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**Original Article**

# Metal Dust Exposure and Respiratory Health of Male Steel Workers in Terengganu, Malaysia

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**Abstract**

**Background:** This cross sectional study was carried out to determine the relationship between metal dust exposure and respiratory health in male steel workers in Terengganu, Malaysia.

**Methods**: Subjects were interviewed using a structured questionnaire from British Medical Research Council (BMRC) Questionnaire regarding respiratory symptoms and were examined their lung function using spirometer.

**Results:** The mean trace metal dusts concentration $TWA_8$ for cobalt and chromium in most of work unit exceeded occupational exposure prescribed values. Prevalence of chest tightness, chronic phlegm, and shortness of breath was 28.0%, 26.8%, 24.1%, and 20.2% respectively. Age and smoking were among the factors associated with respiratory symptoms (OR: 0.92 – 1.78). Smoking and cumulative respirable metal dust were negatively associated with $FEV_1$.

**Conclusion:** The mean metal dust for cobalt and chromium were 1 to 2 times higher than permissible exposure limit (PEL). This study found that respirable cumulative metal dust exposure is one of the contributing factors to lung function values among steel workers.

**Keywords:** Respiratory symptoms, Lung function, Metal dust, Questionnaire

## Introduction

Steel workers are continuously exposed to dust, fumes, gases and hence at risk of developing Occupational Respiratory Diseases (ORD) and becoming a major health problem in many industries. Melting and casting processes process in a steel plant produces fumes and pollutant gases. They were also exposed to a variety of asthmagenic substances leading to ORD including metal dusts from iron ore, coal, silica, fumes, cobalt, zinc, and chromium, which was associated with an increased prevalence of respiratory symptoms and impairment of lung function (1). Chronic exposure to these dust and fumes causes impairment in the respiratory health of the workers involved in various sections of steel production (2-4). Impaired pulmonary function was reported to be one of the health effects in the steel industry with significant lung function loss (5,6). Improper occupational hygiene practice and inadequate control measures in the workplace will affect both of workers wellbeing and productivity. Therefore, monitoring the work environment and workers' health would provide some evidence of any health impairment

There are two local studies published on the respiratory health of steel workers and these showed the higher prevalence of respiratory symptoms and lung function impairment (7-8). However, the previous studies were lacked of appropriate assessment of dust exposure, especially the respirable metal dust thus association between actual amount and respiratory impairment still unanswered. The aim of this study was to determine the pre-valence of respiratory symptoms, to compare the respiratory health according to cumulative exposure or metal dust, and to determine the contributing factors to respiratory health including metal dust exposure and smoking history.

## Methods

### *Workplace risk assessment and definition of exposure zones*

A workplace risk assessment was conducted before the survey undertaken. The purposes of the observation were to obtain and study the production processes and layout; to compile an inventory raw materials, intermediated, by-products, products; to obtain a list job categories and the environmental risk factors to which steel workers were potentially exposed; to observe the work practices and pollution controls associated with job categories, and; the most importantly was to define exposure zones (9) for sampling.

Following the workplace risk assessment, all the workers in the iron and steel making plants were selected because of high exposure of dust in the first half of the production process. Job categories were classified by consensus subjectively according to their individual exposure characteristic as shown in Table 1. The main ingredients of dust in this iron and steel making processes contained iron ore and coal dust, iron oxide, silica dust, and metal dust.

### *Study population*

A cross sectional study was conducted from February to October 2013 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 employing 1000 workers in the production line. Stratified sampling was used and study samples were recruited based on this following criteria; male, age from 18 to 56 years old and at least 1 year of employment. Only 436 were recruited randomly, while 94% completed the questionnaire and spirometry. Subjects who were unable to produce acceptable spirograms meeting the American Thoracic Society criteria (N=23), those who were ill e.g. asthma (N=3) and had an upper respiratory tract infection (URTI) (N=11) were excluded from the statistical analysis. The remaining 402 workers entered the final analysis.

### *Exposure assessment and trace metal concentration analysis*

Personal air sampling was used to assess the respirable metal dust exposure in the subjects' breathing zone. 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.

The personal sampling pumps were charged for 24 hours prior to the sampling day and calibrated. A flow rate of 2.0 litres per minute was maintained during air sampling. To quantify the respirable particulate matter, 37 mm diameter and 25 mm cyclone cones were used respectively. After fixing the filter papers in the sampling cassette (collecting device), the personal samplers were fixed to the waist of employees, on their belts, before they commenced their shifts. Each filter cassette was fixed to his or her lapels to ensure that the filter head was in the correct position for each worker. The samplers were running continuously through the course of work and rest periods during the entire 8-hour shift work. At the end of the shift, the personal samplers were switched off. The filter papers were carefully taken out and kept in the desiccators. Then, the final weights were recorded from the amount of dust particles settled on the paper and the volume of air sampled. Finally, the calculations for dust particles present in the air and their concentration were expressed as $mg/m^3$.

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 metals (11).

During the sampling process, appropriate direction and communication was given to any steelworkers who carried the sampler. Any information or observation that might be significant, e.g. process upsets, ventilation system not operating or use of personal protective equipment were recorded in order to let each samples represent its eight hour time weighted average as accurately as possible (12). Respirable metal dust concentrations were calculated according to different work categories. The survey collected 192 samples, majority of the samples 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 analysis

### *Measurement of respiratory health*

The respiratory health survey was undertaken using a questionnaire and spirometric test for each of the subjects. Respiratory symptoms determined British Medical Respiratory Council (BRMC) questionnaire was pre tested, validated, and administered by trained interviewers. The questionnaire included questions relating to personal information, current and past occupational history in steel works and all other jobs, subjective assessment level of dustiness in all jobs, present respiratory symptoms, past illness history, and smoking habits.

The following definitions of smoking were used: Non-smokers were subjects who had ever smoked of cigarette or tobacco in a lifetime; ex-smokers were those who had stopped smoking at least 6 months before testing, and everybody else were classified as being a current smokers. Several variables representing smoking habits were created. The subjects were grouped into non-current smokers and current smokers using the current smoker variable (yes/no). 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.

Height and weight were measured and read off before the spirometric tests. Lung function was then examined by trained person using the standard spirometric test recommended by the American Thoracic Society (ATS) (13). These were performed with the Spirolab (MIR Model) for the measurement of forced vital capacity (FVC), forced expiratory volume in one second ($FEV_1$), forced expiratory volume in one second as percentage of the forced vital capacity ($FEV_1$/FVC). The machine was calibrated before and after each day's use without any significant differences being found. Each subject was given the opportunity to learn the technique while watching others blew into the spirometer. The subjects were measured in standing position with nose clamped, and the spirometric reading was taken best of three acceptable tracings that met the acceptability and reproducibility criteria. As a spirometer is a flow-measuring device, it was reasonable to neglect the body temperature pressure saturated (BTPS, temperature $37^0$C, ambient pressure, saturated with vapour at $37^0$C) conversion under environmental conditions.

### *Definition of respiratory symptoms*

Chronis 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 and shortness of breath as breathlessness when hurrying on the level or walking up a slight hill. 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, before entering the company and pasty dusty occupations as past dust exposure for more than two years before entering the company.

### *Statistical analysis*

Data analyses were done using "*Statistical Packages for Social Science"* (SPSS) version 20. The means for respirable metal dusts (Co, Cr, and Ni) in different work categorize were calculated. Those who not measured were assigned to similar ones based on the site-visit observation. Due to the lognormal distribution of metal dust samples, median of dust concentrations were more representative. The medians of respirable metal dust in different job categories represented respirable metal dust exposure in the current job, respectively.

Lack of data concerning respirable metal dust exposure in the past, therefore cumulative respirable metal dust exposure was defined as:

$$\sum_{\text{all jobs}} \left( \text{Median concentration of metal dust exposure at job in TWA} \left(\frac{mg}{m^3}\right) \times \text{ duration of employment (year)} \right)$$

According to the above equation and occupational history, the cumulative respirable metal dust for each subjects could be hypnotically estimated in order to investigate the dose-response relationship with biological variables. Chi Square test was used to compare the respiratory symptoms according to cumulative metal dust categories while One Way ANOVA was used to compare the mean difference of lung function indices according to cumulative metal dust categories. Logistic regression analysis was applied to identify factors related to respiratory symptoms. Using the logistic model, adjusted odd ratios and confidence intervals of respiratory symptoms were calculated for any predictive variables. Multiple linear regression analysis was applied to identify the factors associated with lung function values. Separate analyses were performed to check the different effect of metal dust exposure between smokers and the non-smokers. The outcome variables analyzed were FVC, $FEV_1$ and $\%FEV_1/FVC$. An ethnicity was abandoned because it did not significantly contribute to the models of lung function as all the subjects are Malay. Objective metal dust exposure indicators (respirable metal dust) was not normally distributed, therefore transformed logarithmically to yield lognormal distributions before analysis commenced. A stepwise method was carried out as means of assessing the relative priority as associations between multiple variables. The significant level used for evaluating the test of significance was set at $P<0.05$. This study was approved by the Research and Ethics Committee, UKM Medical Center, reference number FF-055-2013 dated 6th February 2013.

## Results

### *Background of the subjects*

Four hundred and two male Malay subjects with mean age of 36.8 years ± 8.81 were assessed. Mean duration of employment was 12.2 years and the mean age was 36.8 years old. Fifty percent of the workers were current smokers. Thirty percent were non-smokers, and 66.5% percent had cigarette consumption more than 10 years. Mean cigarette equivalent was 9.9 ± 9.71 packs per year. Before entering this company, 5.2% had been exposed to occupationally dusty environments and 4.2% had a history of respiratory diseases.

### *Metal dust exposure assessment*

Personal sampling showed the mean concentration for TWA 8-hr cobalt and chromium for most of the work categories were exceeded the occupational exposure limit values as prescribed by Use and Standard Exposure to Chemical Hazardous to Health (USECHH) OSHA 1994. The highest concentration of cobalt was found in caster (0.19 $mg/m^3$) while the lowest concentration was found in electrical and instrumentation work unit (0.01 - 0.02 $mg/m^3$). The highest concentration of chromium was found in scrap bay (0.19 $mg/m^3$) while the lowest concentration was found in crane operation work (0.01- 0.02 $mg/m^3$). In contrast, mean concentrations for nickel was not exceeded the prescribed value (Table 1).

**Table 1:** Respirable metal dust exposure by different work categories

| Job categories | No of workers | Valid sample | Time weight average (mg/m³) TWA 8-hr | | |
|---|---|---|---|---|---|
| **Total number** | 436 | 184 | | | |
| **Metal dust** | | | Co | Cr (VI) | Ni |
| **USECHH PEL (mg/m³)** | | | 0.1 | 0.05 | 1.5 |
| **Furnace** | | | | | |
| **Supervisor & Foreman** | 3 | 1 | 0.15 | 0.11 | 0.60 |
| **Electric Arc Furnace controller** | 1 | 1 | 0.09 | 0.16 | 0.05 |
| **Melter** | 18 | 9 | 0.15 | 0.10 | 0.66 |
| **Ladle furnace** | | | | | |
| **Supervisor** | 3 | 1 | 0.04 | 0.13 | 0.15 |
| **Controlling room operator** | 1 | 1 | 0.03 | 0.14 | 0.07 |
| **Melter** | 7 | 6 | 0.10 | 0.14 | 0.18 |
| **Ladle handling** | | | | | |
| **Supervisor** | 3 | 1 | 0.10 | 0.02 | 0.69 |
| **Controlling room operator** | 1 | 1 | 0.11 | 0.08 | 0.07 |
| ***Ladleman*** | 8 | 6 | 0.15 | 0.12 | 0.73 |
| **Continous casting machine (CCM-MC5)** | | | | | |
| **Supervisor & Foremen In charge** | | | | | |
| **Controlling room operator** | 6 | 2 | 0.12 | 0.14 | 0.61 |
| **Caster** | 4 | 22 | 0.11 | 0.07 | 0.07 |
| | 30 | 11 | 0.19 | 0.15 | 0.62 |
| **CCM-Concast** | | | | | |
| **Supervisor & *Foremen In Charge*** | 6 | 2 | 0.16 | 0.14 | 0.65 |
| **Controlling room operator** | 4 | 2 | 0.10 | 0.07 | 0.05 |
| **Caster** | 30 | 12 | 0.12 | 0.14 | 0.74 |
| **Scrap bay** | | | | | |
| **Supervisor** | 6 | 2 | 0.19 | 0.11 | 0.67 |
| **Heavy equipment driver** | 30 | 12 | 0.14 | 0.19 | 0.76 |
| **Crane operation** | | | | | |
| **Supervisor** | 6 | 2 | ND | 0.01 | 0.10 |
| **Crane operator** | 22 | 10 | ND | 0.02 | 0.10 |
| **DR shed** | | | | | |
| **Supervisor** | 6 | 2 | 0.16 | 0.12 | 0.09 |
| **Material handling technician** | 40 | 11 | 0.17 | 0.14 | 0.14 |
| **DR Cleaning** | | | | | |
| **Supervisor** | 6 | 2 | 0.15 | 0.11 | 0.07 |
| **DR technician** | 45 | 12 | 0.17 | 0.13 | 0.07 |
| **DR operation** | | | | | |
| **Supervisor** | 6 | 2 | 0.14 | 0.11 | 0.04 |
| **DR technician** | 45 | 12 | 0.17 | 0.12 | 0.07 |
| **Fabrication** | | | | | |
| **Supervisor** | 3 | 1 | 0.10 | 0.11 | 0.04 |
| **Fabricator** | 8 | 6 | 0.14 | 0.13 | 0.04 |
| **Refractory** | | | | | |
| **Supervisor** | 3 | 1 | ND | 0. 15 | 0.02 |
| **Welder** | 8 | 6 | ND | 0.16 | 0.08 |
| **Raw material handling** | | | | | |
| **Supervisor** | 3 | 1 | 0.15 | 0.10 | 0.70 |
| **Raw material handler** | 10 | 7 | 0.18 | 0.18 | 0.75 |
| **Upstream conveyor** | | | | | |
| **Supervisor** | 3 | 1 | 0.14 | 0.10 | 0.15 |
| **Conveyor man** | 11 | 7 | 0.16 | 0.18 | 0.18 |
| **Machining & mechanical** | | | | | |
| **Supervisor** | 3 | 1 | 0.03 | 0.05 | ND |
| **Mechanics** | 11 | 7 | 0.05 | 0.04 | ND |
| **Electrical & Instrumentation** | | | | | |
| **Supervisor & engineers** | 3 | 1 | 0.01 | 0.03 | 0.11 |
| **Instrument technician** | 11 | 7 | 0.02 | 0.04 | 0.12 |
| **Electrician** | 11 | 7 | 0.02 | 0.06 | 0.09 |
| **Logistics/workshop** | | | | | |
| **Supervisor** | 3 | 1 | ND | ND | ND |
| **Mechanics** | 8 | 6 | ND | ND | ND |

## *Respiratory health*

Symptoms were grouped into 4 main categories namely chronic cough, chronic phlegm, chest tightness, and shortness of breath. These symptoms were based on their experience in the last 12 months. Chest tightness was the common symptom (28.0 %) claimed by the workers, followed by chronic phlegm (26.8 %), shortness of breath (24.1 %), and chronic cough (20.2 %).

Prevalence of respiratory symptoms and lung function parameters were group according to cumulative exposure respirable metal dust exposure as shown in Table 3. Higher cumulative metal dust exposure gradually increases with higher prevalence respiratory symptoms and the lower of lung function values. The crude prevalence of all respiratory symptoms gradually increased along the groups defined by cumulative respirable metal dust categories. There was significant difference in the prevalence of chronic phlegm among the cumulative respirable dust cobalt ($\chi^2$= 7881, $P$ = 0.049). Their mean value of FVC, $FEV_1$, and $\%FEV_1/FVC$ were 2.91 (SD=0.47) litres, 3.45 (SD=0.52) litres, and 84.3 (SD=5.5) percent respectively. These three values gradually decreased among the groups defined by cumulative respirable metal dust exposure. The difference of $FEV_1$ and FVC in the cumulative exposure to respirable dust cobalt were $P$ = 0.025 and $P$ = 0.022 respectively, while the difference in $FEV_1$ and FVC values in the cumulative exposure to respirable dust chromium were $P$ <0.001 and $P$ = 0.002 respectively (Table 2).

**Table 2:** Comparison of respiratory symptoms and lung function values according to cumulative respirable metal dust categories

| General information | Cumulative respirable dust (Co) mg/m³.year | | | | Total |
|---|---|---|---|---|---|
| | <0.50 | 0.50 - 0.99 | 1.00 - 1.99 | 2.0++ | |
| Number | 55 | 72 | 120 | 155 | 402 |
| Respiratory symptoms [a] | | | | | |
| Chronic cough | 14 (25.5) | 22 (30.6) | 39 (32.5) | 67 (43.2) | 142 (35.3) |
| Chronic phlegm* | 15 (27.3) | 26 (36.1) | 46 (38.3) | 67 (43.2) | 154 (38.3) |
| Chest tightness | 10 (16.4) | 16 (22.2) | 37 (31.0) | 50 (32.5) | 113 (28.1) |
| Dyspnoea | 9 (16.4) | 16 (22.2) | 29 (24.2) | 52 (33.5) | 106 (26.4) |
| Lung function values | | | | | |
| $FEV_1$* | 2.99 ± 0.47 | 2.96 ± 0.38 | 2.88 ± 0.46 | 2.75 ± 0.41 | 2.91 ± 0.47 |
| FVC * | 3.55 ±0.49 | 3.49 ± 0.57 | 3.47 ± 0.45 | 3.27 ± 0.44 | 3.45 ± 0.52 |
| $FEV_1$/FVC (%) | 85.66 ± 3.95 | 84.30 ± 5.31 | 84.24 ± 5.96 | 84.08 ± 6.52 | 84.32 ± 5.52 |
| | Cumulative respirable dust (Cr) mg/m³.year | | | | |
| Number | 55 | 72 | 120 | 155 | 402 |
| Respiratory symptoms [a] | | | | | |
| Chronic cough | 19 (26.4) | 25 (27.8) | 37 (35.2) | 61 (45.2) | 142 (35.3) |
| Chronic phlegm | 15 (20.8) | 26 (28.9) | 32 (30.5) | 54 (40.0) | 127 (31.6) |
| Chest tightness | 15 (20.8) | 23 (25.6) | 31 (29.6) | 42 (31.1) | 111 (27.6) |
| Dyspnoea | 13 (18.1) | 20 (22.2) | 26 (24.8) | 41 (30.4) | 100 (24.9) |
| Lung function values | | | | | |
| $FEV_1$# | 2.96 ± 0.38 | 2.92 ± 0.41 | 2.79 ± 0.40 | 2.75 ± 0.47 | 2.91 ± 0.47 |
| FVC * | 3.64 ± 0.46 | 3.52 ± 0.44 | 3.31 ±0.54 | 3.29 ±0.45 | 3.45 ± 0.52 |
| $FEV_1$/FVC (%) | 84.90 ± 4.55 | 84.87 ± 4.62 | 84.58 ± 7.53 | 83.26 ± 5.21 | 84.32 ± 5.52 |
| | Cumulative respirable dust (Ni) mg/m³.year | | | | |
| Number | 62 | 93 | 105 | 142 | 402 |
| Respiratory symptoms [a] | | | | | |
| Chronic cough | 18 (29.0) | 30 (32.3) | 36 (34.3) | 59 (41.5) | 143 (35.6) |
| Chronic phlegm | 10 (16.1) | 22 (23.7) | 33 (31.4) | 57 (40.1) | 122 (30.3) |
| Chest tightness | 13 (21.0) | 25 (26.9) | 34 (32.4) | 48 (33.8) | 120 (29.9) |
| Dyspnoea | 11 (17.8) | 19 (20.4) | 25 (23.8) | 55 (38.7) | 110 (27.4) |
| Lung function values | | | | | |
| $FEV_1$ | 2.91 ± 0.41 | 2.89 ± 0.45 | 2.87 ±0.40 | 2.86 ±0.51 | 2.91 ± 0.47 |
| FVC | 3.51 ± 0.51 | 3.43 ± 0.48 | 3.41 ± 0.52 | 3.22 ± 0.54 | 3.45 ± 0.52 |
| $FEV_1$/FVC (%) | 84.61 ± 5.82 | 84.55 ± 5.60 | 84.46 ± 5.22 | 84.13 ± 6.21 | 84.32 ± 5.52 |

Abbreviation : FVC-Forced Vital Capacity, $FEV_1$- Forced Expiratory Volume in 1 Second,/ [a] Values in parentheses are percent, [b] Values are mean ± standard deviation/* $P$<0.05, ** $P$<0.01, # $P$<0.001

### *Contributing factors to respiratory health*

Cumulative cigarette equivalent was remained associated with respiratory symptoms after controlling the confounding variables shown in Table 3. The other contributing factors to presence of respiratory symptoms included age and past respiratory illnesses. Age and cumulative cigarette equivalent were the contributing factors to the presence of chronic cough and chronic phlegm. Cumulative cigarette equivalent was associated with chest tightness (OR=2.15, 95% CI: 1.16 - 3.98) and shortness of breath (OR=1.78, 95%CI: 1.16 - 2.72). Past respiratory illnesses (OR=2.14, 95%CI: 1.28-3.59) was found to be the contributing factors to the presence of shortness of breath.

Multiple regression analysis of contributing factors of lung function values is presented in Table 4. As expected, age, height, and weight were the important determinants of lung function values. Cumulative respirable cobalt exposure and chromium were negatively associated with $FEV_1$ among current smokers. However, no effect was found for FVC and $FEV_1$/FVC. Smoking was negatively associated with $FEV_1$ only. On the other hand, when restricted to non-smokers, the effect of past respiratory illnesses significantly reduces the $FEV_1$/FVC.

**Table 3:** Factors contributing to the presence of respiratory symptoms (n=402)

| Respiratory symptom | Crude OR(SK 95%) | Adjusted OR $^b$(SK 95%) |
|---|---|---|
| Chronic cough | | |
| Age (year) | 1.02 (0.98, 1.06) | 1.09 (1.01, 1.08)* |
| Cumulative of Co (mg/m³xyear) | 1.00 (0.92, 1.06) | - |
| Cumulative of Ni (mg/m³x year) | 0.95(0.89, 1.02) | - |
| Cumulative of Cr (mg/m³x year) | 0.94 (0.78, 1.13) | - |
| Cumulative cigarette equivalent (pack/years) | 1.02 (1.00, 1.05)* | 1.05(1.01, 1.09)* |
| Past dusty occupations (yes) | 1.01 (0.62, 1.65) | - |
| Past respiratory illnesses (yes) | 1.35 (0.24,7.63) | - |
| Frequency using mask (yes) | 1.88 (0.6, 4.67) | - |
| Chronic Phlegm | | |
| Age (year) | 1.01(0.98,1.06) | 0.93 (0.88, 0.98)** |
| Cumulative of Co (mg/m³xyear) | 0.96 (0.86, 1.08) | - |
| Cumulative of Ni (mg/m³x year) | 0.98 (0.91, 1.06) | - |
| Cumulative of Cr (mg/m³x year) | 1.10 (0.92, 1.30) | - |
| Cumulative cigarette equivalent (pack/years) | 1.06 (1.04, 1.08)# | 1.06 (1.02, 1.10)* |
| Past dusty occupations (yes) | 1.05 (0.71, 1.57) | - |
| Past respiratory illnesses (yes) | 1.59 (1.08,2.33)# | - |
| Frequency using mask (yes) | 1.33 (0.51, 3.51) | - |
| Chest tightness | | |
| Age (year) | 1.03 (0.97,1.09) | - |
| Cumulative of Co (mg/m³x year) | 0.98 (0.90, 1.07) | - |
| Cumulative Ni (mg/m³x year) | 0.98 (0.92, 1.04) | - |
| Cumulative of Cr (mg/m³ x year) | 1.08 (0.95, 1.24) | - |
| Cumulative cigarette equivalent (pack/years) | 1.05 (1.01, 1.08)* | 2.15 (1.16,3.98)* |
| Past dusty occupations (yes) | 1.03 (0.42, 2.51) | - |
| Past respiratory illnesses (yes) | 1.73 (0.77, 3.86) | - |
| Frequency using mask (yes) | 1.05 (0.42, 2.67) | - |
| Shortness of breath | | |
| Age (year) | 1.03 (0.99, 1.07) | - |
| Cumulative of Co (mg/m³.year) | 1.00 (0.93, 1.05) | - |
| Cumulative of Ni (mg/m³x year) | 1.01 (0.95, 1.07) | - |
| Cumulative of Cr (mg/m³ x year) | 1.86 (1.19, 2.90)* | - |
| Cumulative cigarette equivalent (pack/years) | 1.04 (1.01, 1.06)** | 1.78 (1.16, 2.72)** |
| Past dusty occupations (yes) | 1.04 (0.59, 1.85) | - |
| Past respiratory illnesses (yes) | 2.06 (1.24, 3.42)** | 2.14 (1.28, 3.59)** |
| Frequency using mask (yes) | 0.88 (0.39, 1.99) | - |

Abbreviation :OR: odds ratio, CI: Confidence Interval, * $P<0.05$, ** $P<0.01$, # $P<0.001$

**Table 4:** Predictors of lung function values in simple and multiple regression models

| Predictors | Current Smokers (N=218) | | Non current smokers (N=184) | |
|---|---|---|---|---|
| | SLR[b] | MLR[c] | SLR[b] | MLR[c] |
| | | FEV$_1$ (liter) | | |
| **Constant** | - | 2.723# | - | 2.837# |
| **Age (yr)** | -0.030# | - 0.035* | -0.026# | -0.033# |
| **Height (cm)** | 0.034# | 0.028# | 0.048# | 0.040# |
| **Weight (kg)** | - 0.020* | -0.011* | -0.024* | -0.027* |
| **Cumulative of Co (mg/m³ x year)[a]** | - 0.224** | -0.224** | -0.093 | - |
| **Cumulative of Ni (mg/m³ x year)[a]** | - 0.147* | - | -0.074 | - |
| **Cumulative of Cr (mg/m³ x year)[a]** | - 0.364# | -0.139* | -0.176 | - |
| **Cigarette equivalent (pack/year)[a]** | - 0.303* | - | - | - |
| **Past dusty occupations (yes)** | - 0.341 | - | -0.066 | - |
| **Past respiratory illnesses (yes)** | -0.008 | - | -0.275 | - |
| **Frequency using mask (yes)** | 0.101 | - | - | - |
| | | FVC (litter) | | |
| **Constant** | - | 3.255# | - | 3.360# |
| **Age (yr)** | -0.029# | -0.030# | -0.026# | -0.021# |
| **Height (cm)** | 0.041# | 0.031# | 0.054# | 0.050# |
| **Weight (kg)** | -0.029* | -0.019# | -0.027* | -0.023* |
| **Cumulative of Co (mg/m³ x year)[a]** | -0.393# | -0.017* | -0.085 | - |
| **Cumulative of Ni (mg/m³ x year)[a]** | -0.154* | - | -0.099 | - |
| **Cumulative of Cr (mg/m³ x year)[a]** | -0.411# | - | -0.173 | - |
| **Cigarette equivalent (pack/year)[a]** | -0.312* | - | - | - |
| **Past dusty occupations (yes)** | -0.293 | - | -0.063 | - |
| **Past respiratory illnesses (yes)** | 0.116 | - | -0.376 | - |
| **Frequency using mask (yes)** | 0.197 | - | | |
| | | FEV$_1$ /FVC(%) | | |
| **Constant** | - | 88.43# | - | 90.76* |
| **Age (year)** | -0.196** | -0.189# | -0.123* | -0.197* |
| **Height (cm)** | -0.186** | 0.180# | 0.028* | 0.022* |
| **Weight (kg)** | -0.100 | - | -0.040 | - |
| **Cumulative of Co (mg/m³ x year)[a]** | -1.505 | - | -0.585 | - |
| **Cumulative of Ni (mg/m³ x year)[a]** | -0.558 | - | -0.541* | - |
| **Cumulative of Cr (mg/m³ x year)[a]** | -0.301* | - | -0.947 | - |
| **Cigarette equivalent (pack/year)[a]** | -1.150* | - | - | - |
| **Past dusty occupations (yes)** | -2.793 | - | -0.597 | - |
| **Past respiratory illnesses (yes)** | -2.580 | - | -1.359* | - |
| **Frequency using mask (yes)** | 0.199 | - | - | - |

[a] Logarithm transformation before analysis, * $P$ <0.05, ** $P$ < 0.01, # $P$ < 0.001
SLR- Simple linear regression, MLR -Multiple linear regression
[b] Crude regression coefficients, [c] Adjusted regression coefficients
** 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
Current smokers:
FEV$_1$ = 2.723 – [0.035 * age] + [0.028 * height] – [0.011 * weight] – [0.224 * Cumulative of Co – [0.139 * Cumulative of Cr]
FVC = 3.255 – [0.030 * age] + [0.031 * height] – [0.019 * weight] – [0.017 * Cumulative of Co]
% FEV$_1$/FVC = 88.43 – [0.189 * age] – [0.180 * height]
Non-current smokers:
FEV$_1$ = 2.837 – [0.033 * age] + [0.040 * height] – [0.027 * weight]
FVC = 3.360 – [0.021 * age] + [0.050 * height] – [0.023 * weight]
% FEV$_1$/FVC = 90.76 – [0.197 * age] + [0.022 * height]

## Discussion

### *Metal dust exposure*

The TWA metal dust concentrations for cobalt and chromium were 1 to 2 times higher than Permissible Exposure Limit Values under the Use and Standard of Exposure to Chemicals Hazardous to Health Regulations in Occupational Safety and Health Act (USECHH, OSHA). (14). However, the TWA$_8$ concentration of nickel for each work category did not exceed the occupational exposure values.

The study conducted in a similar type of iron and steel industry in India revealed that the average trace metal concentrations estimated from respirable particulate matters (RPM) like iron, manganese, lead, and chromium did not exceed the ACGIH prescribed levels (15). The chromium levels were 0.66 mg/m$^3$ and 0.60 mg/m$^3$ in blast furnace and continuous casting machine, respectively. Inhalation of dust particles containing metals and their compounds causes impairment to both pulmonary surfactant and respiratory system functions (16-18). Chronic bronchitis, emphysema, pulmonary fibrosis, and impaired lung function also have been observed in nickel-chromium welders and foundry workers. (19,20). Some epidemiological and experimental studies indicated that workers in iron ore processing were exposed to carcinogens, which might affect the lung function (21,22).

### *Respiratory symptoms*

This study found that forty percent of the steel workers complained at least one of the respiratory symptoms. This result was comparable with the study by Chen et al., who found that 60% of steel workers in Taiwan complained one or more respiratory symptoms; including chronic cough (9.3%), chronic phlegm (11.9%), and breathlessness (6.5%) (23). Age and smoking were the factors contributing to the presence of respiratory symptoms among steel workers. Increase one year of age has one time the risk of chronic cough and chronic phlegm among the steel workers. Similarly, increase one pack of years of smoking give one to two times the risk of chronic cough, chronic phlegm, chest tightness, and shortness of breath. In addition, those who had past respiratory illnesses has twice more likely to report shortness of breath.

Coronary artery disease can also be responsible for chest tightness, especially in an all male-study population. The history of chronic cough and chronic phlegm was associated to cigarette smoking. Smokers has one time the risk of chronic cough and phlegm while twice more likely to report chest tightness and shortness of breath. Reported respiratory symptoms were explained by smoking factors where significant association was found among steel workers (24.25) The development of respiratory diseases and other work related respiratory symptoms among the steel workers were related to a combination of dusts (which may acts as irritants in their own right) and irritant gases in the workplace as well as the effects of smoking and other ambient air pollution. How these two etiological factors interact with each other was not known, although it was possible that smoking may alter the handling of agents encountered in the workplace by interfering with the normal mucocillary clearance by more complex mechanisms (26). In some exposures, there was a synergistic effect between exposure to tobacco smoke and workplace contaminants. There was also a possibility of occupational asthma, which might be responsible for chest tightness, shortness of breath, and chronic cough. However, wheezing, an important symptom in asthma was not elicited in this study.

Respiratory symptoms reported in this study showed chronic irritation effects of the respiratory tract due to prolonged and repetitive exposure to metal dust. Metal dust may cause irritation of the respiratory tract resulting in a narrowing of the airways. Longitudinal study conducted by Pham et al. (1979) showed bronchitis rates increased from 37.8% to 45.3% among steelworkers otherwise bronchitis rate among the control group increased from 17.8% to 21.8%. Another finding reported in Taiwan showed significant prevalence rates of respiratory symptoms gradually increased among the groups defined by cumulative exposure.

### *Lung function*

The study demonstrated $FEV_1$, FVC and $FEV_1$/FVC gradually decreased among the groups defined by cumulative respirable metal dust exposure similar reported by Chen et al., who found that the lung function indices gradually decreased towards the cumulative respirable dust exposure. The result also supports from other studies in various populations of steel workers evaluated in cross sectional and longitudinal studies (5, 27-30) which revealed impaired pulmonary functions. Pham et al. (1979) detected a significant deterioration of $FEV_1$ and $FEV_1/FVC$ among steel workers as compared to a reference group of unexposed workers in a five-year longitudinal study (6). Nemery et al. also found a significant decline in the lung function that was consistent with slight obstruction of airway being reported among steel workers specifically in the continuous casting process (27). Furthermore, it was reported that the lung function values for $FEV_1$, FVC, and $FEV_1/FVC$ were also significantly lower among exposed group than control (28). In addition, it is believed that foundry workers had significantly lower of $FEV_1$ and $FEV_1/FVC$ with 16.8 % had an airway obstruction related to occupational asthma (29). Furthermore, longitudinal studies also found significant deterioration of $FEV_1$ and $\%FEV_1/FVC$ among steel workers as compared to a reference group of unexposed workers (30-31).

The multiple linear regression analysis of the lung function values showed the cumulative cobalt and chromium were negatively associated with the lung function in the smoking workers. The lower $FEV_1/FVC$ in non-current smokers was achieved at lower expiratory volume in first second compared with its vital capacity. Chen et al. also reported that average respirable dust exposure was found to decrease the forced vital capacity (FVC) and forced expiratory volume in one second (FEV1) in smoking workers. However, the effect of respirable metal dust on lung function indices could not be seen (23). There was a different effect in the smokers in that increasing cumulative respirable metal dust exposure was associated with reducing $FEV_1$ as well as FVC. In addition, the effect of smoking and cumulative respirable metal dust exposure on $FEV_1$ can be seen in this model (Refer Table 4). The models of FVC and $FEV_1$ among current smokers were explained by 47% and 72% of the independents variables respectively, meanwhile the models of FVC and $FEV_1$ among non-current smokers were explained by 50% and 45% respectively. However, the model of %FEV1 and FVC for both groups were explained within range of 20%-24%.

Previously, there was much debate on whether dusty environments could be etiological factors for obstructive lung disease. In 1970's, Morgan found industrial bronchitis might not be associated with lung function values (32). After almost two decades, Becklace (1989) reviewed the literature on chronic non-specific lung diseases associated with occupational exposure (26). This disease includes a cluster symptoms related to chronic bronchitis and a reduction on lung function associated with obstructive lung disease. During the year 2000-2013, few studies provided strong evidence for the independence role of the dust in the causation of lung function impairment, lung function loss, and chronic obstructive pulmonary diseases among the dusty working population (33-40).

Respiratory illnesses are a result of multiple etiologic factors, thus made it difficult to verify the influence of the various factors on the disease. This study has been able to control the smoking variable, which a known confounder to lung function and respiratory diseases using separate multivariate analyses for current smokers and non-current smoker. It demonstrated statistically significant associations between the outcome variables of interest. Smoking was found to be prominent more roles than dust exposure in the determination of respiratory symptoms with deterioration of lung function values. Thus it provided further corroboration for a deleterious dust related effect on the respiratory system for steelworkers

### *Study Limitation*

This study failed to reveal a clear picture of obstructive respiratory impairments affected by duration of dust exposure as suggested in other studies. This might be due to the inadequate findings of lung function abnormalities, as radiological opacities were not examined. Therefore, the functional impairment in small airways needs to be followed up especially among possible asthmatics workers to find the possible association with chronic bronchial obstruction and respiratory failure

This study was conducted among current employed workers. The possibility of selection bias might have arisen from the subjects who had suffered less exposure as compared to those who already left their jobs. Some of them might be due to the illness sustained from the occupational exposure. A number of studies have shown that workers who have resigned or left their job had a higher prevalence of occupational respiratory diseases (41-42). The nature of dust exposure was another varying factor that may explain the differences in studies of respirable metal dust exposed workers (15). Silica and metal oxides contained in respirable dust could be the potential factors though no silicosis and haemosiderosis were found from annual chest x-ray examinations from this company.

## Conclusion

This study found that respirable cumulative metal dust exposure is one of the contributing factors to lung function values among steel workers. The presence of work-related symptoms was not related to a marker of heavy exposure to respirable metal dust and increasing cumulative metal dust exposure. Smoking already been known to exert deleterious effect to respiratory health, while the additional exposure to respirable metal dusts exacerbate the symptoms even worse.

## Ethical Considerations

Ethical issue (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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