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Respiratory Exposure to Toxic Gases and Metal Fumes Produced by Welding Processes and Pulmonary Function Tests

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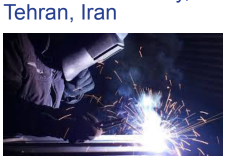

Abstract

Background: Welding is a common industrial process and is harmful to welders' health.

Objective: To determine the effect of toxic gases and metal fumes produced during 3 welding processes on welders' incidence of respiratory symptoms and pulmonary function.

Methods: This cross-sectional study was conducted in an Iranian shipbuilding industrial factory in 2018. Using the simple census method, 60 welders were selected as the exposed group. 45 staff members of the administrative unit were also recruited to be served as the control group. Welders' demographic data and respiratory complaints were collected employing a questionnaire. Fumes and gases produced were sampled from the welders' respiratory tract and analyzed by standard methods suggested by the National Institute of Occupational Safety and Health (NIOSH). Pulmonary function test was also performed for each participant.

Results: The prevalence of respiratory symptoms in all welders was significantly ($p<0.05$) higher than the control group. The mean FVC, FEV_1 and FEV_1/FVC measured in welders involved in all 3 processes were significantly lower than those recorded in the control group. The spirometry pattern in welders involved in flux cored arc welding and shielded metal arc welding was obstructive; that in those involved in gas metal arch welding was mixed (obstructive and restrictive pattern).

Conclusion: Exposure to welding fumes and gases was associated with pulmonary function deterioration. Welders involved in gas metal arch welding had a higher prevalence of pulmonary disorders compared with those involved in gas metal arch welding and flux cored arc welding.

Keywords: Welding; Respiratory function tests; Spirometry; Signs and symptoms, respiratory

Introduction

Compared with gases, noise, heat, and the ultraviolet radiation, fumes produced during the welding process have the most deleterious effects on the welders' health.[1,2] Approximately, 500 000 full-time employees are working in the US in the capacity of welding operators.[3] There are 5.5 million welding-related businesses in the Europe.[4] There are more than 80 types of welding, but arc welding is the

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most commonly used type.[5,6]

Shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and flux cored arc welding (FCAW) are the most commonly used welding techniques.[7] In SMAW, the protection of the molten pool is covered by the electrode coatings. Nowadays, SMAW is the most frequently used technique among other types of arc welding processes.[8] The GMAW is performed through the heat produced by the arc between the filler electrode and the work piece. In this type of welding, gas is used as a guard and covering around the arc to prevent contamination by welding with air.[9] FCAW with a flux cored wire is very similar to metal active gas (MAG) welding, except that instead of using a solid core wire, a special type of welded wire is employed in the form of a hollow tube that contains special powders.[10]

The concentration of the fumes produced during a welding operation is a function of the welding type, the type of alloy of the work piece, the electrical current and voltage used, the temperature created, the chemical reactions taken place, and the elements used in the electrode.[11] Regarding the pathogenic effects of fumes produced in the welding process, the American Conference of Governmental Industrial Hygienists (ACGIH®)[12] has suggested a threshold limit value-time-weighted average (TLV-TWA) for fumes of 5 mg/m^3.

Approximately, 90% to 95% of fumes are emitted from the filler metal of the consumed electrodes.[13] At least 13 metal fumes are emitted during a welding process.[14] The most common metals found in the welding fusion include chromium, manganese, magnesium, copper, iron, and aluminum. These metals are important in terms of their biological and toxicological activities. For example, iron causes lung cirrhosis in welders; manganese may cause an inflammatory response and decrease β-glucuronidase activity in the lung;[15] and chromium is known as a carcinogen.[16]

Incidence and prevalence of respiratory symptoms are higher among welders. This might be attributed to the presence of various gases such as CO, CO_2, and NO_2 and metal fumes such as manganese, chromium, aluminum and nickel produced in the welding process.[17]

Creating very high concentrations of O_3, welding can also lead to obstructive pulmonary diseases.[18] CO is a lethal poison and can cause serious toxicity in welders.[19] Exposure to high concentrations of NO_2 and NO can cause acute inflammation and pulmonary edema.[20]

Welding is one of the most common occupations associated with occupational lung disease.[21] Several studies have so far reported the association between exposure to gases and welding fumes and increasing frequency of respiratory symptoms and decreasing pulmonary function.[22-26] Occupational exposure to welding fumes is a major risk factor for chronic obstructive pulmonary disease (COPD).[26]

Toxic gases and fume particles produced during the welding process enter the respiratory system, leading to acute respiratory effects, including airway burning, chronic bronchitis, emphysema, lung fibrosis, pulmonary edema, cardiovascular disorders, neurobehavioral signs and symptoms, pneumonitis, severe allergy, asthma, emphysema and lung fibrosis.[27-30] The exposure can also cause a significant decrease in spirometry indices—forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and FEV_1/FVC.[31,32]

It seems reasonable to determine the level of welders' exposure to the fumes and toxic gases produced during welding. Iranian shipbuilding industry is growing steadily. The welding process is thus inevitable in terms of working conditions. The present study was conducted to measure the exposure of welders to metal fumes and toxic gases produced during three welding

Table 1: Characteristics of the exposed and unexposed groups. Values are either mean (SD) or median (IQR).

Variables	Exposed group (n=60)	Unexposed group (n=45)	p value
Age (yrs)	35.5 (10.4)	36.3 (9.2)	0.13
Height (cm)	170 (6.0)	168 (4.3)	0.52
Weight (kg)	72.3 (11.0)	77.5 (7.0)	0.20
Work experience (yrs)	10 (7 to 14)	12 (8 to 15)	0.07

processes and to evaluate the associated changes in their spirometry indices.

Materials and Methods

The present cross-sectional study was conducted in 2018 in an Iranian shipbuilding industrial factory. Following a preliminary review of the industry, we decided to focus on toxic gases and fumes produced during SMAW, GMAW and FCAW—the three most commonly used welding types. Through a simple census, 60 male welders were selected as the exposed group; 45 male staff members working in administrative units were also recruited as the control group. The inclusion criteria consisted of not being a smoker; welding for at least six months for an average of three hours per day;[20] having no record of pulmonary diseases at the time of employment and no chest surgery or pulmonary injury; no contraindication for spirometery (*eg*, any history of myocardial infarction or unstable angina during the last six weeks); no active hepatobiliary problem; no known abnormality in the thoracic aorta; and no uncontrolled hypertension. All of the above-mentioned criteria, except for being a welder, were also used for the inclusion of the control group. Respiratory mask was rarely used by the study participants.

Data Collection

Demographic and job profile characteristics such as age, height, weight, work experience in the current job, *etc*, were collected and recorded in a data sheet. In the present study, we decided to include all welders using all the three types of welding—GMAW, SMAW and FCAW. The number of welders was not high (n=66); six welders did not fulfill the criteria for entering the study and thus were excluded from the research, leaving data of 60 welders for analyses.

Table 2: Mean (SD) concentration (ppm) of gases produced during various types of welding

Gases	SMAW*	GMAW†	FCAW‡	TLV-TWA§	p value
CO	48.50 (9.19)	55.13 (12.21)	24.10 (8.16)	25	0.03
NO	7.50 (2.17)	13.32 (3.76)	3.85 (1.02)	50	0.01
NO_2	2.85 (1.14)	3.32 (0.73)	1.02 (0.23)	0.2	0.12
O_3	0.22 (0.06)	0.31 (0.10)	0.15 (0.04)	0.05	0.35
CO_2	4300.34 (1032.10)	5086.03 (1535.47)	2502.90 (751.44)	5000	0.04

*Shielded metal arc welding; †Gas metal arc welding; ‡Flux cored arc welding; §Threshold limit value-time weighted average

To assess the frequency of respiratory symptoms in study participants, we used the standard American Thoracic Society (ATS) Respiratory Symptoms Questionnaire in accordance with the advice of the American Lung Association. The questionnaire includes questions about the symptoms of respiratory disease (such as cough, sputum, wheezing and shortness of breath), smoking, and family and medical records.[33]

Metal Fumes and Gases

Sampling of metal fumes including the total fume and six metals (chromium, manganese, magnesium, copper, iron, and aluminum) at welding stations was performed by mixed cellulose ester (MCE) with a diameter of 37 mm, 0.84-µm pore-size, and discharge coefficient as 2 L/min from the respiratory tract. Method No. 7300 of the American National Institute of Occupational Safety and Health (NIOSH) was used to measure the amounts of these metals. After the preparation, fusion analysis was done with an inductively coupled plasma spectrometry (RL-Liberty model, Varian Medical Systems, Italy). Ozone sampling was done through glass fiber filters (GFF) with a diameter of 37 mm and discharge coefficient of 0.2 L/min with a sampling pump (SKC Co, USA) and based on method No. 214 of the OSHA. The UV-VIS spectrophotometer (SP-3000 Plus model, Japan) was used for analyzing ozone samples. The NIOSH method No. 6014 was used for NO and NO_2 sampling from a UV-VIS spectrophotometer. Direct-reading devices were used to measure CO_2 and CO emissions. These devices included 1372 CO meter and 1370 NDIR CO_2 meter (TES Electrical Electronic Corp, Taiwan).

Spirometry

Pulmonary function test (PFT) was performed according to the standard guidelines using a calibrated MIR spirometry made in Italy. The measured parameters included FVC, FEV_1 and FEV_1/FVC. We employed the criteria set by the American Lung Association (ATS). FVC and FEV_1 ≥80% predicted value and FEV_1/FVC ≥75% predicted value were considered "normal." PFT was performed for each participant for 3–8 times based on acceptability and repeatability criteria.

FEV_1/FVC<75% predicted value, FVC≥80% and FEV_1<80% predicted value indicate obstructive pattern; FEV_1/FVC≥75% predicted value, FVC<80% and FEV_1≥80% predicted value reflect restrictive pattern; and FEV_1/FVC<75% predicted value, FVC<80% and FEV_1<80% predicted value show a mixed pattern.[34,35]

For more information on respiratory problems associated with occupational exposure to asphalt fumes see http://www.theijoem.com/ijoem/index.php/ijoem/article/view/473

Ethics

The objective of the study was explained to the study participants. They were assured that participating in the study is voluntarily and that their personal information will remain confidential. The participants signed a written informed consent to participate in the study.

Statistical Analysis

SPSS® for Windows® ver 21.0 was used for data analysis. *Student's t* test for paired data and one-way ANOVA were used for inferential statistical analysis. A p value <0.05 was considered statistically significant.

Results

We studied 60 welders and 45 administrative staff members working in a shipbuilding industry. They, respectively, had a mean age of 35.5 (SD 10.42) and 36.3 (SD 9.2) years. Their median work experience was 10 (IQR 7 to 14) and 12 (IQR 8 to 15) years, respectively. There was no significant difference between the two groups in terms of mean age, height, weight, and work experience (Table 1).

Table 3: Mean (SD) of concentration (mg/m^3) of various metal fumes produced during various types of welding

Fumes	SMAW*	GMAW†	FCAW‡	TLV-TWA§	p value
Cr	1.11 (0.33)	3.75 (1.55)	0.42 (0.07)	0.5	0.02
Mn	2.37 (0.64)	2.93 (0.70)	1.17 (0.39)	0.2	0.41
Z	1.08 (0.45)	1.76 (0.59)	0.93 (0.32)	5.0	0.09
Cu	0.23 (0.05)	0.44 (0.16)	0.18 (0.06)	0.2	0.61
Fe	5.43 (1.10)	7.50 (2.85)	3.22 (1.66)	5.0	0.01
Al	4.29 (1.63)	5.52 (1.10)	2.47 (0.89)	5.0	0.16
Total fume	5.88 (2.11)	9.04 (3.20)	4.84 (1.50)	5.0	0.05

*Shielded metal arc welding; †Gas metal arc welding; ‡Flux cored arc welding; §Threshold limit value-time weighted average

The mean concentration of O_3, NO_2 and CO was significantly higher than the TLV-TWA set by the American Society for Industrial Hygiene (ACGIH) (Table 2). The mean concentrations of Mn, Al, Cu, Fe, and Cr were also significantly higher than the TLV-TWA (Table 3). The maximum concentrations of the gases and fumes were recorded in welders involved in GMAW.

All respiratory symptoms studied were more frequent in the welders than the control group (Table 4). The prevalence of respiratory symptoms in welders involved in GMAW was significantly higher than that in those involved in SMAW and FCAW, so that more than 60% of GMAW welders suffered from cough with phlegm and more than half of them complained of asthma-like symptoms during the day. The prevalence of respiratory symptoms such as cough and phlegm in SMAW welders (47%) was higher than that in those involved FCAW (more than 20%).

The mean FVC, FEV_1 and FEV_1/FVC indices in welders were significantly lower than those measured in the control group (Table 5). GMAW welders had a worse condition than those involved in SMAW and FCAW.

The frequency of abnormal spirometric patterns (obstructive, restrictive, and mixed) in GMAW welders was higher than that observed in SMAW and FCAW welders (Table 6); 57% of GMAW welders were one of the most abnormal spirometric patterns.

Table 4: The prevalence of respiratory symptoms among the exposed and unexposed groups. Values are n (%).

Respiratory Symptoms	Exposed group (n=60)			Unexposed group (n=45)
	SMAW* (n=17)	GMAW† (n=21)	FCAW‡ (n=22)	
Coughs	8 (47)	14 (67)	5 (23)	1 (2)
Coughs with phlegm	8 (47)	13 (62)	6 (27)	1 (2)
Wheezing	3 (18)	7 (33)	2 (9)	—
Shortness of breath	6 (35)	11 (52)	4 (18)	—

*Shielded metal arc welding; †Gas metal arc welding; ‡Flux cored arc welding

Discussion

We found that the amount of fume and gas produced and inhaled during welding was high. The welders were mainly exposed to NO_2, CO and O_3. The concentration of fumes and gases produced in the GMAW was higher than the other two types of welding studied. PFT indices were also more affected in GMAW welders. The mean concentration of gases and metal fumes produced in SMAW welding was significantly higher than that produced during FCAW. This difference was clearly reflected in spirometry parameters recorded in welders.

Our findings were similar to those reported by Popovice, who shows that the concentration of CO and CO_2 produced during GMAW is higher than that produced during MMAW and SMAW.[19] We showed that the CO, NO_2 and O_3 concentrations were higher than the acceptable occupational exposure limits (TLV-TWA). Mehrifar, *et al*, also showed that welders working in another steel industry are also exposed to concentrations of O_3, CO and NO_2 higher than the TLV-TWA.[36]

The prevalence of asthma and respiratory symptoms such as cough, phlegm, and wheezing was significantly higher in welders than in the control group. These results were consistent with the findings of other studies conducted in this region.[37,38] The symptoms were more common among GMAW welders compared with those involved in FCAW and SMAW.

In a study conducted by Pourtaghi, *et al*, respiratory symptoms were significantly more prevalent in the welders of a production plant than a control group. The spirometry parameters in this occupational group were significantly lower than those of the control group, an observation consistent with the results of the present study.[39] El-Zein, *et al*, studied the prevalence of respiratory and systemic symptoms in welders involved in various processes and showed that the prevalence of asthma, cough, wheezing, and asthma was 21.1% in GMAW welders, 17% in SMAW, and 1.5% in FCAW welders. The prevalence of flu-like, sore throat, fatigue, and

TAKE-HOME MESSAGE

- Welding is a common industrial process. Welders are exposed to various gases and metal fumes produced during the process.
- Gases and metal fumes produced during gas metal arc welding are significantly higher than those produced during shielded metal arc welding and flux cored arc welding.
- Welders involved in gas metal arc welding had worse pulmonary function test results and higher prevalence of respiratory symptoms compared with the unexposed group and also welders involved in shielded metal arc welding and flux cored arc welding.

Table 5: The results of pulmonary function test in the exposed and unexposed groups. Values are mean (SD) percent predicted values.

	Exposed group (n=60)			Unexposed group (n=45)			
Welding types	FVC	FEV_1	FEV_1/FVC	FVC	FEV_1	FEV_1/FVC	p value
SMAW*	80.8 (8.4)	74.6 (9.4)	73.5 (9.2)	97.3 (12.8)	93.1 (10.2)	95.6 (7.4)	<0.001
GMAW†	77.8 (9.2)	73.6 (8.3)	74.4 (7.2)	97.3 (12.8)	93.1 (10.2)	95.6 (7.4)	<0.001
FCAW‡	85.7 (10.3)	76.7 (8.8)	74.1 (4.1)	97.3 (12.8)	93.1 (10.2)	95.6 (7.4)	0.003

*Shielded metal arc welding; †Gas metal arc welding; ‡Flux cored arc welding

Table 6: Frequency (%) of respiratory disease patterns observed among the exposed and unexposed groups

Spirometry patterns	Exposed group (n=60)			Unexposed group (n=45)
	SMAW* (n=17)	GMAW† (n=21)	FCAW‡ (n=22)	
Normal	10 (59)	9 (43)	18 (82)	44 (98)
Obstructive	4 (24)	5 (24)	3 (14)	1 (2)
Restrictive	2 (12)	3 (14)	1 (5)	0 (0)
Mixed	1 (6)	4 (19)	0 (0)	0 (0)

*Shielded metal arc welding; †Gas metal arc welding; ‡Flux cored arc welding

contusion was associated with the severity of respiratory symptoms in the studied welders.[40]

In the present study, the mean of FVC, FEV_1 and FEV_1/FVC in welders was significantly lower than that in the studied administrative staff members. As the subjects in the two groups did not have any medical history of pulmonary disease, chest surgery, and cardiac/chest pain, the observed difference in PFT should be attributed to the exposure of welders to the gases and fumes. Rahimi Moghaddam, *et al*, showed that the mean spirometry indices in welders was significantly decreased after four years of work.[41] Aminian, *et al*, also showed that the spirometry indices of welders significantly decreased over a five-year period in a car manufacturing plant. In this study, smoking welders had respiratory disease with mixed pattern; nonsmokers with pulmonary disease had mostly restrictive pattern.[31]

Hewett, *et al*, showed that the total fume concentration in lungs and airways of GMAW welders is 60% higher than that in SMAW welders. In other words, exposure to fumes produced during GMAW can lead to increased risk of pulmonary problems compared with exposure to fumes produced during SMAW.[42]

We found that most GMAW welders had PFT parameters in favor of obstructive and restrictive pulmonary diseases. This emphasizes use of protective equipment by GMAW welders to reduce the incidence of serious pulmonary diseases. PFT indices in SMAW and FCAW welders, though not normal, were better that the indices recorded in those involved in GMAW. These welders mostly suffered from pulmonary diseases with obstructive pattern.

Ghani, *et al*, in line with our observations, reported that the FVC, FEV_1 and FEV_1/FVC measured in GMAW and SMAW welders were significantly lower than those measured in the control group; the decrease observed in GMAW welders was significantly more than that observed in welders involved in SMAW.[43] In another study, Minov, *et al*, examined spirometry indices in FCAW welders working in a steel industry. Other studies reported similar findings.[44,45]

Investigation into the welders suggests that there is a significant relationship between the occurrence of respiratory diseases such as chronic bronchitis, lung infection, asthma, and lung cancer with work history, duration of work per day, type of welding, and status of the workplace ventilation.[46] In a study conducted on 15 welders with lung fibrosis, Buerke, *et al*, showed a significant positive correlation between the history of welding and the respiratory disturbances.[47] In the study conducted by Meo, *et al*, welders with a work history of >5 years had a significant decrease in FVC, FEV_1 and FEV_1/FVC compared with the control group.[48]

In conclusion, we showed that welding, particularly GMAW, was associated with production of a high amount of gases and metal fumes, seriously deteriorated the pulmonary function of welders. Here, we just examined three types of welding. Other welding processes should be examined to better understand the situation and identify risks of respiratory pollutants among welders.

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Conflicts of Interest: None declared.

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A cooking house, North of Iran (photo courtesy of Nader Rouka)