Original Article

Investigation of Efficiency of Iranian Respiratory Mask Used in Welding Process for Controlling Exposure to Toxic Metal Fumes

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Abstract

Aim: Welding is one of the most common occupations associated with occupational lung disease and is often associated with respiratory symptoms because inhalation is a common way of exposure with welding fume in welders. The aim of this study was to investigate the efficiency and Total Internal Leakage (TIL) valve fabric respiration protection mask made in Iran against different metals in the welding fume. **Methods:** To determine the efficiency of the mask, the concentration of pollutants in the air outside the mask and the concentration of pollutants in the air inside the mask were measured simultaneously. NIOSH 7302 method was used to sample the air inside and outside of the masks. The elements Al, Cu, Fe, Mn, Ti, and Zn in the welding fume were analyzed. **Results:** The efficiency of the mask against titanium and iron metals is higher than other metals. The average efficiency of the respiratory mask is 75.46% and the TIL rate is 23.42%. **Conclusion:** The mask absorbs different metals of welding fumes with different efficiencies. Improving the efficiency of the mask body to create a suitable fit that eliminates or minimizes the leakage caused by the seal is a priority.

Keywords: Efficiency, respiratory mask, total internal leakage, welding fume

Introduction

Today, steel structures have expanded around the world and the importance of welding is unknown to anyone. Globally, more than 2,000,000 and in Europe 730,000 workers are welding full-time. Furthermore, there are 5.5 million work-related welding.[1] Fused welds include shielded metal arc welding (SMAW), submerged arc welding, metal inert gas and metal active gas (MAG) welding, gas tungsten arc welding or TIG welding, flux-cored arc welding, and PAW welding.[2] SMAW welding is the most widely used type of welding. Metal arc welding with a coated electrode depends on the type of electrode.[3] The E7018 alkaline electrode is widely used for welding. This electrode is used in the welding of low-alloy steel that is sensitive to cracking below the welding line, as well as in the welding of thick steel parts with high-carbon content. The advantages of this electrode include the creation of the soft arc, moderate penetration, and low spraying.[4,5] One of the main factors that welders are exposed to it is gases and vapors emitted by the welding process. Welding fumes have a complex composition of gases, metals, and other compounds that are affected by various factors.[6] Welding gaseous pollutants include ozone, nitrous oxide, carbon monoxide, aldehyde compounds, and polycyclic aromatic hydrocarbons. These pollutants also include metal oxides such as Fe, Mn, Zn, Cr, Ni, Co, Cd, Pb, Ti, and V.[7,8] Welding fume can cause adverse health effects such as inflammation and stress oxidative.[9-11] Extremely fine particles of metallic fume (aerodynamic diameter in the range of 0.2–0.6 mm) can lead to airway obstruction, Brooks syndrome, fever syndrome, and chronic diseases such as reduced lung function, asthma, bronchitis, pneumoconiosis, or lung cancer.[12,13] Various metals in welding fumes such as Cr (VI), Be, Cd, and some Ni or Co oxides have been classified as human carcinogenic by the International Agency for Research on Cancer (IARC), European Union, and the German Research Foundation (DFG, 2006, 2012).[14] In addition to the pulmonary effects, inhaled fumes can cause local or

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systemic effects. Chronic aluminum exposure is associated with Alzheimer's disease and lung irritation. Aluminum is one of the most dangerous welding fumes found in alloys of copper, zinc, iron, magnesium, and rice.[15] Copper is one of the fumes found in copper and cobalt alloys, brass, bronze, and welding wire, exposure to this metal fume led to metal fume fever, nausea, vomiting, and irritation of eyes, nose, and throat.[16,17] Iron oxides are found in iron and steel welding processes and the acute effects of exposure to it include irritation and burning of the nose and lungs. Exposure to iron oxides also causes a pulmonary disease called siderosis.[18] Exposure to manganese and zinc oxide fumes in welding process also results in metal fume fever.[17] In Iran, as in other countries, there are many welders in the working areas that are exposed to toxic welding fumes. When engineering controls are unable to control occupational exposure to welding fumes, respiratory protection is recommended. Since, respirator masks are relatively inexpensive and have an acceptable efficiency in particle filtration, studies on respiratory masks have typically included the certification of respiratory mask particle protection (NIOSH 42 CFR 84) using a human model in the laboratory.[19]

The results of Rengasamy and Eimer's study on the rate of particle penetration in two types of N95 masks and a surgical mask showed that the surface resistance of the mask and the leakage around the face are two important factors in determining the effectiveness of the mask.[20] He *et al*., examined the effect of leakage around the face, respiratory flow, and composition of combustible materials on the penetration of particles in half-face and full-face masks with P100 filters. The results showed that the composition of combustible materials and leaks around the face have a significant effect on the rate of penetration.[21] There have been limited studies on the efficacy of respirators in Iran, none of which have examined the efficacy of respiratory masks against welding fume.[22,23] Zare *et al*. examined the respiratory masks used by refractory workers to control exposure against particulate pollutants. The results of the study showed that the resistance of the mask surface and the penetration of air from the empty space between the face and the mask are the main factors in determining the efficiency of the mask.[24] Common types of respiratory protection masks used in most industries are FFP2, single, and double filter masks.

Since respiratory masks that were made in Iran and widely used in welding processes have not been investigated in the field conditions, the aim of this research is assessment concentration of toxic metals in the welding process inside and outside of the common Iranian mask in welding process. Furthermore, in this research, the efficiency and total internal leakage (TIL) of said respiratory protection mask in field conditions will be investigated.

Methods

This is a cross-sectional and descriptive-analytical study conducted in one of the Iranian steel industries.

In this study, three welders who performed SMAW welding were selected and the E7018 alkaline electrode was used in this process. Their average age was 34.3 years, their average height was 177.3 cm, and their average weight was 77.6 kg.

One type of masks, namely FFP2, was studied and the performance of the mask against toxic metals was investigated. Each person was studied three times, and a new mask was prepared and given to the individual each time.

For subjects, only the healthy persons were selected, while those with wheezing, used glasses, did not consent to participate in the study, history of smoking/tobacco chewing, visible chest wall bony, muscular deformities, history of cardiac and respiratory disease (e.g., overt asthma), and history of medications, such as antiasthmatics and others, were excluded from the study.

The data on the health status of the study group were collected using the standard Respirator Medical Evaluation Questionnaire.[25] The questionnaire was translated into the local language.

In this research, after educating welders on how to use respiratory protection masks correctly, sampling was carried out based on the 7302 method of the NIOSH.[26] The calibrated individual sampling pump (SKC, 222-44TX) was used and sampling was performed using a MCE filter with 37 mm diameter and 0.8 µm pore size. Flow rate and sampling time were 3 L/min and 33 min, respectively. For sampling from inside the mask, an 8.1 mm hole in the nose and mouth area was created[27] and input of the holder was connected to the probe that was inserted into the mask hole [Figure 1]. The length of the tube between the cassette and the mask was chosen to be 15 cm in all cases.

Sampling was performed in the welding workshop of one of the country's steel industries. Welding conditions including welding type, electrode type, electrode size, device voltage, welding location, desk height, welding intensity, metal type of welding part, pollution volume of welded fume produced, and individual body posture during welding were the same for all

Figure 1: Sampling from inside the mask

participants in the study. The workshop environment lacked general and local ventilation.

The ambient temperature of the workshop was equal to 21°C ± 2 and the humidity was equal to 37% ± 5. All measurements were performed at the same time (9 AM to 11:30 AM).

To determine the efficiency and TIL rate of the mask, concentrations of toxic metals were measured outside (C_{out}) and inside (C_{in}) the masks simultaneously during welding.[21,28] The following formulas were used to evaluate the effectiveness of respiratory masks against metal fumes and TIL for each respiratory mask.

Equation 1:

$$\text{Efficiency (\%)} = ((C_{out} - C_{in})/C_{out}) \times 100.$$

Equation 2:

$$\text{TIL (\%)} = (C_{in}/C_{out}) \times 100.$$

The samples were analyzed by inductively coupled plasma (ICP) with the aim of determining the concentrations of aluminum, copper, iron, manganese, titanium, and zinc in welding fumes. Finally, according to the concentration of metals in the air of inside and outside the masks, protective efficiency and TIL of each mask against the toxic metals were calculated. Data were analyzed using SPSS statistical software version 26 SPSS statistical software version 26 (IBM Co. Armonk city, New York, USA).

Results

Samples were analyzed using ICP. Concentrations of each element (AL, Cu, Fe, Mn, Ti, and Zn) inside and outside of the masks are reported in Table 1. The reported numbers are the average number of trials (three times) for each subject.

Table 1 reports the average concentration standard deviation of metals inside and outside of the mask.

Table 2 shows the efficacy and TIL rate of respiratory protection mask against the various metals in the welding fume. The efficiency of the selected respirator mask against titanium and iron metals is higher than other metals. In contrast, the lowest efficiency of the studied mask is against zinc metal.

Table 3 lists the average concentrations of contaminants in the welding fume in all samples taken inside and outside of the mask.

The highest and lowest concentrations are related to iron and copper, the amount of which was 0.3956 and 0.0025 [μg/Li] in the outer part of the mask and 0.0310 and 0.0006 [μg/Li]) in the inner part of the mask, respectively.

Figure 2 shows the efficiency and TIL of the mask for the subjects.

Discussion

The amount of leakage in the masks is a very important factor that should be given special attention along with the filtering properties of the mask. This factor depends on specific parameters such as anthropometric characteristics of the users and the dimensions of the mask, the use of face insulation at the location of the mask on the face, the storage conditions of the mask, and its efficiency against particles of different sizes. For this purpose, special attention should be paid to the selection of a suitable mask.

Table 1: The average concentration and standard deviation of metals inside and outside of the mask

	Zn (μg/Li)	Ti (μg/Li)	Mn (μg/Li)	Fe (μg/Li)	Cu (μg/Li)	Al (μg/Li)
Subject A						
Inside of the mask						
Average concentration	0.0023	0.0003267	0.0025	0.0164667	0.0005333	0.0024
SD	0.0007	0.00002517	0.0009165	0.006124	0.0001528	0.0013115
Outside of the mask						
Average concentration	0.0044333	0.0034	0.0203	0.1849	0.0023	0.0074667
SD	0.0011372	0.0006245	0.0059758	0.0373595	0.0008185	0.0012342
Subject B						
Inside of the mask						
Average concentration	0.0024333	0.0002833	0.0024333	0.0196667	0.00062	0.0018
SD	0.0002309	0.0000611	0.0014468	0.0042525	0.0000608	0.0001732
Outside of the mask						
Average concentration	0.0064667	0.0071333	0.0263	0.4751	0.0033	0.0122333
SD	0.0015567	0.0018037	0.0052048	0.0328556	0.0009849	0.0008083
Subject C						
Inside of the mask						
Average concentration	0.0027667	0.0011667	0.0146333	0.057	0.0007	0.0022333
SD	0.000611	0.0004041	0.0051189	0.0192873	0.0001	0.0002517
Outside of the mask						
Average concentration	0.0086667	0.0124667	0.1239667	0.527	0.0021767	0.0189667
SD	0.0096438	0.0157042	0.1541843	0.6124288	0.0012176	0.018216

SD: Standard deviation

Table 2: The efficacy and total internal leakage rate of respiratory protection mask

	Zn (%)	Ti (%)	Mn (%)	Fe (%)	Cu (%)	Al (%)
Subject A						
Efficiency	47.543248	90.059354	86.295746	90.758671	74.984127	65.127381
TIL	51.879699	9.6078431	12.315271	8.9057148	23.188406	32.142857
Subject B						
Efficiency	61.386243	95.814815	91.193791	95.808049	80.139402	85.30021
TIL	37.628866	3.9719626	9.252218	4.1394794	18.787879	14.713896
Subject C						
Efficiency	68.076661	79.526922	74.316109	78.301592	52.288153	79.766041
TIL	31.923339	9.3582888	11.804248	10.815939	32.159265	11.775044

TIL: Total internal leakage

Table 3: The average concentration of different metals in all samples inside and outside of the mask

The average concentration in all samples	Zn (µg/Li)	Ti (µg/Li)	Mn (µg/Li)	Fe (µg/Li)	Cu (µg/Li)	Al (µg/Li)
Inside of the mask	0.0025	0.0005922	0.0065222	0.0310444	0.0006178	0.0021444
Outside of the mask	0.0065222	0.0076667	0.0568556	0.3956667	0.0025922	0.0128889

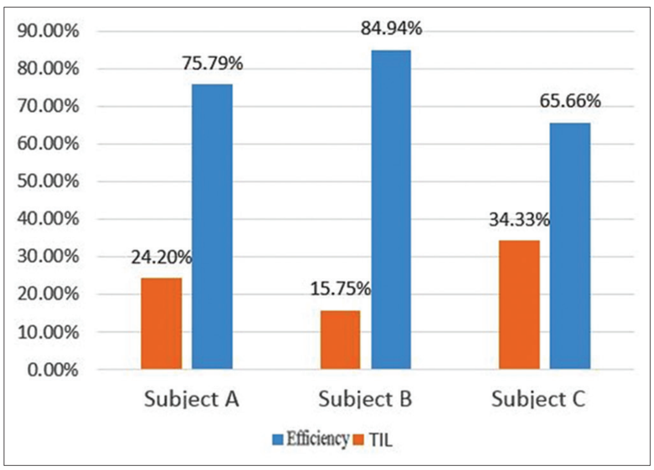

Figure 2: Efficacy and total internal leakage mask in subjects A, B, and C

Table 1 lists the standard deviation and mean concentration for different metals inside and outside of the mask and in different individuals as micrograms per liter. According to the table, the lowest standard deviation in the outside part of the mask was related to the titanium and person A, which indicates that the data are close to each other. The highest standard deviation in the outer part of the mask is related to Fe metal and in the data related to person C, and it expresses the exposure of person C to different concentrations of iron.

Since the exposure to the highest concentration of welding fumes was for the subject C so the efficiency of the respiratory protection mask for this subject was lower in comparison to the subjects A and B. On the other hand, the efficiency of the respiratory protection mask for subject C is less than subject A and B. This result can be explained by the fact that as the concentration of contaminants outside of the mask increases, the efficiency of the mask decreases. The relationship between filter resistance and airflow velocity is as follows:

$$\text{Resistance} = \frac{\text{Area} \times \text{Pressure drop}}{\text{Flow rate}}.$$

Because the surface of the mask is fixed, the resistance is equal to:

$$\text{Resistance} = \frac{\text{Pressure drop}}{\text{Flow rate}}.$$

This relationship shows that the incoming air is inversely related to the resistance of the filter. Increasing the contamination density on the filter surface increases the resistance of the mask and reduces airflow from the filter. As a result, air passes through the pores between the person's face and the mask, which is not fit and has less resistance, and reduces the efficiency of the mask. The air passing around the mask has a high concentration of pollutants (concentration equal to the concentration of air outside the mask). Therefore, the higher the percentage of air passing through the side of the mask, the higher the concentration of contaminants in the indoor air of the mask and the percentage of penetration. Finally, increasing the contamination density on the surface of the mask reduces the efficiency of the mask and increases its leakage. Examination of the data related to the measurement of the concentration outside the mask and its correlation with the analysis of the data related to the efficiency of the mask for subjects A, B, and C confirms the above explanations. The results of some studies are consistent with the present study.[19,20,29]

Table 2 shows that the performance of the mask understudy varies for different metals in the welding fume. The respirator mask filters approximately 89.95% of iron, 88.46% of titanium, and 83.93% of manganese in the welding fume. Although the concentration of manganese in the welding fume is higher than that of titanium, the efficiency of the mask for filtering titanium is higher than that of manganese. This result is probably due to the physical, chemical, and behavioral characteristics of the metal particle in the welding fume.

Mask TIL against some contaminants, including iron, is very low, possibly due to the cumulative nature and high size of these particles. In contrast, the overall internal leakage of the mask against zinc metal is very high (70.20%). The TIL against zinc metal is much higher than the internal leakage of the same mask for iron or manganese fume. The reason for the high general leakage of Zn metal is that the ICP detection limit for this metal was high (2 µg). In other words, the concentration of zinc outside the mask was different, but because the concentration of zinc inside the mask was less than the device detection limit, the detection limit of the device was reported as the internal concentration of zinc inside the mask. The maximum TIL in particle masks according to the BS-EN149: 2001 standard is 22%, 8%, and 2% for FFP1, FFP2, and FFP3 masks, respectively.[30]

The mean concentrations of the metals detected in the metal fume resulting from welding with the E7018 electrode are shown on the inside and outside of the mask in Table 3. The results showed that in SMAW welding with E7018 electrode, iron and manganese are among the most abundant metals in the welding fume, which is consistent with the study of Jenkins and Eagar.[31] The lowest concentration of metal pollutants is related to zinc and copper metals.

In samples where the amount of contamination outside of the mask is high, the efficiency has decreased. Excessive TIL in these samples is due to contamination of the surface of the mask that creates a lot of respiratory resistance and causes air to penetrate into the mask from where the mask is not fitted to the face and has no resistance to air entering. The results of the study are consistent with the studies of Nelson and Colton[29] and Rengasamy and Eimer.[19]

Figure 2 shows the efficiency of the mask for different subjects. In the present study, the TIL level for person B is the lowest value (15.75%). The efficiency of the mask for subject B is higher than for subjects A and C. This could be due to the fact that the mask is more suitable with the face anthropometric profile of subject B. The low efficiency of the subject C mask can be described by the incompatibility of the mask with the person's face and the high concentration of contaminants on the outside of the mask.

The average efficiency of a valve cloth respiratory mask in all samples is 75.46% and the TIL rate is 23.42%. However, the maximum TIL for the FFP2 particle mask is 8% according to BS-EN149: 2001.[30] This difference can be due to factors such as (1) incompatibility of the mask to the worker's face in terms of anthropometric dimensions, (2) the use of face insulation in the place where the mask is placed on the face (the amount of fit of the mask on the face), and (3) conditions for keeping the mask on the face (such as face retaining strips).

Conclusion

In general, it can be mentioned as a general recommendation in the development of respiratory protection masks that improving the efficiency of the mask body to create a suitable fit that eliminates or minimizes the leakage caused by the seal is a priority, which is consistent with the results of other studies.[32] The effectiveness of valve cloth respiratory protection mask is 75.46%. According to the standard, this mask is in the FFP2 category, which means that it has 95% efficiency against particles. This difference in performance is due to the incompatibility of the mask with the worker's face, which causes the mask to leak. The results showed that the mask has different performance against different particles in the welding fume. In other words, the mask absorbs different metals of welding fumes with different efficiencies. Since each new respiratory mask was tested, all data are based on the new respiratory protection mask, and it is not possible to comment on the change in performance of the mask over time and repeated use.

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Conflicts of interest

There are no conflicts of interest.

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