonesia, Thailand, Vietnam and the Philippines, with the assistance of the respective national furniture trade associations. From the total of 2500 workers engaged, 2449 (89.8% of the workforce) accepted the invitation to participate in the study. Excluded from the study were those subjects who had never been exposed to wood and coatings dust (n = 37). An additional group of 88 subjects was also excluded because (a) They were unable to perform pulmonary function tests correctly and (b) Because of a history of previous exposure to substances known to induce bronchial hyper-responsiveness, such as smoking, etc. This left a total of 2324 exposed workers, from which 51% were exposed to wood dust, while the balance 49% was exposed to wood coatings dust. Since the aim was to examine the occurrence of pulmonary abnormalities as a function of exposure, a homogeneous split of the sample across the observed range of exposure was planned. The socioeconomic status of all subjects were recorded to ensure its comparability and the personal information such as age, working hours a day, working duration and occupational history were also collected. Written, informed consent was given by all subjects prior to participation in the study. The subjects were selected with the cooperation of the respective national trade association, which ensured that their family background and work-history were properly recorded and no misinterpretation occurred due to communication and language barrier. Efforts were also made that similar number of subjects were selected from each of the participating countries and the subjects were examined according to a protocol identical to that used in the study by Bohadana *et al*. (2000). Measurement of concentrations of airborne dust was carried out in the factories on the basis of weight difference of glass microfiber filter (GF/C, Whitman) with a flow rate of 1 L min^{-1}. The average inhalable particulate concentration mg m^{-3} was measured from the increased filter weight and rates and duration of airflow. In order to evaluate the effects of dust on the lung function of the subjects, detailed histories of respiratory diseases of the subjects were recorded to capture information on the manifestation of chronic bronchitis, asthma and other respiratory related ailments as per the study by Bohadana *et al.* (2000). Further, lung function assessment was carried out on the subjects by a trained medical technologist using a spirometer (Spiro-Analyzer ST 300, Fukuda-Sangyo, Japan). The following indices were obtained by the subject expiring forcefully and maximally after a maximal inspiratory manoeuvre: Forced Vital Capacity (FVC) and Forced Expiratory Volume after 1 sec (FEV1). The ratio of FEV1/FVC provides a reflection of the extent of obstruction in the airways of the subjects, which in turn allows the assessment of lung function. The results were expressed as the difference between the observed and predicted values of the European Respiratory Society.

RESULTS AND DISCUSSION

The results obtained from this study questions the application of a single inhalable exposure standard for dust to all woodworking scenarios. Firstly, the dust emission levels from the sanding of uncoated and coated samples obtained in this study exceeds the permissible exposure limit of 5 mg m^{-3} based on the 8 h time weighted average. Secondly, sanding of MDF samples resulted in highest dust concentration compared to particleboard and solid wood samples (Table 1) and the proportion of the coarser inhalable dust (<100 μm) was about ten times greater than the amount of the finer respirable dust (<10 μm). Thirdly, the higher the solid content of the wood coating used, the harder is the cured coating film. Consequently, surface roughness reduced in the order of PU<AC<NC wood coatings, which was attributed to the different coating film hardness (Table 2). The harder the surface of the coating film, the lesser is the scratching depth during the sanding operation, which explains the lower surface roughness observed. On the contrary, the power consumed during the sanding process was inversely proportional to the coating film hardness (Table 2). Fourthly, the softer the coating film the higher was amount of sanding dust particles produced and the total concentration of dust particles increased in the order of NC>AC>PU wood coatings. However, from the size distribution analysis it was also apparent that harder coating films produces more fine dust particles compared to the softer coating film (Table 3). The different stock removal rate as well as the polymeric characteristics of the coatings could explain the variations observed in the sanding dust particles distribution (Vorbau *et al.*, 2009; Ratnasingam and Bennet, 2010). In fact, the current industrial air filtration practice of capturing dust above 50 μm in average particle diameter in the industry is not be optimum to minimize the health risks posed by these dust particles (Welling *et al.*, 2008).

A detailed analysis of these exposure data from the twenty five factories showed that wood coating sanding operations were consistently associated with higher exposure levels compared to wood substrates sanding task (Tables 4 and 5). On the basis of these measurements, the sanding task was assigned an estimated dust exposure based on the mean value of all dust measurements for that task. Thus, an estimated average dust exposure of 27 mg m^{-3} was assigned to all workers performing sanding operations on wood-based substrates, whereas an estimated dust exposure of 12 mg m^{-3} was assigned to those in areas of sanding of wood coatings. To assess lifetime exposures the cumulative exposure index was calculated for each worker by multiplying the years mg m^{-3} of work with the assigned exposure Intensity (mg m^{-3}). Of the

Table 1: Dust emission levels from different wood substrates

Parameters	Materials		
	Solid wood	Particle board	Medium density fibre board
Density (kg m^{-3})	560	500	600
Dust particle size distribution (Ø in μm) (%)			
10	9	12	17
50	21	27	33
100	39	33	26
150	31	29	24
Total inhalable dust fraction (<100 μm) in mg m^{-3} on a 8 h weighted average basis	14-24	15-34	18-41
Total respirable dust fraction (<10 μm) in mg m^{-3} on a 8 h weighted average basis	1.6-1.9	1.8-2.3	2.1-3.2
Percentage of workers with allergic reaction after 3 years of exposure	17	33	39
Percentage of workers with dermatitis problems after 3 years of exposure	20	37	42
Percentage of workers with respiratory ailments after 3 years of exposure	8	11	14

Table 2: Characteristics of coated wood substrates

Coating	Specific gravity	Film hardness	Average surface roughness (R_a) (μm)	Stock removal rate during sanding (g m^{-2})	Sanding power consumption (W m^{-2})
Nitro cellulose	0.29	3B	42	22	4.5
Acid curing	0.38	3H	34	17	6.2
Poly urethane	0.53	9H	26	12	8.1

Film hardness test conducted according ASTM 3363 (2011) where 3B is the softest and 9H is the hardest

Table 3: Dust emission characteristics of common wood coatings

Coating	Dust concentration (mg m^{-3}) over 8 h weighted average	Dust particle size distribution (Ø expressed in μm) expressed in (%)				Dust extraction power requirement (W g^{-1})
		10	50	100	150	
Nitro cellulose	28	17	36	30	17	1.14
Acid curing	19	22	34	26	18	1.33
Poly urethane	14	31	40	18	11	1.97

Table 4: Dust exposure assessment of woodworkers

Sanding station	Dust concentration (mg m^{-3})	Years of exposure	Cumulative dust exposure (years mg m^{-3})
Wood	69-109 (76)	5-12 (7.5)	570
Coating	33-74 (41)	3-7 (4.3)	176

Table 5: Pulmonary assessment of woodworkers exposed to dust

Ailments	Type of dust	Percentage of subjects affected	Lung function indices		
			FVC	FEV_1	FEV_1/FVC ratio
Chronic	Wood	14	307	211	0.68
Irritant symptoms	Wood	86	337	259	0.77
Chronic	Coatings	33	286	176	0.61
Irritant symptoms	Coatings	67	303	213	0.71

exposed population 51% (n = 164) had a cumulative exposure to wood dust between 61-109 years mg m^{-3} whereas 159 subjects (49%) had a cumulative exposure to wood coatings dust between 33-74 years mg m^{-3}. It is therefore apparent that the mean cumulative dust exposure levels in the furniture factories in the South East Asian region were much higher that the allowable exposure level, which in turn will negatively impact woodworkers safety and health (Ratnasingam *et al*., 2012).

Overall, the prevalence of chronic respiratory symptoms due to cumulative exposure tended to be low, ranging from 2% for chronic bronchitis, 3% for bouts of bronchitis, 4% for asthma and 5% with dyspnoea, especially among woodworkers exposure to wood dust (group with 61-109 years mg m^{-3}). On the other hand, the prevalence of chronic cough or phlegm was as high as 32%, while subjects with irritant symptoms, such as red (burning) eyes tended to be highest at 54% of the subjects. However, only the prevalence of sore throat increased significantly with increasing exposure, a finding compatible with a dose response relation as observed in other studies (Milanowski *et al*., 1996).

The outcome is markedly different among workers exposed to wood coatings dust (group with 33-74 years mg m^{-3}) in the factories. This population show a higher prevalence of chronic respiratory symptoms with 5% for chronic bronchitis, 8% with bouts of bronchitis, 9% with asthma and 11% with dyspnoea. It was apparent that exposure to wood coatings dust resulted both higher chronic respiratory symptoms as well as irritant symptoms, suggesting that wood coatings dust was more potent as a health hazard compared to wood dust. This could be attributed to the finer particle sizes of the wood coatings dust, which is easily respired deeper into the lungs (Milanowski *et al*., 1996; Schlunssen *et al*., 2002). Table 5 shows the pulmonary function values, as expressed by the lung function indices of the subjects exposed to wood and wood coatings dust. It is obvious that that exposure to wood coatings dust have a more pronounced effect on the pulmonary function of workers, compared to wood dust. The overall reduction in the FEV1/FVC ratio of below than 0.7 indicates a pronounced obstructive airway which suggests a deteriorated lung function (Meo, 2004). The results of this study provide new evidence to suggest that contrary to common belief, wood dust is a more potent cause of irritant respiratory symptoms rather than chronic respiratory diseases. However, wood coatings dust is more potent than wood dust is causing chronic respiratory diseases and hence, its exposure control must be more stringent. This results support the findings of earlier study by Campo *et al*. (2010), who reported that exposure to wood dust often lead to irritant respiratory symptoms among carpentry apprentices. The results of this study have several far reaching implications to the workers of the furniture industry. Firstly, the use of one single standard for Minimum Exposure Level (MEL) for wood and wood coatings dust is not appropriate and compromises the safety and health of the woodworkers. Secondly, wood dust is more harmful as a cause of respiratory irritant symptoms rather than chronic respiratory diseases. However, wood coatings dust is more harmful than wood dust as the cause of irritant symptoms as well as chronic lung diseases. Thirdly, the lung function of woodworkers is severely affected by shorter duration exposure to wood coatings dust compared to longer duration exposure to wood dust, which suggest the need to re-evaluate the dust emission standards in the wooden furniture industry in Malaysia. Fourthly the proportion of subjects with an FEV1/FVC ratio below 70 (chronic) in the exposed workers who had been subject to coating dust was more double compared with workers exposed only to wood dust.

INDUSTRIAL IMPLICATIONS

This study has far reaching implications on the value-added wood products manufacturing industries in the South East Asian region. Despite the prevailing exposure dust standards within the region, it is apparent that its enforcement in the wood products industry is poor, often compromising the workers' health (Ratnasingam *et al*., 2009b; Ratnasingam and Wagner, 2010). Inevitably, as reported previously by Ratnasingam *et al*. (2010a) and Ratnasingam and Ioras (2010), there lack of commitment from the management of wood products manufacturers towards the safety and health agenda, appear to have a profoundly negative effect on the workers' health, which confirms the status of the industry as being unhygienic and unsafe. Further, the report by Ratnasingam *et al*. (2011a) clearly reflects that the prevailing safety culture within the wood products manufacturing industry is rather poor, which explains the preference of employers for foreign workers who could be easily manipulated to forego safety and health issues at the expense of monetary gains. It must also be enunciated that Occupational Safety and Health (OSHA) standards among the different countries in the South East Asian region is inconsistent and this poses a serious challenge to its enforcement. In most instances, even the development of the prevailing standards has been riddled by ambiguous practices that lack fundamental data upon which these standards are built (Ratnasingam and Bennet, 2010). Inevitably, the adoption of threshold values for dust exposure based on existing standards from Europe and North America appears to be misconceived as it does not reflect actual conditions on the ground (Ratnasingam, 2003; Rampal and Nizam, 2006). Therefore, the results of this study, the first of its kind on this subject on a regional basis, lays the platform for intensive discussion and cooperation at the regional level to ensure that the woodworkers safety and health are given due consideration, with the aim of improving working conditions. Unless such concerted efforts are taken, the overall workers' productivity in the woodworking industry in the region may suffer, leading to economic losses that will have far reaching implications on the overall competitiveness of the industry as a whole.

CONCLUSION

The findings, taken with the significantly lower values of FEV1/FVC ratio in exposed woodworkers, indicate that exposure to wood coating dust in these workers could have a serious effect on their respiratory function. Therefore, this study reveals an urgent need to re-examine the current single dust exposure standard applied to all woodworking environments, as the standard may be insufficient to mitigate the safety and health effects posed by the dust emitted from the different wood coatings and wood substrates in the value-added wood products manufacturing environment. Further, the current air filtration standard in use will have to be modified to include multi-level filtration to capture dust particles of different average diameters so as to minimize its ill effects on woodworkers.

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