Original Article

Dust Exposure and Respiratory Health of Workers in a Steel Mill in Terengganu, Malaysia

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ABSTRACT : *Air pollution in steel making operations would lead to adverse effect on respiratory health. This study aimed to measure the dust exposure and evaluate the respiratory health among steel workers. A cross sectional study was conducted among 402 male workers. Respiratory symptoms were assessed using British Medical Research Council (BMRC) Questionnaire while lung function was measured by spirometer. The airborne dust [$PM_{2.5}$, PM_{10}, and Total Particulate Matter (TPM)] were monitored by Handheld 3016 IAQ Particle Counter. All the parameters studied exceeded the limit of Malaysian guideline standard. Prevalence of chronic cough, chronic phlegm, chest of tightness, and shortness of breath were 35.8 %, 32.8 %, 23.4 %, and 22.4 %, respectively. There were significant differences between shortness of breath and work section (χ^2=9.236, p=0.026) and %FEV_1/FVC with work section [F (3, 3.98=3.194), p=0.025]. Smoking was associated with chronic cough (Adj OR =1.07, 95% CI: 1.04 - 1.10), chronic phlegm (Adj OR =1.05, 95% CI: 1.03 - 1.08), and shortness of breath (Adj OR = 1.05, 95% CI: 1.00 - 1.10) while past respiratory illnesses was associated with chest tightness (Adj OR = 2.24, 95% CI: 1.04 - 4.84) and shortness of breath (Adj OR = 4.16, 95% CI: 1.92 - 9.92). Duration of employment was associated with FEV_1 (β=-0.025, 95%CI:-0.030-0.020) while past respiratory illnesses was associated with %FEV_1/FVC (β =-1.784, 95% CI: -3.017 - 0.551). Steel workers are at risk of developing respiratory symptoms and lung function impairment.*

Keywords - *Dust Exposure, Lung Function, Occupational Respiratory Diseases, Respiratory Symptoms, Steel Workers*

1.0 INTRODUCTION

Various raw materials with different physical and chemical properties are used to produce steel. Seventy five percent of them have been developed in the last 20 years (Wilson & Anthony, 2001). Operations in the steel industry create major air pollution and have always been environmental and health hazards. As a consequence, steel workers are exposed to wide range of hazards or workplace activities that may cause incidents, death, illnesses or diseases (ILO, 1983). Pulmonary system (lungs) exposed to harmful agents either through acute effects or chronic effects may eventually develop lung diseases, such as pulmonary dysfunction and lung cancer (Cugell, 1992).

Occupational Respiratory Diseases (ORD) were observed among workers in iron and steel industry (Bogadi-Sare 1990; Lowe et al., 1970; Pham et al., 1979) Acute respiratory symptoms such as cough and phlegm were also observed and a high prevalence of chronic respiratory symptoms was found among steel production workers (Singh et al., 2011; Singh et al., 2013; Kayhan et al., 2013). Exposure to dust could cause airway obstruction (Abdel-Rasoul et al., 2009 & Johnson et al., 1985) and lung function impairment (Kuo et al., 1999, Low & Mithcelli 1985; Nemery et al., 1985). At the moment, the relationship between respirable dust with respiratory symptoms and lung function, as well as the additive effects of smoking and the frequency of mask usage during working hours has yet to be established.

In a steel manufacturing plant, the differences in work schedule, workplace, processes, and materials may lead to variations in intensity, frequency, and types of respirable dust exposure. As a result, workers engaged in different work section might suffer from different respiratory effects. The objective of this study was to assess respirable dust exposure, to determine the respiratory symptoms and lung function of steel workers, as well as to identify the contributing factors to respiratory health.

2.0 METHOD

2.1 Study Design and Population

A cross sectional study was conducted in a steel foundry in Terengganu, located at the eastern coast of Peninsular Malaysia. This 30-year old foundry is the only steel foundry operating in that region during the study period, employing 1675 workers with nearly 900 workers in the production section. A total of 424 workers were recruited by stratified random sampling based on these criteria; male, aged from 18 to 56 years old, and at least 1 year of employment (Table 1). Ninety four percent of them completed the questionnaire and spirometry. Subjects who were unable to produce acceptable spirograms meeting the American Thoracic Society (ATS, 1995) (N=20), those who were ill e.g. asthma (N=3) and had upper respiratory tract infection (URTI) (N=11) were excluded from statistical analysis. Therefore, the remaining 402 data were used in the final analysis.

Table 1: Distribution of Parts, Work Units, Number of Workers and the Samples Required of Steel Manufacturing Plant

Division and work Unit	Number of Workers	Number of Required Samples
1) Steel Making (SM) Plant		
- Furnace	70	34
- Ladle Furnace	29	14
- Ladle Handling	41	20
- Caster	99	48
- Scrap bay	31	15
Total	270	131
2) Direct Reduced (DR) Plant		
- Material Handling	62	30
- DR Operation	56	27
Total	118	57
3) Maintenance		
- Electrical and Instruments	86	40
- Mechanical	93	45
- Machining Facilities	14	7
- Refractory	41	20
- Fabrication	95	46
Total	326	158
4) Support Group	6	3
- Crane operation	6	2
- Raw Material Handling	33	16
- Logistics	19	9
- Upstream Conveyer	43	21
Total	161	78
Total Number	875	424

2.2 Dust Monitoring

Dust monitoring [($PM_{2.5}$, PM_{10}, and Total Particulate Matter (TPM)] was done using Indoor Air Quality (Handheld 3016 IAQ, Model Lighthouse). The location of all sampling spot was recorded on the layout plan and instrument was run simultaneously according to Industry Code of Practice (ICOP) on Indoor Air Quality 2010 (DOSH, 2010). Instruments were located at the center of every sampling location and placed 75 cm above the ground. The numbers of sampling points were estimated based on the total volume of plant area in each building. The sampling points were determined based on the position of respondents and source of contaminants. The measurements of particulates were conducted five days a week continuously from 8 am to 5 pm and data were logged in every 10 minutes for the 8 hours. Fig. 1 represents the monitoring procedure implemented in gathering the data on-site. Partial period of consecutive sampling was performed three times (morning, noon, and evening) to obtain indoor air particles inside the plant throughout all day.

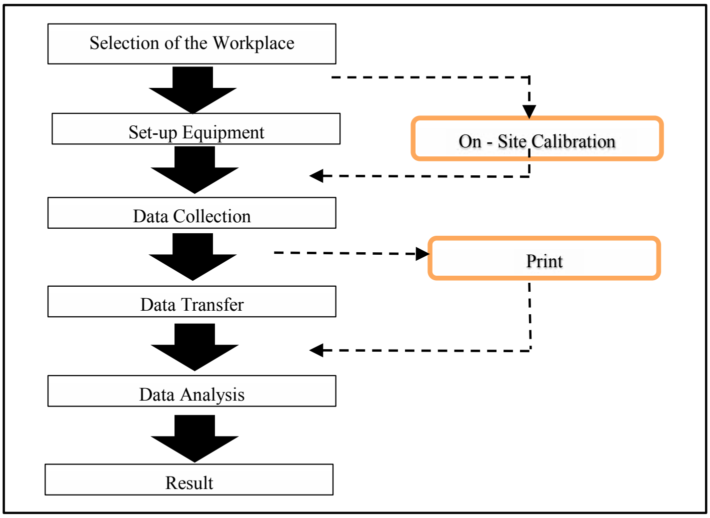

Figure 1: Sampling Procedure 1

Thirteen work areas were assessed within three month. The work sections monitored were: (i) Steel Making (SM) plant [furnace, ladle furnace, ladle handling, continuous casting machine, and crane operation], (ii) Direct Reduced (DR) plant [DR Shed and DR operation], and (iii) support group [raw material handling, refractory, and fabrication center (Fig. 2). The IAQ monitor was placed within the working area and the data were logged in every 10 minutes for 8 hours. Proper calibration was conducted on annual basis and on site just before measurements.

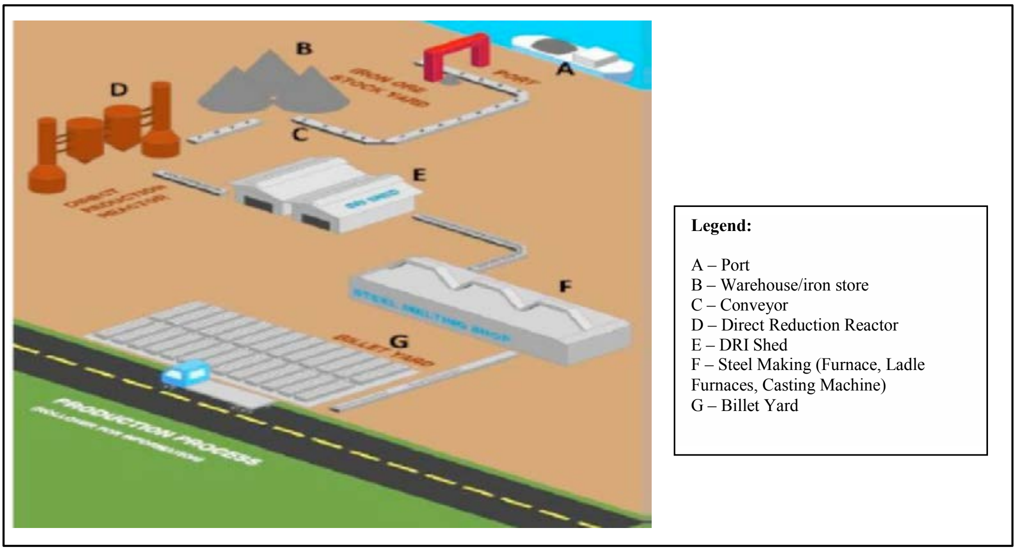

Figure 2: Layout Plan of Iron and Steel Plant

2.3 Measurement of Respiratory Health

A structured questionnaires of respiratory symptoms adopted from British Medical Respiratory Symptoms (BMRS) Questionnaire (BMRC, 1960) was pre tested, validated, and administered by the authors. The demographics, respiratory symptoms, current and past occupational history, subjective assessment regarding levels of dust in current job, smoking habits, past respiratory illnesses, and frequency of mask usage were covered in the questionnaires. The respiratory questionnaire responses also yielded subjective indicators of dust exposure i.e., subjective dustiness in current job corresponding to slight, moderate, and severe. Hours exposed to dust per day were also asked in the questionnaire and were divided into five levels corresponding to 0, 1-2, 3-4, 5-6, and 7-8 hours per day.

The following definitions of smoking were used: non-smokers were subjects who had never smoked of cigarette or tobacco in their lifetime: ex-smokers were those who had stopped smoking at least six months before the study was commenced, and everybody else were classified as current smokers. Lifetime cigarette consumption was coded and analyzed as a continuous variable-cigarette equivalent (packs per day multiplied by number of years smoked). The frequency of mask usage during the working period was divided into three levels corresponding to often, seldom, and always.

Lung function measurement was performed with Spiro lab (MIR) Model according to the American Thoracic Society 1995 (ATS, 1995) standard. Height and weight were measured beforehand. However, those who were unable to produce acceptable spirograms meeting the American Thoracic Society criteria (N=22) were excluded from the analysis to enhance the valid contrast. Daily instrument calibration was done before and after use. Each subject was given the opportunity to learn the technique while watching the others performed the lung function measurement. The subjects were measured in standing position with their nose clamped. The best forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) out of a minimum of three acceptable forced expirations were used as outcomes. Percentage of FEV_1/FVC was also calculated. As the spirometer is a flow-measuring devices, it was reasonable to neglect the body temperature pressure saturated (BTPS, temperature 37 ^oC, ambient pressure, saturated with water vapor at 37 ^oC) conversion under environmental conditions.

2.4 Definition of Respiratory Symptoms

Chronic cough refers to cough symptoms for at least three days a week for at least three months a year for two consecutive years or more. Chronic phlegm refers to phlegm production for at least three days a week for at least three months a year for two consecutive years or more. Chest tightness is defined as discomfort or pain anywhere along the front of body between the neck and upper abdomen and shortness of breath as breathlessness when hurrying on the level or walking up a slight incline. The respondents also must had reported the occurrence at least 1-3 days per week during the last four weeks and must had reported that the symptoms subsided when they were away from their workplace (Hodgson, 2002).

Past respiratory illnesses are defined as any history of respiratory diseases including bronchitis, pneumonia, chronic bronchitis, emphysema, asthma, pleurisies, pulmonary tuberculosis or any chest operation confirmed by medical doctors, and past occupational dust exposures for more than two years prior to joining the company.

2.5 Statistical Analysis

Data was analyzed using IBM SPSS version 21.0. Frequencies, percentages, mean, and standard deviations were calculated for appropriate variables. Chi Square test was used to compare percentages of respiratory symptoms according to work section. Analysis of variance (ANOVA) was used to evaluate differences between the means of lung function values according to work section. A Bonferroni test was used to explore the differences between groups if ANOVA showed a significant result.

Logistic regression analysis was used to determine the most important factors (predictors) to the presence of respiratory symptoms. The outcome variables analyzed were chronic cough, chronic phlegm, chest tightness, and shortness of breath. The exposure variables used were duration of employment and subjective dustiness in current job. The confounding variables controlled were age, duration of employment, cigarette equivalent, past dusty occupations, past respiratory illnesses, and frequency of using mask. Using the logistic model, adjusted odds ratios and confidence intervals of respiratory symptoms were calculated for any predictive variable.

Multiple linear regression was used to determine the contributing factors to lung function values. The outcome variables used were duration of employment and subjective dustiness in current job. The confounding variables controlled were age, Body Mass Index (BMI), cigarette equivalent, past dusty occupations, past respiratory illnesses, and frequency of mask usage. Ethnicity factor was abandoned because it did not significantly contribute to the model of lung function values as subjects were all Malays. Cigarette equivalent was not normally distributed and was therefore transformed logarithmically to yield log-normal distributions before the analysis commenced. An enter method was carried out as a mean of assessing the associations between multiple variables.

2.6 Ethical Considerations

All the procedures were explained to these workers and their willingness to participate was confirmed by their signatures on the consent form. The study was approved by the Research and Ethics Committee, Universiti Kebangsaan Malaysia (UKM) Medical Center (Reference number UKM 1.5.3.5/244/FF-055-2013 dated on 6th February 2013). All data were kept confidential throughout the study.

3.0 RESULTS

3.1 Background of the Subjects

Four hundred and two male Malay subjects were assessed. The mean age was 36.8 years ± 8.81 and the mean duration of employment was 12.2 years ± 8.23 years of work. Fifty percent of the workers were current smokers while 66.5% percent of them had been consuming for more than 10 years. Mean cigarette equivalent was 9.9 ± 9.71 packs per year. Prior to joining this company, 5.2% had been working in dusty occupations and 4.2% had a history of respiratory diseases. Majority of the workers (65.7%) did not wear mask frequently during the working period.

Various types of masks were available for all workers. One hundred and thirty eight (34.3%) workers used masks 'full time' during the working hours, 188 workers (46.8%) used masks 'most of the time', and 76 workers (18.9 %) were 'seldom' using masks. From the observation and walk-through survey, most of the workers used 'traditional methods' to protect themselves from the dust by using ordinary cloth, handkerchief, and T-shirt. (Table 2).

Table 2: Sociodemographic, Occupations, Smoking Characteristics and Frequency of Mask Usage

Demographic	Frequency, (%)	Mean ± SD	Average
Age (year)		36.8 ± 8.81	19 –56
Height (cm)		1.67 ± 0.06	150 –183
Weight (kg)		72.4 ± 13.89	44 –125
Body Mass Index (kg/ms^2)		26.00 ± 4.68	13.89 – 44.08
Duration of employment (years)		12.2 ± 8.23	1 – 30
Work Section			
- Steel Making (SM) Plant	108 (26.3)		
- Direct Reduced (DR) Plant	54 (13.2)		
- Scrap Bay	15 (3.7)		
- Raw Material Handling	16 (3.9)		
- Crane Operation	32 (7.8)		
- Fabrication	46 (11.2)		
- Refractory	20 (4.9)		
- Machining & Mechanical	52 (12.7)		
- Logistic & Workshop	9 (2.2)		
- Electrical & Instrumentation	37 (9.0)		
- Upstream Conveyor	21 (5.1)		
Pasty dusty occupations (Yes)	21 (5.2)		
Past respiratory illnesses (Yes)	17 (4.2)		
Subjective dustiness (Grades)			
- None	9 (2.2)		
- Slight	81 (20.1)		
- Moderate	119 (29.6)		
- Severe	193 (48.0)		
Smoking			
- Non Smoker	129 (31.7)		
- Ex Smoker (Quit since 12 months)	55 (13.7)		
- Current Smoker	218 (54.2)		
Year of Smoked (N=218)		15.1 ± 11.97	1 – 34
Number of cigarette (per day)		11.8 ± 6.78	1 – 40
Mean cigarette equivalent (pack/year)		9.9 ± 9.71	0.20 – 64.0
Frequency of mask usage			
- Full time	138 (34.3%)		
- Most of the time	188 (46.8)		
- Random	76 (18.9)		

3.2 Dust Concentrations

The distribution of mean particulate matters [(PM $_{2.5}$, PM $_{10}$, and Total Particulate Matter (TPM)] according to different section is presented in Table 3. In the Steel Making (SM) plant, the highest PM $_{2.5}$ showed a mean of 0.50 mg/m^3 in ladle handling section, and the range was within 0.01 – 0.11 mg/m^3. The mean concentration of PM$_{10}$ was 1.58 mg/m^3 within range 0.09 – 5.37 mg/m^3 while the mean concentration and the range of Total Particulate Matter (TPM) was 2.76 mg/m, and 0.13 – 11.18 mg/m^3 respectively. The proportion of PM $_{2.5}$ and PM $_{10}$ in TPM were found to be 18.11 % and 57.25 % which more inhalable than in other sections.

Table 3: Mean of Respirable Dust according to the Work Section

	Section	PM 2.5 (mg/m^3)	PM 10 (mg/m^3)	TPM (mg/m^3)	Proportion of PM 2.5 in TPM (%)	Proportion of PM 10 in TPM (%)
1	Steel Making (SM) Plant					
	Furnace	0.11 (0.03 – 0.29)	0.76 (0.10 – 3.73	0.97 (0.12 – 4.47)	11.34	78.35
	Ladle furnace	0.10 (0.02 – 0.16)	1.21 (0.03 – 7.27)	1.95 (0.04 – 12.59)	5.13	62.05
	Ladle handing	0.50 (0.01– 0.11)	1.58 (0.09 – 5.37)	2.76 (0.13 – 11.18)	18.11	57.25
	Continuous Casting Machine (CCM)					
	(I) MC5	0.35 (0.01 – 0.63)	0.18 (0.05 – 2.50)	1.24 (0.06 – 3.80)	12.10	75.00
	(II) Concast	0.25 (0.01 – 0.64)	0.38 (0.04 – 2.53)	1.55 (0.05 – 3.84)	9.68	69.10
	Crane operation	0.02 (0.01 – 0.08)	0.08 (0.02 – 0.50)	0.15 (0.08 – 0.70)	13.33	53.33
	Scrap bay	0.205 (0.05 –0.64)	1.28 (0.15 – 7.88)	2.14 (0.14 – 13.45)	16.35	59.81
2	Direct Reduced (DR) Plant					
	DR shed	0.08 (0.02 – 4.23)	1.48 (0.09 – 12.07)	2.06 (0.11 – 16.35)	3.88	76.70
	DR operation	0.02 (0.01 – 0.03)	0.10 (0.06 – 0.19)	0.12 (0.06 – 0.24)	16.67	83.33
3	Support Group					
	Fabrication Centre	0.04 (0.01 – 0.09)	0.21 (0.03 – 0.41)	0.25 (0.04 – 0.51)	16.00	84.00
	Refractory Centre	0.18 (0.01 – 0.50)	1.79 (0.07 – 9.13)	2.96 (0.10 – 17.95)	6.08	60.47
	Raw Material House (RMH)	0.02 (0.01 – 0.04)	0.18 (0.05 – 0.52)	0.25 (0.06 – 0.72)	8.00	72.00
	Machining & Mechanical Centre	0.02 (0.01 – 0.06)	0.10 (0.04 – 0.38)	0.12 (0.04 – 0.73)	16.67	83.33
	Electrical & Instrumentation	0.01 (0.01 – 0.06)	0.07 (0.02 – 0.40)	0.09 (0.02 – 0.46)	11.11	77.78

( ) range

In the Direct Reduced (DR) plant, the highest mean of PM$_{2.5}$ observed in the DR Shed section was 0.08 mg/m^3 within the range of 0.02-4.23 mg/m^3. The mean concentration of PM$_{10}$ was 1.58 mg/m^3 within the range of 0.09-12.07 mg/m^3, while the mean concentration and range of TPM was 2.06 mg/m^{3}m and 0.11-16.35 mg/m^3, respectively. The proportions of PM $_{2.5}$ and PM $_{10}$ in TPM were found to be 3.88 % and 76.70 %. The support group for both plants consisted of fabrication center, refractory, raw material handling, mechanical and machining center. The highest average of PM$_{2.5}$ was observed in refractory section was 0.18 mg/m^3 within the range of 0.01-0.50 mg/m^3. The mean PM $_{10}$ was 1.79 mg/m^3, within the range of 0.07 – 9.13 mg/m^3, while TPM was 2.96 mg/m^3 and 0.10-17.95 mg/m^3, respectively. The proportions of PM $_{2.5}$ and PM $_{10}$ in TPM were found to be 6.08 % and 60.47 %.

3.3 Respiratory Symptoms and Lung Function

Symptoms were grouped into four main categories namely chronic cough, chronic phlegm, chest tightness, and shortness of breath. These symptoms were based on workers' experience during the last 12 months. Chronic cough was the common symptoms (35.8 %) as claimed by the workers, followed by chronic phlegm (32.8 %), chest of tightness (23.4 %), and shortness of breath (22.4 %).

Respiratory symptoms of the workers were grouped according to four main work section namely SM Plant, DR plant, support plant group, and maintenance. The prevalence of chronic cough, chronic phlegm, chest tightness, and shortness of breath was the highest in the SM Plant. There was a significant difference of chronic cough with work section ($\chi^2 = 9.236$, $p = 0.026$). In contrast, no significant difference was found between chronic phlegm, chest tightness, and shortness of breath with work section (Table 4). Lung function factor was divided into four main work section namely SM Plant, DR plant, support plant group, and maintenance. There was a significant mean difference between %FEV_1/FVC with work section ($p = 0.025$). Furthermore, Bonferroni test showed a significance difference of FEV_1/FVC (%) for SM Plant and DR plant ($p=0.014$). However, no significance different was found between FEV_1 and FVC with work section (Table 5).

Table 4: Comparison of Respiratory Symptoms according to Work Section

Work section	Respiratory Symptoms (n, %)			
	Chronic Cough			
	Yes	No	χ^2 (df)	p-value
SM Plant	53 (43.8)	68 (56.2)	9.236	0.026*
DR plant	26 (29.5)	62 (70.5)		
Support plant group	41 (39.4)	63 (60.6)		
Maintenance	24 (27.0)	65 (73.0)		
	Chronic Phlegm			
	Yes	No	χ^2 (df)	p
SM Plant	44 (36.4)	77 (63.6)	2.177 (3)	0.536
DR plant	25 (28.4)	63 (71.6)		
Support plant group	37 (35.6)	67 (64.4)		
Maintenance	26 (29.2)	63 (70.8)		
	Chest of Tightness			
	Yes	No	χ^2 (df)	p
SM Plant	30 (24.8)	91 (75.2)	0.252 (3)	0.969
DR plant	20 (22.7)	68 (77.3)		
Support plant group	25 (24.0)	79 (76.0)		
Maintenance	19 (21.3)	70 (78.7)		
	Shortness of Breath (Dsypnea)			
	Yes	No	χ^2 (df)	p
SM Plant	30 (24.8)	91 (75.3)	1.952 (3)	0.583
DR plant	15 (17.0)	69 (83.0)		
Support plant group	25 (24.0)	79 (76.0)		
Maintenance	20 (22.5)	69 (77.5)		

χ^2 Chi Square Values
* Significant at p at 0.05 or less

Table 5: Comparison of Lung Function according to Work Section

Work section	n	Mean ± S.D	F stat (df) [a]	p-value
		FEV_1 (liter)		
SM Plant	121	2.88 ± 0.406	0.380	0.767
DR Plant	88	2.93 ± 0.443	(3; 398)	
Support Plant	104	2.89 ± 0.517		
Maintenance	89	2.94 ±0.050		
		FVC (liter)		
SM Plant	121	3.41 ± 0.445	0.410	0.746
DR Plant	88	3.48 ± 0.572	(3; 398)	
Support Plant group	104	3.44 ±0.544		
Maintenance	89	3.48 ± 0.533		
		FEV_1/FVC (%)		
SM Plant	121	82.99 ± 5.37	3.154	0.025[b]
DR Plant	88	84.47 ± 5.35	(3; 398)	
Support Plant group	104	84.23 ± 5.64		
Maintenance	89	85.35 ± 5.64		

[a] One Way ANOVA
[b] Bonferroni test showed significance differences of FEV_1/FVC (%) for SM Plant and DR Plant at p=0.014

3.4 Contributing Factors to Respiratory Symptoms and Lung Function

Each of respiratory symptom was further analyzed for any relationship with age, duration of employment, cigarette equivalent, past dusty occupations, past respiratory illnesses, subjective dustiness, and frequency of using mask. Smoking (cigarette equivalent) was associated with chronic cough (*Adj* OR =1.07, 95% CI: 1.04 - 1.10), chronic phlegm (*Adj* OR =1.05, 95% CI: 1.03 - 1.08), and shortness of breath (*Adj* OR = 1.05, 95% CI: 1.00 - 1.10) while past respiratory illnesses was associated with chest tightness (*Adj* OR = 2.24, 95% CI: 1.04 - 4.84) and shortness of breath (*Adj* OR = 4.16, 95% CI: 1.92 - 9.92) after controlling the confounding variables. In addition, duration of employment also found to be associated with reported shortness of breath (*Adj* OR = 1.05, 95% CI: 1.00 – 1.10). However, level of dustiness (subjective dustiness) and frequency of using mask had no relationship with all the reported symptoms (Table 6).

Table 6: Contributing Factors to the Presence of Respiratory Symptoms

Respiratory symptoms	Crude OR [a] (95% C.I.)	*p* -value	Adjusted OR (95% C.I.)	Wald stat (df)	*p*- value
Chronic cough					
Age (year)	1.02 (0.98, 1.06)	0.286	0.99 (0.91, 1.08)	0.029 (1)	0.865
Duration of employment (year)	1.01 (0.99, 1.04)	0.295	0.98 (0.92, 1.04)	0.516 (1)	0.473
Cigarette equivalent (packs/year)	1.05 (1.01, 1.09)	0.011*	1.07 (1.04, 1.10)	6.40 (1)	<0.001**
Past dusty occupations (Yes)	0.74 (0.13, 4.16)	0.731	1.58 (0.14, 8.35)	0.133 (1)	0.176
Past respiratory illnesses (Yes)	1.21 (0.36, 4.11)	0.763	1.60 (1.11, 3.27)	0.348 (1)	0.554
Subjective dustiness (Grades)	0.89 (0.66, 1.22)	0.478	0.83 (0.57, 1.22)	0.860 (1)	0.354
Frequency of using mask (Yes)	1.21 (0.48, 3.03)	0.689	1.49 (0.40, 5.51)	0.350 (1)	0.250
Nagekel R = 0.101					
Chronic phlegm					
Age (year)	1.03 (0.99, 1.07)	0.195	1.00 (0.91, 1.09)	0.501 (1)	0.997
Duration of employment (year)	1.02 (1.00, 1.05)	0.120	0.99 (0.94, 1.04)	0.116 (1)	0.733
Cigarette equivalent (packs/year)	1.06 (1.02, 1.10)	0.002*	1.05 (1.03, 1.08)	9.767 (1)	<0.001**
Past dusty occupations (Yes)	1.52 (0.27, 8.60)	0.634	2.38 (0.21, 16.47)	1.496 (1)	0.481
Past respiratory illnesses (Yes)	1.98 (0.61, 6.39)	0.250	1.00 (0.21, 4.62)	0.786 (1)	0.990
Subjective dustiness (Grades)	0.81 (0.60, 1.11)	0.193	0.87 (0.60. 1.27)	0.525 (1)	0.206
Frequency of using mask (Yes)	1.33 (0.51, 3.51)	0.560	1.61 (0.43, 6.03)	0.492 (1)	0.483
Nagekel R= 0.113					
Chest tightness					
Age (year)	1.02 (0.99, 1.05)	0.087	1.03 (0.98, 1.08)	1.339 (1)	0.247

Duration of employment (year)	1.02 (0.99, 1.040	0.148	0.94 (0.89, 0.99)	0.117 (1)	0.733
Cigarette equivalent (packs/year)	1.02 (0.99, 1.06)	0.196	1.01 (0.98, 1.04)	0.849 (1)	0.357
Past dusty occupations (Yes)	2.30 (0.45, 11.72)	0.318	2.29 (0.25, 20.71)	0.543 (1)	0.462
Past respiratory illnesses (Yes)	4.71 (2.21, 10.04)	<0.001**	2.24 (1.04, 4.84)	4.255 (1)	0.039*
Subjective dustiness (Grades)	0.83 (0.59, 1.16)	0.271	0.87 (0.59, 1.27)	0.525 (1)	0.469
Frequency of using mask (Yes)	1.00 (0.42, 2.35)	0.994	0.83 (0.453, 1.52)	0.361 (1)	0.548
Nagekel R = 0.23					
Shortness of breath					
Age (year)	1.01 (0.99, 1.04)	0.295	0.96 (0.91, 1.01)	2.275 (1)	0.131
Duration of employment (year)	1.02 (1.00, 1.05)	0.04*	1.05 (1.00, 1.10)	4.371(1)	0.037*
Cigarette equivalent (packs/year)	1.04 (1.01, 1.06)	0.004*	1.03 (1.00, 1.06)	6.376 (1)	0.012*
Past dusty occupations (Yes)	1.78 (0.11, 28.96)	0.679	2.13 (0.13, 36.57)	0.273(1)	0.601
Past respiratory illnesses (Yes)	4.05 (1.09, 8.62)	<0.001**	4.16 (1.92, 9.92)	13.05 (1)	<0.001**
Subjective dustiness (Grades)	0.90 (0.66, 1.22)	0.895	0.78 (0.57, 1.11)	1.800 (1)	0.180
Frequency of using mask (Yes)	1.26 (0.74, 2.15)	0.392	1.39 (0.79, 2.46)	1.303 (1)	0.254
Nagekel R = 0.25					

* Significant at $p < 0.05$, ** significant at $p < 0.001$

The FEV_1, FVC and $\%FEV_1/FVC$ were further analyzed to find out the association with demographic and occupational exposure after controlled the confounding variables. As expected, age, BMI and smoking were the important determinants of lung function values. Duration of employment was found to be associated with FEV_1 (*Adj* OR = -0.025, 95% CI: -0.030 – 0.020) and past respiratory illnesses were significantly reduced the $\%FEV_1/FVC$ (*Adj* OR = -1.784, 95% CI: -3.017 – 0.551). However, no associations were found between the lung function values with subjective dustiness, smoking and frequency use of mask (Table 7).

Table 7: Predictors of Lung Functions Values in Simple and Multiple Linear Regression

Predictors	SLR[a]		MLR[b]		
	b (95% CI)	p value	*Adj b* (95% CI)	t-stat	p value
			FEV_1 (litre)		
Constant	-	-	2.974 (2.656 3.292)	18.541	<0.001**
Age (year)	-0.031 (-0.035, -0.026)	<0.001**	-0.027 (-0.038,-0.016)	-4.747	<0.001**
Duration of employment (year)	-0.027 (-0.032, -0.022)	<0.001**	-0.025 (-0.030, 0.020)	-4.721	0.004*
BMI (kg/ms^2)	-0.020 (-0.029, -0.010)	<0.001**	-0.010 (-0.020, 0.000)	-1.899	0.059
Cigarette equivalent (packs/year)[c]	-0.275 (-0.397, -0.154)	<0.001**	-0.166 (-0.371,0.039)	-1.606	0.112
Past dusty occupations (yes)	-0.565 (-1.212, 0.081)	0.086	-0.255 (-0.678.0.168)	-1.196	0.234
Past respiratory illness (yes)	-0.039 (-0.290,0.212)	0.760	-0.025 (-0.251, 0.201)	-0.219	0.827
Subjective dustiness (grades)	-0.091 (-0.257, 0.076)	0.286	-0.007 (-0.080, 0.067)	-0.180	0.857
Frequency of using mask (yes)	0.085 (-0.032, 0.201)	0.153	0.165 (-0.009, 0.340)	0.977	0.063
R^2					0.388
			FVC (litre)		
Constant	-	-	3.655 (2.148, 5.162)	4.558	<0.001**
Age (year)	-0.033 (-0.037, -0.028)	<0.001**	-0.028 (-0.041, - 0.015)	-4.154	<0.001*
Duration of employment (year)	-0.028 (-0.034, -0.023)	<0.001**	-0.001 (-0.014, 0.013)	-0.127	0.899
BMI (kg/ms^2)	-0.023 (-0.033, -0.012)	<0.001**	-0.014 (-0.026, -0.020	-2.333	0.021*
Cigarette equivalent (packs/year)[c]	-0.342 (-0.477, -0.206)	<0.001**	-0.046 (-0.187, 0.095)	-0.646	0.519
Past dusty occupations (yes)	-0.728 (-1.451, -0.005)	0.048*	-0.786 (-1.601, 0.030)	-1.899	0.059
Past respiratory illness (yes)	-0.173 (-0.359, 0.2012)	0.067	-0.149 (-0.338, 0.041)	-1.550	0.123
Subjective dustiness (grades)	-0.045 (-0.121, 0.032)	0.252	-0.073 (-0.159, 0.013)	-1.681	0.094
Frequency of using mask (yes)	0.111 (-0.019,0.241)	0.095	0.049 (-0.098, 0.196)	0.653	0.514
R^2					0.342
			FEV_1/FVC (%)		
Constant	-	-	106.87 (74.49, 139.25)	6.553	<0.001**
Age (year)	- 0.097 (-0.158, -0.036)	0.002*	-0.104 (-0.292, 0.084)	-1.088	0.278
Duration of employment (year)	-0.098 (-0.164, -0.032)	0.004*	-0.133 (-0.328, 0.062)	-1.345	0.180
BMI (kg/ms^2)	-0.023 (-0.140,0.094)	0.700	-0.052 (-0.221, 1.118)	-0.598	0.550
Cigarette equivalent (packs/year)[c]	-1.150 (-3.777, 1.477)	0.387	-1.709 (-3.736, 0.317)	-1.663	0.098
Past dusty occupations (yes)	-1.395 (-4.501,1.711	0.377	-2.847 (-14.554, 8.859)	-0.479	0.632
Past respiratory illness (yes)	-1.207 (-4.00, -2.018)	0.003*	-1.784 (-3.017, 0.551)	-2.854	0.005*
Subjective dustiness (grades)	-1.947 (-6.429, 2.535)	0.393	-0.177 (-2.897, 2.544)	-0.128	0.898
Frequency of using mask (yes)	0.186 (-2.003, 2.375	0.867	1.428 (-0.684, 3.539)	1.313	0.184
R^2					0.117

SLR- Simple linear regression, MLR -Multiple linear regression

[a] Crude regression coefficients, [b] Adjusted regression coefficients

[c] Logarithm transformation before analysis, * p <0.05, ** p < 0.01, # p < 0.001

** Significance at p or below than 0.05, ** Significance at p or below than 0.001

The model reasonably fits well. Model assumptions are met. There are no interaction between independent variables and no multicollinearity problem

Model of lung function among steel workers

FEV_1 (litre) = 2.974 – [0.027*age] – [0.025 * duration of employment]

FVC (litre) = 3.655 – [0.028 * age] – [0.014 * BMI]

FEV_1/FVC (%) = 106.87 – [1.784* past respiratory illnesses]

4.0 DISCUSSION

4.1 Dust Concentrations

In this study, measurement of dust in the working environment was done by using static sampling strategy. The instrument was placed in different workplaces throughout the shift to trap the dust. There was significantly higher $PM_{2.5}$, PM_{10} and TPM level indoor air (in most of SM plant, DR shed, Fabrication and Refractory center) as compared to the allowable limit of 0.15 mg/m^3 by Industry Code of Practice of Indoor Air Quality, 2010 by the Department of Occupational Safety and Health (DOSH), Malaysia.

Similarly, previous studies reported Steel Making (SM) plant had recorded higher occupational exposure to respirable dust which was consistent (Singh et al., 2013, Kayhan et al., 2013, Gomes et al., 2001). Substantial amount of dust was generated at many points in the steel manufacturing process (such as sintering, melting in furnaces, tapping, and slag removal process), and the warm dust clouds tended to rise upwards. In contrast to the physics concept of gas distribution that distributes equilibrium in an enclosed space, the higher the dimension size of the area the lower the concentration of $PM_{2.5}$ became as compared to the lesser dimension size of the area.

Air pollution in the steel plant cause health effects to cardio-respiratory fitness although at the exposure below than exposure standards (Nezhad & Siahkuhian, 2012). A study conducted by Singh et al. (2011) and Singh et al. (2013) in the Indian steel mills reported that exposure levels of respirable suspended particulate matter (RSPM) in the casting section was high, while the low dust concentrations was reported in the machining section. The RSPM level was also found to be above the limit of 5 mg/m^3 as prescribed by Indian Factory Act. Kayhan et al. (2013) also found that the dust concentrations in the core making and casting were more than 10 mg/m^3, while the smelting and after processing did not exceed 10 mg/m^3. Rafiei et al. (2009) stated that respirable particulate matter (RPM) in steel production was also higher as compared to Industry Code of Practice of Indoor Air Quality, 2010 by the Department of Occupational Safety and Health (DOSH), Malaysia.

The average dust concentrations in fabrication and refractory center were recorded higher than other support plant groups. Fabrication workers (fabricators and welders) exposed to high respirable dust as compared to ambient dust exposure in the workplace (Gomes et al., 2001). They were also exposed to high concentrations of metal dust during welding as compared to other groups. Most of support groups for both plants were exposed to high respirable dust while doing regular repairs as well as bi-annual maintenance.

Dust concentrations varied between work sections and types of work in each unit due to the efficiency of local exhaust ventilation (LEV) in removing the dust out of the plant. High ambient temperatures in smelting and casting also encouraged the accumulation of dust in such area. Therefore, the average dust concentration was higher in the upstream (smelting) and downstream (casting) as compared to other working groups in the Steel Making (SM) Plant. In general, airborne contaminants in the SM plant were well controlled through enclosed and Local Exhaust Ventilation (LEV) systems. Since PM_{10} particles were bigger, they moved at slower speed and shorter travelling distance in the air before settled to the ground. Therefore, the LEV would help in removing more PM_{10} particles out from the plant successfully. However, the result indicated that respirable dust exposure in the workplace still required more effective control to reduce the exposure as suggested by Andersson et al. (2009) and Cotton & Underwood (2009). Therefore, workers are required to wear mask or other respiratory protective equipment while doing work in order to reduce such exposure. However, the practice of using mask 'full time' was also relatively low. Most of the workers were observed to use traditional methods by using towel, handkerchief, and T-shirt to cover their nose and face to protect them from exposure to dust.

4.2 Comparison of Respiratory Symptoms and Lung Function According to Work Section

The prevalence rates of chronic cough, chronic phlegm, chest tightness, and shortness of breath were higher among workers in SM plant as compared to workers in other work section. Only chronic cough was significantly different with work section as reported in other studies in the developing counties. Some researchers reported that prevalence of cough, phlegm, chest tightness, and shortness of breath was more frequent among workers in casting (Singh et al., 2012, Kayhan et al., 2013, foundry (Gomes et al., 2001), and furnace (Low & Mithcelli 1985; Andersson et al., 2009) as compared to other work section. In contrast, Low & Mitchell (1985) reported no significant difference between chronic cough and shortness of breath among different working groups. However, the signs of acute respiratory such as sneezing and rhinorrhea were found to be more frequent among foundry and core making workers while cough and phlegm were high among casting workers.

High respiratory symptoms in the population studied showed the existence of chronic irritation to the respiratory tracts due to prolonged and repetitive exposure to airborne dust. The occurrence of respiratory symptoms may represent the earlier response to dust exposure followed by lung function changes. Early respiratory symptoms have been suggestive as risk factors to subsequent loss of pulmonary function in steel workers (Abdel-Rasoul et al., 2009; Kayhan et al., 2013; Singh et al., 2013). Respiratory symptoms reflecting airway inflammation resulting from dust, even occurring early and reversibly, have a 'lagged effect' on subsequent on pulmonary function (Nurul et al, 2015). The authors suggested that workers who develop respiratory symptoms at the early stage are more susceptible to subsequent pulmonary function loss.

The lung function values (FEV_1, FVC, and $\%FEV_1/FVC$) were to be found lower among workers in SM plant as compared to other work section. Only the $\%FEV_1/FVC$ had a significant difference with all of the work sections. It was apparent that the lowering of lung function values showed a combination of obstructive and restrictive pattern among the subjects. This might be due to some occupational asthma (OA) cases among the population studied but the description of the diseases has not been investigated in detail. Occupational asthma (OA) may cause symptoms of chest tightness, shortness of breath, and chronic cough. Despite this, wheezing which was an important symptom of asthma was not assessed. Therefore, the decline of the small airways should be investigated among those who may be experiencing an early symptom of asthma in order to examine the relationship between chronic bronchial obstructions with respiratory failure.

These findings were in agreement with several studies done elsewhere in the steel manufacturing. Prevalence of OA was higher among foundry workers as compared to other working section (Gomes et al., 2001). In addition, furnace and fabrication workers were also found to have lower of lung function values as compared to other working section (Low & Mitchelli 1985; Andersson et al., 2009). Besides, local study also found that workers in manufacturing section stated significant difference of FEV_1 and FVC between the working sections (Azlihanis et al., 2007).

4.3 Contributing Factors to Respiratory Symptoms and Lung Function

Smoking was found to be the predictor of chronic cough, chronic phlegm and shortness of breath while duration of employment and past respiratory illnesses as well as smoking was the predictors to shortness of breath. Those who smoked 1 cigarette pack per year had 1.07 times the risk of chronic cough, 1.05 times the risk of chronic phlegm, and 1.03 times of risk of shortness of breath. Those who had past respiratory illnesses had 2.24 times risk of chest tightness and 4.04 times of risk of shortness of breath. Furthermore, another year of employment putting the workers 1.05 times more likely to experience shortness of breath. Similar findings were reported by few researchers. Smoker had higher risk of morning cough and morning phlegm (Razlan et al., 2000). Those had been working for many years had higher risk of reporting shortness of breath, chest tightness, morning cough, and morning phlegm (Razlan et al., 2000;2002; Nurul et al., 2015). High smoking prevalence (54.2%) found in this study was also likely to explain the high prevalence of reported respiratory symptoms. Earlier studies documented that smoking prevalence among the steel workers were 67.7% (Nurul et al., 2005) and 65.0% (Azlihanis et al., 2006).

Some researchers reported that air pollution in the workplace was significantly associated with cough (Rafiei et al, 2009) and reduced respiratory function of the workers (Nezhad and Siahkuhian, 2012). In comparison, Chen at al. reported smoking, duration of employment, and subjective dustiness as predictors of cough, phlegm, and breathlessness while past respiratory illnesses as the only predictor of breathlessness (Chen et al. 2006). Likewise, a dose-response relationship between cigarette-years of smoking and chronic cough and chronic phlegm was also well documented (Hu et al., 2006). According to Mohammadien et al. (2013) the prevalence of respiratory symptoms increased with duration of employment while prevalence of respiratory disorders increased with both duration of employment and dust level.

This study failed to reveal the association of subjective dustiness with all the reported respiratory symptoms and lung function values. This might be due to the inadequate findings of dust indicator measurement whereas further protocol of personal respirable measurement based on the regulations stated are needed. Exposure assessment is important in all environmental/occupational-epidemiologic studies. Associations have been clarified by improved use of exposure assessment even where indirect methods have been used. Thus, causal relation between exposure to certain chemical agents and adverse health effect can be determined as well as to measure and characterize any cause relations (to assess the exposure-response relationship or dose-response relationship). The estimation of cumulative doses also an important component of many occupational-exposure studies, though such measures may not be valid even in occupational settings. Therefore, the exposure-dose relation should be examined for nonlinearity before cumulative estimates are calculated. The relation between cumulative exposure and peak exposure is known in many occupational-epidemiologic studies, particularly those involving hazardous- site exposures or exposures to episodic pollution (Hamzah et al. 2014; Hamzah et al., 2016; Qian et al, 2016).

Age and body mass index (BMI) were independent predictors to lung function, which is a well-documented fact (Leslie & Lunau 1992; Corn 1993). It should be noted that the subjective dustiness (grades in dust exposure based on job task) was also appeared to be an independent predictor of $\%FEV_1/FVC$. Furthermore, the duration of employment had negative association with all the parameters of pulmonary function and was an independent predictor of FEV_1. This study also failed to reveal a clear picture of obstructive and restrictive impairments and the relationship with duration of exposure as suggested in other studied. This might be due to the inadequate findings of lung function abnormalities as chest x-ray and radiological opacities were not examined. Large range of duration employment can provide significant results for both pattern of lung function.

Smoking was also negatively associated with lung function but it was not found to an independent predictor of lung function. The misclassification of smoking indices especially among ex-smokers in calculating packs/year might lead to zero value within each category. Separate analysis based on smoking category is warranted to better evaluate the effect of smoking. Past respiratory illnesses also increased the deterioration of lung function, where an association was found with %FEV_1/FVC. One out of five cases of chronic obstructive pulmonary diseases (COPD) may be attributable to occupational exposures (Silvana & Afrim 2010). Therefore, physicians and health policy makers should address this potential causes and consequences of COPD as well as introducing an ambient air-safety protection at the workplace.

The current study showed that exposure to respirable dust in the steel making could lead to the development of respiratory symptoms and impairment of lung function. Therefore, preventive measures or control measures should be adopted (Corn 1993; Harrington et al., 1992; Vincent 1999; Williams & James 2000). Local exhaust ventilation (LEV) is required in the SM plant to remove out the pollution from the main source, while general ventilation is suitable for those working in the fabrication, refractory, machining and mechanical center as well as in the DR shed. In addition, protective respirable equipment such as air-purifying air respirator should be provided. Workers may also get benefit from the health surveillance and educational program. In fact, Malaysia mandates the annual health examinations, including lung functions test and chest X-ray for workers exposed in the dusty environments. Although smoking did not appear to be a significant predictor to lung function, its effect to lung by enhancing the toxicities of other occupational hazards by interfering the lung defense mechanism are well documented (Vincent 1999; Williams & James 2000). Therefore, anti-smoking campaigns are still desirable especially in the male working population.

No significance association was found between frequency of mask usage with the presence of respiratory symptoms and lung function values. This might be due to inappropriate (poor quality and not very effective) facemasks available to the workers in this study as compared to the respirator masks available in other studies (Ahmed & Abdullah 2002; Lee et al., 2005; Wu 2002). Furthermore, compliance of Personal Protective Equipment (PPE) especially usage of mask was low and being ignored, only 34.3% of the workers were frequently using mask during the working period. Similar percentages of mask usage were reported by other researchers. Sirajuddin et al. (2005) reported that 34.4% of steel workers wore masks all the time while Singh et al. (2013) found that 25.0% of casting workers used nose/mouth mask properly. Mwaiselage et al. also mentioned that 41.2% of highly exposed workers used face masks but not during the whole shift (Mwaiselage et al., 2006). Yasin et al., (2002) found that 21.7% of farmers wore oral-nasal masks during handling of pesticides. Providing a safe working environments can minimize exposure to harmful effect of dust and adopting safe work practices. There is strong evidence that working environments and unsafe practices are associated with adverse health effects outcomes in working population (Ahmed & Abdullah 2002; Yassin et al., 2002; Lee et al., 2005; Wu 2002; Mwaiselage et al., 2006).

4.4 Limitation of the Study.

Self-reporting could cause underestimation of respiratory symptoms among the workers. Some workers might have feared of losing jobs if they admitted to have health problems. This was probably reduced in the present study by the private setting of the interview, and the assurance of privacy of the information they provided.

Both personal dust exposure and the extent of radiological opacities were not well measured in this study. These factors might link to the respiratory symptoms and pulmonary function. The subjective dustiness and duration of employment were not good indicators for exposure as there were various categories of steel workers with different level of exposures. The composition of dust exposure also contributes primarily to the respiratory health effect other than particle size and concentration. This study also did not analyse the components of dust. Care should be taken in assessing the adequacy by applying the threshold limit values for nuisance particles.

Besides, this study was conducted among current employed workers. The possibility of Healthy Worker Effect (HWE) might have arisen from the subjects who had suffered less exposure as compared to those who already left their jobs. Some of the subjects might be due to the illness sustained from the occupational exposure. This would be typically result in underestimate of the association between exposure and respiratory health effects. Confounding from previous job exposures prior to joining this factory was not considered much. Most of the workers were of lower educational group. They joined the factory soon after leaving school, were trained to become semi-skilled workers, and satisfied with their salaries. Therefore, they stayed with the factory for the rest of their working lives.

5.0 CONCLUSION

It has been shown that workers engaged in steel manufacturing are at risk of developing respiratory symptoms and lung function impairment even though at low exposure level. Smoking has already been known to exert deleterious effect to respiratory health, while the additional exposures to respirable dusts exacerbate the symptoms even worse. Air Purifying Respirator and N95 should be provided and the workers should be encouraged to use them during working hours to reduce the dust exposure as low as reasonably practicable (ALARP).

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