Metal Dust Exposure and Respiratory Symptoms among Steel Workers: A Dose-Response Relationship

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Abstract

Background: Exposure to metal dust and fumes are leading cause of respiratory problems by increased likelihood of reversible narrowing of the airways and greater prevalence of chronic respiratory symptoms among steel workers.

Material and Methods: A cross sectional study was conducted in a steel factory in Terengganu, Malaysia to assess the metal dust exposure and its relationship to respiratory symptoms among 184 workers. Metal dust concentration values (Co, Cr, and Ni) for each worker was collected using personal air sampling. Respiratory symptoms were determined using British Medical Research Council (BMRC) Questionnaire.

Results: Exposure to cobalt and chromium were 1 to 3 times higher than permissible exposure limit (PEL) while nickel was not exceeding the PEL. Cumulative of chromium was the predictor to all of the respiratory symptoms while cumulative of cobalt was the predictor to chronic cough. Smoking was the contributing factor to the presence of shortness of breath (OR=1.06, 95%CI: 1.02-1.10) while past respiratory illnesses were found to be the predicting factor to the presence of chest of tightness (OR=2.14, 95% CI: 1.28 – 3.59) and shortness of breath (OR=1.93, 95% CI: 1.37 – 10.15). Only few workers (36.4%) were found to wear their masks all the times during the working hours.

Conclusions: There is a dose-response relationship of cumulative metal dust exposure with the elevation of respiratory symptoms prevalence. Improvements of control measures are needed to reduce the metal dust exposure and workers should be encouraged to use respiratory protection devices during their working hours.

Key words: Metal dust, respiratory symptoms, dose-response relationship, cumulative metal dust, respiratory protection equipment

Introduction

Steel is manufactured through a series of process through melting and casting to the loading of finished product. Emission of fumes and particulates is a major potential problem for employers working with molten metals, coke, and charging and tapping furnaces. There is evidence that steelworkers are more susceptible to reversible narrowing of the airways [1], greater prevalence of chronic respiratory symptoms [2] and signs such as coughing, sputum, wheezing, and dyspnoea as well as altering the pulmonary function indices. [3-5]

Although there have been many previous studies on the effect of occupational dust concerning the relationship between the dust exposure and respiratory health locally and abroad [6-9], none of them reported the dose–response relationship between cumulative metal dust exposure and elevation of respiratory symptoms prevalence. Therefore, this research aims to fill this gap by studying the concentration of metal dust and estimating the cumulative exposure of respirable metal dust for the lifetime working in steel industry.

The objective of this study was to determine the relationship between cumulative respirable metal dust exposure and respiratory symptoms by applying a standardized measurement and questionnaire. In order to achieve this, the dose-response of cumulative respirable metal dust exposure (Co, Cr, and Ni) for the lifetime working with the elevation of respiratory symptoms prevalence was explored. The contributing factors to the presence of respiratory symptoms including smoking history and workers' practice regarding the frequency use of mask were also determined

Methods

Study population

A cross sectional study was conducted in Terengganu, located at the eastern coast of Peninsular Malaysia. This 30-year old factory is the only steel factory in the eastern region during the study period which employs 1000 workers in the production line. A stratified random sampling was used and study samples were recruited based on these following criteria; male, age from 18 to 56 years old and at least 1 year of employment. Female workers are working in administration department and they did not directly expose to metal dust. Therefore they were excluded in this study. Only 192 were recruited randomly, while 95.8% completed the questionnaire and spirometric measurement.

Metal dust assessment and trace metal concentration analysis

Personal metal dust measurements were carried out for selected workers from production section within the factory. The sampling procedures were done according to the occupational exposure sampling strategy manual "Method for Exposure Monitoring" by the US National Institute for Occupational Safety and Health (NIOSH). [10] The number of workers and valid samples are presented in Table 1.

Personal air samplers were collected on pre weighed cellulose ester filter membrane (SKC Omega; MCE; 0.8 µm, 37 mm diameter) placed in a closed face filter cassette connected to GilAir 5 Gillian pump with a flow rate of 2.0 L/min. The sampling time varied from 165 to 775 min. The sampling pump was calibrated before and after sampling, and the average of two readings was used to calculate the volume of the air sampled. The filter membrane was weighed before and after sampling using a microbalance with a detection limit of 0.01 mg. Finally the concentration of dust was calculated as follows:

Weight of the dust (mg) = Weight of the filter after sampling – Weight of the filter before sampling.
Volume of air sampled (m^3)= flow rate of the pump in m^3 per minute x time of sampling (minutes)
Concentration of the dust (mg/m^3) = weight of the dust (mg) / volume of air sampled (m^3)

The respirable metal particulate samples were subjected to wet mineral acid mixture digestion (9:1 mixture of concentrated analytical grade nitric acid and perchloric acid) on a slow heating hot plate. The acid digested matter was filtered and made up to 10 ml using quartz double distilled water. Precautions were taken to prevent extraneous contamination by usage of thoroughly cleaned Borosil glassware. The end analysis for trace metal concentration was performed by atomic absorption spectrophotometer (AAS). All of the procedure analyses were done according to NIOSH Manual Analytical Methods (NMAM) for selected trace metal. [11]

The survey collected 192 samples, majority of which were representative of an eight-hour shift. Five samples were excluded from the analysis because of abnormal work routines, and three samples for technical problems, e.g. substantially decreased flow rate. As a result, 184 valid samples were included in the final analysis.

Respiratory symptoms

An interviewer-administered questionnaire, based on the British Medical Research Council (BMRC) Questionnaire on Respiratory Symptoms [12] was pretested, validated, and used in this study. The questionnaire included questions about demographics, work history, use of personal respiratory protective equipment, smoking habits, and 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. 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 while shortness of breath as breathlessness when hurrying on the level or walking up a slight incline. 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 dusty occupations as past dust exposure for more than two years before joining the company.

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 wearing mask during the entire work shift was divided into three levels corresponding to often, seldom, and always. All interviews were conducted face to face in Malay language by researchers. Objectives of the study were explained to each participant and consent form was obtained at the beginning of the interview. The subjects were informed that all information collected would be kept confidential.

Walk-through survey

During the sampling process, appropriate direction and communication were given to any steelworkers who carried the sampler. Any information or observation that might be significant, e.g. production halt, ventilation system not operating or use of personal protective equipment were recorded in order to let each sample represent its eight hour time weighted average (8-hr TWA) as accurately as possible.[13]

Statistical analysis

Data analyses were done using Statistical Packages for Social Science (SPSS) Version 21 and Origin Version 6.1. Dose-response relationships were examined for percentage rate of respiratory symptoms over the cumulative respirable metal dust. The cumulative respirable metal dust exposure (Co, Cr, and Ni) for each worker was calculated according to the duration of employment and total of metal dust concentrations during working hours. The cumulative respirable metal dust exposure (Co, Cr, and Ni) for each worker was calculated as follows:

$$\sum \left(\text{Total concentration of metals dust exposure for each worker } \left(\frac{mg}{m^3}\right) x \text{ duration of employment (year)} \right)$$

Due to the lognormal distribution of metal dust samples, logarithms of metal dust concentrations were more representative. According to the above equation and occupational history, the cumulative respirable metal dust (Co, Cr, and Ni) for each subjects could be hypnotically estimated to investigate the dose-response relationship with prevalence rates of respiratory symptoms. Chi Square test was used to compare the respiratory symptoms according to cumulative respirable metal dust categories.

Logistic regression analysis was used to determine the predicting factors to the presence of respiratory symptoms. Using the logistic model, adjusted odd ratios and confidence intervals of respiratory symptoms were calculated for any predictive variables. Cumulative metal dust exposure indicators (respirable metal dust) and cigarette equivalent were not normally distributed, therefore transformed logarithmically to yield lognormal distributions before analysis commenced. The significant level used for evaluating the test of significance was set at $p<0.05$.

Ethics

Written informed consent was provided to all subjects prior to their participation in the study. The study was approved by the Research and Ethics Committee, UKM Medical Centre, reference number UKM 1.5.3.5/244/FF-055-2013 dated 6th February 2013.

Results

Background of the subjects

A hundred and eighty four subjects with mean age of 36.7 years ± 8.36 were assessed. Mean duration of employment was 11.2 years ± 7.76 years. Fifty eight percent of the workers were current smokers and 75.5% percent had cigarette consumption for more than 10 years. Mean cigarette equivalent was 10.7 ± 9.62 packs per year. Prior to joining this company, 3.8% had been exposed to occupational dusty environments while 8.5% had a history of respiratory diseases. Only 35.8% of workers wore mask 'full time' during the working hours.

Metal dust exposure assessment

Personal sampling showed the 8-hr TWA concentration for cobalt and chromium exceeded the occupational exposure limit (OEL) as prescribed by the Use and Standard Exposure to Chemical Hazardous to Health (USECHH) in Occupational Safety and Health Act 1994 [14] while the 8-hr TWA concentration for nickel did not exceed the prescribed value. The highest mean concentration for cobalt was found in caster (0.19 mg/m^3) while the highest mean concentration for chromium and nickel was found in welder (0.19 mg/m^3 and 0.67 mg/m^3 respectively). The highest cumulative respirable exposure for cobalt (mg/m^3 x year) was found in melter (11.84 mg/m^3) while the highest cumulative respirable of chromium and nickel were found in refractory man (5.43 mg/m^3) and caster (16.64 mg/m^3) respectively (Table 1).

Respiratory symptoms

Respiratory symptoms were based on their experience during the last 12 months. Chronic cough was the common symptom (35.3%) claimed by the workers, followed by chronic phlegm (31.0 %), chest tightness (27.2 %), and shortness of breath (25.0 %).

Prevalence of respiratory symptoms were grouped according to cumulative respirable metal dust exposure for the lifetime working (mg/m^3 x year) as shown in Table 2. The crude prevalence of respiratory symptoms was gradually increased by cumulative respirable metal dust. There was significant difference of cumulative cobalt with chronic cough (χ^2 = 13.81, p=0.003), chronic phlegm (χ^2 = 22.84, p<0.001), chest of tightness (χ^2 = 27.18, p<0.001), and shortness of breath (χ^2 = 28.72, p<0.001). Cumulative chromium was significantly different with chronic cough (χ^2 = 14.59, p = 0.002), chronic phlegm (χ^2 = 14.56, p = 0.002), chest tightness (χ^2 = 14.49, p = 0.002), and shortness of breath (χ^2 = 17.28, p = 0.001). Cumulative of nickel was also significantly different with chest tightness (χ^2 = 9.02, p = 0.029) and shortness of breath (χ^2 = 10.28, p = 0.013).

Dose-response relationship

Further relationship for each cumulative respirable metal dust and prevalence rates of respiratory symptoms were explored with dose-response graph. Higher cumulative of respirable metal dust exposure was gradually increased with higher prevalence rates of respiratory symptoms (Figure 1 to 3). There was a dose-response relationship between cobalt and chronic cough (χ^2 = 15.77, R^2 = 0.962), chronic phlegm (χ^2 = 20.72, R^2 = 0.96), chest tightness (χ^2 = 3.54, R^2 = 0.99), and shortness of breath (χ^2 = 34.27, R^2 = 0.91). Cumulative chromium also showed a dose-response relationship with chronic cough (χ^2 = 15.18, R^2 = 0.97), chronic phlegm (χ^2 = 18.24, R^2 = 0.97), chest tightness (χ^2 = 7.96, R^2 = 0.99), and shortness of breath (χ^2 = 16.39, R^2 = 0.98). Cumulative nickel had a dose-response relationship with chronic cough (χ^2 = 25.41, R^2 = 0.98), chronic phlegm (χ^2 = 52.78, R^2 = 0.99), chest tightness (χ^2 = 4.41, R^2 = 0.99), and shortness of breath (χ^2 = 68.77, R^2 = 0.93).

Logistic regression analysis of contributing factors to the presence of respiratory symptoms is presented in Table 3. Cumulative of chromium was the predictor of respiratory symptoms while cumulative of cobalt was the only predictor of chronic cough (OR= 1.32, 95% CI: 1.05 - 1.67). The other contributing factors to the presence of respiratory symptoms included cigarette equivalent and past respiratory illnesses. Cigarette equivalent was the contributing factor to the presence of shortness of breath (OR=1.06, 95%CI: 1.02-1.10) while past respiratory illnesses was found to be the predicting factors to the presence of chest of tightness (OR=2.14, 95% CI: 1.28 – 3.59) and shortness of breath (OR=1.93, 95% CI: 1.37 – 10.15).

Practice

Respiratory protection devices (N95 particulate respirator masks) and masks were available for all factory workers. Sixty seven (36.4%) workers claimed that they used masks ‘full time’ during the working hours, 88 (47.8%), subjects used masks ‘most of the time’, and 29 (15.8%) were ‘seldom’ using masks. During the walk-through survey, most subjects were found to use ‘traditional method’ such as an ordinary cloth, handkerchief, and T-shirt to protect themselves from the dust. However, the frequency of using mask during working hours was not found to be associated with the presence of respiratory symptoms.

Discussion

Metal dust exposure

Occupational exposures to metal dust are known to be an important factor in the causation of respiratory symptoms and lung diseases. [15-19] Exposure to metal dust in steel industries could be reduced through effective engineering control measures and/or proper use of appropriate respiratory protection equipment.

Sixty five percent of steel workers exposed to a high concentrations of cobalt and chromium for magnitude 8 hr of daily exposure above the Permissible Exposure Limit (PEL) as prescribed by the Use and Standard of Exposure to Chemicals Hazardous to Health Regulations in Occupational Safety and Health Act 1994. [14] The results indicated that workers exposed 1 to 3 times higher than Permissible Exposure Limit (PEL). In contrast, the 8-hr TWA concentration of nickel for each work unit did not exceed the occupational exposure values. However, Ravichandaran et al reported that chromium as well as other trace metal dust (iron, manganese, and lead) did not exceed the ACGIH prescribed levels. [20] Gomes et al also found that iron and manganese were lower than ACGIH TWA values. [21] Rafeie et al stated that respirable particulate matter (RPM) in steel production was higher as compared to NIOSH standard. [22] The concentrations of the respirable metal dust reported were lower than previous studies conducted in other developing countries. [20-21] This is probably due to newer technology and effective control measured adopted in this factory.

Providing a safe working environment can minimise exposure to harmful effect of metal dust and adopting safe work practices. There was strong evidence that poor working environment and unsafe practices were associated with adverse health effects outcomes in other working populations. [23-26]

Respiratory symptoms

The prevalence of respiratory symptoms reported was comparable to previous studies conducted among populations of steel industry both local and abroad. Most of the symptoms observed were chronic cough, chronic phlegm, chest tightness, and shortness of breath, however wheezing among them was not observed. Azwan et al reported 53.2% work-related respiratory symptoms were wheezing (30.2%), shortness of breath (44.2%), and chest tightness (30.3%), and cough (41.1%) [7]. The prevalence of respiratory symptoms were lower as compared to previous studies done by Singh et al [4], Abdel-Rasoul et al [8] and Singh et al [27], was probably due to introduction of effective safety measures such as modified filter for reducing the exposure of employees to respiratory hazards. However, the prevalence of respiratory symptoms in this study was still high as compared to the prevalence of respiratory symptoms in other steel workers population in developing countries. [3,9]

This relatively higher prevalence of respiratory symptoms among respondents in this study may be due to several factors including age, duration of exposure, and higher cigarette consumption. The study by Chen et al reported the younger workforce have a shorter duration of employment and lower cigarette consumption.[9] The current study has older workers with large range of duration of employment similarly reported by Razlan et al among rice mills and quarry workers. [28-29] Smoking can explains some of the respiratory symptoms reported. The history of cough and phlegm may be due to concomitant of cigarette smoking. Higher cigarette consumption may also contribute to the higher prevalence of respiratory symptoms especially among the male population studied.

Dose-response relationship

Cumulative respirable metal dust exposure (mg/m^3 x year) was used as a surrogate for metal dust exposure for each worker. Personal monitoring for metal dust was available for every worker. Therefore, cumulative respirable metal dust exposure for individual worker was determined according to tasks and locations.

This study demonstrated a dose-response relationship of cumulative respirable dust exposure for the lifetime working (mg/m^3 x year) increased the rate of respiratory symptoms reported even at low exposure. A strong correlation ($R^2 > 0.90$) was found for each cumulative respirable metal dust (Co, Cr, and Ni) with prevalence rates of respiratory symptoms. These findings are in agreement with previous studies that reported the prevalence of several respiratory symptoms increased with cumulative dust exposure. Huy et al reported a dose-response relationship between exposure to dust grains with the presence of chronic phlegm and shortness of breath. [30] Schlünssen et al also found a dose response relationship between exposure to wood dust and asthma symptoms as well as a significant positive interaction between gender and exposure to dust. [31]

Both cumulative exposure to chromium and smoking were found to be predictors of shortness of breath while cumulative of cobalt was the only predictor to chronic cough. Increased cumulative of exposure by 1 mg/m^3 x year increased the risk of chronic cough, chronic phlegm, chest tightness, and shortness of breath by once to twice. Similarly, the increase of cigarette smoking (one pack/year) increased the risk of shortness of breath by once. Smoking has long been known to be an important contributing factor in the development of respiratory symptoms. In addition, chest tightness might also affect by coronary artery disease and should be taken into consideration especially in male population studied.

Few studies showed that increasing of dust exposure and smoking increased the prevalence of respiratory symptoms. Ahmed et al. revealed that exposure to dust and smoking were the predictors of the cough and phlegm, while smoking was the predictor for chronic bronchitis. [32] Mohammadien et al [33] and Kassahan et al [34] also reported respiratory symptoms increased with duration of employment and cumulative dust exposure. However, Chen et al reported dust exposure was the predictor to all of the reported respiratory symptoms, while smoking and duration of employment were predictors of cough, phlegm, wheezing, and breathlessness[9]. Those who had past respiratory illnesses were as twice to report chest tightness and shortness of breath.

Practice

The use of appropriate respiratory protection devices during working hours might protect workers from hazardous dust. Despite the availability of respiratory protective equipment for the workers, only 36.4% of them used mask 'full time' during working hours. Similar and higher percentages of mask usage were reported by other researchers. Sirajuddin et al [35] reported 34.4% of steel workers wore masks all the time while Singh et al [27] found 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.[36] Yasin and his colleagues found that 21.7% of farmers wore oral-nasal masks during handling of pesticides.[37]

However, this study failed to find an association between frequencies of mask usage with prevalence of respiratory symptoms. This showed a serious problem from the view point of occupational health management in educating safety and health among workers at the workplace. Besides, inappropriate (poor quality and not very effective) facemasks available to the workers at the site of the study compared to the N95 particulate respirator masks available to the workers in the other studies. [32, 40-41] Mwaiselage et al found that face-mask users had a significantly higher prevalence of chronic sputum than those not using them and no significant difference between two groups for the other respiratory symptoms. [36]

From the observation and available information, factors such as financial constrains, inappropriate or unfit PPE, and their unavailability were not the contributing factors to the lower usage of the protective mask. The perception of traditional methods (usage of towel, handkerchief, and T-shirt) offered the similar protection factor as compared to proper mask usage might explain the observed findings. However, this study did not explore the possible factors that might influence the use of PPE among workers. These might show a better understanding of contributing factors to the usage and compliance of PPE

Limitations of the study

The main limitation of this study was in relation to cumulative metal dust exposure. No historical data were available to construct a cumulative exposure index over the life time working among the workers. Only the cumulative metal dust exposure according to duration of employment could be estimated. Level of current metal dust measurements were taken as indicator of exposure. The assumption has to be made that current dust concentrations were reasonable proxy for total dust concentrations experienced in those jobs over the previous two or three decades. The above assumption might be reasonable achieved with some degree of accuracy, since it was revealed that there were hardly any technological or change in the work process during the last several decades.

The reported respiratory symptoms and past respiratory illnesses were based on self-reporting, hence subjected to reliability issues. It would be better to have proper personal and detailed clinical records. However, these were not available and not readily accessible during the study period.

Conclusion

This study revealed dose-response relationships between cumulative respirable metal dust exposures with the elevation of respiratory symptoms prevalence among steel workers. Cumulative chromium was a significant predictor to all the elevated respiratory symptoms. Smoking was a significant contributor to elevated prevalence of shortness of breath after adjustment for occupational exposure indicators. However, the use of mask was found not to be associated with the elevation of respiratory symptom prevalence. Therefore, occupational health management as well as control measures should be improved to reduce the metal dust exposure in the workplace while at the same time educating workers to comply with the PPE during working hours.

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Ethics Approval

All procedures performed studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Table 1: Concentration and cumulative respirable metal dust by different work unit

Work unit	No	Time Weight Average (mg/m^3) 8-hr TWA			Cumulative respirable metal dust exposure (mg/m^3 x year)		
Total number	184						
Metal dust		Co	Cr (VI)	Ni	Co	Cr (VI)	Ni
USECHH PEL (mg/m^3)		0.10	0.05	1.5		Mean	
Furnace							
Supervisor & Foreman	1	0.15	0.11	0.60	3.88	2.90	7.19
Electric Arc Furnace controller	1	0.09	0.10	0.05	1.23	1.39	4.33
Melter	8	0.15	0.15	0.66	11.84	3.47	11.46
Ladle furnace							
Supervisor	1	0.04	0.13	0.15	0.43	0.70	4.00
Controlling room operator	1	0.03	0.14	0.07	0.05	0.27	1.26
Melter	6	0.10	0.14	0.18	6.94	2.30	12.91
Ladle handling							
Supervisor	1	0.10	0.02	0.49	4.80	0.41	8.64
Controlling room operator	1	0.11	0.08	0.07	0.85	0.47	1.58
Ladleman	6	0.15	0.12	0.63	5.26	1.63	9.11
Continuous casting machine (MC-5)							
Supervisor & Foremen In charge	2	0.12	0.14	0.61	2.44	2.70	9.28
Controlling room operator	1	0.11	0.07	0.07	0.47	0.32	2.58
Caster	11	0.19	0.16	0.62	2.71	2.82	13.92
Continuous casting machine-Concast							
Supervisor & *Foremen In Charge*	2	0.12	0.14	0.60	2.91	1.28	5.38
Controlling room operator	1	0.10	0.07	0.05	0.54	0.87	2.82
Caster	11	0.16	0.16	0.64	3.88	3.48	16.64
Scrap bay							
Supervisor	2	0.10	0.11	0.55	3.82	2.05	10.4
Heavy equipment driver	11	0.14	0.15	0.60	4.83	2.20	12.19
Crane operation							
Supervisor	2	ND	0.01	0.10	0	1.44	0.58
Crane operator	11	ND	0.02	0.10	0	1.88	1.12
DR shed							
Supervisor	1	0.13	0.12	0.09	0.72	0.33	0.19
Material handling technician	11	0.15	0.15	0.17	0.88	0.60	0.22
DR Cleaning							
Supervisor	1	0.15	0.11	0.05	1.80	0.94	0.26
DR technician	11	0.16	0.13	0.17	4.29	1.40	0.50
Product handler	11	0.17	0.13	0.17	10.27	1.85	0.76
DR operation							
Supervisor	1	0.10	0.09	0.13	2.29	1.96	0.56
DR man	11	0.14	0.11	0.14	4.12	3.15	0.58
Fabrication							
Supervisor	1	0.10	0.11	0.24	0.25	0.80	0.63
Fabricator	3	0.12	0.13	0.54	1.78	1.59	0.46
Welder	3	0.14	0.19	0.67	1.40	3.07	2.74
Refractory							
Supervisor	1	0.02	0.15	0.02	0.24	2.99	0.70
Refractory man	6	0.04	0.16	0.08	0.48	5.43	1.70
Raw material handling							
Supervisor	1	0.12	0.10	0.45	1.31	1.98	7.13
Raw material handler	7	0.15	0.14	0.60	2.79	2.00	7.43
Upstream conveyor							
Supervisor	1	0.10	0.10	0.15	2.17	1.08	5.30
Conveyor man	7	0.14	0.16	0.18	3.71	2.33	6.93
Machining & mechanical							
Supervisor	1	0.03	0.03	ND	0.05	0.15	0
Mechanics	6	0.05	0.05	ND	0.14	0.19	0
Electrical & Instrumentation							
Supervisor & engineers	1	0.01	0.03	0.11	0.08	0.10	0.18
Instrument technician	6	0.02	0.04	0.12	0.16	0.18	0.38
Electrician	6	0.02	0.06	0.09	0.15	0.16	0.35
Logistics/workshop							
Mechanics	7	ND	ND	ND	0	0	0

Abbreviation: PEL, Permissible Exposure Limit; DR-Direct Reduced, ND-Not detected

Table 2: Comparison of prevalence rates of respiratory symptoms by different cumulative respirable metal dust exposure groups

General information	Cumulative respirable metal dust (Co) mg/m^3 x year						Total
	<0.50	0.50 - 0.99	1.00 - 1.99	2.00++			
Number	55	25	33	71	χ^2 (df)	*p*-value	184
Respiratory symptoms [a]							
Chronic cough	9(16.4)	9 (36.0)	13 (39.4)	34 (47.9)	13.81 (3)	0.003*	65 (35.3)
Chronic phlegm	5 (9.1)	6 (24.0)	12 (36.4)	34 (47.9)	22.84 (3)	<0.001*	57 (31.0)
Chest tightness	2 (3.6)	6 (24.0)	10 (30.3)	32 (45.1)	27.18 (3)	<0.001*	50 (27.2)
Shortness of breath	3 (5.5)	3 (12.0)	8 (24.2)	32(45.1)	28.72 (3)	<0.001*	46 (25.0)
	Cumulative respirable metal dust (Cr) mg/m^3x year						
Number	33	41	48	62	χ^2 (df)	*p*-value	184
Chronic cough	6 (18.2)	11 (26.8)	15 (31.2)	33 (53.2)	14.59 (3)	0.002*	65 (35.3)
Chronic phlegm	5 (15.2)	9 (22.0)	13 (27.1)	30 (48.4)	14.56 (3)	0.002*	57 (31.0)
Chest tightness	3 (9.1)	7 (17.1)	14 (29.2)	26 (41.9)	14.49 (3)	0.002*	50 (27.2)
Shortness of breath	2 (5.9)	2 (6.1)	7 (17.1)	26 (41.9)	17.28 (3)	0.001*	46 (25.0)
	Cumulative respirable metal dust (Ni) mg/m^3x year						
Number	42	19	16	107	χ^2 (df)	*p*-value	184
Chronic cough	10 (23.8)	5 (26.3)	5 (31.2)	45 (42.1)	5.35 (3)	0.148	65 (35.3)
Chronic phlegm	8 (19.0)	4 (21.1)	5 (31.2)	40 (37.4)	5.73 (3)	0.126	57 (31.0)
Chest tightness	4 (9.5)	5 (26.3)	5 (31.2)	36 (33.6)	9.02 (3)	0.029*	50 (27.2)
Shortness of breath	4 (9.5)	3 (15.8)	3 (18.8)	36 (33.6)	10.28 (3)	0.013*	46 (25.0)

Abbreviation; Values in parentheses are percentage

*significant at p<0.05

Table 3: 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)	1.06 (1.02, 1.10)	0.003*	1.00 (0.94, 1.05)	0.01 (1)	0.908
Cumulative of Co (mg/m^3 x year)	1.34 (1.13, 1.59)	<0.001**	1.32 (1.05, 1.67)	5.76 (1)	0.016*
Cumulative of Cr (mg/m^3 x year)	1.52 (1.29, 1.81)	<0.001**	1.69 (1.32, 2.16)	17.72 (1)	<0.001**
Cumulative of Ni (mg/m^3 x year)	1.10 (1.03, 1.17)	0.003*	0.93 (0.85, 1.03)	2.06(1)	0.151
Cigarette equivalent (packs/year)	1.05 (1.01,1.09)	0.011*	1.00 (0.97, 1.04)	2.34 (1)	0.126
Past dusty occupations (Yes)	1.87 (0.37, 9.54)	0.451	1.53 (0.18, 13.34)	0.13(1)	0.700
Past respiratory illnesses (Yes)	1.21 (0.36, 4.11)	0.763	1.60 (1.11,3.27)	0.35 (1)	0.554
Frequency of using mask (Yes)	1.88 (0.76, 4.67)	0.175	2.43 (0.78, 7.59)	6.15 (1)	0.128
Chronic phlegm					
Age (year)	1.06 (1.02, 1.01)	0.003*	1.00 (0.95,1.07)	0.05 (1)	0.826
Cumulative of Co (mg/m^3 x year)	1.28 (1.09, 1.52)	0.004*	1.19 (0.94,1.52)	2.07 (1)	0.150
Cumulative of Cr (mg/m^3 x year)	1.51 (1.28, 1.78)	<0.001**	1.48 (1.21, 1.82)	14.61 (1)	<0.001**
Cumulative of Ni (mg/m^3 x year)	1.14 (1.07, 1.21)	0.001*	1.02 (0.93, 1.11)	1.88(1)	0.700
Cigarette equivalent (packs/year)	1.06 (1.02, 1.10)	0.002*	0.97 (0.92, 1.02)	1.44 (1)	0.230
Past dusty occupations (Yes)	1.52 (0.27, 8.60)	0.634	2.38 (0.21,16.47)	1.50 (1)	0.482
Past respiratory illnesses (Yes)	1.98 (0.61, 6.39)	0.250	1.00 (0.21, 4.62)	0.79 (1)	0.990
Frequency of using mask (Yes)	1.33 (0.51, 3.51)	0.560	1.59 (0.51, 4.99)	0.64(1)	0.422
Chest tightness					
Age (year)	1.07 (1.02, 1.11)	0.003*	1.01 (0.95, 1.07)	0.07 (1)	0.791
Cumulative of Co (mg/m^3 x year)	1.28 (1.08, 1.52)	0.005*	1.15 (0.91,1.46)	1.39 (1)	0.239
Cumulative of Cr (mg/m^3 x year)	1.45 (1.26, 1.68)	<0.001**	1.43 (1.20,1.69)	16.76 (1)	<0.001**
Cumulative of Ni (mg/m^3 x year)	1.11 (1.04, 1.18)	0.001*	0.99 (0.91, 1.07)	0.10 (1)	0.751
Cigarette equivalent (packs/year)	1.02 (0.98, 1.05)	0.326	1.01 (0.96, 1.05)	0.07 (1)	0.788
Past dusty occupations (Yes)	2.30 (0.45, 11.72)	0.078	2.29 (0.25,20.71)	0.54 (1)	0.461
Past respiratory illnesses (Yes)	2.06 (1.24, 3.42)	0.001*	2.14 (1.28, 3.59)	10.22 (1)	0.010*
Frequency of using mask (Yes)	1.05 (0.42, 2.67)	0.907	1.40 (0.40, 4.89)	0.28 (1)	0.599
Shortness of breath					
Age (year)	1.07 (1.02, 1.11)	0.012*	1.02 (0.93, 1.11)	0.18 (1)	0.671
Cumulative of Co (mg/m^{3}x year)	1.34 (1.13, 1.60)	0.001*	1.26 (0.97, 1.63)	2.90 (1)	0.089
Cumulative of Cr (mg/m^{3}x year)	1.73 (1.41, 2.11)	<0.001**	1.71 (1.34, 2.19)	18.43 (1)	<0.001*
Cumulative of Ni (mg/m^{3}x year)	1.17 (1.09, 1.25)	<0.001**	1.04 (0.95,1.08)	0.67 (1)	0.015*
Cigarette equivalent (packs/year)	1.07 (1.03, 1.11)	0.001*	1.06 (1.02, 1.10)	6.70(1)	0.002*
Past dusty occupations (Yes)	1.52 (0.27, 8.60)	0.634	1.92 (0.22, 9.52)	1.01(1)	0.315
Past respiratory illnesses (Yes)	2.81 (1.36, 8.84)	0.014*	1.93 (1.37, 10.15)	0.60 (1)	0.010*
Frequency of using mask (Yes)	1.21 (0.48, 3.03)	0.749	1.71 (0.43,6.90)	2.88(1)	0.449

Abbreviation: OR: odds ratio, C.I.: Confidence Interval, * p<0.05, ** p<0.01, # p<0.001

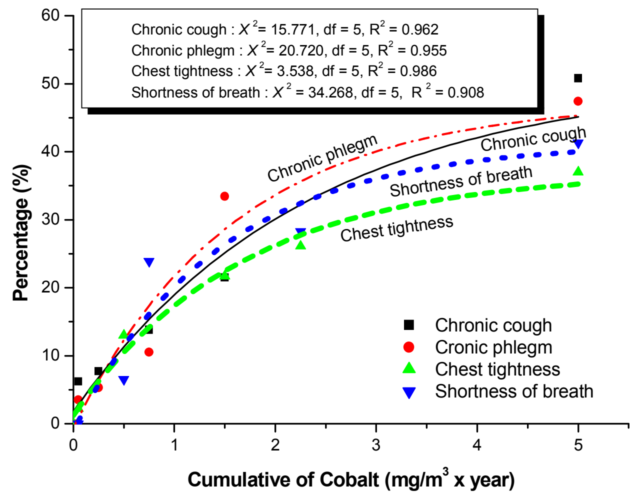

Figure 1: Dose-response relationship between cumulative of cobalt with prevalence rates of respiratory symptoms

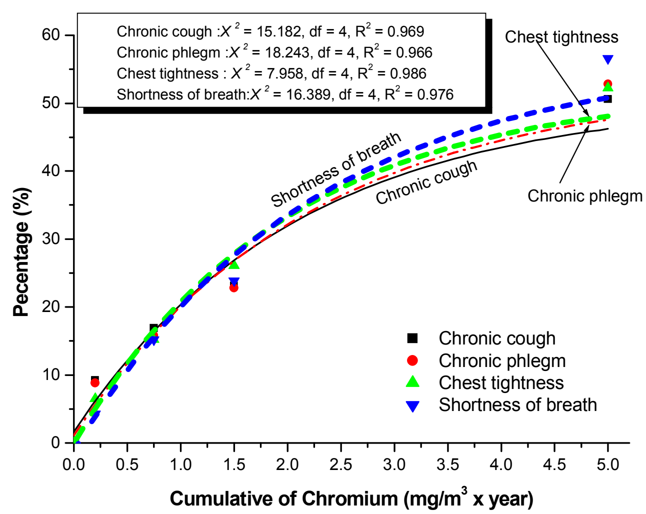

Figure 2: Dose-response relationship between cumulative of chromium with prevalence rates of respiratory symptoms

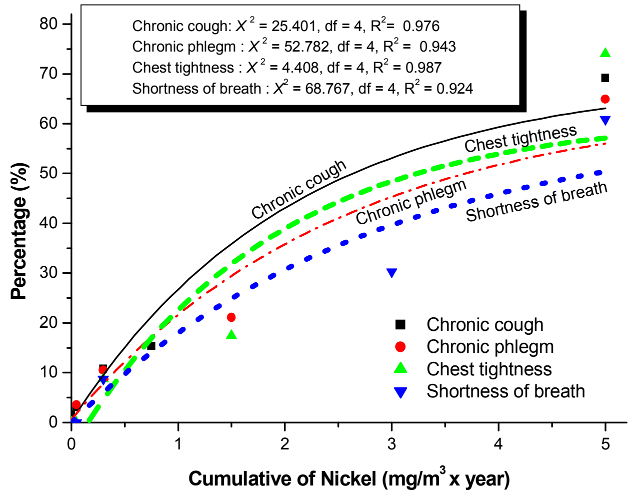

Figure 3: Dose-response relationship between cumulative of nickel with prevalence rates of respiratory symptoms