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Occupational Health Risk Assessment of Inhalation Exposure to Welding Fumes

Siti Farhana Zainal Bakri[1], Azian Hariri[2], Marzuki Ismail[3]
[1]Faculty of Engineering and Technology, DRB-HICOM University of Automotive Malaysia, 26607 Pekan, Malaysia, farhana@dhu.edu.my
[2]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Malaysia, azian@uthm.edu.my
[3]School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Malaysia, marzuki@umt.edu.my

ABSTRACT

This study is to assess the health risk of heavy metal in welding fumes that may affect the human respiratory system. It is imperative to evaluate the current condition in the automotive industry in Malaysia, the welders exposed to welding fumes via inhalation before any risk control implemented. In this study, three manufacturing industries associated with automotive production were selected for health risk assessment from hazardous chemical exposure among welders. The developed method by Malaysian Department of Occupational Safety and Health (DOSH) and EPA inhalation risk assessment model were adopted in this study. The result indicates that exposure to heavy metals in welding fumes was found significantly higher for both occupational hazard risk and EPA inhalation risk assessment method at the range of 82% to 89% in which exceeded the permissible exposure limit (PELs). The finding of the corrective measures at all selected plants should be implemented to reduce heavy metal fumes in welding areas, thus lesser the occupational risk among automotive industry welders.

Key words: Automotive Production, Health Risk Assessment, Inhalation Exposure, Welding Fumes, Welders.

1. INTRODUCTION

The issues of welding fume exposure have received considerable critical attention, especially that relates to the impacts towards welder's health all over the world. In Malaysian automotive industries, metal inert gas (MIG), spot weld and the robotic weld are the common tools that used for metal joining of automotive part and components [1]. The principal function of welding is normally applied for fabrication, joining and repairing of metal product in manufacturing sectors and it is extensively applied in the automotive industries. In automotive industries, a welding technique is used to join a wide variety of automobile components. MIG is often used in the automotive industry because of its versatility, quality and low or high speed. Normally, in this conventional welding, additional material (reinforcement pad) is added to the weld joint to produce a strong bond. The resistance spot welding is also a significant process in the automotive industry that carries an advantage of the economic process, adaptable to material variety, and have a short cycle time. The past decade has seen the rapid development of welding application in many manufacturing industries. With the advance in prevailing manufacturing process especially in targeting a mass production demand, a mechanized, automatic and robotic tool for industrial welding have become crucial in automotive industries. However, in Malaysian automotive industries, the application of robotic welding is still limited due to the operation cost.

Despite its technological advanced, welding has some problems in use. Currently, exposure to welding fume is a growing public health concern worldwide. Fumes generated from welding process is commonly contributed to the increased of lung impairment among welders due to chemical toxicity and long-term exposure [2]. Aluminium (Al), beryllium (Be), cadmium oxides (CdO/Cd), chromium (Cr), copper (Cu), fluorides (F), iron oxide (Fe_2O_3), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), vanadium (V) and zinc oxide (ZnO) are the metals that commonly existed in the welding fumes [3]. The direct or indirect exposure and inhalation of welding fumes in a long time can lead to local or systemic effect among the welders [4]. Not only affected respiratory systems when the fumes enter the lungs, but also other health problems caused by the penetration of fined particles into the bloodstream, nerve cells or other organs. This may cause either short-term such as irritation to the eye, fever, metallic taste in the mouth; or long-term effects such as the decline of lung function or the existence of occupational asthma. The risk assessments conducted following the standard procedure from the Malaysian Department of Occupational Safety and Health and Environmental Protection Agency.

In Malaysia, it is a crucial duty for the employer to protect their employees at the workplace and this has been stipulated under the Occupational Safety and Health Act 1994. To ensure this duty is taken care, the assessment for all chemicals that were used in the workplace is mandatory and this includes the identification, evaluation and mitigation of chemical risk exposure to health. The assessment is conducted following the guideline provided under the Occupational Safety and Health (Use of Standard of Exposure of Chemicals Hazardous to Health) Regulations 2000 and is known as chemical health risk assessment (CHRA). The similar assessment of risk is applied internationally under the Environmental Protection Agency.

The main objective of this paper is to assess the occupational health risk arising from the welding fume. The finding from this research provides beneficial in the formulation of occupational health policy in Malaysia as well as to enable managerial decision in industries which relates to the appropriate control measures; exposure monitoring and medical surveillance.

2. MATERIALS AND METHODS

2.1 Study Population

Three private sectors of large scale automotive industries in Peninsular Malaysia are selected to investigate the effect of metal fumes exposure emitted from metal inert gas welding (MIG), spot weld and robotic weld towards welders. All these companies are involved in the manufacture, assembly, supply, equipment and spare parts of vehicles. In normal working hours, these welders had an average exposure time of 8hrs/day or 40hrs/week to contaminant at the workplace. Welders working in these industries participated voluntarily and are aware of the study objectives. In this study, the area of welder was divided to Plant 1 in which the welder worked in a closed area, Plant 2 and 3 in the semi-closed area at mean temperatures of 27.18^{o}C, 30.13^{o}C, 30.92^{o}C and air movement 0.48 m/s, 0.22 m/s and 0.37 m/s, respectively.

2.2 Sample Collection and Analysis

The personal samplings have been conducted where the sampling equipment was attached to selected welders that represent welding points. Fourteen elements were weighed by using inductively coupled plasma mass spectrometry (ICP-MS). The concentrations were converted into unit milligram per meter cubic at ambient condition (mg/m3) and the exposure limit of traced metal was calculated in 8-hours TWA according to the formula stated in (1) [5].

$$E = (C1T1 + C2T2 + \ldots + CnTn) / (T1 + T2 + \ldots + Tn) \quad (1)$$

In Equation (1), E is the exposure in the working shift; C is the concentration (mg/m^3); T is the duration in hours of the exposure at the concentration C (hour), and n is the total number of intervals measured. The result obtained from this mathematical computation and then divided to the permissible exposure limit (PELs) stipulated under Occupational Safety and Health (Use and Standard of Exposure Chemical Hazardous to Health) Regulations 2000 (USECHH Regulations) to determine the exposure rating [6]. The statistical analyses of the arithmetic mean, geometric mean and geometric standard deviation are computed using Microsoft Excel 2010.

2.3 Exposure and Health Risk Assessment Method

The health risk assessment of welders with prolong exposure to fumes is conduct by adopting the manual provided by the Malaysian Department of Occupational Safety and Health and the United States Environmental Protection Agency method [7], [8]. The assessment begins by gathering the concentration of chemical exposure at the workplace using a personal sampling method. The risk assessment is conducted through a generic approach during the work activities and the time exposure is similar and with a comparable level of risk. In the evaluation of exposure time to welding fume, the welders exposed to this risk have been assigned to a work unit. The unit is classified as a group of workers that faced a similar potential exposure of metal fumes emitted from welding activities. In determining a degree of hazard, the hazard rating (1 to 5 scales) is used depends on the potential health effects of the chemical with rating 1 is considers as non-hazardous while rating 5 is most hazardous to health. The H-Code for each chemical constituent that exists in the welding fumes is referred to the Malaysian Industry Code of Practice on Chemical Classification and Hazard Communication that has been approved by the Minister under Section 37 of Occupational Safety and Health Act 1994 (Act 514) since the industries do not have the Safety Data Sheet (SDS) that related to the welding. The list of chemicals is referring to Part 1 of the Industry Code of Practice (ICOP) as stated under Classification, Labelling and Safety Data Sheet of Hazardous Chemicals Regulations 2013 (CLASS Regulations).

For any chemicals that are not listed in ICOP, the information on health effects, hazard classification, hazard statement or acute toxicity data through inhalation is examined to determine the hazard rating. Generally, this in line with the Globally Harmonised System of Classification and Labelling of Chemicals (GHS) 2017 [9]. In case of the hazard statement unable to be differentiating for its category or sub-category of hazard classification, the highest category or sub-category is assumed. This study is focusing on the health hazards that enter through the body via inhalation exposure and its impact on respiratory systems since this is the common route of entry in the industry as tabulated in Table 1. Also, the information on chemical toxicity data is been explored from other sources available [10]. The evaluation of exposure is carried out by using a quantitative method as shown in (2).

$$RR = HR \times ER \quad (2)$$

In Equation (2), RR indicates the likelihood of injury or illness (rating 1 to 25); HR indicates the severity of adverse effects (rating 1 to 5), and ER indicates the chance of overexposure to the chemical hazardous to health (rating 1 to 5). The detail health risk assessment of inhaled toxic metal fumes is conducted according to the personal health risk assessment issued by the [8]. The assessment of occupational health risk is comprised of the evaluation of chemical concentration at the workplace, cancer and non-carcinogenic risk assessment. The exposure concentration of toxic and hazardous metal fumes is computed according to (3):

$$EC = (CA \times ET \times EF \times ED) / AT \quad (3)$$

From this equation, EC is the exposure concentration (mg/m^3); CA is the hazardous air concentration at the workplace (mg/m^3); ET is the exposure time of employees in the workplace (hr/day); EF is the exposure frequency of employees in the workplace (240 days/year); ED is the exposure duration (constant 40 years, provided that an employee begins working at 20 years old and retires at 60 years old); AT is the average exposure time (h) equivalent to ED × 24 × 365. In the health risk assessment, the non-carcinogenic risk is calculated by (4) while the cancer risk is computed by (5) respectively [11]. The RfC is the inhalation toxicity reference value or also known as reference concentration value (mg/m^3) while hazard quotient (HQ) is evaluated for the non-carcinogenic risk. If the value of HQ is greater than or equal to 1, this indicates the toxic chemical has a higher non-carcinogenicity risk and vice versa. In this study, the evaluation of HQ is only estimated for the Mn as the RfC value for other metals (Cu, Zn, and Ag) is not available.

$$HQ = EF / RfC \quad (4)$$

$$\text{Risk Cancer} = IUR \times EC \quad (5)$$

The IUR is the inhalation unit risk (m^3/mg). The finding value shows the toxic chemical in the workplace environment have a higher cancer risk if the risk value is greater than 1 x 10^{-6} while if the finding is lower than this, it indicates a lower cancer risk. The computation of cancer risk is focusing only on five traced metals of Cr, Co, Ni, As and Pb as the IUR for both Al and Fe is not available [12],[13]. The specific value for both RfC and IUR for the inhalation exposure is assessed from the Integrated Risk Information System database [14]-[17].

This study is focusing on the health hazards that enter through the body via inhalation since this is the common route of entry in the industry as presented in Table 1. The purpose of evaluating workplace exposure is to identify the potential of health impact due to exposure to welding fume entering the body through inhalation and the severity of adverse health effects towards welders. The intensity or magnitude, duration and frequency of exposure are taking into consideration to evaluate the degree of exposure at the workplace represented as exposure rating (ER). Metal that less or none found in the personal sampling such as Mo, Be and Cd are not considered for the assessment in this study. The result obtained from a measurement of personal sampling that has been attached to workers' breathing zone shows the distribution of exposure concentration as the worker exposure concentration is fluctuated either in work shift or day-to-day manner.

Table 1: Hazard rating for inhalation exposure based on H-Code of welding fumes constituents and its impact on human respiratory systems

Trace Metal	CASRN	GHS Classification*		Assign HR	HR
		Hazard Category	H-Code		
Al	7429-90-5	1	H370	5	5
		1	H372	4	
Cr	7440-47-3	1	H334	4	4
		3	H335	3	
Mn	7439-96-5	2	H373	3	3
Fe	1309-37-1	-	-	-	-
Co	7440-48-4	1, 2	H330	5	5
Ni	7440-02-0	2	H351	3	4
		1	H372	4	
Cu	7440-50-8	3	H331	3	3
		3	H335	3	
Zn	1314-13-2	1	H370	5	5
As	7440-38-2	3	H331	3	3
Ag	7440-22-4	1	H370	5	5
		1	H372	4	
Pb	7439-92-1	4	H332	2	3
		2	H351	3	
Be	7440-41-7	1 , 2	H330	5	5
		3	H335	3	
		1A, 1B	H350i	5	
		1	H372	4	
Mo	7439-98-7	3	H335	3	3
Cd	7440-43-9	1 , 2	H330	5	5
		1A, 1B	H350	5	
		1	H372	4	

CASRN = Chemical Abstracts Service Registry Number; GHS = Globally Harmonised System of Classification and Labelling of Chemicals; HR = hazard rating (highest).

3. RESULTS AND DISCUSSIONS

Table 2 shows the geometric mean (GM), geometric standard deviation (GSD), permissible exposure limit (PEL) and assigned exposure rating based on the PELs. The results of GSD had shown that there is a high variation of chemical concentration in Plant 1 (Cr, Co, Cu and As), Plant 2 (Ag) and Plant 3 (Mn, Fe, Zn, and Ag) respectively. The geometric mean from the 8-hours TWA of full period consecutive samples in the data measurement is used to determine the exposure rating and the results are presented in Table 3. The permissible exposure limit value is interpreted from the ratio of the geometric mean concentration of a pollutant in the air (in unit mg/m^3) to the metals permissible concentration (in unit mg/m^3) as stipulated under USECHH Regulations 2000. The data interpretation of exposure measurement had shown that 82% had exceeded the PEL; 3% is more than 0.75 PEL but still does not exceeded the reference concentration; while the 9% is lower than 0.5 PEL. The finding is crucial as this risk assessment can help in the development and adopt a managerial decision in both regional and national level to minimize the health impact among workers from job environment. The risk determination is presented in Table 4. This quantitative assessment has found that generally metal fumes that emitted from welding activities had the potential to pose welders to high risk. The application of local exhaust ventilation systems in both closed or semi-closed environment is practical to remove fume and gases from welder's breathing zone by keeping the fume extractor guns, fume hood and vacuum nozzle close to the plume source.

From the overall risk determination level based on RR in Table 4, 89% of the heavy metal such as chromium, manganese nickel, copper, arsenic, silver and lead accumulated in the welding area is considered as high risk while 11% is a moderate risk (for aluminium, cobalt and zinc found in Plant 1). In this comprehensive analysis of risk assessment results, the results of the EPA inhalation risk assessment model shows quite a significant similarity with the occupational hazard risk (based on RR) in the workplace (refer Figure 1). The result of inhalation risk evaluation for non-carcinogenic and carcinogenic risk according to EPA method is shown in Table 5. The chemical concentration emitted from MIG process is found highest in Plant 1. For non-carcinogenic risk, the existence of Mn in welding fumes for all industries had shown a high occupational health risk in all tested posts where the highest of non-carcinogenic hazard quotient (HQ) for Mn is exhibited from MIG welding at Plant 1 with result finding is 1.143×10^7 compared to other types of welding in Plant 2 and Plant 3 [18]. The occupational health risk of carcinogenic metal exposure had shown that all carcinogenic traced metal is a high risk especially in Plant 2 for spot weld where the highest concentration is recorded for Co, Ni and Pb elements compared to Plant 3. However, the emission of Cr, Ni and As from robotic welding is higher compared to Plant 2. The emission of welding fumes is varies depending on many factors and not only influenced by the method and materials used. Most of the metal constituents from welding fumes are originated from welding consumable and little percentage had arisen from the base material [19].

Similar to the other study, the chromium concentration generated from welding activities in these industries are exceeded compared to other metal fumes [20]. The previous research had highlighted that 90% to 95% of metal fumes generated from welding activities came from the filler metal and flux coating [21]. In mitigating the arising problem due to welding fumes exposure, source control is a crucial solution to reduce the number of metal concentration generated from welding activities. In overall, the risk is classified as higher with inadequately control. Plant 1 had installed local exhaust ventilation to reduce the number of contaminants in breathing zone while there is no LEV was installed in Plant 2.

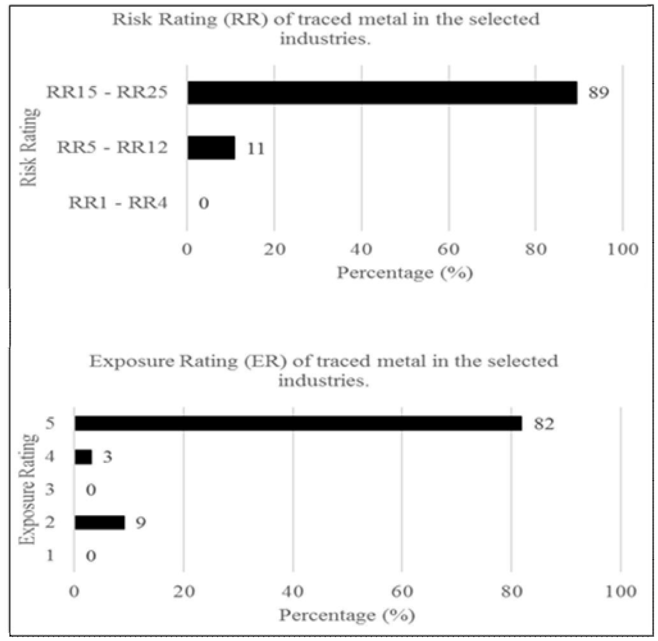

Figure 1: Comparison of EPA inhalation risk assessment model (ER) with the occupational hazard risk (RR) of the welding area in the selected industries.

However, the position and the usage of LEV installed are questioned as the concentration of traced metal in Plant 1 is quite similar or higher than in another plant. In Plant 3, only one LEV is applicable and was installed on the robotic welding. The use of fan at the workstation is the main ventilation at the welding area for both Plant 2 and 3. Only workers that handle MIG is wearing the respiratory devices while the rest of welders that handle spot welding and work near to robotic welding did not wear any respiratory protective equipment during working activities.

In improvised the workplace conditions and minimize the occupational health effects due to exposure to the toxic and hazardous chemical, the employer is responsible to conduct a regular workplace assessment to ensure the concentration of the hazardous substance is below than PELs and need to take a serious action in any related aspects according to the hierarchy of control due to welders can be considered as a high-risk group and have a potential to get cancer [22]. Thus, the control measures for moderate and high risk need to take into consideration immediately and establish an action plan to be implemented where the consideration of the combination control measures following the hierarchy of control as specified in the USECHH Regulations is recommended. Meanwhile, all employers must adhere to Section 15 subsection (2) (e) and Section 24 subsection (1) (c) stipulated under OSHA law 1994 for responsibilities to taken care the safety, health and welfare as well as the purpose of preventing risks to their employees.

Table 2: The general distribution of welding exposure concentration in industries.

Metal	Plant 1			Plant 2			Plant 3		
	AM	GM	GSD	AM	GM	GSD	AM	GM	GSD
Al	1.388	1.387	1.048	67.082	66.458	1.168	45.023	42.606	1.430
Cr	101.706	51.736	6.260	197.172	194.182	1.219	293.866	291.480	1.149
Mn	2607.870	2578.711	1.237	7.132	6.830	1.406	32.475	23.317	2.454
Fe	1914.947	1887.652	1.272	205.830	182.659	1.718	201.416	31.676	32.155
Co	0.032	0.007	25.184	0.825	0.768	1.479	0.423	0.388	1.554
Ni	56.292	51.519	1.830	2.083	1.720	1.957	1.363	1.233	1.663
Cu	15.074	11.388	3.032	6.716	6.507	1.334	5.595	5.047	1.641
Zn	0.748	0.745	1.141	19.865	18.085	1.623	7.226	5.206	2.512
As	78.792	6.040	100.539	56.074	55.330	1.204	65.915	65.657	1.101
Ag	n.d	n.d	n.d	5.609	1.950	5.672	1.371	0.795	2.778
Pb	n.d	n.d	n.d	82.533	79.580	1.335	62.596	57.242	1.564

AM = arithmetic mean; GM = geometric mean; GSD = geometric standard deviation; n.d = not detected.

Table 3: Inhalation exposure rating based on airborne exposure measurement in industries

Metal	Plant 1		Plant 2		Plant 3		USECHH Regulation 2000 (mg/m^3) in 8-hours TWA
	PEL	ER	PEL	ER	PEL	ER	
Al	0.277	2	13.292	5	8.521	5	5
Cr	103.473	5	388.364	5	582.96	5	0.5
Mn	12893.553	5	34.149	5	116.586	5	0.2
Fe	377.53	5	36.532	5	6.335	5	5
Co	0.327	2	38.395	5	19.375	5	0.02
Ni	34.346	5	1.147	5	0.822	4	1.5
Cu	56.942	5	32.533	5	25.236	5	0.2
Zn	0.149	2	3.617	5	1.041	5	5
As	603.956	5	5533.033	5	6565.731	5	0.01
Ag	n.d	-	19.499	5	7.953	5	0.1
Pb	n.d	-	1591.606	5	1144.833	5	0.05

PEL = permissible exposure limit; ER = exposure rating; n.d = not detected;
ER: ≥ PEL (5); ≥ 0.75 PEL but < PEL (4); ≥ 0.5 PEL but < 0.75 PEL (3); ≥ 0.1 PEL but < 0.5 PEL (2); < 0.1 PEL (1).

Table 4: Risk determination level of traced metal at the welding area in the selected industries.

Traced Metal	Risk Rating (RR)		
	Plant 1	Plant 2	Plant 3
Al	RR10 (M)	RR25 (H)	RR25 (H)
Cr	RR20 (H)	RR20 (H)	RR20 (H)
Mn	RR15 (H)	RR15 (H)	RR15 (H)
Fe	**	**	**
Co	RR10 (M)	RR 25 (H)	RR25 (H)
Ni	RR20 (H)	RR20 (H)	RR16 (H)
Cu	RR15 (H)	RR15 (H)	RR15 (H)
Zn	RR10 (M)	RR25 (H)	RR25 (H)
As	RR15 (H)	RR15 (H)	RR15 (H)
Ag	n/a	RR25 (H)	RR25 (H)
Pb	n/a	RR15 (H)	RR15 (H)

***H-code for inhalation exposure to respiratory systems is not available; n/a: data not available; M = moderate; H = high. Low risk = RR1 to RR4; Moderate risk = RR5 to RR12; High risk = RR15 to RR25.*

Table 5: EPA inhalation risk assessment model for non-carcinogenic and carcinogenic metal according to welding type in selected industries.

Welding Type / Plant	Non-carcinogenic (HQ)	Risk of Carcinogenicity				
	Mn	Cr	Co	Ni	As	Pb
MIG weld						
Plant 1	$1.143x10^{7}$	$2.430x10^{2}$	$5.500x10^{-2}$	3.208	$5.699x10^{1}$	n/a
Plant 2	$2.792x10^{4}$	$5.584x10^{2}$	1.065	$7.900x10^{-2}$	$4.735x10^{1}$	$2.610x10^{-1}$
Plant 3	$1.839x10^{5}$	$7.020x10^{2}$	$7.390x10^{-1}$	$7.800x10^{-2}$	$4.802x10^{1}$	$1.800x10^{-1}$
SpotWeld						
Plant 2	$2.393x10^{4}$	$3.493x10^{2}$	2.628	$2.670x10^{-1}$	$3.031x10^{1}$	$1.670x10^{-1}$
Plant 3	$3.260x10^{4}$	$6.287x10^{2}$	$8.790x10^{-1}$	$5.200x10^{-2}$	$4.431x10^{1}$	$1.650x10^{-1}$
Robotic Weld						
Plant 2	$3.827x10^{4}$	$4.445x10^{2}$	1.145	$8.4x10^{-2}$	$3.889x10^{1}$	$1.990x10^{-1}$
Plant 3	$4.437x10^{4}$	$7.759x10^{2}$	$4.930x10^{-1}$	$1.040x10^{-1}$	$4.933x10^{1}$	$8.700x10^{-2}$

HQ = Hazard Quotient; n/a = not available.

4. CONCLUSION

This study evaluates the current condition among welders due to exposure to welding fumes in the selected automotive industry in Malaysia by comparing the developed method by Malaysian Department of Occupational Safety and Health (DOSH) with EPA inhalation risk assessment model. The risk assessment is fundamental to conduct before the appropriate risk control can be applied to reduce the severity of illness. The results of this study show a significantly higher concentration of heavy metals from welding activities in all selected automotive plants. This finding is relevant to both practitioners and policymakers to improvise mitigation measures at the workplace to minimize the exposure to toxic and hazardous chemical arising from metal fumes. Measures that can take into consideration to lessen the exposure comprises of selecting the appropriate types of welding procedure, fillers and base metal before any implementation of appropriate engineering control and respiratory protection devices.

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