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Heavy metal emitting from welding fumes in automotive industry

Norhidayah Abdull[1*], Nurul Wahida Mat Hassan[1], Ahmad Rasdan Ismail[1], Abdul Mutalib Leman[2] and Azian Hariri[2]

[1]Faculty of Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM)
Corresponding author

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A B S T R A C T

Heavy metal emitting from welding fumes in the automotive industry provide the significant health impacts to workers. Objectives of this study was to investigate the characteristics of the occupational environment setting in an automotive industry, to study the concentration of heavy metals in the welding fumes and to propose the appropriate control measure of welding fumes emission toward safe work environment in an automotive industry. A personal monitoring and area monitoring was conducted to determine the workers exposures to welding fumes. The concentration of welding fumes was analyzed by using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) with referring to ASTM. All the heavy metals were permitted the OSHA PEL-TWA except Arsenic. The appropriate control measures was proposed such as substitution and local exhaust ventilation which towards safe and healthy environment

Introduction

Automotive industry in Malaysia was begun as one of the most important industries under manufacturing sector to increase the country’s economy. In 1960s, Malaysia had completely imported all the cars from the other countries. Automotive industry has a higher potential in the welding process that the workers used it in the daily work. Welding is the process in which metal or other thermoplastic materials are joined together by the application of heat or pressure, or both with or without the use of filler metal (Meo and Al-Khlaiwi, 2003). Welding process produces fumes that may give bad significant hazards to the workers. One of the hazard is the exposures to gases and fine particles created by arc welding which collectively known as fume. Inhaling these fumes can potentially cause a short and long term health complications (Lucas, 2008).

The previous studies proved that only in the United States has nearly 0.5 million people performing welding and cutting operations full-time, and additional 1-2 million workers who weld intermittently (Jenkins, 2003). The total amount estimating from fume that emitted from the welding industry is about 5000 tons/year (Redding, 2002). Hence, particles from welding processes are enriched in metals. Heavy metals characterized are designate natural metallic elements by an important mass density (superior to 5 grams by cubic centimetre). It can be concluded that the welding process that doing by the workers at the industrial may produces the hazardous agents or heavy metals which are acetylene, carbon monoxide, oxides of nitrogen, ozone, phosgene, tungsten, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, silver, tin, and zinc. The aim of this study are to investigate the characteristics of the occupational environment setting in an automotive industry, to study the concentration of heavy metals in the welding fumes and to propose the appropriate control measure of welding fumes emission toward safe work environment in an automotive industry.

Materials and Methods

The research design involves the workers who are worked in automotive industry which produces the spare part of car. The workstations of this industry which generate the welding fumes are spot welding area, fuel lid assy, assy robot line welding area, spot gun welding and MIG area. Each of the workstation has the different number of workers who are performed a different job description and then, different exposures to the workers. A total number of workers who are worked at welding station are 25 workers. All respondents to be monitored are randomly selected at the workstations as tabulated in Table 1

Walkthrough inspection

Walkthrough inspection was done in the workplace area to determine the characteristics of the work task, the work area and the existing control measure. Characteristics of the work task determined by the type of jobs which conducted by the workers.

Personal sampling

Air sampling pump that attached with 0.8 µm mixed cellulose ester (MCE) in the 37 mm SKC Sureseal cassette were used to measure the welding fume that exposed to the workers. The pump is calibrated for the 2 L/min of flow rate. The method that used in this measurement is Metal and Metalloid Particulates in Workplace Atmospheres (Inductive Coupled Plasma [ICP] Analysis) Method Number ID-125G (Bisesi, 2006).The sampling cassette will be attached to the neck collar near to the breathing zone. The types of sampling period are the full period consecutive samples. The study conducted during eight hours working shift from 8.00 am until 5.30 pm with morning breaks from 10.00 am till 10.15 am and lunch breaks from 1.00 pm till 2.00 pm After sampling, the cassette were removed from the air sampling pump, the cassette must be seal with the appropriate way and the inlet and outlet must be covering differently (OSHA Technical Manual, 2008) to give the easy way to recognise during analysis.

Area sampling

Area sampling used the direct reading instrumentation such as TSI-Dustrax and TSO Velocicalc. They were used to determine temperature and particulate matter 2.5µm or less in diameter size (P.M2.5) and to determine velocity (m/s), pressure (Pa), Temperature (Celcius) and Relative Humidity (%RH), respectively. The instruments are assembled approximately

150 cm from the floor. The data logging of instruments is every 15 minutes.

Determination of Concentration Heavy Metals

The MCE filters which exposed to the welding fumed were digested according to the ASTM International Standard Test Method for Determination of Elements in Airborne Particulate Matter by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) D7439-08. After the digestion process, the solid form of the MCE filters were transform into liquid form. The standard solution for the determination of concentration of heavy metals was prepared by mixing 5% of Nitric acid (HNO3) and 10 mg/L of the multi element calibration standard 3. The heavy metals (Aluminium, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Nickel, Silver and Tin) were analyzed by using the ICP-Mass Spectrometer NEXion 300X (Perkin Elmer).

Results and Discussion

Existing control measure

The walkthrough observation shows that the ventilation used in this industry is only general mechanical ventilation which is fans. General ventilation is the natural of forced movement of fresh air that can be used to minimize or reduce the fumes at the workplace (OSHA Fact Sheet, 2013). Unfortunately, the mechanical ventilation used is insufficient because the areas of the workstation area were enclosed space and small. The fans used could not dilute the concentration of the welding fumes thoroughly. Besides, only one working area used the curtain in order to isolate between Assy Robot Line area and Fuel Lid Assy area. This condition increased the contamination of the welding fumes concentration at the workstation. Dispersion of the welding fumes will be in a short distance and circulated at the same area of the welding process. The workers were applied face mask and goggle but they do not wear the personal protective equipment which is required and approved by the Occupational Safety and Health (Use and Standard of Exposure of Chemical Hazardous To Health) Regulation 2000 section 16 (1) : Use of approved personal protective equipment accordingly.

Environmental setting

The environmental setting such as velocity, relative humidity and temperature in industry was tabulated in Table 2.

Concentration of heavy metals

The welding fumes that collected were analysed to measure the concentration of heavy metals. There were 15 elements of heavy metals that were analysed which are aluminium, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, molybdenum, nickel, argentum, manganese, tin, and antimony (Ashby, 2002; Texas Department of Insurance, 2006). Electrode metal, flux material and coating on the base metal are the major sources of the fume formation. To decrease the fume formation, voltage, electrode diameter and base metals can be substitute to the less formation of fumes materials (Harris, 2009).Table 3 shows the data analysis of the TWA 8 hours of concentration heavy metals that has been analysed.

Environmental setting

Each of the sampling point has the difference measurement for velocity, temperature and relative humidity. In slot 1, the highest velocity measurement was located at Spot Gun Welding Area (0.48 m/s), the second highest was located at MIG area (0.39 m/s) and the lowest velocity measurement was at entrance of the factory (0.18 m/s). In the slot 2, the highest velocity measurement was at Spot Welding area (0.30 m/s) the second highest was at Spot Gun Welding area (0.25 m/s) and the lowest velocity measurement was at Assy Robot Line area and Fuel Lid Assy (0.07 m/s), respectively.

Velocity in the welding area is depending on the type of ventilation which is mechanical fans. Mechanical fans that used in the industry effect the movement of air velocity of the welding fumes. Spot Gun Welding Area has the velocity for the slot 1 because of the fan are well functioned. For the lowest part at the entrance, there is no fan and there only have natural ventilation which depends to the weather on that day. Furthermore, the highest for the slot 2 was in Spot Welding area that was located in then small area and the entire fan are functioned.

The velocity was increased due to the small area in that particular area.

The highest and lowest temperature measurement in slot 1 were in Spot Gun Welding area (30.5 °C) and entrance of the factory (25. 6°C), respectively. In slot 2, the highest of the temperature measurements were in Assy Robot Line area and Fuel Lid Assy area (33.6°C) respectively, the second highest was in entrance of the factory (33.5°C) and the lowest of the temperature measurement were in Spot Gun Welding Area (29.9°C).The highest temperature can affect the productivity of the workers when doing welding job. The standard for the temperature in the automotive industry are in the range of 20-26°C. Based on the finding, all the welding area in this industry did not complied with the standard which produced the uncomfortable environment to the workers.

For the relative humidity measurement in slot 1, the highest measurement was 73.1% in the three areas which were MIG area, Assy Robot Line area and Fuel Lid Assy area, respectively. For the second highest of measurement of relative humidity which were 73 % were at the Spot Welding Area and Entrance of the factory respectively. The lowest of the relative humidity measurement was at Spot Gun Welding (71.7 %).

In slot 2, the highest of the relative humidity measurement was in Fuel Lid Assy area (71.1 %), the second highest of the relative humidity measurement was 70.1 % at the Spot Gun Welding area and the lowest of the relative humidity measurement was 67.7 % at the Assy Robot Line area. The standard stated that the normal relative humidity is 40-60 %. Based on the finding, the relative humidity was stated in the range between 67 and 73 %. It was exceeding the limit of the parameter of the indoor occupational setting at the workplace by Industry Code of Practice on Indoor Air Quality (Department of Occupational Safety and Health, 2005) in DOSH standard of 8-hrs TWA.

Concentration of heavy metals

All the TWA – 8 hours of heavy metals (except *As*) at all workstations are not exceeded the standard concentration which stated in OSHA PEL-TWA. However, the TWA 8 hours of arsenic in five assembly point was higher than OSHA PEL-TWA value (10 ppb). Exceeding the standard limit of arsenic of OSHA PEL-TWA can give harmful effects to the workers who are working more than 8 hours per day. Exposures of arsenic resulted in acute health effect which is acute arsenic poisoning including vomiting, abdominal pain and diarrhea. For the chronic effect, this can caused numbness and muscle cramping and death (World Health Organisation, 2010).

The TWA-8 hours of heavy metals concentration stated that *Fe* has the highest concentration in the welding fumes followed by the *Al*, *Be* and *Sn*. *Fe* commonly presence in the form of iron oxide is the major contaminant in all iron and steel welding processes (Gonser and Hogan, 2011). Inhalation of iron oxide can give irritation to the nose and lungs over an extended period of time. The highest TWA-8 hours of *Fe* concentration (860.450 ppb) was obtained at assy robot line area.

Aluminium is a common component of some alloy and filler materials in the welding industry (Workplace Health and Safety Bulletin, 2009). Over exposures of aluminium give negative health effects to the workers such as respiratory irritant. According to the OSHA PEL-TWA, the concentration of the total aluminium and respirable aluminium are about 1500 ppb and 5000 ppb, respectively. The highest TWA-8 hours for the aluminium can be found at fuel lid assy area with the concentration of 193.600 ppb and it did not exceeded the standard concentration (Ashby, 2002).

According to the OSHA PEL-TWA, the standard value for beryllium is about 2 ppb. The highest value of beryllium can be found at fuel lid assy area approximately 0.043 ppb. It was permitted to the standard then, do not harm the workers even though the concentration of beryllium was higher than the TWA-8 hour value. According to the OSHA PEL-TWA, the standard value for beryllium is around 2 ppb. The highest value of beryllium can be found at fuel lid assy area approximately 0.043 ppb. It was complied the standard then, do not harm the workers even though the concentration of beryllium was higher than the TWA value. Tin is commonly presence in bronzes and some solder alloys and coating materials (Harris, 2009). The value of exposure limit of tin (metal) is about 2000 ppb according to the OSHA PEL-TWA. From the result obtained the highest value of TWA-8 hours at fuel lid assy area with the value of 1.770 ppb. It can be concluded that TWA-8 hours value of tin did not exceed the OSHA PEL-TWA standard. Exposure of tin can gives irritation to the lung known as stannosis (Workplace Health and Safety Bulletin, 2009).

Appropriate control measure of welding fumes emission toward safe work environment in an automotive industry.

The recommended control measures are based on the hierarchy of control which are elimination, substitution, engineering control, administration control and personal protective equipment (PPE). In this study, only three type of control that been proposed which are substitution, engineering control and personal protective equipment (PPE).Substitution of the less hazardous compositions of the welding electrode that used in the welding process without altering welding characteristics can give less smoke to the workers.

Many industries also can substitute from manual welding to the robotic welding to decrease the exposure to the workers. Engineering control in the industry also presents the important roles to reduce the exposures of welding fumes to the workers. An appropriate engineering control which recommended is ventilation system. Ventilation systems are used to reduce the fume exposures such as local exhaust ventilation and dilution ventilation. Local exhaust ventilations are the most preferred system of ventilation that captured the fumes at the source and remove process emissions prior to their escape into the workplace environment (ACGIH, 1998). Local exhaust ventilation is provided with the hood which creates air flows to efficiently capture the contaminant. Exterior hoods are the suitable hood for the welding because it was located adjacent to an emission source without enclosing it.

When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used pursuant to this standard (29 CFR 1910.134). Selection of respirators is based on actual exposures levels of regulated metals and permissible exposure limit of metals. Assigned Protection Factors (APF) is needed to classify each of the respirators.

Permissible Exposure Limit (PEL) and Assigned Protection Factors (APF) are used to calculate the Maximum Use Concentration (MUC). The MUC is the upper limit at which the class of respirator is expected to provide protection. The selection class of respirator must higher than the concentration of exposures (Occupational Safety and Health Administration, 2009).

Hand protection such as glove also a part of personal protection equipment that used to protect the workers when doing welding process. For hand protection, OSHA recommends that selection be based upon the tasks to be performed and the performance and construction characteristics of the glove material (Occupational Safety and Health Administration, 2003). Safe work practice is important because it can control the workers from over exposures. This practice would lead to the habits of the workers such as using the equipment correctly, housekeeping and maintenance. If the workers doing well at the workplace, the exposures of welding fumes can be reduces constantly (Ashby, 2002).

Conclusions

As a conclusion, the finding of this study gives a comprehensive understanding on the workers exposure to welding fumes in automotive industry. The concentration of heavy metals stated that iron (*Fe*) has the highest concentration in the welding fumes followed by the aluminium (*Al*), beryllium (*Be*) and antimony (*Sn*).

The concentrations of heavy metals in the welding fumes never exceeded the limit which published by the OSHA standard except for the Arsenic. The appropriate control measures towards emission the welding fumes been purposed accordingly the hierarchy of control which are substitution of the less hazardous electrode during welding process, use the engineering control such as local exhaust ventilation to reduce exposures of welding fumes to the workers and used correct personal protective equipment such as respiratory equipment, eye protection and skin protection.

Table.1 Summary of the number of the workers planned to be monitored at each workstation

Workstation	Number of Workers (N)	Number of Workers Monitored by The Personal Exposures (n)
(1) MIG	2	2
(2) Assy Robot Line Area	12	10
(3) Fuel Lid Assy	1	1
(4) Spot Welding Area	7	7
(5) Spot Gun Welding	3	3

Notations for Table 1:
N = Original equal risk group size
n = Sample size for subgroup size
n = N if N < 7

Source: Guidelines Monitoring Airborne of Airborne Contaminant for Chemicals Hazardous to Health (Bisesi, 2006)

Table.2 Data collection for area monitoring

SAMPLING POINT	PARAMETER	AVERAGE	
		SLOT 1 (Morning Shift)	SLOT 2 (Afternoon Shift)
1 (MIG)	Velocity (m/s)	0.39	0.20
	Temperature (Celsius)	28.4	33
	Relative Humidity (%)	73.1	69
2 (Assy Robot Line)	Velocity (m/s)	0.46	0.07
	Temperature (Celsius)	28.9	33.6
	Relative Humidity (%)	73.1	67.7
3 (Fuel Lid Assy)	Velocity (m/s)	0.23	0.18
	Temperature (Celsius)	27.8	31
	Relative Humidity (%)	73	71.7
4 (Spot Welding)	Velocity (m/s)	0.34	0.30
	Temperature (Celsius)	28.7	31.9
	Relative Humidity (%)	73	68.5
5 (Spot Gun Welding)	Velocity (m/s)	0.48	0.25
	Temperature (Celsius)	30.5	29.9
	Relative Humidity (%)	71.7	70.1
6 (Entrance)	Velocity (m/s)	0.18	0.17
	Temperature (Celsius)	25.6	33.5
	Relative Humidity (%)	73	69

Table.3 TWA 8 hours of concentration of Heavy Metals

Heavy metals	Workstation					
	Assy robot line area	Spot welding	Spot gun welding	MIG	Fuel lid assy	OSHA PEL-TWA
Al (Aluminium)	92.6	115	111	62	193	1 500 (total) 5 000 (respirable).
Ag (Argentum)	0.029	0.092	0.018	0.01	0.005	10
As (Arsenic)	78.960	96.640	115.767	46.537	15.500	10
Be (Beryllium)	0.009	0.019	0.007	0.013	0.043	2
Cd (Cadmium)	0.033	0.046	0.028	0.019	0.010	5
Cr (Cromium)	10.440	9.140	18.333	11.146	7.800	1 000
Co (Cobalt)	0.260	0.230	0.258	0.174	0.010	100
Cu (Copper)	20.3	10.13	12.767	5.298	1.480	100
Fe (Ferum)	860.450	360.170	360.000	121.697	251.100	10 000
Pb (Plumbum)	3.570	1.208	2.834	3.850	3.420	50
Mn (Manganese)	148.530	97.39	44.633	30.048	19.700	5 000
Mo (Molybdenum)	4.500	0.210	0.258	0.112	0.480	5000 (soluble) ppb 15000 (insoluble)
Ni (Nickel)	3.170	2.120	2.295	5.154	0.040	1 000
Sb (Antimony)	0.270	0.170	0.125	0.092	0.170	500
Sn (Tin)	0.830	0	0.702	0.092	1.770	2 000

- Unit = ppb (part per billion)

Table.4 Example of Respirator

Type of Contaminant	Respirator
Particle, such as a dust, spray, mist, fog, fume, or aerosol	• Select respirators with filters certified to be at least 95% efficient by NIOSH – For example, N95s, R99s, P100s, or High Efficiency Particulate Air (HEPA) filters

Source: Washington State Department of Labor and Industries (Washington State Department of Labor & Industries, 2013)

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