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ORIGINAL ARTICLE

Occupational Exposure to Fumes and Gases during Different Arc Welding Processes

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ABSTRACT

The fumes and gases releasing from welding processes may seriously affect welders' health compared to other hazardous agents arising from welding like, noise, and ultraviolet radiation. The present study was aimed to measure the exposure levels of welders to fumes and gases at seven of arc welding processes in a melting company. This descriptive-cross sectional study was carried out on several types of arc welding including TIG, GMAW, PAW ،SAW, and MMAW in a melting industry. In order to measure the concentrations of welding fumes, NIOSH 7300 method was applied. Direct reading instruments were used for sampling of welding gases. The median concentration of all studied metals among different types of welding process were significantly different ($P<0.02$). The median concentration of some released gases among different types of welding process were not significantly different ($P >0.05$). The average exposure levels for metals of Cu (from TIG), Fe (from PAW and MMAW processes), Mn (from GMAW, MMAW processes), and Cr (from PAW and MMAW processes) were higher than Occupational Exposure Limit-Time Weighted Average. The finding showed that the nitrogen dioxide average concentrations and ozone gases were higher than the other gases. The welder's exposure levels to toxic metals and gases in some stations exceeded from recommended levels; so, it is necessary to apply the appropriate preventive methods like engineering control measures to effectively protect welders' health.

KEYWORDS: *Welding Processes, Occupational Exposure, Metal Fume, Melting Company*

INTRODUCTION

The fumes released during welding process are one of the most harmful factors to the welders' health compared to other hazardous agents like gas, noise, heat stress, and ultraviolet radiation [1]-[2]. Welding fume are defined as a carcinogenic possibility to humans based on the evaluation of the human, animal, and mechanistic evidence conducted by the International Agency for Research on Cancer (IARC) [3]. Almost 500,000 full-time workers are engaged in welding operations in the United States [4]. There are 5.5 million welding-related jobs in Europe [5]. More than eighty welding types were found, but electrical arc welding was the highly common operation [6]-[7]. The shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and flux-cored arc welding (FCAW) are the most prevalently used welding methods [8]. Nowadays, SMAW are the most commonly-used method among other arc welding processes [9]. The GMAW welding process is made via the heat generated by the arc between the filler electrode and the work piece. Shielding is made entirely from an external source of a gas or a mixture of gases [10]. FCAW utilizes flux-cored wires which is very similar to arc welding with the MAG, except that cored and solid wire, a special kind of welded wire that is in the form of a hollow tube [11]. Moreover, GTAW, SAW, and PAW are common welding methods in different industries. In GTAW process, the arc appears between the tungsten electrode and a molten pool. Electrode protection and welding area are provided by neutral gases such as argon and helium [12]. In SAW, there is one or more arcs between the bare metal electrodes or the electrodes (welded wire) and the pots. Powders used in the sub-powder welding are often granular grains including metallic oxides of natural or melted minerals [13]. PAW welding is an appropriate method for non-ferrous metals, high-alloy stainless steels, and high-speed plasma heat welding. The ionized gases were created when the gases are heated and placed between the two poles of high voltage current. In order to melt metals and eventually weld them, it is necessary to focus ionized gases using a nozzle in high temperature and speed [14]. Various types of welding processes development raised different welding pollutants exposure subjects [15].

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The size of aerosol in the welder's airborne ranges from 100 nm to 1 mm, which are easily respirable [16]. Welding fumes may cause acute respiratory effects including airway irritation, acute bronchitis, metal fume fever, cardiovascular effects, and less commonly, hypersensitivity pneumonitis or occupational asthma [17,18]. Excess cancer risk among welders has been reported in several cohorts [19] and case-control [20] studies. Concentration of fumes produced in a welding operation is a function of welding operation, type of alloy, voltage, impedance volume, and gas content in the environment, evaporation, temperature, chemical reactions, and the elements used in electrode [19].

Nearly, 90 to 95% of the fumes are released from the filler metal of consumable electrodes [20]. Approximately, 13 metal fume is produced during the welding process [21]. Risks of cancers among welders may also be increased by exposure to several known or suspected carcinogens including lead, nickel, hexavalent chromium, and cadmium [22]. Gaseous pollutants are also generated during welding operation including nitrogen dioxide, carbon monoxide, carbon dioxide, ozone, and nitrogen oxide. O_3 is a strong oxidant that induces the production of reactive oxygen species (ROS) in tissue, and even causes DNA mutation [23]. Welding operations are producing comparatively high concentrations of O3 which can cause occlusive impairment of the welders' bronchioles [24] . Co is a colorless, tasteless, odorless and non-irritating gas which can be a lethal poison [25]. CO_2 acts as a “greenhouse gas” which plays an important role in global warming and climate change [26]. Exposure to high concentrations of oxidant gas, NO_2, and NO can induce respiratory diseases such as acute inflammation and pulmonary edema [27, 28].

Considering different types of welding processes and the growing number of welders who are at risk of exposure with metal fumes and hazardous gases, identifying and determining the level of exposure to them considerably help to prioritize control measures and identify high risk groups. So, the present study was aimed to measure the exposure levels of welders to fumes and gases in seven of arc welding processes in a melting company.

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MATERIALS AND METHODS

STUDY DESIGN AND WELDING TYPES:

A descriptive cross-sectional study was performed for arc welding processes in a melting company. The processes were TIG, SAW, MMA and GMAW. For determining the exposure level of welders, fourteen welding stations were randomly selected as a sample size. In each station, three samples of the respiratory zone of the welders were investigated.

SAMPLING AND ANALYTICAL METHOD:

The personal sampling and analysis of metal fumes was done according to National Institute of Safety and Health (NIOSH 7300) method [29]. For this purpose, cellulose ester membrane (MCE) (25 mm, 0.8 µm, SKC Inc., USA), nylon cyclone, a personal sampling pumps with a flow rate of 2 L/min (224-PCMTX8, SKC Inc.), and a digital calibrator (SKC Inc., USA) were used. The samplers were connected to the collar of the welders on their breathing zone with a sampling pump, trapping metal fumes in MCE filters from the air. At the end of sampling (1-4 hours), the sampling holders were collected, sealed with cover, and handled to the lab.

Analysis was conducted using inductively-coupled plasma. Chromium (VI) was analyzed based on the NIOSH 7601 method using a visible absorption spectrophotometry (Cary 100, Varian, USA) [30]. Ozone sampling was done through glass fiber filters (GFF) with a diameter of 37 mm and a discharge coefficient of 0.2 L/min with a sampling pump (SKC Co, USA) and based on method No. 214 of the Occupational Safety and Health Administration (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 NO2 sampling from a UV-VIS spectrophotometer.

Direct reading devices were used to measure CO2 and CO emissions. These devices included 1372 NDIR CO meter and 1370 NDIR CO2 meter (TES Electrical Electronic Corp, Taiwan). For each sample, a blank sample was also considered. The psychometric corrections were done for the air pressure and temperature of the sampling location [33].

STATISTICAL ANALYSIS:

All statistical analyses were carried out via SPSS software Ver.21. In order to check the normality of data, the Kolmogorov-Smirnov statistical test was done. The level of significance was taken as 0.05.

RESULTS

The characteristics of the all of the welding processes have been presented in Table 1. The exposure concentration of welding fumes and gases for each welding type have been shown in Table 2 and 3. The metal fumes measurement amounts in the breathing zone of the welders according to different welding types were: 29 $\mu g/m^3$–750 $\mu g/m^3$ (TIG process), 10$\mu g/m^3$–130.9 $\mu g/m^3$ (SAW process), 16 $\mu g/m^3$–4634 $\mu g/m^3$ (PAW process), 13.33 $\mu g/m^3$–3050 $\mu g/m^3$ (MIG process), 2.66 $\mu g/m^3$–2670 $\mu g/m^3$ (MAG process), 17 $\mu g/m^3$–5375 $\mu g/m^3$ (MMAW-720 process), and 62.87 $\mu g/m^3$–5286.66 $\mu g/m^3$ (MMAW-7108 process).

The results showed that the average exposure values for chemical elements of Copper (in TIG process: 750±93.88 $\mu g/m^3$), Iron (in PAW: 4750±765.9 $\mu g/m^3$, MMAW-730: 5375±2255.67 $\mu g/m^3$, and MMAW-E7108: 5286.66±2119.46 $\mu g/m^3$), Manganese (in MIG: 308.33±130.03$\mu g/m^3$, MAG: 343.33±124.32, MMAW-730: 814.5±398.10 $\mu g/m^3$, and MMAW-7108: 755.63±697.41$\mu g/m^3$), and chromium VI (in PAW: 47±55.24 $\mu g/m^3$), MMAW-E720: 1035±304.76 $\mu g/m^3$, and MMAW-7018: 62.87±13 $\mu g/m^3$) were higher than occupational exposure limit-time weighted average (OEL-TWA) recommended by Iran Environmental and Occupational Health Center [31].

The average exposure levels of chemical elements including aluminum, calcium and other of elements in all welding processes were lower than TWA-OEL. The concentrations of welders' exposure to the gases have been shown in Table 3. The average range of exposure level to NO, Ozone, CO, NO_2, and CO_2 were 6.5-12 ppm, 0.16-0.5 ppm, 30-50 ppm, 3.5-6 ppm and 2456-5000 ppm, respectively. This study showed that the average concentrations of exposure to NO_2 and ozone gases in all welding processes were higher than the OEL-TWA. Among all welding types, the maximum exposure concentrations for all of gases were observed in metal inert gas welding (MIG). As

Table 1. Characteristics of welding types understudy

Welding Type		**TIG**	**SAW**	**PAW**	**MAG**	**MIG**	***MMAW-720**	****MMAW-7108**
No. of Welders		2	2	2	2	2	2	2
No. of Welding Station		2	2	2	2	2	2	2
Local Exhaust Ventilation	Yes			✓				
	No	✓	✓		✓	✓	✓	✓
General Ventilation	Yes		✓	✓	✓	✓		
	No						✓	✓
Electrode, Flux or Wire Type		Tungsten (WC)	KJF-920	-	KJG-220	KJG-220	E-7200	E-7108

Table 2 illustrates, the median concentration of all studied metals between different types of welding process were significantly different (P<0.02). According to result of this table, the median concentration of iron, manganese, and chromium metals in MMAW was higher than that of other.

The results also indicated that the median concentration of the some released gases between different types of welding process was not significantly different (P >0.05), (Table 3). The highest median concentration of all interest gases was observed in MIG welding.

Table 2. Median and first quartile (Q1) of welding fume concentration ($\mu g/m^3$)

Welding Type Elements	TIG		SAW		PAW		MAG		MIG		MMAW-720		MMAW-7108		P-value
	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	
Aluminum	185	50	134	33	362	92	862	217	216	54	172	45	196	50	<0.001
Calcium	64	15	57	13	323	80	59	14	77	19	303	75	1639	409	<0.001
Copper	750	188	49	11	14	4	57	14	69	18	24	7	117	29	0.02
Iron	63	15	38	10	4750	1188	2672	668	3054	763	5375	1344	5286	1322	0.01
Magnesium	70	18	32	8	311	78	52	13	10	4	19	5	242	60	0.02
Manganese	71	19	34	10	115	28	343	86	308	77	814	203	755	189	<0.001
Chromium (VI)	38	9	13	3	47	12	4	1	21	6	1035	259	62	16	<0.001

Table 3. Median and first quartile (Q1) of the some released gases during welding process concentrations (ppm)

Welding Type Gas	TIG		SAW		PAW		MAG		MIG		MMAW-720		MMAW-7108		P-value
	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	Median	Q1	
Carbon Monoxide	32	9	42	11	28	8	43	11	48	13	40	11	10	3	0.08
Carbon Dioxide	4602	1150	2460	814	3504	875	4903	1225	4995	1250	4152	1038	3594	900	0.06
Nitric Oxide	11	3	10	2	9	2	5	2	14	3	9	2	11	3	0.06
Nitric Dioxide	7	2	7	2	5	1	5	1	8	2	6	1	7	2	0.07
Ozone	0.3	0.05	0.3	0.05	0.18	0.04	0.52	0.11	0.59	0.13	0.50	0.06	0.2	0.08	0.05

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DISCUSSION

Welding process is an important industrial activity for joining the pieces, however, welding fumes generated during it can be injurious to the welder's health. The level of welding aerosol are key parameters in the health risk of welding fumes.

In the present study, the exposure level to welding fumes and gases released from 7 different types of welding was assessed, although most previous study in this field only were considered 2 to 3 types of welding process for exposure assessment among welders [32].

According to the finding, four metals including Mn, Cr, Cu, and Fe had higher values than others; particularly the level of Mn, Cr, and Cu was significantly high in the MMAW-720 and MMAW-7108 process. So that measured values for Mn (814.5± 398.10μg/m^3), Cr (1035±304.76 μg/m^3), and Cu (750±93.88μg/m^3) were 4.07, 3.75, and 20.7 times of OEL-TWA, respectively. It may be due to factors such as the structure of the metal, plating, types of electrodes, wire of electrodes, voltage, and current [7]. These findings were consistent with the previous studies [27-36] that showed in SMAW welding higher fume generation rates. Yarmohammdi et al. reported that out of 15 samples taken from the breathing zone area of welders, 20% were in standard level and 80% exceeded the recommended level for total fume [19].

In the current study, exposure to the cupper fume emitted during TIG with tungsten electrode was higher than OEL. High copper concentration may be related to the copper electrodes of chemical composition, higher temperatures required to weld, current, voltage, shielding gas, and inadequate ventilation, which cause to high Cu emission [16]. Wang et al. reported that saliva concentration of Cu was significantly higher in welders than in controls ($p < 0.01$); the variation in saliva level of Cu was likely to be associated with airborne Cu levels among study populations [33].

The health effects of exposure to welding fumes on welders has been confirmed [34]. Sinczuk et al. reported that airborne Mn amounts within the range of 0.004 to 2.67 mg/m^3 could induce subclinical disorders on the nervous system [35]. Sriram et al. demonstrated that exposure to Mn-containing welding fume can cause an penetration of Mn in dopaminergic pathways in the brain causing of Parkinson's disease [36].

Generally, the rate of fume emission was depended on the welding type. According to the results, the highest level of fume was observed for MMAW and lowest for SAW processes. This result was also similar to Keane et al. study [37]. Exposure to carcinogenic hexavalent chromium resulting from gas metal arc welding (GMAW) was assumed to be low in comparison with other techniques such as the use of shielded metal arc welding (MMAW), which was known to emit the larger quantities of Cr (VI) [38].

Furthermore, in this study, the level of exposure of welders to gases released during welding processes was investigated. Welding gases can easily enter the respiratory tract and may affect harmfully the health of the welders. This study indicated that the concentrations of NO2 and ozone gases were in critical status. This may be due to the welding process generally in the hot zone of the melting industry, performing long-term welding, applying the high electrical voltage, being covered in the welding area, and lack of proper local exhaust ventilation. Similarity, Schoonover et al. reported that welders were exposed to higher concentrations of NO_2 and ozone than non-welders [39]. Perhaps one of the reasons for the high values of these gases was the welding in the closed space and the duration of welding.

In this regard, most studies have been focused on the related health effects of exposure to NO_2 and ozone. Among all nitrogen oxides, NO_2 was seriously affected welders' health when exposed to high concentrations of NO_2 [40, 41]. Ozone was a strong oxidant that generates reactive oxygen species (ROS) in tissue, and also ambient ROS exposure associated with particles has been determined to cause DNA damage [42]. In the present study, the mean exposure level to NO and CO_2 was less than the OEL-TWA, which was in line with Golbabaei et al. findings [43].They reported that welders exposure to the NO and CO_2 was lower than the OEL-TWA [43]. Halpern et al. reported that exposure to high concentrations CO_2 may lead to cardiac complications among exposed subjects [44]. Our finding showed that during welding processes, MIG welders were exposed to a high concentration of gases. It may be due to day-long welding activity and application of protective gas for correct welding and untrue ventilation.

The exposure level and its duration time must be minimized as much as possible in order to decrease the risk of diseases and probable side effects caused by exposure to welding fumes and gases. Administrative procedure and engineering controls such as improving the efficiency of ventilation systems or applying new control strategy for gas and fume control like thermal plasma technology [45], job-rest rotation, intermittent air sampling and bio monitoring, and appropriate personal protective equipment application can be the preventive measures.

CONCLUSIONS

The results indicated that the metals including Mn, Cr, Cu, and Fe had the highest airborne concentration than others; particularly the level of Mn, Cr, and Cu were significantly higher in the MMAW and SMAW-E7018 processes compared to others. Also, MIG welders were exposed to a higher concentration of gases among the studied welding processes. In our study, welder's exposure levels to toxic metals and gases in some welding types were exceeded from OEL, thus, it is necessary to apply appropriate preventive methods like engineering control measures to effectively keep the good health of welders.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests for any of authors.

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